3RD ANNUAL ENERGY HARVESTING SOCIETY MEETING (EHS 2019)

CONFERENCE GUIDE

Google play

SEPTEMBER 4–6, 2019

Falls Church, Virginia USA

ceramics.org/ehs19

Apple Store

ORGANIZERS

The American Ceramic Society
www.ceramics.org

ENERGY HARVESTING SOCIETY

3RD ANNUAL ENERGY HARVESTING SOCIETY MEETING (EHS 2019)

SEPTEMBER 4–6, 2019

Falls Church, Virginia USA

WELCOME!

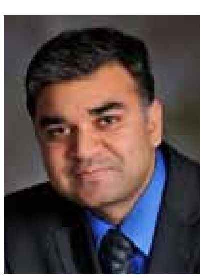
Welcome to the 3rd Annual Energy Harvesting Society Meeting. We hope that you will find this meeting relevant toward your professional career development, and at the same time find it to be an excellent event for learning about energy generation, storage, and management. Our organizing committee strives toward developing an informative and engaging agenda that surpasses the expectations of all attendees.

The Energy Harvesting Society is growing and we are excited about the new path and vision being forged. You'll hear more about those changes and opportunities, including a new website, in the days to come. Our partnership with The American Ceramic Society has grown tremendously and together we continue to find ways to strengthen the program for this event. Thanks to Mark Mecklenborg and his team comprising of Greg Geiger, Marilyn Stoltz, Greg Phelps, Faye Oney, and Andrea Ross. They have done phenomenal work in organizing this meeting. Thanks to Jennifer Leedy at Penn State for her great support and assistance throughout the planning and execution phase. She has been dedicated to ensuring the success of this meeting.

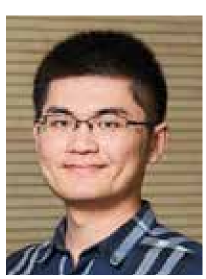
Thank you to all the sponsors and organizations who support both the society and this meeting. Thank you to our plenary speakers. We know you are extremely busy and we much appreciate your time and effort. Thank you to all participants from multiple academic institutions, industry, and government agencies. Without you this would not be possible. And thank you to our friends and colleagues serving on the international planning committee. Over the past several months, you have provided countless hours in developing this program and continue to refine and improve the agenda. Thank you team!

We again appreciate your participation and welcome your questions, suggestions, and ideas about how we can collaborate over the coming years to continue to grow the Energy Harvesting Society, this annual meeting, and Materials Valley.

PROGRAM CHAIRS:



Shashank Priya
Associate Vice President for Research
Director of Strategic Initiatives
Penn State University, University Park, USA



Yang Bai
Assistant Professor
Microelectronics Research Unit
University of Oulu, Finland

Jungho Ryu
Professor
School of Materials Science and Engineering,
Yeungnam University, Korea

TABLE OF CONTENTS

THANK YOU TO SPONSORS

Sapphire sponsor

Media sponsor

SCHEDULE AT A GLANCE

Wednesday, September 4, 2019

Conference registration	7:00 a.m. – 6:00 p.m.
Opening remarks and Plenary 1	8:00 a.m. – 9:00 a.m.
Coffee service	10:50 a.m.
Concurrent sessions	9:20 a.m. – 12:30 p.m.
Lunch	12:30 p.m. – 1:30 p.m.
Plenary 2	1:30 p.m. – 2:15 p.m.
Concurrent sessions	2:30 p.m. – 4:30 p.m.
Plenary 3	4:45 p.m. – 5:30 p.m.
Poster session	6:00 p.m. – 7:30 p.m.

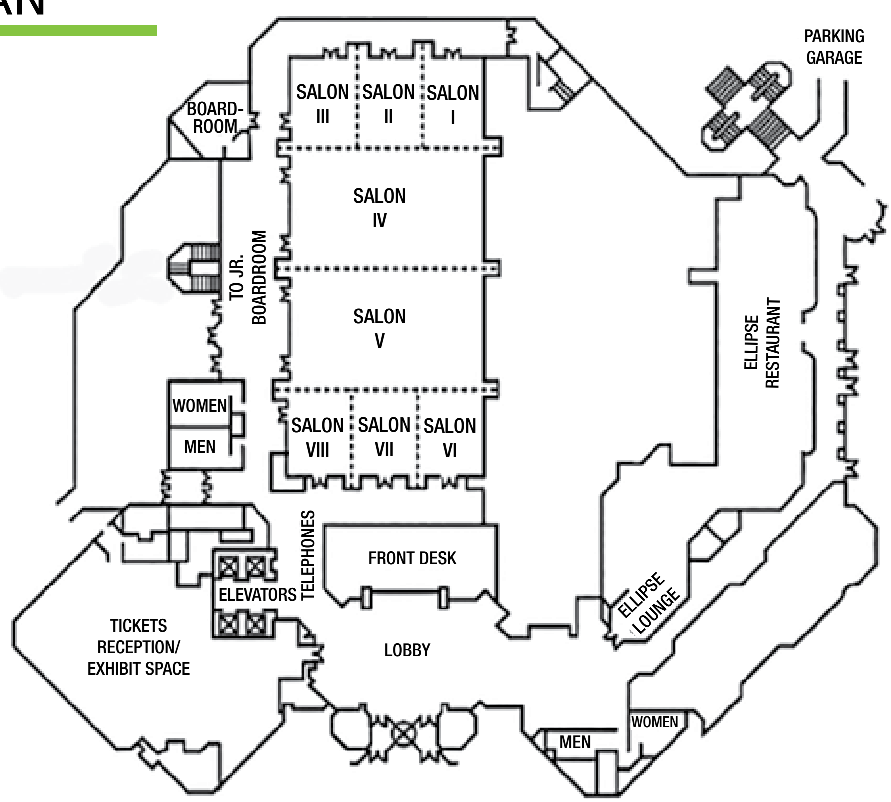
Thursday, September 5, 2019

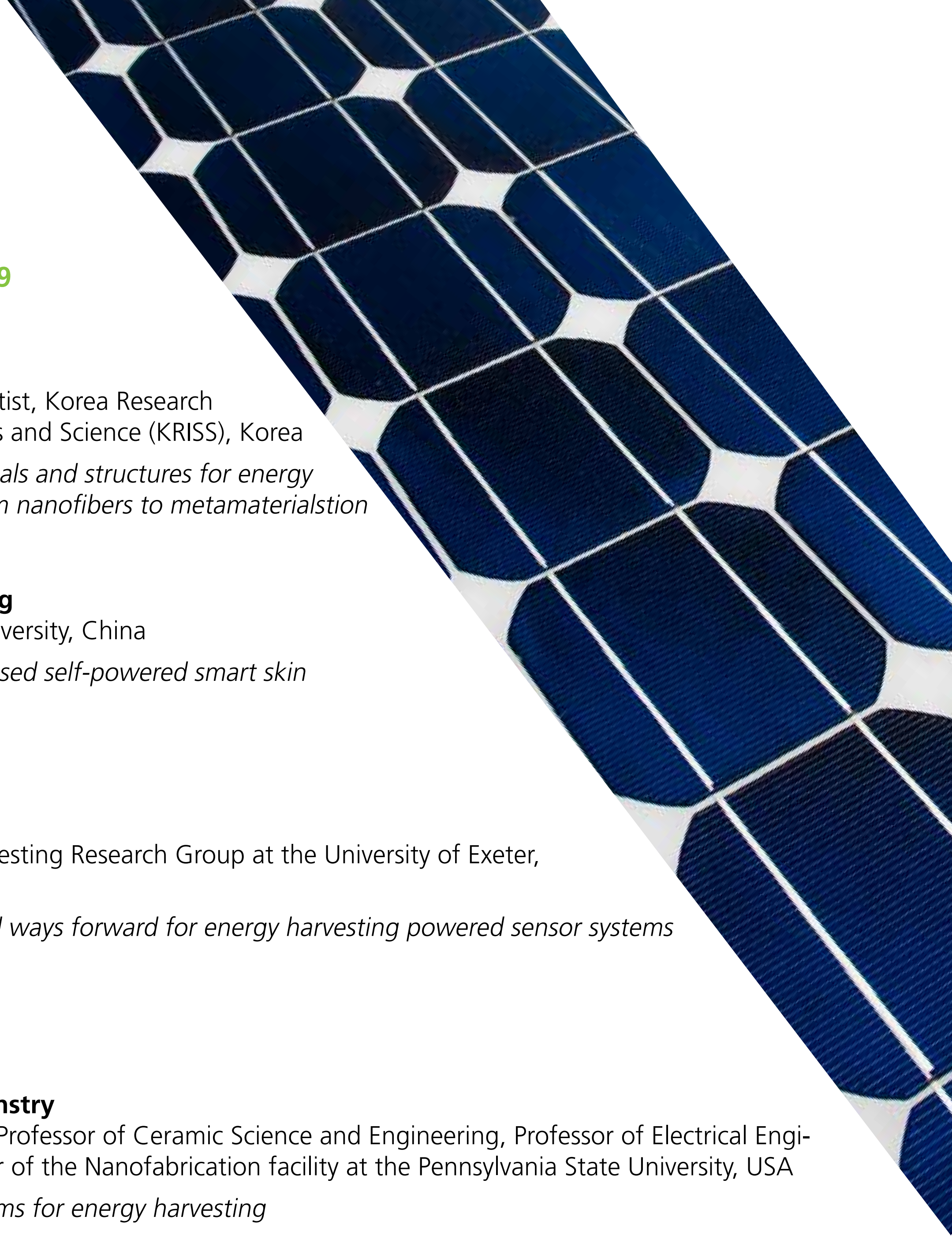
Conference registration	7:30 a.m. – 5:30 p.m.
Plenary 4	8:00 a.m. – 8:45 p.m.
Coffee service	10:30 a.m.
Concurrent sessions	9:00 a.m. – 12:00 p.m.
Lunch	12:00 p.m. – 1:30 p.m.
Plenary 5	1:30 p.m. – 2:15 p.m.
Coffee service	3:40 p.m.
Concurrent sessions	2:30 p.m. – 5:30 p.m.

Friday, September 6, 2019

Conference registration	7:30 a.m. – 12:00 p.m.
Plenary 6	8:00 a.m. – 8:45 a.m.
Coffee service	10:20 a.m.
Concurrent sessions	9:00 a.m. – 12:00 p.m.

FLOOR PLAN





PLENARY SPEAKERS

Wednesday, September 4, 2019

8:15 - 9:00 a.m.

Miso Kim
Senior research scientist, Korea Research Institute of Standards and Science (KRISS), Korea

Title: *Tailoring materials and structures for energy harvesting: From nanofibers to metamaterialstion*

1:35 – 2:15 p.m.

Haixia (Alice) Zhang
Professor, Peking University, China

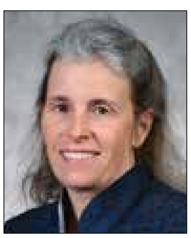
Title: *Triboelectric-based self-powered smart skin*

4:50 – 5:30 p.m.

Meiling Zhu
Head of Energy Harvesting Research Group at the University of Exeter, United Kingdom

Title: *Challenges and ways forward for energy harvesting powered sensor systems*

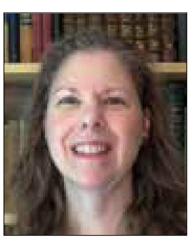
Thursday, September 5, 2019



8:05 – 8:45 a.m.

Susan Trolier-McKinstry
Steward S. Flaschen Professor of Ceramic Science and Engineering, Professor of Electrical Engineering, and Director of the Nanofabrication facility at the Pennsylvania State University, USA

Title: *Piezoelectric films for energy harvesting*



1:35 – 2:15 p.m.

Lynnette Madsen
Program Director of Ceramics, National Science Foundation, USA

Title: *Working towards a sustainable world with clean abundant energy*

Friday, September 6, 2019

8:05 – 8:45 a.m.

Olfa Kanoun
Chair for Measurement and Sensor Technology, Technische Universität Chemnitz, Germany

Title: *Symbiosis of energy conversion and system design for efficient energy harvesting solutions*


Polytec
Harvesting energy
Motion characterization
2.3
Electro-mechanical transducers are used to harvest kinetic energy. They convert mechanical energy into electrical energy. Polytec solutions offer ways for researchers and technical professionals to characterize transducers. We invite you to visit us and discuss your particular application.
Learn more:
www.polytec.com

Oral Presenters

Name	Date	Time	Room	Page Number
B				
Bader, S.	6-Sep	9:00AM	Salon 2	8
Baglio, S.	4-Sep	12:00PM	Salon 2	4
Bai, Y.	5-Sep	3:20PM	Salon 2	8
Beeby, S.	4-Sep	11:00AM	Salon 2	4
Beeby, S.	5-Sep	3:00PM	Salon 3	7
Borowiec, M.	5-Sep	3:00PM	Salon 1	7
Bradai, S.	5-Sep	11:30AM	Salon 1	6
C				
Caliari, F.	4-Sep	3:50PM	Salon 3	5
Chae, S.	5-Sep	10:40AM	Salon 2	6
Correia, V.M.	5-Sep	4:50PM	Salon 2	8
Costa, P.	4-Sep	4:10PM	Salon 2	4
D				
Dong, S.	4-Sep	3:30PM	Salon 1	4
Dunn, S.	4-Sep	3:00PM	Salon 2	4
F				
Feldhoff, A.	4-Sep	9:20AM	Salon 3	3
Finkel, P.	5-Sep	10:00AM	Salon 1	6
Freer, R.	4-Sep	11:10AM	Salon 3	3
G				
Groen, P.	5-Sep	9:30AM	Salon 2	6
Groen, P.	5-Sep	2:30PM	Salon 2	7
H				
Hadas, Z.	5-Sep	4:00PM	Salon 3	7
Hanrahan, B.	5-Sep	4:10PM	Salon 2	8
Hu, X.	4-Sep	11:30AM	Salon 3	3
J				
Jo, W.	4-Sep	10:20AM	Salon 1	3
Juuti, J.	4-Sep	9:50AM	Salon 2	3
K				
Kang, H.	4-Sep	3:30PM	Salon 3	5
Kang, M.	5-Sep	9:30AM	Salon 1	6
Kanno, I.	5-Sep	2:30PM	Salon 1	7
Kanoun, O.	6-Sep	8:05AM	Salon 4	8
Kar-Narayan, S.	5-Sep	9:00AM	Salon 2	6
Kar-Narayan, S.	6-Sep	10:00AM	Salon 1	9
Karan, S.K.	5-Sep	4:30PM	Salon 2	8
Kiani, M.	6-Sep	10:00AM	Salon 2	8
Kiani, M.	6-Sep	11:40AM	Salon 1	9
Kim, H.	6-Sep	10:30AM	Salon 1	9
Kim, M.	4-Sep	8:20AM	Salon 4	3
Kim, S.	4-Sep	3:50PM	Salon 2	4
Kordas, K.	6-Sep	10:30AM	Salon 2	9
L				
Lanceros-Mendez, S.	4-Sep	9:20AM	Salon 1	3
Lee, P.	6-Sep	11:00AM	Salon 1	9
Leng, H.	5-Sep	11:00AM	Salon 2	6
Li, P.	4-Sep	3:00PM	Salon 1	4
Li, W.	4-Sep	10:50AM	Salon 3	3
Li, X.	5-Sep	5:10PM	Salon 2	8
Litak, G.	5-Sep	5:00PM	Salon 3	7
M				
Madsen, L.D.	5-Sep	1:35PM	Salon 4	7
Magno, M.	4-Sep	11:30AM	Salon 2	4
Magno, M.	5-Sep	2:30PM	Salon 3	7
Maiti, S.	5-Sep	4:50PM	Salon 1	8
Malleron, K.	4-Sep	10:50AM	Salon 1	3
Mech, R.	4-Sep	10:20AM	Salon 2	4
Mohammed, O.	5-Sep	2:50PM	Salon 2	8
Muhtaroglu, A.	6-Sep	9:30AM	Salon 2	8
N				
Nahm, S.	5-Sep	3:50PM	Salon 1	8
Nozariasbmarz, A.	5-Sep	11:20AM	Salon 3	7
O				
Ozturk, M.C.	5-Sep	9:00AM	Salon 3	6
P				
Pakrashi, V.	4-Sep	9:20AM	Salon 2	3
Pakrashi, V.	5-Sep	4:30PM	Salon 3	7
Palneedi, H.	4-Sep	9:50AM	Salon 1	3
Park, S.	4-Sep	11:10AM	Salon 1	3
Pearson, M.R.	5-Sep	10:30AM	Salon 3	7
Poon, J.	4-Sep	2:30PM	Salon 3	5
Poudel, B.	4-Sep	3:00PM	Salon 3	5
R				
Rai, G.	5-Sep	3:30PM	Salon 3	7
Randall, C.	5-Sep	11:40AM	Salon 2	6
Reed, E.	4-Sep	2:30PM	Salon 2	4
Roscow, J.	5-Sep	10:00AM	Salon 2	6
Ryu, J.	5-Sep	9:00AM	Salon 1	6
S				
Saparamadu, U.	5-Sep	11:00AM	Salon 3	7
Seo, J.	6-Sep	11:00AM	Salon 2	9
Shang, S.	4-Sep	10:20AM	Salon 3	3
Shi, D.	5-Sep	3:50PM	Salon 2	8
Shim, W.	5-Sep	4:20PM	Salon 1	8
Sobola, D.	4-Sep	3:30PM	Salon 2	4
Song, H.	4-Sep	4:00PM	Salon 1	4
Song, H.	5-Sep	11:50AM	Salon 1	6
Sriramdas, R.	5-Sep	3:20PM	Salon 1	7
Sun, N.	4-Sep	11:30AM	Salon 1	3
T				
Tan, G.	4-Sep	9:50AM	Salon 3	3
Trolier-McKinstry, S.	5-Sep	8:05AM	Salon 4	5
Tsuji, K.	5-Sep	11:20AM	Salon 2	6
U				
Uddin, M.	6-Sep	11:20AM	Salon 1	9
V				
Vashaee, D.	5-Sep	9:30AM	Salon 3	6
W				
Wang, Y.	4-Sep	4:10PM	Salon 3	5
Wang, Y.	5-Sep	11:00AM	Salon 1	6
Wen, Y.	4-Sep	2:30PM	Salon 1	4
Wu, W.	6-Sep	9:30AM	Salon 1	9
Y				
Yan, Y.	5-Sep	5:30PM	Salon 2	8
Yang, R.	6-Sep	9:00AM	Salon 1	9
Yang, S.	5-Sep	10:30AM	Salon 1	6
Yuan, H.	5-Sep	5:10PM	Salon 1	8
Z				
Zebarjadi, M.	5-Sep	10:00AM	Salon 3	6
Zhang, H.	4-Sep	1:35PM	Salon 4	4
Zhang, X.	5-Sep	11:40AM	Salon 3	7
Zhu, M.	4-Sep	4:50PM	Salon 4	5

Presenting Author List

Poster Presenters

Name	Date	Time	Room	Page Number
		B		
Bouattour, G.	4-Sep	6:00PM	Ballroom Foyer	5
		E		
Eom, S.	4-Sep	6:00PM	Ballroom Foyer	5
		K		
Kim, J.	4-Sep	6:00PM	Ballroom Foyer	5
Kim, S.	4-Sep	6:00PM	Ballroom Foyer	5
		M		
Markovska, I.G.	4-Sep	6:00PM	Ballroom Foyer	5
Mech, R.	4-Sep	6:00PM	Ballroom Foyer	5
		R		
Rita, P.	4-Sep	6:00PM	Ballroom Foyer	5
Rubes, O.	4-Sep	6:00PM	Ballroom Foyer	5
Ryu, J.	4-Sep	6:00PM	Ballroom Foyer	5
		S		
Sobola, D.	4-Sep	6:00PM	Ballroom Foyer	5
Song, H.	4-Sep	6:00PM	Ballroom Foyer	5
		T		
Tofel, P.	4-Sep	6:00PM	Ballroom Foyer	5
		Y		
Ye, G.	4-Sep	6:00PM	Ballroom Foyer	5

Wednesday, September 4, 2019

Plenary I

Room: Salon 4
Session Chair: Jungho Ryu, Yeungnam University

8:00 AM

Welcome and Introduction

8:20 AM

(EHS-PLEN-001-2019) Tailoring Materials and Structures for Energy Harvesting: From Nanofibers To Metamaterials

M. Kim*[1]

1. Korea Research Institute of Standards and Science, Republic of Korea

S1: Mechano-Magneto-Electric Energy Harvesting

Mechano-Magneto-Electric Energy Harvesting I

Room: Salon 1
Session Chair: Su Chul Yang, Dong-A University

9:20 AM

(EHS-S1-001-2019) Polymer-based Magnetoelectric Materials for Sensors, Actuators and Energy Harvesting: Materials, applications, challenges (Invited)

S. Lanceros-Mendez*[1]

1. BCMaterials, Basque Center for Materials, Applications and Nanostructures, Spain

9:50 AM

(EHS-S1-002-2019) Laser-induced phenomena and enhancement of magnetoelectric coupling in piezoelectric/magnetostrictive film composites (Invited)

H. Palneedi*[1]; D. Maurya[2]; J. Ryu[3]; S. Priya[1]

1. The Pennsylvania State University, Materials Science and Engineering, USA
2. Virginia Tech, Center for Energy Harvesting Materials and Systems, USA
3. Yeungnam University, Materials Science and Engineering, Republic of Korea

10:20 AM

(EHS-S1-003-2019) Magnetoelectrically-coupled room-temperature single-phase ferromagnetic-ferroelectric ceramics (Invited)

J. Cho[1]; J. Lee[1]; H. Lee[2]; N. Lee[3]; G. Lee[1]; G. Hwang[4]; S. Kim[3]; J. Lee[2]; W. Jo*[1]

1. Ulsan National Institute of Science and Technology, School of Materials Science and Engineering, Republic of Korea
2. Ulsan National Institute of Science and Technology, School of Energy and Chemical Engineering, Republic of Korea
3. University of Ulsan, Department of Physics, Republic of Korea
4. Korea Institute of Materials Science, Functional Ceramics Group, Republic of Korea

10:50 AM

(EHS-S1-004-2019) Automatic low cost magnetoelectric coefficient at resonance and effective deliverable power measurement bench

K. Malleron*[1]; A. Gensbittel[2]; H. Talleb[2]

1. Institut Superieur d'Electronique de Paris, LISITE, France
2. Sorbonne Universite, L2E, France

11:10 AM

(EHS-S1-005-2019) Layer structured face shear 36 mode Magnetoelectric composites with Piezoelectric single crystal and Metglas

S. Park*[1]; M. Peddigari[2]; G. Hwang[2]; A. Kumar[1]; W. Yoon[2]; J. Ryu[1]

1. Yeungnam University, Materials Science and Engineering, Republic of Korea
2. Korea Institute of Materials Science, Gyeongnam, Korea, Republic of Korea

11:30 AM

(EHS-S1-006-2019) Pico-Tesla Wheatstone Bridge Magnetoelectric Magnetometer Based on ΔE Effect (Invited)

N. Sun*[1]; C. Dong[1]; Y. He[1]

1. Northeastern University, USA

S4: Thermoelectric Energy Harvesting

Thermoelectric Energy Harvesting I

Room: Salon 3
Session Chair: Daryoosh Vashaee, North Carolina State University

9:20 AM

(EHS-S4-001-2019) Power conversion and it efficiency in thermoelectric materials (Invited)

A. Feldhoff*[1]

1. Leibniz University Hannover, Institute of Physical Chemistry and Electrochemistry, Germany

9:50 AM

(EHS-S4-002-2019) Rapid synthesis and band engineering of advanced thermoelectric materials (Invited)

G. Tan*[1]

1. Wuhan University of Technology, State Key Lab of Advanced Technology for Materials Synthesis and Processing, China

10:20 AM

(EHS-S4-003-2019) Understanding phase stability and thermoelectric properties of $(Bi,Sb)_2(Se,Te)_3$ from an integrated first-principles and experimental approach (Invited)

S. Shang*[1]; Y. Wang[1]; A. Nozariasbmarz[1]; B. Poudel[1]; S. Priya[1]; Z. Liu[1]

1. Pennsylvania State University, Materials Science and Engineering, USA

10:50 AM

(EHS-S4-004-2019) Enhanced materials and module performance of Yb-single-filled skutterudite

W. Li*[1]; J. Wang[2]; Y. Xie[2]; J. Gray[1]; J. Heremans[2]; H. Kang[2]; B. Poudel[1]; A. Nozariasbmarz[1]; U. Saparamadu[1]; S. Huxtable[2]; S. Priya[1]

1. The Pennsylvania State University, Department of Materials Science and Engineering, USA
2. Virginia Tech, USA

11:10 AM

(EHS-S4-005-2019) Enhancing the thermoelectric performance of $SrTiO_3$-based ceramics by microstructural and nanostructural engineering

F. Azough[1]; D. Ekren[1]; Y. Lin[2]; I. Kinloch[1]; R. Freer*[1]

1. University of Manchester, Materials, United Kingdom
2. Northwestern University, Materials Science and Engineering, USA

11:30 AM

(EHS-S4-006-2019) Thermoelectric properties of Bi-Sb alloys at cryogenic temperature

X. Hu*[1]; S. Gao[1]; J. Gaskins[2]; P. E. Hopkins[2]; J. Poon[1]

1. University of Virginia, Physics, USA
2. University of Virginia, Mechanical and Aerospace Engineering, USA

S6: Special Symposium - The European Energy Harvesting Workshop

Special Symposium – The European Energy Harvesting Workshop

Room: Salon 2
Session Chair: Grzegorz Litak, Lubin University of Technology

9:20 AM

(EHS-S6-001-2019) Energy Harvesting for Structural Health Monitoring of our Built Infrastructure: Recent Advances (Invited)

V. Pakrashi*[1]

1. University College Dublin, Mechanical and Materials Engineering, Ireland

9:50 AM

(EHS-S6-002-2019) Advances in kinetic piezoelectric energy harvesters and future directions – Oulu perspective (Invited)

J. Palosaari[1]; M. Leinonen[1]; Y. Bai[1]; T. Siponkoski[1]; J. Hannu[1]; J. Juuti*[1]

1. University of Oulu, Microelectronics Research Unit, Finland

*Denotes Presenter

10:20 AM

(EHS-S6-003-2019) Composite Magnetostrictive-Nanocrystalline Materials for Use in the Field of Energy Harvesting and Energy Transformation (Invited)

R. Mech*[1]

1. Wroclaw Univeristy of Science and Technology, Poland

10:50 AM

Break

11:00 AM

(EHS-S6-004-2019) EnABLES: European Infrastructure Powering the Internet of Things (Invited)

S. Beeby*[1]; M. Hayes[2]; J. Donnelly[2]; R. Salot[3]; G. Savelli[3]; P. Spies[4]; G. vom Boegel[5]; M. Konijnenburg[6]; B. Breitung[7]; A. Romani[8]; C. Gerbaldi[9]; L. Gammaitoni[10]

1. University of Southampton, School of Electronics and Computer Science, United Kingdom
2. Tyndall National Institute, Ireland
3. CEA-Leti, France
4. Fraunhofer IIS, Germany
5. Fraunhofer IMS, Germany
6. IMEC-NL, Netherlands
7. KIT/HIU, Germany
8. University of Bologna, Italy
9. Politecnico di Torino, Italy
10. University of Perugia, Italy

11:30 AM

(EHS-S6-005-2019) Energy Autonomous and Smart Devices For A New Generation Of IoT (Invited)

M. Magno*[1]

1. ETH Zurich, D-ITET, Switzerland

12:00 PM

(EHS-S6-006-2019) Piezoelectric Beams, Magnets and Stoppers as Building Blocks for Transducers and Autonomous Sensors (Invited)

C. Trigona[1]; S. Baglio*[1]

1. University of Catania, DIEEI, Italy

Plenary II

Room: Salon 4

Session Chair: Yang Bai, University of Oulu

1:30 PM

Introduction

1:35 PM

(EHS-PLEN-002-2019) Triboelectric-based Self-Powered Smart Skin

H. Zhang*[1]

1. Peking University, China

S1: Mechano-Magneto-Electric Energy Harvesting

Mechano-Magneto-Electric Energy Harvesting II

Room: Salon 1

Session Chair: Yaojin Wang, Nanjing University of Science and Technology

2:30 PM

(EHS-S1-007-2019) Nonlinear Control Circuit for Piezoelectric Energy Harvesting Circuit (Invited)

Y. Wen*[1]; P. Li[1]; T. Han[1]; X. Ji[1]

1. Shanghai Jiao Tong University, China

3:00 PM

(EHS-S1-008-2019) High-efficiency Double-resonance, Self-powered Harvesting Circuit for Weak Piezoelectric Energy Harvester (Invited)

P. Li*[1]; Y. Wen[1]; T. Han[1]; X. Ji[1]

1. Shanghai Jiao Tong University, China

3:30 PM

(EHS-S1-009-2019) Multiple physical mechanisms based micro-energy harvesters for powering wireless sensor network (WSN) (Invited)

S. Dong*[1]

1. Peking University, Materials Science & Engineering, China

4:00 PM

(EHS-S1-010-2019) Automatic Resonance Tuning Mechanism for Ultra-wide Bandwidth Mechanical Energy Harvesting (Invited)

H. Song*[1]

1. Korea Institute of Science and Technology, Center for Electronic Materials, Republic of Korea

S3: Multi-functional Energy Conversion Materials and Devices for Energy Harvesting and/or Sensing

Multi-functional Energy Conversion Materials and Devices for Energy Harvesting and/or Sensing I

Room: Salon 2

Session Chair: James Roscow, University of Bath

2:30 PM

(EHS-S3-001-2019) Layered materials exhibiting piezoelectric and structural phase change properties (Invited)

D. Rehn[1]; G. Cheon[1]; E. Reed*[1]

1. Stanford University, USA

3:00 PM

(EHS-S3-002-2019) Ferroelectric materials ~ advantages of harnessing inherrent functionality (Invited)

S. Dunn*[1]

1. London South Bank University, United Kingdom

3:30 PM

(EHS-S3-003-2019) Probing of ferroelectric and magnetic properties of $BiFeO_3$ thin films

D. Sobola*[1]; S. Ramazanov[2]; P. Tofel[1]; V. Holcman[1]

1. Brno University of Technology, Department of Physics, Czechia
2. Dagestan State University, Faculty of Physics, Russian Federation

3:50 PM

(EHS-S3-004-2019) Determination of the suitable piezoelectric ceramics depending on various types of piezoelectric energy harvesters for large output power

S. Kim*[1]; C. Kang[2]; S. Nahm[1]

1. Korea University, Materials Science & Engineering, Republic of Korea
2. Korea Institute of Science and Technology, Center for Electronic Materials, Republic of Korea

4:10 PM

(EHS-S3-005-2019) Printable energy harvesters based on polymer nanocomposites

P. Costa*[1]; T. Marinho[1]; S. Gonçalves[2]; V. M. Correia[2]; J. C. Viana[3]; S. Lanceros-Mendez[4]

1. University of Minho, Physics, Portugal
2. University of Minho, Algoritmi, Portugal
3. University of Minho, Polymers Engineering, Portugal
4. Basque Centre for Materials, Physics, Spain

S4: Thermoelectric Energy Harvesting

Thermoelectric Energy Harvesting II

Room: Salon 3

Session Chair: Armin Feldhoff, Leibniz University Hannover

2:30 PM

(EHS-S4-007-2019) Half-Heusler Thermoelectric Materials Coming of Age (Invited)

J. Poon*[1]

1. University of Virginia, Physics, USA

3:00 PM

(EHS-S4-008-2019) High Performance Thermoelectric Modules Based on Half-Heusler Alloys (Invited)

B. Poudel*[1]; U. Saparamadu[1]; H. Kang[1]; A. Nozariasbmarz[1]; W. Li[1]; S. Priya[1]

1. Penn State University, Materials Science and Engineering, USA

3:30 PM

(EHS-S4-009-2019) High Temperature Air Stability of Half-Heusler Alloys for Thermoelectric Energy Harvesting

H. Kang*[1]; U. Saparamadu[2]; A. Nozariasbmarz[2]; W. Li[2]; B. Poudel[2]; S. Priya[2]

1. Virginia Tech, USA
2. Pennsylvania State University, Materials Science and Engineering, USA

3:50 PM

(EHS-S4-010-2019) Synthesis, Design and Fabrication of Oxide Thermoelectrics via Plasma Spray Technology

F. Caliari*[1]; H. Lee[2]; S. Sampath[1]

1. Stony Brook University, Center for Thermal Spray Research, USA
2. Oerlikon Metco, USA

4:10 PM

(EHS-S4-011-2019) A Thermodynamic Perspective on Seebeck Coefficient

Y. Wang*[1]; S. Shang[1]; F. R. Drymiotis[2]; S. Firdosy[2]; K. E. Star[2]; J. Fleurial[2]; V. Ravi[2]; L. Chen[1]; Z. Liu[1]

1. The Pennsylvania State University, Department of Materials Science and Engineering, USA
2. Jet Propulsion Laboratory, USA

Plenary III

Room: Salon 4

Session Chair: Shashank Priya, Pennsylvania State University

4:45 PM

Introduction

4:50 PM

(EHS-PLEN-003-2019) Challenges and Ways Forward for Energy Harvesting Powered Sensor Systems

M. Zhu*[1]

1. University of Exeter, United Kingdom

Poster Session

Room: Ballroom Foyer

6:00 PM

(EHS-P001-2019) Preparation of graphene-based materials and dielectrics suitable for supercapacitors using pure and waste materials

I. G. Markovska*[1]; M. Mitkova[1]; F. Yovkova[1]; D. Georgiev[1]

1. Prof. Assen Zlatarov University, Bulgaria

(EHS-P002-2019) BCZT, BCZTCe and BCST system used in Energy Harvesting

P. Tofel*[1]

1. BUT Brno, Czechia

(EHS-P003-2019) SPM techniques for characterization of PVDF nanofibers

D. Sobola*[1]; P. Tofel[1]; P. Škarvada[1]; V. Holcman[1]

1. Brno University of Technology, Department of Physics, Czechia

(EHS-P004-2019) Stretchable fiber-type piezoelectric nanogenerator and strain sensor

J. Ryu*[1]; S. Eom[1]; J. Kim[1]; S. Park[1]; S. Hong[1]

1. Korea Advanced Institute of Science and Technology, Materials Science and Engineering, Republic of Korea

(EHS-P005-2019) Polymer-based all-printed piezo-magnetically responsive sensors and actuators

A. C. Lima[2]; P. Rita*[2]; N. Perinka[1]; N. Pereira[3]; V. M. Correia[3]; P. Martins[2]; S. Lanceros-Mendez[1]

1. BCMaterials, Basque Center for Materials, Applications and Nanostructures, Spain
2. University of Minho, Center of Physics, Portugal
3. Center Algoritmi, University of Minho, Portugal

(EHS-P006-2019) Energy Recovery Method from Shock Demagnetisation of NdFeB-GMM-Ceramic of Magnetic Resonator

R. Mech*[1]

1. Wroclaw Univeristy of Science and Technology, Poland

(EHS-P007-2019) Low Frequency, Low Vibration Multi-Lever Energy Harvesting System

S. Eom*[1]; J. Ryu[1]; J. Kim[1]; S. Cho[1]; S. Hong[1]

1. Korea Advanced Institute of Science and Technology (KAIST), Materials Science & Engineering, Republic of Korea

(EHS-P008-2019) Bistable Piezoelectric Energy Harvester with Novel Layered Architecture

O. Rubes*[1]; Z. Hadas[1]

1. Brno University of Technology, Czechia

(EHS-P009-2019) Fabric-based wearable piezoelectric energy harvester with heterostructure

J. Kim*[1]; S. Byun[2]; S. Lee[3]; J. Ryu[1]; C. Oh[1]; S. Cho[1]; K. No[1]; S. Ryu[3]; Y. Lee[2]; S. Hong[1]

1. KAIST, Materials Science and Engineering, Republic of Korea
2. DGIST, Energy Science and Engineering, Republic of Korea
3. KAIST, Mechanical Engineering, Republic of Korea

(EHS-P010-2019) Pure KNN piezoelectric ceramics fabricated by two-step sintering for energy harvester application

G. Ye*[1]

1. University of Birmingham, Metallurgy and Materials, United Kingdom

(EHS-P011-2019) Detetction and Control of Multi-Arrays Inductive Power Transmission System

G. Bouattour*[1]; H. D. Ben Jmeaa[2]; O. Kanoun[1]

1. Technische Universität Chemnitz, Germany
2. University of Sfax, Tunisia

(EHS-P012-2019) Adhesion layer study on the energy harvesting performance of the magneto-mechano-electric harvester

S. Kim*[1]; A. Thakre[1]; S. Park[1]; J. Ryu[1]

1. Yeungnam University, Materials Science and Engineering, Republic of Korea

(EHS-P013-2019) Enhancing output power of Magneto-Mechano-Electric Generator by Magnetic Flux Concentration

H. Song*[1]; J. Ryu[1]

1. Yeungnam University, Material Science and Engineering, Republic of Korea

Thursday, September 5, 2019

Plenary IV

Room: Salon 4

Session Chair: Jungho Ryu, Yeungnam University

8:00 AM

Introduction

8:05 AM

(EHS-PLEN-004-2019) Piezoelectric Films for Energy Harvesting

D. Wang[1]; V. Kovacova[1]; J. Yang[1]; S. Trolier-McKinstry*[1]

1. Pennsylvania State University, Materials Scienece and Engineering, USA

*Denotes Presenter

S1: Mechano-Magneto-Electric Energy Harvesting

Mechano-Magneto-Electric Energy Harvesting III

Room: Salon 1

Session Chair: Isaku Kanno, Kobe University

9:00 AM

(EHS-S1-011-2019) A high power Magneto-mechano-triboelectric generator (MMTEG) for IoT systems (Invited)

G. Hwang[2]; K. Lim[2]; W. Yoon[2]; J. Ryu*[1]

1. Yeungnam University, Republic of Korea
2. Korea Institute of Materials Science, Republic of Korea

9:30 AM

(EHS-S1-012-2019) Magneto-mechano-electric energy generator for efficient energy harvesting from low magnetic field (Invited)

M. Kang*[1]; R. Sriramdas[1]; S. Priya[1]

1. Pennsylvania State University, Department of Materials Science and Engineering, USA

10:00 AM

(EHS-S1-013-2019) Magnetoelectric vibrational energy harvester utilizing a phase transitional approach (Invited)

P. Finkel*[1]; M. Staruch[1]

1. 1. Naval Research Laboratory, Washington, DC, United States., USA

10:30 AM

(EHS-S1-014-2019) Polymer-based magnetoelectric films for wearable energy harvesters (Invited)

S. Yang*[1]

1. Dong-A University, Republic of Korea

11:00 AM

(EHS-S1-015-2019) All-inorganic flexible piezoelectrics for energy conversion and sense applications (Invited)

Y. Wang*[1]

1. Nanjing University of Science and Technology, Department of Materials Science and Engineering, China

11:30 AM

(EHS-S1-016-2019) Hybrid vibration converter for energy harvesting under weak vibration sources

S. Bradai*[1]; O. Kanoun[1]

1. Chemnitz University of Techmology, Electrical Engineering, Germany

11:50 AM

(EHS-S1-017-2019) Magnetoelectric (ME) Coupling of Textured Galfenol/(011) PMN-PZT Single Crystal Composite

H. Song*[1]; J. Ryu[1]

1. Yeungnam University, Material Science and Engineering, Republic of Korea

S3: Multi-functional Energy Conversion Materials and Devices for Energy Harvesting and/or Sensing

Multi-functional Energy Conversion Materials and Devices for Energy Harvesting and/or Sensing II

Room: Salon 2

Session Chair: Carlo Trigona, University of Catania

9:00 AM

(EHS-S3-006-2019) Flexible energy harvesters and sensors based on multi-functional device platforms (Invited)

S. Kar-Narayan*[1]

1. University of Cambridge, United Kingdom

9:30 AM

(EHS-S3-007-2019) Energy Harvesting Using Flexible Lead-free Piezoelectric Composites (Invited)

P. Groen*[1]

1. Technical University Delft, Faculty of Aerospace Engineering, Netherlands

10:00 AM

(EHS-S3-008-2019) Maximising energy harvesting performance using piezoceramic composites (Invited)

J. Roscow*[1]

1. University of Bath, United Kingdom

10:30 AM

Break

10:40 AM

(EHS-S3-009-2019) Piezoelectric properties of (Li, Na, K)(Nb, Sb)O_3-$CaZrO_3$ lead-free ceramics and thick-films for piezoelectric energy harvester

S. Chae*[1]; S. Nahm[1]

1. KU-KIST Graduate School of Converging Science and Technology, Korea University, Republic of Korea

11:00 AM

(EHS-S3-010-2019) <001> textured Mn-doped PZT-PZN-PNN hard piezoelectric ceramics

H. Leng*[1]; Y. Yan[1]; H. Liu[1]; S. Priya[1]

1. The Pennsylvania State University, Department of Materials Science and Engineering, USA

11:20 AM

(EHS-S3-011-2019) Cold Sintering for Lead-Free Piezoelectric Ceramics

K. Tsuji*[1]; C. Randall[1]

1. The Pennsylvania State University, Materials Science and Engineering, USA

11:40 AM

(EHS-S3-012-2019) Cold Sintering of Materials for Energy Storage

C. Randall*[2]; A. Ndayishimiye[2]; J. Seo[1]; H. Nakaya[3]; S. Bang[1]; K. Tsuji[1]; Z. Grady[1]

1. Penn State University, Materials Science and Engineering, USA
2. Penn Sate University, Materials Research Institute, USA
3. NGK SPARK PLUG CO., LTD., Komaki, Aichi, Japan., Japan

S4: Thermoelectric Energy Harvesting

Thermoelectric Energy Harvesting III

Room: Salon 3

Session Chair: Bed Poudel, Penn State University

9:00 AM

(EHS-S4-012-2019) Flexible Thermoelectric Generators with Bulk Thermoelectric Materials and Stretchable, Low-Resistivity Liquid Metal Interconnects (Invited)

M. C. Ozturk*[1]

1. North Carolina State University, Electrical and Computer Engineering, USA

9:30 AM

(EHS-S4-013-2019) The Rise of Paramagnetic Thermoelectric Materials (Invited)

D. Vashaee*[1]; M. H. Polash[2]; V. Perelygin[3]; A. Smirnov[3]

1. North Carolina State University, Dept. of Electrical and Computer Engineering, USA
2. North Carolina State University, Dept. of Materials Science and Engineering, USA
3. North Carolina State University, Dept. of Chemistry, USA

10:00 AM

(EHS-S4-014-2019) Solid-state thermionic devices based on 2D van der Waals heterostructures (Invited)

M. Zebarjadi*[1]; G. Rosul[1]

1. University of Virginia, Electrical and Computer Eng., USA

10:30 AM

(EHS-S4-015-2019) Sizing a thermoelectric energy harvester for maximum performance in a constantly varying aerospace environment (Invited)

M. R. Pearson*[1]; W. Veronesi[1]
1. United Technologies Research Center, Thermal Fluid Sciences, USA

11:00 AM

(EHS-S4-016-2019) Highly efficient NbFeSb based thermoelectric devices for waste heat recovery applications

U. Saparamadu*[1]; B. Poudel[1]; A. Nozariasbmarz[1]; W. Li[1]; H. Kang[2]; C. Dettor[1]; S. Priya[1]
1. The Pennsylvania State University, Material Science and Engineering, USA
2. Bio-inspired Materials and Devices Laboratory (BMDL), Mechanical Engineering, USA

11:20 AM

(EHS-S4-017-2019) Thermoelectric Modules Optimization for Low-grade Heat Recovery

A. Nozariasbmarz*[1]; B. Poudel[1]; R. Kishore[2]; U. Saparamadu[1]; W. Li[1]; S. Priya[1]
1. Pennsylvania State University, Materials Science and Engineering, USA
2. Center for Energy Harvesting Materials and Systems, Virginia Tech, USA

11:40 AM

(EHS-S4-018-2019) Tuning thermoelectric power factor in flexible device made by two-dimensional crystals of MoS_2

X. Zhang*[1]
1. Stevens Institute of Technology, Mechanical Engineering, USA

Plenary V

Room: Salon 4

Session Chair: Shashank Priya, Pennsylvania State University

1:30 PM

Introduction

1:35 PM

(EHS-PLEN-005-2019) Working Towards a Sustainable World with Clean Abundant Energy

L. D. Madsen*[1]
1. National Science Foundation, USA

S1: Mechano-Magneto-Electric Energy Harvesting

Mechano-Magneto-Electric Energy Harvesting IV

Room: Salon 1

Session Chair: Peter Finkel, Naval Research Laboratory, Washington, DC, United States.

2:30 PM

(EHS-S1-018-2019) Flexible PZT thin films on stainless steel foils for energy harvesters (Invited)

I. Kanno*[1]
1. Kobe University, Mechanical Engineering, Japan

3:00 PM

(EHS-S1-019-2019) Energy Harvesting of a Composite Beam with Optimizing Stacking Sequence of Layers

M. Borowiec*[1]; M. Bochenski[1]; J. Gawryluk[1]
1. Lublin University of Technology, Department of Applied Mechanics, Poland

3:20 PM

(EHS-S1-020-2019) Power Amplification through Distributed Forcing at 60 Hz Frequency in Magnetoelectric Energy Harvesters

R. Sriramdas*[1]; M. Kang[1]; S. Priya[1]
1. Pennsylvania State University, Materials Science and Engineering, USA

S2: Integrated Energy Harvesting and Storage Systems for Wearables and IoT

Integrated Energy Harvesting and Storage Systems for Wearables and IoT I

Room: Salon 3

Session Chair: Sebastian Bader, Mid Sweden University

2:30 PM

(EHS-S2-001-2019) Is Energy Wearable? Toward Self-Sustaining Smart Wearable and IoT Devices (Invited)

M. Magno*[1]
1. ETH Zurich, D-ITET, Switzerland

3:00 PM

(EHS-S2-002-2019) Fabric Power Modules for e-Textiles Applications (Invited)

S. Beeby*[1]
1. University of Southampton, School of Electronics and Computer Science, United Kingdom

3:30 PM

(EHS-S2-003-2019) Power Estimation for Wearable Energy Harvesting Devices

G. Rai*[1]; T. Safwat[1]; C. Rahn[1]; Z. Ounaies[1]
1. The Pennsylavnia State University, Mechanical Engineering, USA

3:50 PM

Break

4:00 PM

(EHS-S2-004-2019) Rail trackside energy harvesting devices: Feasibility study, development, tests and future potential (Invited)

Z. Hadas*[1]; O. Rubes[1]; P. Tofel[2]
1. Brno University of Technology, Faculty of Mechanical Engineering, Czechia
2. Brno University of Technologi, Czechia

4:30 PM

(EHS-S2-005-2019) Modelling Validation of Vibration Energy Harvesting for Structural Health Monitoring of Water Pipes (Invited)

V. Pakrashi*[1]; F. O. Okosun[1]
1. University College Dublin, Mechanical and Materials Engineering, Ireland

5:00 PM

(EHS-S2-006-2019) Nonlinear vibration energy harvesting systems with a piezoelectric transducer in presence of harmonic excitations and additional noise (Invited)

G. Litak*[1]
1. Lubin University of Technology, Poland

S3: Multi-functional Energy Conversion Materials and Devices for Energy Harvesting and/or Sensing

Multi-functional Energy Conversion Materials and Devices for Energy Harvesting and/or Sensing III

Room: Salon 2

Session Chair: Evan Reed, Stanford University

2:30 PM

(EHS-S3-013-2019) Roll-to-Roll Slot Die Coated Perovskite for Efficient Flexible Solar Cells

P. Groen*[1]
1. Holst Centre, Netherlands

2:50 PM

(EHS-S3-014-2019) Treated Perovskite Single Crystals for Solar Cell with Unprecedented Power Conversion Efficiency (Invited)

O. Mohammed*[1]
1. KAUST, Chemistry, Saudi Arabia

3:20 PM

(EHS-S3-015-2019) A solar-powered piezoelectric/pyroelectric sensor containing a single energy conversion/sensing material

Y. Bai*[1]; J. Palosaari[1]; H. M. Jantunen[1]; J. Juuti[1]
1. University of Oulu, Finland

3:40 PM

Break

3:50 PM

(EHS-S3-016-2019) Development of photothermal chlorophyll thin-films for energy applications

D. Shi*[1]; Y. Zhao[1]
1. University of Cincinnati, Mechanical and Materials Engineering, USA

4:10 PM

(EHS-S3-017-2019) Surface Reaction-Driven Pyroelectric Energy Conversion

B. Hanrahan*[1]; A. Smith[2]; S. Karnani[1]; H. Kareem[1]; L. Mahoney[1]
1. U.S. Army Research Laboratory, USA
2. U.S. Naval Academy, USA

4:30 PM

(EHS-S3-018-2019) Bio-inspired Vitamin Assisted Single-Structured based Self-Powered Piezoelectric/Wind/Acoustic Multi-Energy Harvester with Remarkable Power Density

S. K. Karan*[1]; S. Maiti[1]; B. Khatua[1]
1. Indian Institute of Technology Kharagpur, India, Materials Science Centre, India

4:50 PM

(EHS-S3-019-2019) All- printed magnetic power transformer and power transmission systems for wearable sensors and actuators

V. M. Correia*[1]; N. Pereira[1]; A. C. Lima[2]; P. Martins[2]; N. Perinka[3]; S. Lanceros-Mendez[3]
1. Universidade do Minho, Algoritmi, Portugal
2. Universidade do Minho, Centro de Fisica, Portugal
3. Basque Center for Materials, Applications and Nanostructures, Spain

5:10 PM

(EHS-S3-020-2019) Low-temperature cofired magnetoelectric voltage tunable inductor (VTIs) with high current saturation

X. Li*[1]; Y. Yan[1]; S. Priya[1]
1. Penn State University, USA

5:30 PM

(EHS-S3-021-2019) Material design of magnetoelectric voltage tunable inductors

Y. Yan*[1]; S. Priya[1]
1. Pennsylvania State University, Materials Science and Engineering, USA

S5: Piezoelectric and Triboelectric Energy Harvesting using Low-Dimensional Materials

Piezoelectric and Triboelectric Energy Harvesting using Low-Dimensional Materials I

Room: Salon 1
Session Chair: M. Jasim Uddin, University of Texas Rio Grande Valley

3:50 PM

(EHS-S5-001-2019) New lead-free piezoelectric thin film fabricated using metal-oxide nanosheets for piezoelectric energy harvester (Invited)

M. Im[1]; W. Lee[1]; S. Kweon[2]; S. Nahm*[1]
1. Korea University, Department of Materials Science and Engineering, Republic of Korea
2. Kobe University, Department of Mechanical Engineering, Japan

4:20 PM

(EHS-S5-002-2019) Neuron-like Energy Harvesting (Invited)

W. Shim*[1]
1. Yonsei University, Department of Materials Science and Engineering, Republic of Korea

4:50 PM

(EHS-S5-003-2019) Nature driven bio-waste spider silk as high energy conversion efficient biopiezoelectric nanogenerator

S. Maiti*[1]; J. Kim[1]
1. Pohang University of Science and Technology South Korea, Department of Chemical Engineering, Republic of Korea

5:10 PM

(EHS-S5-004-2019) Flexible electronic skins based on piezoelectric nanogenerators and piezotronics

H. Yuan*[1]
1. Xidian University, China

Friday, September 6, 2019

Plenary VI

Room: Salon 4
Session Chair: Yang Bai, University of Oulu

8:00 AM

Introduction

8:05 AM

(EHS-PLEN-006-2019) Symbiosis of energy conversion and system design for efficient energy harvesting solutions

O. Kanoun*[1]; T. Keutel[1]; C. Viehweger[1]; S. Naifar[1]; S. Bradai[1]; G. Bouattour[1]; S. Khriji[1]; D. El Houssaini[1]
1. Chemnitz University of Technology, Chair for Measurement and Sensor Technology, Germany

S2: Integrated Energy Harvesting and Storage Systems for Wearables and IoT

Integrated Energy Harvesting and Storage Systems for Wearables and IoT II

Room: Salon 2
Session Chair: Zdenek Hadas, Brno University of Technology

9:00 AM

(EHS-S2-007-2019) On-rotor Sensor Systems based on Variable Reluctance Energy Harvesting (Invited)

S. Bader*[1]
1. Mid Sweden University, Department of Electronics Design, Sweden

9:30 AM

(EHS-S2-008-2019) A New Generation of mm-Scale Harvesting Interface Circuits to Enable mW-Scale IoT (Invited)

A. Muhtaroglu*[1]; H. O. Tabrizi[2]; P. Jayaweera[2]
1. METU Northern Cyprus Campus, Electrical-Electronics Engineering, Turkey
2. METU Northern Cyprus Campus, Sustainable Environment and Energy Systems, Turkey

10:00 AM

(EHS-S2-009-2019) A Single-Stage-Multi-Output Reconfigurable Shared-Inductor Buck-Boost-Converter/Current-Mode Inductive Power Management

H. Sadeghi Gougheri[1]; M. Kiani*[1]
1. Penn State University, EE, USA

10:20 AM

Break

10:30 AM

(EHS-S2-010-2019) Strategies for integrating super and pseudocapapcitor devices (Invited)

O. Pitkänen[1]; H. M. Jantunen[1]; K. Kordas*[1]

1. University of Oulu, Finland

11:00 AM

(EHS-S2-011-2019) Cold sintering process for developement of all-solid-state Li batteries

J. Seo*[3]; E. Gomez[1]; T. Mallouk[2]; C. Randall[3]

1. Penn State University, Chemical Engineering, USA
2. Penn State Univeristy, Chemistry, USA
3. Penn State University, Materials Science and Engineering, USA

S5: Piezoelectric and Triboelectric Energy Harvesting using Low-Dimensional Materials

Piezoelectric and Triboelectric Energy Harvesting using Low-Dimensional Materials II

Room: Salon 1

Session Chairs: Miso Kim, Korea Research Institute of Standards and Science; Sohini Kar-Narayan, University of Cambridge

9:00 AM

(EHS-S5-008-2019) Design and Energy Application of Piezoelectric Biomaterials (Invited)

R. Yang*[1]

1. Xidian University, School of Advanced Materials and Nanotechnology, China

9:30 AM

(EHS-S5-006-2019) Hybrid nanomanufacturing of hierarchical wearable devices for self-powered user interface (Invited)

W. Wu*[1]

1. Purdue University, School of Industrial Engineering; Birck Nanotechnology Center; Regenstrief Center for Healthcare Engineering, USA

10:00 AM

(EHS-S5-007-2019) Nanostructured polymers for piezoelectric and triboelectric energy harvesting applications (Invited)

S. Kar-Narayan*[1]

1. University of Cambridge, United Kingdom

10:30 AM

(EHS-S5-005-2019) Self-resonant Energy Harvester with a Passively Tuned Sliding Mass (Invited)

H. Kim*[1]

1. Virginia Tech, USA

11:00 AM

(EHS-S5-009-2019) Compliant triboelectric nanogenerator for human machine interface (Invited)

P. Lee*[1]

1. Nanyang Technological University, School of Materials Science and Engineering, Singapore

11:20 AM

(EHS-S5-010-2019) Surface Modified One-Dimensional Lithium Doped Zinc Oxide in a Piezo-Tribo Hybrid Nanogenerator for Cost Effective Load and Stress Measurement

M. Uddin*[1]; A. Chowdhury[1]; A. Abdullah[2]

1. University of Texas Rio Grande Valley, Chemistry, USA
2. University of Texas Rio Grande Valley, Mechanical Engineering, USA

11:40 AM

(EHS-S5-011-2019) Multi-Beam Shared-Inductor Reconfigurable Voltage/SECE-Mode Piezoelectric Energy Harvesting of Multi-Axial Human Motion

M. Meng[1]; M. Kiani*[1]

1. Penn State University, EE, USA

Wednesday, September 4, 2019

Plenary I
Room: Salon 4
Session Chair: Jungho Ryu, Yeungnam University

8:20 AM

(EHS-PLEN-001-2019) Tailoring Materials and Structures for Energy Harvesting: From Nanofibers To Metamaterials

M. Kim*[1]

1. Korea Research Institute of Standards and Science, Republic of Korea

A key challenge has been insufficient sustainable power generation for practical applications, despite all the benefits of self-powering and green enabling technology. Metamaterials, an ideal platform to manipulate mechanical waves, enable amplification of input mechanical wave energy such as sound, vibration and ultrasonic waves, thus providing a way of drastic enhancement in energy harvesting. Here, we summarize a collection of advances that push the boundaries to achieve a new paradigm of energy harvesting systems using various metamaterial designs ranging from phononic crystals to elastic and acoustic Gradient Index (GRIN) metamaterials. Engineering structural morphology of piezoelectric materials from molecular to device scales will also be discussed as a route to achieving improvement in the key figures of merit for energy harvesting and sensing, along with our unfolding new understanding of the underlying physics.

S1: Mechano-Magneto-Electric Energy Harvesting

Mechano-Magneto-Electric Energy Harvesting I
Room: Salon 1
Session Chair: Su Chul Yang, Dong-A University

9:20 AM

(EHS-S1-001-2019) Polymer-based Magnetoelectric Materials for Sensors, Actuators and Energy Harvesting: Materials, applications, challenges (Invited)

S. Lanceros-Mendez*[1]

1. BCMaterials, Basque Center for Materials, Applications and Nanostructures, Spain

A decade ago, the ‘polymer-based magnetoelectric” idea changed thinking in multiferroic magnetoelectric (ME) materials research, resulting in a new generation of high-performance materials and an increased focus on controlling structure, flexibility and electrical output, as well as in implementation into proof of concept applications. The present talk will report and discuss on the main materials, applications and challenges of polymer based ME materials. An overview of the main physical phenomena involved will allow to define the best materials for specific ME ouputs. Further, polymer based ME materials topologies will be defined and the main characteristics and advantages of each of them discussed. Processing technologies, including those allowing up scaled production of the materials will be presented before applications in the areas of sensors, actuators and energy harvesting are highlighted, with some particular remarks on the applicability of the materials in the biomedical area. Finally, the main open challenges and some guidelines for future research will be introduced.

9:50 AM

(EHS-S1-002-2019) Laser-induced phenomena and enhancement of magnetoelectric coupling in piezoelectric/magnetostrictive film composites (Invited)

H. Palneedi*[1]; D. Maurya[2]; J. Ryu[3]; S. Priya[1]

1. The Pennsylvania State University, Materials Science and Engineering, USA
2. Virginia Tech, Center for Energy Harvesting Materials and Systems, USA
3. Yeungnam University, Materials Science and Engineering, Republic of Korea

Multiferroic magnetoelectric (ME) materials are attractive for various electrically and magnetically cross-coupled devices in sensing, transduction, memory, and energy harvesting applications. ME composites formed with piezoelectric and magnetostrictive constituents exhibit orders of magnitude larger ME coupling than that observed in single phase ME compounds at room temperature. This work addresses the processing issues raised by the thermodynamic incompatibility between piezoelectric ceramic ($Pb(Zr,Ti)O_3$, PZT) films and magnetostrictive metal (Metglas, Ni) substrates. To this end, an emerging additive manufacturing approach, involving a combination of room temperature deposition by Granule Spray in Vacuum (GSV) technique and localized annealing of the PZT films using laser radiation, was adopted. Some interesting optical and microstructural phenomena, induced by laser-material interaction, in the ME composites are discussed. By exploiting the critical structural and magneto-mechanical parameters in the ME composites, near-theoretical ME coupling (7 V/cm.Oe) was achieved in PZT/Metglas while a strong and fully self-biased ME response (3 V/cm.Oe) was obtained from PZT/Ni. These results are some of the best reported values among similar ME composite systems. The significant outcomes of this study will expedite the development of ME based practical devices.

10:20 AM

(EHS-S1-003-2019) Magnetoelectrically-coupled room-temperature single-phase ferromagnetic-ferroelectric ceramics (Invited)

J. Cho[1]; J. Lee[1]; H. Lee[2]; N. Lee[3]; G. Lee[1]; G. Hwang[4]; S. Kim[3]; J. Lee[2]; W. Jo*[1]

1. Ulsan National Institute of Science and Technology, School of Materials Science and Engineering, Republic of Korea
2. Ulsan National Institute of Science and Technology, School of Energy and Chemical Engineering, Republic of Korea
3. University of Ulsan, Department of Physics, Republic of Korea
4. Korea Institute of Materials Science, Functional Ceramics Group, Republic of Korea

Multiferroicity, defined as an ensemble of more than two ferroic properties among ferromagnetism, ferroelectricity, and ferroelasticity, has been studied extensively due to its high potential for entirely new application opportunities such as ferroelectric photovoltaics, next-generation memory devices, etc.. Nevertheless, room-temperature ferroelectric-ferromagnetic multiferroicity relevant for practical applications has not been realized in a single-phase material, yet. The state of the art for room-temperature multiferroics is limited mostly to antiferromagnetic-ferroelectric $BiFeO_3$ or some elaborately fabricated thin film type of materials with an improper ferroelectricity. Here we report that a ferromagnetic order can be induced and directly coupled to an existing ferroelectric order persisting well above room temperature. We expect that the current work will open vast opportunities for developing practically viable room-temperature single-phase multiferroic ceramics with a strong coupling between ferromagnetism and ferroelectricity.

10:50 AM

(EHS-S1-004-2019) Automatic low cost magnetoelectric coefficient at resonance and effective deliverable power measurement bench

K. Malleron*[1]; A. Gensbittel[2]; H. Talleb[2]

1. Institut Superieur d'Electronique de Paris, LISITE, France
2. Sorbonne Universite, L2E, France

A magnetoelectric (ME) transducers used to wirelessly power some devices for biomedical applications or monitoring systems for example. In order to characterize those laminated composite transducers, a compact and low cost new measurement bench has been developed to apply static and dynamic magnetic fields. Electromagnets are widely use to impose a uniform static magnetic field to magnetically polarize the magnetoelectric transducers. In this work, this new measurement set-up uses a layout of permanent magnets driven by a DC motor to impose a uniform static field. This solution reduce the input power needed and one can imagine that the final device will use a magnetic circuit with permanent magnets embedded resulting in a more compact system. This new bench also allows to measure automatically the ME open load voltage. To evaluate the effective deliverable power, the bench finds the resonant frequency and calculate the voltage for the adapted purely resistive load determined by the internal impedance of the transducer measured a priori. Measurements on thin ME laminate 2-2 composites, respecting the biomedical guidelines on magnetic fields, will be presented to show the expected power for a specified volume. Performances of the transducer will be derived from the amplitude of the AC magnetic field and different strategy to choose the DC magnetic field will be tested.

11:10 AM

(EHS-S1-005-2019) Layer structured face shear 36 mode Magnetoelectric composites with Piezoelectric single crystal and Metglas

S. Park*[1]; M. Peddigari[2]; G. Hwang[2]; A. Kumar[1]; W. Yoon[2]; J. Ryu[1]

1. Yeungnam University, Materials Science and Engineering, Republic of Korea
2. Korea Institute of Materials Science, Gyeongnam, Korea, Republic of Korea

The magnetoelectric (ME) composites are composed of magnetostrictive and piezoelectric materials and utilizing the product properties of the magnetic and electric behaviors of each constituents i.e., an electric signal can be generated from the composite under magnetic stimulus or vice versa. This characteristic is originated from the coupling between magnetostrictive strain and resultant piezoelectric charge generation. The magnetoelectric coupling has high potential for various applications, including high sensitivity magnetic sensors, current sensors, tunable inductors, energy harvesters, etc. Since ME coupling is the most important factor for the usage of ME composites in aforementioned applications, various approaches to enhance the coupling have being conducted by many research groups. Thus, to make ME composties with high ME coupling, the ME composite was fabricated using face shear 36 mode PMN-PZT single crystals and Metglas. As a result, the ME characteristic value of the 36 mode has a high ME coupling that is approximately 90% similar to the 32 mode in off-resonance and resonance condition. And the magnetic field sensitivity of 36 mode has very good sensitivity which can detect up to 2pT at resonant condition.

11:30 AM

(EHS-S1-006-2019) Pico-Tesla Wheatstone Bridge Magnetoelectric Magnetometer Based on ΔE Effect (Invited)

N. Sun*[1]; C. Dong[1]; Y. He[1]

1. Northeastern University, USA

Ultra-sensitive, compact size, and low cost magnetometers for DC and low frequency magnetic field measurement are significant in bio-magnetic sensing and magnetic anomaly detection. We present a resonant magnetoelectric (ME) magnetometer, which utilizes the magnetic field induced elastic modulus change, i.e. the ΔE effect in the magnetostrictive layers. The sensor is based on a magnetostrictive/piezoelectric heterostructure, and the magnetic field induced elastic modulus change will result in electromechanical resonant frequency shift in the ME heterostructure, which can be read out through the impedance of the piezoelectric layers. By integrating four of such ME sensors into a Wheatstone Bridge circuit structure, the impedance change in each sensor unit will induce a voltage output between the two branches of the circuit, which can accurately reflect the change of magnetic field. The maximum frequency shift of the ME sensor unit due to magnetization has been characterized as 11.5%, and with 0.3 mT bias magnetic field, the sensor has the highest frequency sensitivity of 8.2 kHz/mT. By driving all the sensor units at frequency between the resonance and anti-resonance, where the slope of the impedance curve over frequency gives the highest impedance sensitivity of 318 Ohm/Hz, the magnetometer has an overall sensitivity of 66501 V/T, and a extremely low limit of detection of 90 pT for DC magnetic field.

S4: Thermoelectric Energy Harvesting

Thermoelectric Energy Harvesting I

Room: Salon 3

Session Chair: Daryoosh Vashaee, North Carolina State University

9:20 AM

(EHS-S4-001-2019) Power conversion and it efficiency in thermoelectric materials (Invited)

A. Feldhoff*[1]

1. Leibniz University Hannover, Institute of Physical Chemistry and Electrochemistry, Germany

The thermoelectric generator relies on the thermal-induction of an electrical current (Seebeck effect). Usually, such device is considered to treat thermal to electrical power conversion and its efficiency. Here, an alternative approach is suggested, which allows consider the thermo-electric power conversion and its efficiency for a single thermoelectric material regardless of how it is implemented into a device. Starting point is an equation for the coupled flux of entropy and electrical charge, which utilizes a thermoelectric material tensor to describe the thermoelectric material, which is placed in thermodynamic potential gradients, i.e. of temperature (thermal) and electrical potential. It is emphasized that power conversion takes place in the thermoelectric material and the efficiency of power conversion can be treated apart from a device. Furtheron, it is shown that optimizing a thermoelectric material for maximum electrical power output - which relies on the power factor and is the prime interest of thermoelectric energy harvesting - or optimizing it for maximum efficiency - which relies on the figure-of-merit - are different tasks. Some prominent thermoelectric materials are assessed for their use in a thermoelectric harvester.

9:50 AM

(EHS-S4-002-2019) Rapid synthesis and band engineering of advanced thermoelectric materials (Invited)

G. Tan*[1]

1. Wuhan University of Technology, State Key Lab of Advanced Technology for Materials Synthesis and Processing, China

Thermoelectric materials are able to realize the direct conversion between heat and electricity. As such, thermoelectricity is supposed to be a good manner for energy harvesting and management. However, the use of thermoelectrics has two main limitations: (i) high cost from time- and energy-consuming materials synthesis procedures and (ii) low conversion efficiency from low performance of materials. Here in this talk we will share our recent work on rapid synthesis and band engineering of advanced thermoelectric materials. Specifically, we start with our recent efforts on employing self-propagating-high-temperature-syntheis (SHS) to prepare most conventional thermoelectric materials reported so far. The phase and microstructure evolutions during SHS are discussed. We then give a detailed introduction about band engineering (band convergence, resonant states, band gap enlargement, etc) to tailor the thermoelectric properties of thermoelectric materials with a focus on IV-VI semiconductors.

10:20 AM

(EHS-S4-003-2019) Understanding phase stability and thermoelectric properties of $(Bi,Sb)_2(Se,Te)_3$ from an integrated first-principles and experimental approach (Invited)

S. Shang*[1]; Y. Wang[1]; A. Nozariasbmarz[1]; B. Poudel[1]; S. Priya[1]; Z. Liu[1]

1. Pennsylvania State University, Materials Science and Engineering, USA

Bi_2Te_3-based thermoelectric (TE) materials are promising candidates to achieve exceptionally high figure of merit, ZT, by optimizing structure and chemistry. However, reliable digital data for materials design are lagging far behind the development of stable TE materials with high ZT. Here, we present a data-driven study of phase stability and TE properties of $(Bi,Sb)_2(Se,Te)_3$ as a function of temperature, composition, and defects via an integrated approach of first-principles calculations and experimental verifications. Phase stability of $(Bi,Sb)_2(Se,Te)_3$ is predicted via the quasiharmonic approach with vibrational contribution from phonon calculations; and TE properties including Seebeck coefficient, electrical conductivity, thermal conductivity, and carrier density are predicted by first-principles based Boltzmann transport theory and anharmonic phonon calculations. In addition, Seebeck coefficient is also predicted by a unique thermodynamic theory by calculating the change of electronic chemical potential induced by temperature. Predicted phase stability and TE properties are verified by temperature-dependent experiments, hence, the underlying science discovered from the created digital data can be used to understand and enable a robust design of Bi_2Te_3-based TE materials with exceptional stability and superior ZT.

10:50 AM

(EHS-S4-004-2019) Enhanced materials and module performance of Yb-single-filled skutterudite

W. Li*[1]; J. Wang[2]; Y. Xie[2]; J. Gray[1]; J. Heremans[2]; H. Kang[2]; B. Poudel[1]; A. Nozariasbmarz[1]; U. Saparamadu[1]; S. Huxtable[2]; S. Priya[1]

1. The Pennsylvania State University, Department of Materials Science and Engineering, USA
2. Virginia Tech, USA

The filling-fraction-limitation (FFL) in n-type $CoSb_3$ skutterudites is far below that of p-type $(Fe,Co)Sb_3$-base skutterudites and it is critical to increase FFL for accomplishing high thermoelectric figure of merit (ZT_{max}). Here a series of $Yb_xCo_{4-y}Fe_ySb_{12}$ alloys with x = 0.25-0.5 and y = 0.1-0.5 were synthesized that demonstrate a clear increase of the FFL of Yb from ~0.3 in $CoSb_3$ to 0.5. Ultra-low thermal conductivities of 2.0-2.5 W/m-K at 300 K and 1.75 W/m-K at ~600 K have been achieved, which are the lowest values reported among skutterudite materials, and comparable with p-type skutterudites. These ultra-low thermal conductivities result from the combination of secondary phase scattering and phonon scattering from dynamic electron exchange between Fe^{2+} and Co^{3+}. A high ZT_{max} value of 1.28 at 740 K and 1.34 at 780 K is obtained, which are among the best values reported in temperature range of 740-800 K. The temperature at which the maximum ZT_{max} appears is shifted to below 850 K. Combined with our p-type materials, we achieved output power of 785.5 mW and efficiency of 6.7% for uni-couple single stage module when hot side temperature is 500 °C under vacuum. These results are highly exciting towards development of multi-stage segmented and cascade thermoelectric power generators.

11:10 AM

(EHS-S4-005-2019) Enhancing the thermoelectric performance of $SrTiO_3$-based ceramics by microstructural and nanostructural engineering

F. Azough[1]; D. Ekren[1]; Y. Lin[2]; I. Kinloch[1]; R. Freer*[1]

1. University of Manchester, Materials, United Kingdom
2. Northwestern University, Materials Science and Engineering, USA

Donor-doped $SrTiO_3$-based ceramics are very promising n-type oxide thermoelectrics. We show that significant improvements in the thermoelectric power factor and the thermoelectric figure of merit (ZT) can be achieved by control of the nanostructure and microstructure in different ways. Self nano-structuring of ceramics of $Sr_{0.9}La_{0.1}TiO_3$ was achieved by the use of controlled heat treatment in air followed by annealing in a reducing atmosphere. High resolution transmission electron microscopy (HRTEM) showed the formation of a core-shell type structure within the grains; the cores contain nanosize features comprising pairs of nano-size voids and particles. The resulting nanostructure reduced thermal conductivity and increased power factor to 1600 $mW/m.K^2$ at 540 K. Low level doping of $(Sr,Nd)TiO_3$ by Zr promoted atomic level homogenization and a uniform distribution of Nd and Sr in the lattice, inducing greatly enhanced carrier mobility. Transport property measurements showed a significant increase in the power factor to 2000 $mW/m.K^2$, as a result of enhanced electrical conductivity. Finally single crystal-like charge transport was achieved in $(Sr,La)TiO_3$ by use of graphene additions. The great benefit of incorporating graphene into the microstructure was the massive expansion in the thermoelectric operating window from near to room temperature to 600C.

11:30 AM

(EHS-S4-006-2019) Thermoelectric properties of Bi-Sb alloys at cryogenic temperature

X. Hu*[1]; S. Gao[1]; J. Gaskins[2]; P. E. Hopkins[2]; J. Poon[1]

1. University of Virginia, Physics, USA
2. University of Virginia, Mechanical and Aerospace Engineering, USA

Bi-Sb alloys have shown promising thermoelectric (TE) properties at cryogenic temperature (<200 K). Over six decades, the figure of merit zT of n-type polycrystalline Bi-Sb has plateaued at ~0.4, while its p-type counterpart has remained even lower at ~0.1. We have studied the TE properties of melt-spun and spark plasma sintered (SPS) Bi-Sb alloys. We obtained a zT of 0.55 @100-150 K for n-type undoped $Bi_{85}Sb_{15}$ based on a low thermal conductivity 1.5 W/(m*K) measured with the hot-disk method. For p-type Bi-Sb, doping effects of Ge, Sn, and Pb were explored. A high doping level of Ge and a high doping efficiency of Pb were obtained with the help of low-temperature SPS processing. The transport properties of n-type undoped and p-type doped $Bi_{85}Sb_{15}$ were analyzed using the two-band effective mass model. A band gap closing phenomenon was observed which poses challenges to the improvement of p-type Bi-Sb TE properties.

S6: Special Symposium - The European Energy Harvesting Workshop

Special Symposium – The European Energy Harvesting Workshop

Room: Salon 2

Session Chair: Grzegorz Litak, Lubin University of Technology

9:20 AM

(EHS-S6-001-2019) Energy Harvesting for Structural Health Monitoring of our Built Infrastructure: Recent Advances (Invited)

V. Pakrashi*[1]

1. University College Dublin, Mechanical and Materials Engineering, Ireland

The paper will focus on the recent developments by the Dynamical Systems and Risk Laboratory in School of Mechanical and Materials Engineering, University College Dublin, Ireland on the topic of using teh responses of vibration energy harvesters connected to our built infrastructure to assess their structural health. The paper discusses how vibration energy harvesters in their own right can be a monitor for built infrastructure systems. In this regard, the paper discusses applications in traditional systems like bridges and pipelines - along with bourgeoning infrastructure systems like renewable energy devices. The paper further discusses the directions in which this nascent topic of vibration energy harvesting based structural health monitoring can lead to in the neat future and how their Technological Readiness Levels can be improved. in this regard through theoretical, numerical, laboratory experiments and full scale implementation. The potential of a European Network to address this challenge will also be presented.

9:50 AM

(EHS-S6-002-2019) Advances in kinetic piezoelectric energy harvesters and future directions – Oulu perspective (Invited)

J. Palosaari[1]; M. Leinonen[1]; Y. Bai[1]; T. Siponkoski[1]; J. Hannu[1]; J. Juuti*[1]

1. University of Oulu, Microelectronics Research Unit, Finland

Energy harvesters for low power applications have been under intense research to enable energy autonomous wireless sensor systems. Aim is to develop devices deployable as plug-and-forget basis without relying for the replacement of batteries or power cables with high costs. One way to achieve this is piezoelectric energy harvesters transforming various types of abundant kinetic energies into electricity. While great efforts and advances has been made in this field, shifting from μW's into dozens of mW's power levels nowadays, clear challenges still remain in practical applications. Successful development of harvesters requires understanding of whole energy-chain from source to storage and usage of the energy. Harvesters are often considered as discrete components to be fitted into existing sensor system platforms. This type of approach leads easily into non-optimal solutions and in the worst case, it neglects the interplay between harvesters, mechanics and electronics, which can lead to greatly reduced performance. The same may occur if level, behaviour and statistical occurrence of energies and their coupling with the harvester in the applications are not understood properly. Here, some practical application cases are shown to identify few of the mentioned challenges and highlight directions for future research based on understanding gained during numerous projects.

10:20 AM

(EHS-S6-003-2019) Composite Magnetostrictive-Nanocrystalline Materials for Use in the Field of Energy Harvesting and Energy Transformation (Invited)

R. Mech*[1]

1. Wroclaw Univeristy of Science and Technology, Poland

The presented subject regards to the development of new composite materials based on particles of material with giant magnetostriction and nanocrystalline structures with improved magnetic induction for use in the area of recovery and conversion of mechanical energy into electricity (so-called Energy Harvesting). The need to develop this type of innovative materials is fully justified. The material with the appropriate parameters is still being sought. This material should has high efficiency in the event of conversion of mechanical energy into electric energy and made it possible to use this energy to supply various types of electronic components. This is mainly due to the desire to minimize the costs associated with the supply of electricity to the receivers in the traditional way, i.e. through wires, but also the limitation of capacity in the case of currently used lithium ion batteries. One of the proposed directions is the creation of composite material, which will include nanocrystalline materials with improved magnetic properties, which are characterized by much better parameters than typical metallic crystalline materials. These material will be use in the area of transformation of mechanical power into useful electric energy.

11:00 AM

(EHS-S6-004-2019) EnABLES: European Infrastructure Powering the Internet of Things (Invited)

S. Beeby*[1]; M. Hayes[2]; J. Donnelly[2]; R. Salot[3]; G. Savelli[3]; P. Spies[4]; G. vom Boegel[5]; M. Konijnenburg[6]; B. Breitung[7]; A. Romani[8]; C. Gerbaldi[9]; L. Gammaitoni[10]

1. University of Southampton, School of Electronics and Computer Science, United Kingdom
2. Tyndall National Institute, Ireland
3. CEA-Leti, France
4. Fraunhofer IIS, Germany
5. Fraunhofer IMS, Germany
6. IMEC-NL, Netherlands
7. KIT/HIU, Germany
8. University of Bologna, Italy
9. Politecnico di Torino, Italy
10. University of Perugia, Italy

The mission of EnABLES is to open up key research infrastructure in the Internet of Things (IoT) to all European researchers, from both academia and industry. Six research Institutes together with 5 knowledge hubs are providing access to enable researchers to create 'self-sustaining' energy solutions to 'power the internet of things' based on energy harvesting, storage, micro-power management and system integration activities. This paper provides an overview of the motivation for EnABLES enabling researchers address key challenges such as extending battery life of wireless IoT edge devices, and potentially eliminating the need for battery replacement. The ultimate goal of EnABLES is to create a 'starting community' to foster collaborations to address these challenges and opportunities & accelerate technology development. The 2 primary approaches used in EnABLES are outlined:- (i) A transnational access (TA) and virtual access (VA) program open to all external stakeholders to do free-of-charge feasibility studies. (ii) Joint Research Activities (JRAs) between partners. Simulations and data libraries are retained in an open access repository with an emphasis on creating standardized and interoperable parts and understanding their system level behaviour. A key goal of the project is to create standardised and inter-operable libraries of parts & simulation tools for optimising system level performance

11:30 AM

(EHS-S6-005-2019) Energy Autonomous and Smart Devices For A New Generation Of IoT (Invited)

M. Magno*[1]

1. ETH Zurich, D-ITET, Switzerland

A new generation of Information Technology is revolutionizing products and people's everyday life. Intelligent sensors are gaining popularity, with people surrounded by everything "smart," from smart houses to smartphones, from smart trains to smart cities. However present-day sensor devices are mainly battery-powered and due to limited energy, they are simple with limited computational capabilities or they need to be recharged every day or even hours and thus they miss the expectations for truly unobtrusive user experience. This talk will explore theoretical limitations as well as design methods for this new kind of distributed smart sensors under the extreme constraint of tiny energy buffers (batteries). Specifically, the talk will focus on the basis for low-power/autonomous systems for distributed smart sensors that (i) can go in a zero-power but with change status fast when important events are detected (ii) have long lifetime and where possible be self-sustaining, (iii) adopts artificial intelligence connecting buildings, sensors, users, wearable devices achieving true ambient intelligence. This goal can be achieved by developing novel hardware, sensors, energy harvesting and devising low-power techniques for data computation, machine learning, communication. This work presents the vision of the Digital Circuits and System at ETH Zurich on energy autonomous and smart sensing for a new generation of IoT.

12:00 PM

(EHS-S6-006-2019) Piezoelectric Beams, Magnets and Stoppers as Building Blocks for Transducers and Autonomous Sensors (Invited)

C. Trigona[1]; S. Baglio*[1]

1. University of Catania, DIEEI, Italy

Transducers for vibration energy harvesting are receiving a considerable amount of interest in the scientific community. It is worth noting that several works focused on autonomous solutions to power small-scale electronic mobile devices also through the adoption of piezoelectric materials. Furthermore, novel configurations of management architectures arouse interest also in vibrationally noisy environments and in presence of weak levels of generated voltage. This specific task has been studied and, in particular, here will be addressed a family of devices which exploit the interaction of piezoelectric materials, flexible beams, magnets and mechanical stoppers together with the study of nonlinear dynamics used to develop architectures for autonomous sensors, smart nodes and measurement systems in vibrating environments. Will be here addressed a review, starting from a single block (main block), able to work in presence of kinetic sources, to convert this mechanical signal into an electrical power and it is capable to manage the power also in presence of voltage levels <100 mV (voltage levels less than the diodes threshold, which typically, must be accounted in "classical" conditioning circuits for harvesting and sensing).

Plenary II

Room: Salon 4
Session Chair: Yang Bai, University of Oulu

1:35 PM

(EHS-PLEN-002-2019) Triboelectric-based Self-Powered Smart Skin

H. Zhang*[1]

1. Peking University, China

In the past decades, the development of new material and fabrication process make the electronics engineering bloom again from the traditional silicon-based electronics to the polymer based stretchable electronics. This talk will focus on the TENG based self-powered smart devices, which is beneficial for solving the energy supply problem of sensor networks in the stretchable electronic system. We firstly summarize the choice of the working mode and the detection mode, which is the fundamental point for designing a proper e-skin with the expected function. Furthermore, the method to mimic the properties of human skin, which must meets the demands of mechanical stretchability and electrical conductance at the same time, is reviewed from the electrode aspect and dielectric aspect, respectively. The material development and structure construction are two main approaches for making the conductor into stretchability. For the dielectric, the methods to improve the performance and endow more human skin functions like biocompatibility, self-healing and humidity-resistance are also stated. Furthermore, the state-of-the-art functional self-powered e-skins such as pressure sensor, position sensor, strain sensor and sliding sensor, are demonstrated to discuss their great potential in different application fields.

S1: Mechano-Magneto-Electric Energy Harvesting

Mechano-Magneto-Electric Energy Harvesting II

Room: Salon 1
Session Chair: Yaojin Wang, Nanjing University of Science and Technology

2:30 PM

(EHS-S1-007-2019) Nonlinear Control Circuit for Piezoelectric Energy Harvesting Circuit (Invited)

Y. Wen*[1]; P. Li[1]; T. Han[1]; X. Ji[1]

1. Shanghai Jiao Tong University, China

MPPT (Maximum Power Point Track) is high-efficient energy harvesting method that can convert the maximum power of the energy harvester into the store capacitor. But traditional MPPT circuits with MCU (microcontroller unit) have high power consumption (>40μW). For piezoelectric energy harvester, the average charging power for the store capacitor varies with the duty cycle of the control switch. However, the charging power will decrease with the increase/decrease of the duty cycle at the maximum power point. The traditional feedback control circuits hardly lock in the maximum charging power point by adjusting the duty cycle. This paper presents a nonlinear control method for the piezoelectric MPPT energy harvesting circuit. Two auxiliary judgment circuits detecting the maximum current of the transducer and the charging voltage of the middle capacitor can track the maximum average charging power of the store capacitor. Thus both the transducer and the store capacitor can obtain maximum powers. In order to increase the tracking speed, the low-power hardware circuit is designed. This method can obtain 30% stronger average charging power than the traditional control circuits. Compared with traditional complex nonlinear-carrier (NLC) control circuits and MPPT circuits, the proposed circuit can quickly track the maximum power at a lower power consumption.

3:00 PM

(EHS-S1-008-2019) High-efficiency Double-resonance, Self-powered Harvesting Circuit for Weak Piezoelectric Energy Harvester (Invited)

P. Li*[1]; Y. Wen[1]; T. Han[1]; X. Ji[1]

1. Shanghai Jiao Tong University, China

In order to store the weak energy for driving the wireless sensor, the store capacitor is very large (such as 0.1F). The standard circuit, DC-DC converter, series SSHI (synchronized switching harvesting with inductor), parallel SSHI and SECE (synchronous electric charge extraction) circuits have a low efficiency due to mismatching between the transducer and the store capacitor. The loss of DSSH (double synchronized switch harvesting) circuit obviously increases with the middle capacitor voltage due to the resistance increase of the rectifier diode. This paper proposes a high-efficiency double-resonance self-powered harvesting circuit that can automatically match weak different piezoelectric energy harvesters by adjusting the turn-on time of two switches. The self-powered control circuits only work at the peak point of the input signal, and the loss is very small. The proposed circuit has much less loss and higher output power than the other traditional energy harvesting circuits. This circuit can realize conjugate matching of piezoelectric transducers at an equivalent internal capacitance range of 1-30nF. This circuit can efficiently accumulate weak energy during a long period, and driving the wireless sensor (>60mW) at a short time. This circuit can also be used in many other weak capacitive energy harvesters.

3:30 PM

(EHS-S1-009-2019) Multiple physical mechanisms based micro-energy harvesters for powering wireless sensor network (WSN) (Invited)

S. Dong*[1]

1. Peking University, Materials Science & Engineering, China

With the rapid development of new energy materials, it is possible to harvest the different micro-energy from the environment on a large-scale for powering low-power electronics, especially, powering wireless sensor network (WSN) in the Internet of Thing (IoT). Because of a huge number of sensors included in IoT, it becomes impossible to replace battery in each sensor. The distributed energy supply from the environment for self-powering IoT will be future development direction. In this work, we report piezoelectric and magnetoelectric multiple physical mechanisms based micro-energy harvesters, which shows great benefits in continuous powering sensors in comparison to traditional single energy source harvesting method. Our research purpose lies in the application of new materials and the realization of harvesting from multiple energy sources in the environment. The main contents of this report include the following three parts: (i) researches on high power generation functional material; (ii) structure design of efficient energy harvesting; (iii) mechanisms of energy harvesting in multi-physics field. We also introduce the recent progress of other multiple physical mechanisms based micro-energy harvesters, such as light, heat, magnetic, sound, force and strain energy, etc.

4:00 PM

(EHS-S1-010-2019) Automatic Resonance Tuning Mechanism for Ultra-wide Bandwidth Mechanical Energy Harvesting (Invited)

H. Song*[1]

1. Korea Institute of Science and Technology, Center for Electronic Materials, Republic of Korea

Piezoelectric energy harvesters typically exhibit sharp output power peak around resonance frequency, which presents complexity in harvesting ambient vibrations. Prior attempts in designing energy harvesters with broadband response have met with practical challenges in terms of low output power, large mass and weight, and small improvements in bandwidth. In this presentation, I introduce a breakthrough in demonstrating ultra-wide bandwidth energy harvesters through the discovery of automatic resonance tuning (ART) phenomenon. ART provides energy harvester ability to adjust its natural frequency in conjunction with ambient vibration without human intervention or additional tuning energy. The ART energy harvester utilizes the motion of the mobile proof mass in a doubly clamped oscillating beam structure to modulate the natural frequency of the beam. Detailed investigations are conducted in providing a fundamental understanding of the operation mechanism of the ART harvester by invoking beam dynamics over a wide range of vibration conditions. It is shown that bandwidth of the ART harvester (36 Hz) is 1400% larger compared to the fixed resonance energy harvester. The practical feasibility of the ART mechanism is demonstrated by evaluating the performance of harvester mounted on a rotary pump.

S3: Multi-functional Energy Conversion Materials and Devices for Energy Harvesting and/or Sensing

Multi-functional Energy Conversion Materials and Devices for Energy Harvesting and/or Sensing I

Room: Salon 2
Session Chair: James Roscow, University of Bath

2:30 PM

(EHS-S3-001-2019) Layered materials exhibiting piezoelectric and structural phase change properties (Invited)

D. Rehn[1]; G. Cheon[1]; E. Reed*[1]

1. Stanford University, USA

We have utilized data mining approaches to elucidate over 1000 2D materials, of which find that hundreds of these 2D materials have the potential to exhibit observable piezoelectric effects when exfoliated into individual layers, representing a new class of piezoelectrics. Another subset of these 2D materials has the potential to exhibit structural changes under a variety of external stimuli including electrostatic gating. I will discuss calculations of phase diagrams, kinetics, some experimental results, potential phase change applications for these materials. We also provide theoretical predictions for an alternative cooling mechanism, accomplished by utilizing electrostatic gating to induce structural phase transitions in monolayer materials. We refer to this mechanism as the electrostaticaloric effect in reference to the mechanism of electrostatic doping that drives the structural phase transformation and entropy change in the material.

3:00 PM

(EHS-S3-002-2019) Ferroelectric materials ~ advantages of harnessing inherrent functionality (Invited)

S. Dunn*[1]

1. London South Bank University, United Kingdom

Ferroelectric materials have an inherrent dipole that can be harnessed to drive a number of unique features. Over the past ten years there has been increased understanding of what unique chemistry the dipole can drive. Aspects of photochemistry, such as those associated with enehanced exciton lifetimes, energy harvesting through vibration and photovoltaic devices are all applications that are increasingly studied. Most recently the use of thermal fluctuations have been investigated for disinfection and the produciton of hydrogen from water. Water splitting by thermal cycling of a pyroelectric element acting as a charge source is an attractive method to produce hydrogen using transient low-grade waste heat. This presentation will take a meandering review of the growing body of work that focuses on ferroelectric materials in energy conversion technologies. Current work is focused on alternative reactions and increasing the surface area of the electrode to enhance the rate of conversion by releasing more charge.

3:30 PM

(EHS-S3-003-2019) Probing of ferroelectric and magnetic properties of $BiFeO_3$ thin films

D. Sobola*[1]; S. Ramazanov[2]; P. Tofel[1]; V. Holcman[1]

1. Brno University of Technology, Department of Physics, Czechia
2. Dagestan State University, Faculty of Physics, Russian Federation

A promising approach to the next generation of low-power, functional and "green" nanoelectronics is based on achievements in the field of control of the electric field by lattice, charge, orbital and spin degrees of freedom in new materials. The ability to control the electric field for various functional devices opens up prospects for a variety of modern technologies, including information communication, computing processes, data storage, active components, etc.

BiFeO3, being room temperature multiferroic material, is perspective for new generation of memrisitive devices. Here we report local study of the BiFeO3 films, prepared by pulsed laser deposition on Pt-coated silicon substrates. The results indicate strong dependence of multiferroic properties on the deposing process temperature. The influence of impurity phases and oxygen vacancies on electric properties is investigated. Local properties of the films are described in correspondence with current-voltage characteristics, which were measured at both planar and sandwich-geometry of electrodes.

3:50 PM

(EHS-S3-004-2019) Determination of the suitable piezoelectric ceramics depending on various types of piezoelectric energy harvesters for large output power

S. Kim*[1]; C. Kang[2]; S. Nahm[1]

1. Korea University, Materials Science & Engineering, Republic of Korea
2. Korea Institute of Science and Technology, Center for Electronic Materials, Republic of Korea

In case of a type-1 piezoelectric energy harvesters (PEH), in which stress develops in the supporting material of the piezoelectric ceramics, the electromechanical coupling factor (k_{ij}) of the piezoelectric ceramics is important for the output power at the resonance frequency. Therefore, soft-piezoelectric ceramics are good candidates for type-1 PEHs. In case of a type-2 PEH, in which stress develops in the piezoelectric ceramics and supporting material, the figure of merit (FOM) of the output power at the resonance frequency is $(k_{ij}^2 x Q_m)/S_{11}^E$, where Q_m and S_{11}^E are the mechanical quality factor and the elastic compliance of piezoelectric ceramics, respectively. In particular, the effect of Q_m is dominant, indicating that hard-piezoelectric ceramics are good candidates for type-2 PEHs operating at the resonance frequency. For both type-1 and type-2 PEHs operating at off-resonance frequency, the $k_{ij}^2 x d_{ij} x g_{ij}$ is the FOM of the output power of the PEHs, where g_{ij} is a piezoelectric voltage constant. Therefore, soft-piezoelectric ceramics are also good candidates for both type-1 and type-2 PEHs operating at the off-resonance frequency.

4:10 PM

(EHS-S3-005-2019) Printable energy harvesters based on polymer nanocomposites

P. Costa*[1]; T. Marinho[1]; S. Gonçalves[2]; V. M. Correia[2]; J. C. Viana[3]; S. Lanceros-Mendez[4]

1. University of Minho, Physics, Portugal
2. University of Minho, Algoritmi, Portugal
3. University of Minho, Polymers Engineering, Portugal
4. Basque Centre for Materials, Physics, Spain

Nanomaterials, including nanocarbonaceous, nanowires or nanoceramic, incorporated into polymer matrices and processed by additive manufacturing technologies, allow to improve the development and integration of advanced energy harvesting materials for an increasing range of applications. The demand of innovative and a larger variety of energy harvesters (EH) is particularly enhanced by the strong development of wearables and the Internet of Things (IoT) concepts. This work reports on piezoelectric (PE), pyroelectric (PyE) and triboelectric (TE) energy generators fabricated by printing technologies. PE effect explores the conversion of mechanical energy into electrical and vice-versa, whereas PyE develop an electrical potential when heated. Finally, TE effect takes advantage of the charges generated on the material surface upon frictional contact to induce a potential variation. Composite materials based on poly (vinylidene fluoride) filler with high dielectric constant nanofillers, such as $BaTiO_3$ and ferrite oxides have been prepared, fully characterized in terms of physico-chemical properties and prepared in the form of inks. Finally, different energy harvesters have been developed and their performance optimized. The power output of the different materials will be comparatively discussed as well as their different application possibilities.

S4: Thermoelectric Energy Harvesting

Thermoelectric Energy Harvesting II

Room: Salon 3

Session Chair: Armin Feldhoff, Leibniz University Hannover

2:30 PM

(EHS-S4-007-2019) Half-Heusler Thermoelectric Materials Coming of Age (Invited)

J. Poon*[1]

1. University of Virginia, Physics, USA

Half-Heusler compounds (space group Fmm) have garnered increasing attention in recent years in the thermoelectric community. Three decades ago, refractory RNiSn half-Heusler compounds (R=Hf, Zr, Ti) were found to be narrow-gap semiconductors with a large Seebeck coefficient ~100s μV/K by Aliev et al. Today, half-Heusler (HH) compounds have emerged as promising materials for heat-to-electricity conversion in the intermediate temperature range (400-800ºC). HH materials are endowed with good thermal stability and scalability as well as high power density output. Despite a moderate dimensionless figure of merit ZT~1, state-of-the-art conversion efficiency near 9% was achieved in practical p-n couple modules based on HH alloys. We will review the research and development of thermoelectric HH compounds. Particularly, there have been notable achievements since 2012 thanks to the implementation of new approaches. As a result, ZT has risen from ~1 to 1.5. We will recount the advances over the years around three generations (Gen) of thermoelectric half-Heusler materials: Gen-1 Gen-2, and Gen-3 HH materials.

3:00 PM

(EHS-S4-008-2019) High Performance Thermoelectric Modules Based on Half-Heusler Alloys (Invited)

B. Poudel*[1]; U. Saparamadu[1]; H. Kang[1]; A. Nozariasbmarz[1]; W. Li[1]; S. Priya[1]

1. Penn State University, Materials Science and Engineering, USA

Half-Heusler (hH) based alloys are promising thermoelectric (TE) materials because of their high figure of merit (e.g., the average $ZT_{avg} > 0.9$), high mechanical strength and stability at high temperatures. Making hH modules feasible requires a systematic study of material composition tuning, diffusion barrier layer, bonding process, leg geometry optimization, and overall fabrication process. In this paper, we discuss the hH module fabrication process and challenges to achieve high efficiency thermal to electrical conversion. By optimizing bonding process with brazing alloys, we have achieved very low contact resistance ($< 1\ \mu\Omega cm^2$) and excellent module conversion efficiency of 9.5%, thus promoting the development of TE devices to revolutionize our future need of energy conversion at temperatures of 200-600°C.

3:30 PM

(EHS-S4-009-2019) High Temperature Air Stability of Half-Heusler Alloys for Thermoelectric Energy Harvesting

H. Kang*[1]; U. Saparamadu[2]; A. Nozariasbmarz[2]; W. Li[2]; B. Poudel[2]; S. Priya[2]

1. Virginia Tech, USA
2. Pennsylvania State University, Materials Science and Engineering, USA

High temperature waste heat has a great technical work potential based on their exergy content (Carnot's potential) estimation by larger quality of heat energy. A rapid development in thermoelectrics, which can directly convert heat to electricity by the Seebeck effect, facilitates a feasible application in harvesting the waste heat energy from the surroundings to generate electrical power for devices. In order to utilize the high quality of waste heat at elevated temperature, a good thermal stability of the thermoelectric materials is vital in especially a sustainable energy harvesting application. Half-Heusler (hH) alloys are promising thermoelectric materials for use in the waste heat recovery systems due to their exceptional thermal and mechanical stability and excellent electrical transport properties. This work demonstrates the high temperature thermal stability of MNiSn and MCoSb (M = Hf, Zr, and Ti) based hH compounds in the air. The n-type MNiSn compounds shows highly stable performance at high temperature and the compositional modification in p-type MCoSb provides stability improvement.

3:50 PM

(EHS-S4-010-2019) Synthesis, Design and Fabrication of Oxide Thermoelectrics via Plasma Spray Technology

F. Caliari*[1]; H. Lee[2]; S. Sampath[1]

1. Stony Brook University, Center for Thermal Spray Research, USA
2. Oerlikon Metco, USA

Widespread thermoelectric energy harvesting application requires not only high performance materials but also cost effective and scalable processing of devices. Secondly, integration of the devices into thermal system is also a consideration for efficient conversion of waste heat. In this study, we show the capability of plasma spray materials processing technology to not only synthesize oxide based thermoelectric materials through novel processing concepts, but also demonstrate patterned and multilayer assemblies of devices with consideration of their integration into waste heat energy systems. The p-n junction type devices were synthesized using plasma spraying of TiO_{2-x} suboxides (n-type) and $Ca_2Co_2O_5$. In the case of TiO_{2-x}, the plasma environment can be controlled to produce deposits with ZT of 0.13 at 500C while the $Ca_2Co_2O_5$ showed a ZT of 0.27 at 550C. By strategically combining the two oxides in series and parallel thermoelectric devices were fabricated and tested.

4:10 PM

(EHS-S4-011-2019) A Thermodynamic Perspective on Seebeck Coefficient

Y. Wang*[1]; S. Shang[1]; F. R. Drymiotis[2]; S. Firdosy[2]; K. E. Star[2]; J. Fleurial[2]; V. Ravi[2]; L. Chen[1]; Z. Liu[1]

1. The Pennsylvania State University, Department of Materials Science and Engineering, USA
2. Jet Propulsion Laboratory, USA

Thermoelectric energy conversion exploits the Seebeck coefficient to convert heat to useful electrical energy. In this work, we present an approach for calculating the Seebeck coefficient, which is based solely on thermodynamic principles. This method provides an alternative calculation approach to the existing time-consuming kinetic Boltzmann transport theory. Based on the finite-temperature extension of density functional theory proposed by Mermin, we advocate that a thermoelectric electromotive force originates from the variation of the electronic chemical potential induced by the temperature change. As a result, we formulate the Seebeck coefficient solely based on the electronic density of states, making it simple to search for high performance thermoelectric materials by means of first-principles calculations. With the rigid band approximation, the calculated temperature dependences of the Seebeck coefficients of $La_{3-x}Te_4$ as a function of carrier concentration show excellent agreements with experimental data. Applications to other thermoelectric materials will also be discussed.

Plenary III

Room: Salon 4

Session Chair: Shashank Priya, Pennsylvania State University

4:50 PM

(EHS-PLEN-003-2019) Challenges and Ways Forward for Energy Harvesting Powered Sensor Systems

M. Zhu*[1]

1. University of Exeter, United Kingdom

Energy harvesting (EH) captures localised ambient energy (e.g. vibration, motion, airflow, thermal) to power small electric and electronic devices, including wireless sensor networks (WSNs). The energy harvested will allow, e.g., WSNs to operate in an energy autonomous manner - with no need for mains power or batteries for energy supply, eliminating wiring and the cost for cabling and battery replacement. There will therefore be minimum human involvement in maintenance and the system will be "truly fit-and-forget". Great progress has been made over the last 10 years in EH technology research. The current-state-of-art solutions have been successful in some cases but industry has been slow to uptake the technology into their products, processes and services. There are significant research challenges regarding the technology in terms of power output, bandwidth, reliability, efficiency, adaptation, configuration and deplorability prohibiting widespread industry take-up for deployments. Prof Zhu will present the research challenges and ways forward for energy harvesting powered wireless sensor systems in her talk with focus on how such the systems can be designed for industrial deployment.

Poster Session

Room: Ballroom Foyer

6:00 PM

(EHS-P001-2019) Preparation of graphene-based materials and dielectrics suitable for supercapacitors using pure and waste materials

I. G. Markovska*[1]; M. Mitkova[1]; F. Yovkova[1]; D. Georgiev[1]

1. Prof. Assen Zlatarov University, Bulgaria

Supercapacitors are energy storage devices which consist of two electrodes separated by a porous separator. The present paper introduces engineering of graphene and related material called reduced graphene oxide, as well as engineering of dielectric materials for use in supercapacitors. It is believed that graphene is a next-generation conducting material with the potential to be used for obtaining of electrodes for supercapacitors. Graphene is a flat honeycomb lattice made of a single layer of carbon atoms and possed an unique properties - very high electrical conductivity, excellent mechanical properties, etc. The present work is related to solving of two main problems. The first one is related to obtaining of electrodes for capacitors. A series of graphene oxide precursors were synthesized from finely powdered graphite powder via the chemical treatment with acids, followed by ultrasonic treatment in an ultrasonic bath filled with deionized water. Several porous graphene-based materials have been developed and their performance investigated as supercapacitor electrodes. The second problem is related to the development of porous dielectric materials using pure and waste materials. The methods of X-ray analysis, infrared spectroscopy, differential thermal analysis and scanning electron microscopy were used mainly in this study.

(EHS-P002-2019) BCZT, BCZTCe and BCST system used in Energy Harvesting

P. Tofel*[1]

1. BUT Brno, Czechia

A lead-free (Ba,Ca)(Zr,Ti)O_3 system is widely used in piezoelectric ceramics research because of high functional properties. The work shows how the BCZT, BCZTCe and BCST system can be used in Energy Harvesting Applications. We reached piezoelectric constant (d_{33}), 480 pC/N for pure BCST ceramics, d_{33} ~ 450 pC/N for BCZTCe ceramics and 720 pC/N for BCST ceramics. All materials were examined from energy harvesting point of view. Piezoelectric properties were measured and energy harvesting figures of merit were calculated. Simple piezoelectric energy harvester devices were prepared and then maximal energy obtained from materials was also investigated. All parameters are compared and discussed.

(EHS-P003-2019) SPM techniques for characterization of PVDF nanofibers

D. Sobola*[1]; P. Tofel[1]; P. Škarvada[1]; V. Holcman[1]

1. Brno University of Technology, Department of Physics, Czechia

Explanation of piezoelectric properties of nanomaterials demands application of precise characterization techniques. Scanning probe microscopy is high accuracy method, which provides evaluation of the sample geometrical sizes at nanometer scale. Piezoresponse force microscopy, being one of SPM techniques, allows imaging of electrically active phases of PVDF nanofibers. Optimal geometry of electrodes is reported, based on maximum magnitude of piezoelectric response. Impact of electrodes material on the measurement results was evaluated. The study is supported by compositional analysis of the samples by FTIR, Raman spectroscopy and X-ray diffractometry. Characterization of nanoelectromechanical properties is essential for design of NEMS and MEMS.

(EHS-P004-2019) Stretchable fiber-type piezoelectric nanogenerator and strain sensor

J. Ryu*[1]; S. Eom[1]; J. Kim[1]; S. Park[1]; S. Hong[1]

1. Korea Advanced Institute of Science and Technology, Materials Science and Engineering, Republic of Korea

We present a polyvinylidene fluoride-trifluoroethylene nanoparticles (PVDF-TrFE NPs)-based hollow fiber as a nanogenerator and strain sensor. The device consists of PVDF-TrFE NPs- polydimethylsiloxane (PDMS) composite and MWCNTs. The hollow fiber can be used to convert mechanical energy from diverse directions into electrical energy due to piezoelectric effect and measure strain due to piezoresistive effect. The fiber was light weight, flexible, bendable and twistable. Further, the fiber can be stretched to 100 % without breakage. During finger tapping or stretching process, the fiber exhibited 1.2 or 0.8 V, respectively. The fiber was also confirmed to harvest mechanical energy from liquid pressure fluctuation. No degradation in the generated output voltage and relative resistance both was observed even after 1000 cycles. These results support that our device might be of potential use for applications in wearable devices and robotics.

(EHS-P005-2019) Polymer-based all-printed piezo-magnetically responsive sensors and actuators

A. C. Lima[2]; P. Rita*[2]; N. Perinka[1]; N. Pereira[3]; V. M. Correia[3]; P. Martins[2]; S. Lanceros-Mendez[1]

1. BCMaterials, Basque Center for Materials, Applications and Nanostructures, Spain
2. University of Minho, Center of Physics, Portugal
3. Center Algoritmi, University of Minho, Portugal

Piezoelectric, magnetostrictive and magnetoelectric (ME) polymer-based smart devices can support the 4.0 industries, being a key factor for the development of sustainable, wireless and interconnected autonomous smart devices, systems and cities. The use of polymers on those printed systems will allow the development of devices with unique features such as flexibility, conformability, transparency and biocompatibility. This work reports on the fabrication and characterization of three magnetoresponsive fully printed devices obtained from polymeric nanocomposites: 1) Piezoelectric ((PVDF-TrFE), 2) magnetostrictive (PVDF+$CoFe_2O_4$); and 3) magnetoelectric (PVDF+$CoFe_2O_4$/(PVDF-TrFE)), the first suitable for actuator and the second for sensor and actuator applications. Additionally, all necessary printed components (filters, resistors, capacitors, inductors and coils) for interface electronics all also developed printing technologies. The fabrication process, characterization of the materials and functional response will be presented and discussed. Acknowledgements Fundação para a Ciência e Tecnologia - UID/FIS/04650/2019, PTDC/EEI-SII/5582/2014, PTDC/CTM-ENE/5387/2014, SFRH/BD/131729/2017 (N.P), SFRH/BD/132624/2017 (ACL). Spanish Ministry of Economy and Competitiveness (MINECO)- MAT2016-76039-C4-3-R (AEI/FEDER, UE). Basque Government - ELKARTEK and HAZITEK programs and PIBA program (PIBA-2018-06).

(EHS-P006-2019) Energy Recovery Method from Shock Demagnetisation of NdFeB-GMM-Ceramic of Magnetic Resonator

R. Mech*[1]

1. Wroclaw Univeristy of Science and Technology, Poland

The method of energy transformation presented in this paper allows to use NdFeB-GMM-Ceramic material (NGC) as a source of power supply for electronic autonomous systems. It is shown that mechanical impact of magnetic couplers is capable to generate the high power electric current in peak as microsecond range waveform. The amplitude of useful electrical current is determined by the magnetic resonance frequency of magnetic-ceramic stack couplers. The main concept is, to build device based on permanent magnet NdFeB with addition of the magnetostrictive and nanocrystaline materials. This type of NGC materials is specified as Energy Harvesting Device (EHD) with a high cost effective per watt. Due to special preparation of coil on the manufactured material high efficiency of energy recovery from electromagnetic waves was obtained. It has to be remembered that estimated efficiency value of the energy conversion between the mechanical shock, which occurs during the demagnetization of the NdFeB-GMM-Ceramic material, and the electric current is still not satisfying, therfore, further development is necessary.

(EHS-P007-2019) Low Frequency, Low Vibration Multi-Lever Energy Harvesting System

S. Eom*[1]; J. Ryu[1]; J. Kim[1]; S. Cho[1]; S. Hong[1]

1. Korea Advanced Institute of Science and Technology (KAIST), Materials Science & Engineering, Republic of Korea

The 4th industrial revolution has become a major trend, and autonomous navigation and smart factory research has surged. In order to monitor the machines and structures of the systems, huge number of sensors and power are required. In particular, there are low frequency and low vibration systems, which are difficult to access the electric wires. In order to solve the difficulty and satisfy the demands in the low frequency and low vibration systems, we designed multi-lever piezoelectric energy harvesting system. We selected multi-lever to improve harvesting power, using bimorph cantilevers and the metal foil substrate. In addition, we measured the harvesting power in the 8 Hz, 0.2 g vibration environment.

(EHS-P008-2019) Bistable Piezoelectric Energy Harvester with Novel Layered Architecture

O. Rubes*[1]; Z. Hadas[1]

1. Brno University of Technology, Czechia

Bimorph cantilever beam piezoelectric energy harvester is used for harvesting energy from vibrations in its resonance frequency. However, outside this resonance bandwidth, the output power of the harvester is decreased dramatically. Auxiliary nonlinear characteristic of the cantilever might improve the behaviour around resonance. One of the possible nonlinearities is a bistable configuration of the beam. In this contribution is demonstrated a configuration with auxiliary magnets. In the bistable configuration, the high amplitudes of the tip cause high strain of the beam and could lead to a crack of it. The novel layered architecture of the piezoelectric cantilever beam is demonstrated to protect it from its crack. Due to this novelty, higher amplitudes of oscillations are allowed. Through these higher amplitudes, higher output power could be reached, or it could be used as a wearable device.

(EHS-P009-2019) Fabric-based wearable piezoelectric energy harvester with heterostructure

J. Kim*[1]; S. Byun[2]; S. Lee[3]; J. Ryu[1]; C. Oh[1]; S. Cho[1]; K. No[1]; S. Ryu[3]; Y. Lee[2]; S. Hong[1]

1. KAIST, Materials Science and Engineering, Republic of Korea
2. DGIST, Energy Science and Engineering, Republic of Korea
3. KAIST, Mechanical Engineering, Republic of Korea

Fiber and fabric type wearable electronics are attracting more attention due to their comfort and durability in textiles. In this study, we demonstrate a fabric-based wearable piezoelectric energy harvester with heterostructure which can generate output voltage and current of 5.3 V and 69 nA from human motions, respectively. The heterostructure of a ferroelectric P(VDF-TrFE) film and conductive fabrics was realized by a simple fabrication process, hot pressing. The P(VDF-TrFE) film had a ferroelectric β phase and a high piezoelectric d_{33} coefficient of -32.0 pC/N which were comfirmed by COMSOL simulation and experimental analysis. To prove the stability, we quantitatively measured an interfacial adhesion strength of 22.013 N/cm between the P(VDF-TrFE) film and the conductive fabrics using surface and interfacial cutting analysis system (SAICAS).

(EHS-P010-2019) Pure KNN piezoelectric ceramics fabricated by two-step sintering for energy harvester application

G. Ye*[1]

1. University of Birmingham, Metallurgy and Materials, United Kingdom

To fabricate a high performance piezoelectric energy harvester, one key requirement is to obtain piezoelectric ceramics with high density and good piezoelectric properties. A two-step sintering(TSS) method has been successfully applied to fabricate alkaline niobate ($K_{0.5}Na_{0.5}NbO_3$)piezoelectric ceramics. Investigation of the sintering behaviour of these ceramics in terms of densification, microstructural evolution and piezoelectric properties demonstrated that the TSS method can effectively enhance densification at lower sintering temperatures. Compared to a conventional one step sintering approach(COSS), the TSS-sintered KNN ceramics demonstrated an improved density of 95% of theoretical density and a smaller grain size, about 8 μm, compared to 91% and about 15μm, respectively for the COSS ceramics. When the optimum two-step conditions were used the samples exhibited improvements in piezoelectric and dielectric characteristics of 10-50%. These compare favourably with the typical values of conventionally sintered KNN ceramics of the same composition. Also, simple energy harvester devices made using TSS samples exhibit higher output power than similar devices made with COSS samples. The results suggest that two-step sintering could be an effective approach to solving the problem of poor sinterability of KNN ceramics and hence allow the fabrication of high-performance KNN-based energy harvesters.

(EHS-P011-2019) Detetction and Control of Multi-Arrays Inductive Power Transmission System

G. Bouattour*[1]; H. D. Ben Jmeaa[2]; O. Kanoun[1]

1. Technische Universität Chemnitz, Germany
2. University of Sfax, Tunisia

Inductive power transmission systems are more and more developed but nevertheless still have limitations. Especially, in term of coaxiality of receiving and transmitting coils. Receiving coil position is one of the most critical influencing parameter for the system performance. For an efficient wireless charging, different geometries, architectures and arrangements for the coil should be investigated to increase the receiving coil position area tolerances. For that, implementation and controlling of multi coil system present a real challenge. In this purpose, this paper proposes an efficient multi coil pad based on ferrite cores coil array arranged into 4 rows and 4 columns. The advantage of this solution is its potential tolerance to the receiving coils located in different position. Further, a receiving coil detection circuit is developed to reduce the system losses during charging and increase the safety. The presented system is an inductive coils pad. Experimental evaluation shows the system a real time ability of the proposed sending side system to detect and switch on the valid sending coil situated under the receiving coil.

(EHS-P012-2019) Adhesion layer study on the energy harvesting performance of the magneto-mechano-electric harvester

S. Kim*[1]; A. Thakre[1]; S. Park[1]; J. Ryu[1]

1. Yeungnam University, Materials Science and Engineering, Republic of Korea

The modern era of autonomous electronics demands an on-board power supply with high fatigue resistance. The solid-state batteries have been hindering deployability of such devices for advanced applications as it needs regular maintenances. Among various proposed energy harvester paradigms, the cantilever structured magneto–mechano-electric (MME) energy harvester consists of an anisotropic piezoelectric crystals mounted on a magnetostrictive Ni plate along with a Nd permanent magnet proof mass has exhibited excellent performance owing to its electromechanical properties and high efficiency. As the mechanical properties of the adhesive epoxy, sandwiched between the piezoelectric crystals and magnetostrictive Ni layer, affect harvester's generation performance drastically. Therefore, in this study, the effect of four different adhesive epoxies on output power of the harvesters and its fatigue resistance have been studied. A colossal enhancement (~ 250%) in the output power of the MME energy harvester was achieved using altering the adhesive epoxy. The maximum output power density of 44.53 mW/cm^3 at 10 G magnetic field with 60 Hz frequency was obtained.

(EHS-P013-2019) Enhancing output power of Magneto-Mechano-Electric Generator by Magnetic Flux Concentration

H. Song*[1]; J. Ryu[1]

1. Yeungnam University, Material Science and Engineering, Republic of Korea

Magneto-Mechano-Electric (MME) generators composed of cantilever structured Magnetoelectric (ME) Composite and magnet proof mass have high potential for magnetic noise harvesting device for autonomous IoT sensor network driving. To enhance the power density of MME generator, magnetic flux concentration structure is investigated in this work. For increasing the magnetic flux density to the MME generator, Ferromagnetic materials (Metglas, Galfenol, etc.) with different geometry and location to the MME generator is adjusted based on FEM modeling results. The magnetic flux concentration is strongly affected by the materials, volume, area, geometry, and location (distance from the magnetic tip mass). With combination of these parameters, the power density of MME generator reached to over 300 % higher than that without magnetic flux concentration structure. In this presentation, output power of MME generator affected by magnetic flux concentration will be discussed along with the experimental data and FEM modeling.

Thursday, September 5, 2019

Plenary IV

Room: Salon 4
Session Chair: Jungho Ryu, Yeungnam University

8:05 AM

(EHS-PLEN-004-2019) Piezoelectric Films for Energy Harvesting

D. Wang[1]; V. Kovacova[1]; J. Yang[1]; S. Trolier-McKinstry*[1]

1. Pennsylvania State University, Materials Scienece and Engineering, USA

Harvesting energy from ambient motion using piezoelectric elements is a promising approach to extend the working hours of electronic devices, including wearables, without recharging or replacing batteries. This talk will describe the development of piezoelectric thin films for this application, along with the processing science associated with film preparation. For lead zirconate titanate (PZT) films, cold sintering has been explored as a means of bridging the gap between thin film (typically < 5 micron) and bulk ceramic processing. Ceramics can be sintered to very high densities (~98%) using cold sintering with either lead acetate or moistened lead nitrate at 500 MPa and 300°C, with a post-cold-sintering anneal step at 900°C. When layers of PZT are sintered on metal foils, constrained sintering and metal oxidation issues both need to be addressed. This paper will discuss approaches to solving both of these issues by cold sintering of metal and piezoelectric composites from powders, with subsequent heat treatments in a reducing atmosphere. For lead-free piezoelectrics, both $(Bi,Sm)FeO_3$ and $Na_{0.5}K_{0.5}NbO_3$ thin films are also under investigation for energy harvesting. In both cases, there are trade-downs in the achievable piezoelectric response, but some of this can be offset by lower dielectric permittivities.

S1: Mechano-Magneto-Electric Energy Harvesting

Mechano-Magneto-Electric Energy Harvesting III

Room: Salon 1
Session Chair: Isaku Kanno, Kobe University

9:00 AM

(EHS-S1-011-2019) A high power Magneto-mechano-triboelectric generator (MMTEG) for IoT systems (Invited)

G. Hwang[2]; K. Lim[2]; W. Yoon[2]; J. Ryu*[1]

1. Yeungnam University, Republic of Korea
2. Korea Institute of Materials Science, Republic of Korea

We are always surrounded by stray AC magnetic fields arising from electric power cables by Ampere's law. Magneto-mechano-electric (MME) generators have provided effective acquisition of electric power from the wasted magnetic noise. In this work, we introduce a high power MME generator by utilizing the triboelectric effect and water-soluble nano-bullet modified nanostructures to supply power to IoT systems. A magneto-mechano-triboelectric nanogenerator (MMTEG) is designed and fabricated by introducing accelerated water-soluble nano-bullet modified nanostructures to convert a gentle magnetic field into electric energy. NaCl salt nanoparticles were accelerated by an aerosol deposition (AD) process to collide on a perfluoroalkoxy (PFA) film with a high kinetic energy for the formation of a complicated nanomorphology on the triboelectric active surface. Under an alternating current (AC) magnetic field of 7 Oe, the MMTEG generated an open-circuit peak to peak voltage (V_{pp}) and a short-circuit current of 708 V and 277 mA, respectively. The harvesting device also presented a maximum peak power of 21.8 mW as well as a continuous AC output power of 4.8 mW (4.8 mJ per second. The MMTEG generated an open-circuit V_{pp} and a short-circuit current of 330 V and 23 mA, respectively, near a 60 Hz power cable connected to home appliances, which were large enough to turn on 108 blue light emitting diodes (LEDs).

9:30 AM

(EHS-S1-012-2019) Magneto-mechano-electric energy generator for efficient energy harvesting from low magnetic field (Invited)

M. Kang*[1]; R. Sriramdas[1]; S. Priya[1]

1. Pennsylvania State University, Department of Materials Science and Engineering, USA

Smart infrastructure functionalized with Internet of Things (IoT) technology is driving need of the wireless sensor network system and its sustainable power source. Magneto-mechano-electric (MME) energy conversion is the most promising technology to supply a sustainable power into the IoT sensor devices as it efficiently converts low frequency stray magnetic field (50/60 Hz), which exists everywhere in modern infrastructure, into the electricity. However, currently reported MME generators produce relatively low power under low magnetic field (≤300 μT), which commonly exist in infrastructure. In this presentation, comprehensive energy conversion mechanisms of the MME generator are discussed in order to achieve high energy conversion efficiency in low amplitude magnetic field. Building upon the mechanism study, an optimum MME generator, producing milliwatt power below 300 μT magnetic field, is realized utilizing commercially available piezoelectric and magnetostrictive materials. Exploiting the harvested power near a home appliance in the infrastructure, sustainable powering integrated sensors and wireless communication system is demonstrated. The fundamental study performed in this work provides a direction to achieve the efficient MME energy conversion from the low stray magnetic field and this will enable practical implantation of the IoT devices into the smart infrastructure.

10:00 AM

(EHS-S1-013-2019) Magnetoelectric vibrational energy harvester utilizing a phase transitional approach (Invited)

P. Finkel*[1]; M. Staruch[1]

1. 1. Naval Research Laboratory, Washington, DC, United States., USA

A broadband magnetoelectric energy harvester, consisting of Fe1−xGax (Galfenol) as the magnetostrictor and a relaxor ferroelectric single crystal as the piezoelectric, has been designed and optimized. Finite element analysis (FEA) has been employed to show that either a linear displacement or a 180° rotation of a magnet is sufficient to achieve maximum stroke from the Galfenol rod, which induces a rhombohedral to orthorhombic phase transition in Pb(In1/2Nb1/2)O3−Pb(Mg1/3Nb2/3)O3−PbTiO3 that produces a large jump in voltage. A rotational design based on a pendulum with an unbalanced mass was fabricated and used to confirm the validity of our FEA model.

10:30 AM

(EHS-S1-014-2019) Polymer-based magnetoelectric films for wearable energy harvesters (Invited)

S. Yang*[1]

1. Dong-A University, Republic of Korea

PVDF(polyvinylidene fluoride)-based polymers have interested due to its unique ferroelectric characteristic, which can be used in flexible devices such as actuators, sensors, energy harvesters, and so on. The high flexibility of polymers provides an easy shape change leading to high piezoelectric voltage constant g_{33} for feasible devices. Therefore, PVDF-based magnetoelectric (ME) composites have been studied for obtaining reliable ME responses, however, there is still a critical problem of low piezoelectric charge constant d_{33} from nature of polymers. Typically, piezoelectric polymers exhibited insufficient d_{33} values of ~50 pC/N compared to d_{33} values of 200 ~ 600 pC/N from ceramic-based piezoelectric materials so far. Even though enhancement of piezoelectric properties has been conducted by alignment of asymmetric β-phase in a polymer phase via various approaches such as annealing, quenching, uniaxial stretching, pressing, and poling, there is still a need to improve d_{33} above

100 pC/N for feasible ME applications. In this study, we have developed polymer based magnetoelectric films consisting of electrospun PVDF polymers and magnetostrictive CFO($CoFe_2O_4$) fillers. Piezoelectric properties and ME responses were investigated from the polymer-based ME films with regard to different magnetostrictive-piezoelectric structures of core-shell, conjugated, mixture, respectively.

11:00 AM

(EHS-S1-015-2019) All-inorganic flexible piezoelectrics for energy conversion and sense applications (Invited)

Y. Wang*[1]

1. Nanjing University of Science and Technology, Department of Materials Science and Engineering, China

A rapid surge in the research on flexible electronics and wearable devices is occurring with the arrival of artificial intelligent and the Internet of Things. In particular, piezoelectric materials are intensively studied and finding applications for bio-devices. However, most of the high-performance piezoelectric materials are based on perovskite-structured oxides, such as $Pb(Zr,Ti)O_3$ ceramics, which are commonly rigid, brittle. In this talk, we will demonstrate a cost-effective one-step process to fabricate large-scale, lightweight and all-inorganic piezoelectric/ferroelectric materials, assisted by unique flexible two-dimensional mica substrates, with the motivation for flexible piezoelectric energy harvesting. We will introduce: 1) an all-inorganic, flexible piezoelectric $Pb(Zr_{0.52}Ti_{0.48})O_3$ energy harvester is fabricated with an outstanding performance (i.e., open-circuit voltage of 120 V, short-circuit current density of 150 μA cm^{-2} and power density of 42.7 mW cm^{-3}), which are comparable to those via conventional "grow-transfer" technique from rigid substrates to organic soft ribbons, and are much greater by one to four orders of magnitude than previous reported ones based on piezoelectric nanofibers and organic thick films. 2) thereafter, an electrochromic thin film was integrated with the piezoelectric layer, to form a piezo-electrochromic mechnovisualization sensor.

11:30 AM

(EHS-S1-016-2019) Hybrid vibration converter for energy harvesting under weak vibration sources

S. Bradai*[1]; O. Kanoun[1]

1. Chemnitz University of Techmology, Electrical Engineering, Germany

Due to its availability and its relatively high energy density, vibration source is highly demanded to supply wireless sensors for a higher flexibility of use and low system maintenance costs. The focus is to design a compact and an efficient vibration converter able to work under an applied vibration up to 1 mm of amplitude and a frequency range between 20 and 30 Hz. For this purpose, this work proposes to combine the magnetoelectric (ME) and electromagnetic (EM) principles. The main advantage is that both principles can use the same changes of the magnetic field to harvest energy. To improve the converter energy density, the ME converter is incorporated within the relatively large coil housing of the EM converter. For a better reliability, the proposed design enables both principles to work independently. The converter consists of transmitting the applied vibration to the converter based on the magnetic spring principle to ensure a larger working frequency range. The converter has a total volume of 20 cm^3, which is able to harvest energy with a maximum power density of 0.11 mW/cm^3, a frequency bandwidth of 12 Hz for a resonance frequency of 24 Hz under an applied amplitude vibration of 1 mm. As conclusion, the combination of both principles is synergetic, so that the performance of each converter is improved through the combined design due to the Joule and Villari effect acting on the MS material.

11:50 AM

(EHS-S1-017-2019) Magnetoelectric (ME) Coupling of Textured Galfenol/(011) PMN-PZT Single Crystal Composite

H. Song*[1]; J. Ryu[1]

1. Yeungnam University, Material Science and Engineering, Republic of Korea

Magnetoelectric (ME) coupling phenomena is highly attractive for magnetic-electric energy conversion applications including energy harvesters, sensors, etc. In order to obtain superior ME coupling, piezoelectric and magnetostrictive properties of constituents are crucial properties most of all. It is known that the crystal orientation of the piezoelectric material can mediate the ME coupling drastically, for example. In this context, effect of crystallographic orientation in Galfenol (Fe-17at.% Ga) and PMN-PZT ($Pb(Mg_{1/3}Nb_{2/3})O_3$ $PbZrTiO_3$) laminates on ME coupling is investigated. (001) oriented magnetostrictive Galfenol is fabricated by Directional solidification and the plate forms are machined with two different orientation direction, i.e., (001) along thickness direction and (001) along plane direction, and laminated with PMN-PZT 32 mode, i.e., (011) oriented along thickness direction, and (100) oriented along plane direction, piezoelectric single crystals. Under the magnetic field stimulus, the composite with the Galfenol (001) textured along plane direction showed 45.58V/cm. Oe and 221% higher ME coupling compare to that of thickness direction Galfenol used composite at off-resonance and resonance condition, respectively. In this presentation, we will discuss about the magnetostrictive texturing effect of ME laminate composite based on the experimental data and FEM modeling.

S3: Multi-functional Energy Conversion Materials and Devices for Energy Harvesting and/or Sensing

Multi-functional Energy Conversion Materials and Devices for Energy Harvesting and/or Sensing II

Room: Salon 2

Session Chair: Carlo Trigona, University of Catania

9:00 AM

(EHS-S3-006-2019) Flexible energy harvesters and sensors based on multi-functional device platforms (Invited)

S. Kar-Narayan*[1]

1. University of Cambridge, United Kingdom

Modern electronics is rapidly evolving away from rigid devices to soft, flexible and stretchable devices. This evolution is being driven largely by the growing demand for wearable and human health monitoring applications, which require the development of conformal electronics with added functionality. Much of the effort in this area has relied on printing or transferring structures onto elastomeric substrates. However, the processing involved can often be cumbersome, and the structures themselves tend to suffer from poor fatigue characteristics. Here, I will describe a customised aerosol-jet printing process to fabricate fully freestanding stretchable multi-layered devices, incorporating multiple materials for added functionality, to be used as stretchable interconnects or as strain and humidity sensors, or for printed thermoelectric energy harvesters. Desired structures consisting comprising both conductive and functional layers can be printed layer by layer on a substrate with a sacrificial film, that is subsequently dissolved to release the printed structures, thus yielding freestanding self-supported stretchable interconnects and/or functional devices. Devices made from this approach showed good electrical stability and stretchability, and are thus well-suited for applications in flexible/stretchable electronics, such as in conformal tactile, strain and humidity sensing applications.

9:30 AM

(EHS-S3-007-2019) Energy Harvesting Using Flexible Lead-free Piezoelectric Composites (Invited)

P. Groen*[1]

1. Technical University Delft, Faculty of Aerospace Engineering, Netherlands

Piezoelectric materials can directly convert mechanical energy from vibration or direct strain into electrical energy and can be used to harvest energy from the environment. Various types of piezoelectric materials are available like inorganic ceramics, with Lead Zirconium Titanate (PZT) being the most commercially used due to the high piezoelectric properties. However, they have the drawback of being brittle, making them unsuitable to handle large cyclic strains, while also containing a relative high content of the toxic substance lead. Piezoelectric polymers such as poly(vinylidine fluoride) (PVDF) have the advantage of being flexible, but have only limited energy harvesting potential. Piezoelectric composites combine a polymeric matrix with a piezoelectric ceramic in order to obtain a piezoelectric material with more attractive combinations of desirable properties. The polymeric matrix makes the material more flexible and tougher, while the ceramic filler makes the composites piezoelectric. Very good properties can be obtained for the lead free composites containing Lithium doped Sodium Potassium Niobate (KLNN). Various composites have been investigated ranging from micron-sized particles 0-3 composites to oriented 1-3 composited containing oriented fibres. Finally, the polymer which is used as matrix has a big influence on the final piezoelectric properties.

10:00 AM

(EHS-S3-008-2019) Maximising energy harvesting performance using piezoceramic composites (Invited)

J. Roscow*[1]

1. University of Bath, United Kingdom

Piezoelectric ceramic-based composites offer a number of advantages over their dense counterparts for energy harvesting. Introducing a low permittivity second phase, e.g. air or a polymer, into a piezoceramic leads to significant reductions in the effective permittivity ($\varepsilon_{33}^{\sigma}$) of the material, whilst the piezoelectric strain coefficient, d_{33}, can be maintained, and in certain cases improved, compared to the dense system. This can lead to large increases in the energy harvesting figure of merit, $d_{33}^2/\varepsilon_{33}^{\sigma}$, and the rate at which mechanical energy can be converted into useful electrical power. This figure of merit, however, neglects the influence of the mechanical properties of the active material on the energy harvesting performance. While in many cases high stiffness materials (i.e. dense piezoceramics) are favourable, the use of composite structures also enables the tuning of mechanical properties to provide more efficient transfer of mechanical energy into the active material, as well as providing the aforementioned functional benefits. In this talk, the advantages of using composite systems for piezoelectric energy harvesting will be discussed with reference to advanced fabrication techniques and the fundamental structure-property relationships that give clues to how these materials could be improved in the future.

10:40 AM

(EHS-S3-009-2019) Piezoelectric properties of (Li, Na, K)(Nb, Sb)O_3-$CaZrO_3$ lead-free ceramics and thick-films for piezoelectric energy harvester

S. Chae*[1]; S. Nahm[1]

1. KU-KIST Graduate School of Converging Science and Technology, Korea University, Republic of Korea

1.0 mol% CuO-doped $0.97(Li_{0.04}Na_{0.46}K_{0.5})(Nb_{0.89}Sb_{0.11})O_3$-$0.03CaZrO_3$ [C(LNK)(NS)-CZ] ceramic exhibits an orthorhombic-tetragonal (O-T) polymorphic phase boundary (PPB) structure. This ceramic shows a high piezoelectric constant (d_{33}) of 502 pC/N and an electric-field strain of 0.16% at 4.0 kV/mm owing to its O-T PPB structure. Also, this specimen has good thermal stability; it maintains a large strain of 0.16% at 150 ºC and a high d_{33} value 475 pC/N at 130 ºC. The thick-films were fabricated by using C(LNK)(NS)-CZ composition through tape-casting method. The C(LNK)(NS)-CZ thick-films, which were sintered at 1050 ºC for 6 h, displayed a homogeneous perovskite structure without the secondary phase. This thick-film also exhibited a dense microstructure with a high relative density (96.1% of the theoretical density). The high d_{33} (480 pC/N) and strain (0.13% at 4.0 kV/mm) were obtained from this thick-film. Furthermore, the piezoelectric energy harvesters were produced using the C(LNK)(NS)-CZ ceramics and thick-films and their properties were investigated in this work.

11:00 AM

(EHS-S3-010-2019) <001> textured Mn-doped PZT-PZN-PNN hard piezoelectric ceramics

H. Leng*[1]; Y. Yan[1]; H. Liu[1]; S. Priya[1]

1. The Pennsylvania State University, Department of Materials Science and Engineering, USA

For high power piezoelectric application, high coercive fields and low dielectric/mechanical losses are required. Ultrahigh piezoelectric response is frequently reported in relaxor piezoelectric single crystals. However, most of relaxor single crystals reveal low coercive field E_C and the low ferroelectric rhombohedral to tetragonal phase transition temperature T_{R-T}, significantly limiting high-power applications. Growth of high-power piezoelectric single crystals still faces a fundamental challenge due to the incongruent melting behavior. The templated grain growth technique enables large amount of grains to be oriented along a specific crystallographic orientation, therefore offering a solution to produce single crystal-like high-power piezoelectric materials. In this study, we are targeting to develop <001> textured high power piezoelectric ceramics with increased coercive field over 10 kV/cm. $Pb(Zr,Ti)O_3$-$Pb(Zn_{1/3}Nb_{2/3})O_3$-$Pb(Ni_{1/3}Nb_{2/3})O_3$ (PZT-PZN-PNN), was selected as matrix compounds. MnO_2, and $Pb(Mn_{1/3}Nb_{2/3})O_3$ (PMnN) were added to increase the coercive field and mechanical quality factor Q_m. Using $BaTiO_3$ templates, we successfully synthesized highly textured Mn-PZT-PZN-PNN piezoelectric ceramics. It was found that textured ceramics show an increased E field-induced strain and E_c. We believe this work will expand the application of textured piezoelectric ceramics into high power fields.

11:20 AM

(EHS-S3-011-2019) Cold Sintering for Lead-Free Piezoelectric Ceramics

K. Tsuji*[1]; C. Randall[1]

1. The Pennsylvania State University, Materials Science and Engineering, USA

Piezoelectric energy harvesting has been extensively investigated to harness low frequency vibration. From the viewpoint of materials, there is enormous demand for the development of lead-free piezoelectric materials due to a potentially hazardous risk of lead. One of the major issues in the lead-free ceramics is related to material processing. Namely, loss of volatile elements that compose the ceramics significantly worsen the properties. Here, we demonstrate cold sintering to densify piezoelectric ceramics under 400 degree Celcius. We will show the electrical and piezoelectric property as well as microstructure.

11:40 AM

(EHS-S3-012-2019) Cold Sintering of Materials for Energy Storage

C. Randall*[2]; A. Ndayishimiye[2]; J. Seo[1]; H. Nakaya[3]; S. Bang[1]; K. Tsuji[1]; Z. Grady[1]

1. Penn State University, Materials Science and Engineering, USA
2. Penn Sate University, Materials Research Institute, USA
3. NGK SPARK PLUG CO., LTD., Komaki, Aichi, Japan., Japan

Cold Sintering involves a transient phase that permits the densification of particulate materials at low temperatures 300 °C and below. Sintering at such low temperature offers so many new opportunities. It permits the integration of metastable materials that would typically decompose at high temperatures. So cold sinter enables a platform for better unification of material science. Now ceramics, metal and polymers can be processed under a common platform in one step processes. With controlling the forming process new nanocomposites can be fabricated. Polymers, gels and nanoparticulates can be dispersed, interconnected and sintered in the grain boundaries of a ceramic matrix phase. With the ability to sinter metal phases, multilayer devices can be co-sintered with electrodes made from metals such as Al, Ag, Fe and Cu. With appropriate binder selection, polypropylene carbonate and its de-binding at 130 °C we can remove organic binders and leave metals and other more stable polymers within the layers that then can be co-sintered under the cold sintering process and form unique combinations of materials in multilayers. Utilizing this technology, there are many opportunities for energy storage, including lithium and sodium all solid-state batteries, and also fuel cells. Examples will be given for each.

S4: Thermoelectric Energy Harvesting

Thermoelectric Energy Harvesting III

Room: Salon 3
Session Chair: Bed Poudel, Penn State University

9:00 AM

(EHS-S4-012-2019) Flexible Thermoelectric Generators with Bulk Thermoelectric Materials and Stretchable, Low-Resistivity Liquid Metal Interconnects (Invited)

M. C. Ozturk*[1]

1. North Carolina State University, Electrical and Computer Engineering, USA

Thermoelectric generators (TEGs) that convert waste heat into electricity are of great interest for a variety of applications ranging from self-powered wearables to industrial applications with continuous sensing needs. For many of these applications, flexible TEGs that conform to the shape of the heat source are highly desirable. For wearables, a flexible TEG would provide a better contact to the skin and reduce the thermal contact resistance between the body and the device. Furthermore, without a flexible TEG, one would have to connect many rigid TEGs on a flexible band, an approach that would result in an aesthetically inferior wearable, which would also suffer from a high parasitic interconnect resistance. A variety of approaches have been previously proposed for manufacturing flexible TEGs. Unfortunately, none of these approaches were able to produce flexible TEGs that were able to rival the performance of their rigid counterparts for reasons that include poor quality of new flexible materials, limitations on leg dimensions imposed by fabrication techniques and parasitic resistances. With their maximum power levels limited to a few microwatts (or nanowatts in many of the cases), these modules were short of meeting the power needs of most applications including wearables.

9:30 AM

(EHS-S4-013-2019) The Rise of Paramagnetic Thermoelectric Materials (Invited)

D. Vashaee*[1]; M. H. Polash[2]; V. Perelygin[3]; A. Smirnov[3]

1. North Carolina State University, Dept. of Electrical and Computer Engineering, USA
2. North Carolina State University, Dept. of Materials Science and Engineering, USA
3. North Carolina State University, Dept. of Chemistry, USA

Thermal spin transport is a relatively new area of science with significant prospects for materials innovations. Paramagnon drag has been experimentally observed in some paramagnetic spin fluctuation systems; however, the physical parameters for designing such materials remained mostly unknown. Some materials like MnTe have shown robust spin effects in the paramagnetic phase leading to zT>1 at 1000K, i.e., three times higher than the long-range ordering temperature. Understanding the key parameters that control such interactions enables us to identify and design materials to harness the spin effects on thermopower and create fundamentally new kinds of high zT semiconductors. In this talk, we will first outline how magnon drag increases the thermopower of the antiferromagnetic (AFM) and ferromagnetic (FM) semiconductors. The prospect of a large thermopower originated from the mid- or short-range magnetic ordering will be discussed. Some competing effects such as the spin-fluctuations and spin entropy will be presented, which can also lead to thermopower enhancement in magnetic materials even in the paramagnetic regime. The agreements and disagreements of different spin-based theories in describing the recent experimental results based on the transport and thermal data, magnetic study, and the electron paramagnetic resonance spectroscopy will be discussed.

10:00 AM

(EHS-S4-014-2019) Solid-state thermionic devices based on 2D van der Waals heterostructures (Invited)

M. Zebarjadi*[1]; G. Rosul[1]

1. University of Virginia, Electrical and Computer Eng., USA

Solid state thermionic devices based on van der Waals structures were proposed for nanoscale thermal to electrical energy conversion and integrated electronic cooling. Here, we study thermionic cooling across gold-graphene-few layers of WSe_2-graphene-gold structures computationally and experimentally. Using first principles calculations combined with real space Green's function (GF) formalism, we show while this structure has a low equivalent figure of merit at room temperature, it is expected to be highly efficient with ZT values above 1, at high temperatures (T ~ 800K). We use layer resolved split technique to stack graphene and WSe_2 layers with single atom thickness precision. This is followed by deposition of top/bottom gold contacts on top/bottom graphene. The I-V curve of the final fabricated structure demonstrates relatively Ohmic contact. The measured Seebeck coefficient of the structure (72 μV/K at room temperature) is in close agreement with the theoretical prediction. We present a new measurement technique which combines thermo-reflectance and cooling curve measurements to extract equivalent device figure of merit, ZT. In agreement with theoretical predictions, a small ZT was estimated at room temperature using this method. We discuss design strategies to improve the efficiency and lay the pathway toward highly efficient thermionic devices.

10:30 AM

(EHS-S4-015-2019) Sizing a thermoelectric energy harvester for maximum performance in a constantly varying aerospace environment (Invited)

M. R. Pearson*[1]; W. Veronesi[1]

1. United Technologies Research Center, Thermal Fluid Sciences, USA

Wireless sensors are gathering significant interest across the aerospace industry because they can be placed virtually anywhere and potentially eliminate many kilograms of wiring weight. They are also useful for retrofit or aftermarket situations where the sensor is

an add-on to existing FAA-certified hardware. However, to truly be wireless, they need a local energy source to preclude the wiring of a power cable. Many equipment items that benefit from onboard sensing also have a degree of heat generation which can be leveraged for a thermal energy harvesting solution (e.g. thermoelectrics). However, as the aircraft climbs, cruises, and descends, these thermal sources and sinks can exhibit significant variations including changes in cabin altitude, external air pressure and temperature, and also the amount of work done by the equipment as these conditions vary. For shorter regional flights, a significant portion of an aircraft's flight is spent in climb or descent phase where the conditions are changing, and thus appropriate sizing of a thermoelectric harvester must adequately consider these flight phases. We demonstrate an example of how to size and optimize a thermal energy harvester not for a fixed operating point but for a spectrum of conditions in order to truly maximize the harvested power and minimize the weight of the harvester.

11:00 AM

(EHS-S4-016-2019) Highly efficient NbFeSb based thermoelectric devices for waste heat recovery applications

U. Saparamadu*[1]; B. Poudel[1]; A. Nozariasbmarz[1]; W. Li[1]; H. Kang[2]; C. Dettor[1]; S. Priya[1]

1. The Pennsylvania State University, Material Science and Engineering, USA
2. Bio-inspired Materials and Devices Laboratory (BMDL), Mechanical Engineering, USA

Half-Heusler thermoelectric materials have been extensively studied as high-temperature thermoelectric materials due to its thermal stability, mechanical strength and high ZTs for both p-type and n-type materials. To achieve good module performance, electrical and thermal contact resistances play critical roles besides material properties. In this work, we have fabricated NbFeSb based half-Heusler thermoelectric device. Low electrical contact resistance between electrode and thermoelectric material interface is critical for device performance where poor contacts can cause Joule heating which can significantly degrade the power output. Ideally, the contact resistivity should be <1 $\mu\Omega$ cm^2 where many material systems are far from achieving this value. We were able to achieve a very low contact resistivity of ~1 $\mu\Omega$ cm^2 resulting in an efficiency close to theoretically predicted value. This device fabrication technique may lead to a potential breakthrough in high-temperature power generation technology for various applications such as waste heat recovery vehicle engine exhaust and other industrial processes.

11:20 AM

(EHS-S4-017-2019) Thermoelectric Modules Optimization for Low-grade Heat Recovery

A. Nozariasbmarz*[1]; B. Poudel[1]; R. Kishore[2]; U. Saparamadu[1]; W. Li[1]; S. Priya[1]

1. Pennsylvania State University, Materials Science and Engineering, USA
2. Center for Energy Harvesting Materials and Systems, Virginia Tech, USA

Thermoelectric generators (TEGs) are environmentally friendly devices that can directly convert heat to electricity. TEGs are the most reliable technology for waste heat recovery and power generation applications. Different power generation applications require specific materials and module design to provide the maximum harvested energy. The external thermal resistance and boundary condition influence the performance of the TEGs. Commercial modules are not designed for specific applications such as when the thermal resistance of the heat source or sink is high. In this research, we study the requirement for module design to achieve the highest power in such environment. By optimization of leg aspect ratio and fill fraction, we have achieved more than 100% improvement in power output and further improvement is possible with material design.

11:40 AM

(EHS-S4-018-2019) Tuning thermoelectric power factor in flexible device made by two-dimensional crystals of MoS_2

X. Zhang*[1]

1. Stevens Institute of Technology, Mechanical Engineering, USA

The demand for high-efficiency heat-to-electricity conversion has been one of the major driving forces toward renewable energy harvesting for the future. Low dimensional materials open new routes to a high power factor due to their unique density of states of confined electrons and holes. Among them, two-dimensional (2-D) crystal MoS_2 exhibits high thermoelectric power factor. On the other hand, the immense growth of skin-like electronic devices based on 2-D materials is considered to revolutionize technologies in the crux of the communication, health, and fitness for grand applications in healthcare monitoring and human-machine interfaces. Understanding of fundamental thermoelectric property in response to mechanical loading is expected to lay foundation for widespread of these devices with controllable energy harvesting. In this presentation, we will present the fabrication of flexible energy harvesting devices, and the tuning of thermoelectric power factor in flexible device made by 2-D MoS_2.

Plenary V

Room: Salon 4
Session Chair: Shashank Priya, Pennsylvania State University

1:35 PM

(EHS-PLEN-005-2019) Working Towards a Sustainable World with Clean Abundant Energy

L. D. Madsen*[1]

1. National Science Foundation, USA

I will discuss four aspects of obtaining a sustainable world with clean abundant energy: (i) who the researchers are that are engaged in this endeavour, (ii) how researchers worldwide can be connected, (iii) methods to ensure that sustainability is a central focus, and finally (iv) educating the next generation. While science, technology, engineering, and mathematics (STEM) fields have been dominated by men, there are some rays of hope when it comes to energy research. I will show a sampling of women in the field; while not representing 50%, they are visible, significant, and leaders. Also, researchers are distributed around the world – but are they united and are there mechanisms for bringing them together? A few avenues will be described that support country-to-country collaborative research. This conference and other platforms are essential to introduce researchers, facilitate interactions, and provide a venue for on-going collaboration. Not all energy solutions are environmentally-friendly and take into consideration the entire lifecycle. Sustainability of resources is key to moving forward long-term. Finally, reaching the next generation of students has required adaptations to traditional teaching methods – more effort in this direction is needed to bring diversity, international engagement, and sustainability to the forefront.

S1: Mechano-Magneto-Electric Energy Harvesting

Mechano-Magneto-Electric Energy Harvesting IV

Room: Salon 1
Session Chair: Peter Finkel, Naval Research Laboratory, Washington, DC, United States.

2:30 PM

(EHS-S1-018-2019) Flexible PZT thin films on stainless steel foils for energy harvesters (Invited)

I. Kanno*[1]

1. Kobe University, Mechanical Engineering, Japan

In recent years, piezoelectric vibration energy harvesters (PVEHs) have attracted attention as a power source for an autonomous sensor node. Because of the strong demand for small and high-efficient power generators, PZT thin films have been tried to be used for MEMS-based PVEHs. However, one of the serious technical issues is the brittleness because conventional PZT thin films are generally deposited on Si substrates and the fracture toughness of PVEHs is determined by that of base structure of Si. In our laboratory, we have deposited PZT thin films on thin metal foils for flexible PVEHs. 3 μm-thick PZT thin films are deposited on Pt-coated stainless steel foils of 50 μm by rf-magnetron sputtering. The PZT thin-film PVEHs generated stable power as high as 70 μW by large bending motion of around 90 degree with the radius of curvature of 7 mm and we successfully transmit the data of temperature and humidity using bluetooth low energy (BLE) module powered by the flexible PZT thin-film PVEHs.

3:00 PM

(EHS-S1-019-2019) Energy Harvesting of a Composite Beam with Optimizing Stacking Sequence of Layers

M. Borowiec*[1]; M. Bochenski[1]; J. Gawryluk[1]

1. Lublin University of Technology, Department of Applied Mechanics, Poland

The vibrations of mechanical systems in resonance areas manifest both, the risk amplitudes of device response and an expected efficiency of energy harvesting. In laboratory conditions to keep the relatively high energy harvesting productivity, the assumed parameters of the shaker have to be secured. In general, the technical parameters of excitation source devices are restricted by the control system. In this work the main goal is to examine the coupling conditions of composite beam, which initiate the vibrations response in different directions than excitation force. Then a save range of parameters of vibration source devices can be obtained, for energy harvesting tests. A proper stacking sequence of the beam layers, results displacements of the beam points in perpendicular way against the excitation direction. We analyse the influence of the excitation in the rigid beam direction on the response of the beam in the perpendicular flexible direction. For this purpose the composite beams with determined sets of composite layers have been modelled and simulated the appeared effect. The beam are equipped with Macro Fiber Composite MFC and the energy harvesting has been charged by piezo – elements for all examined stacking sequence of beam layers. We focused on mechanical coupling of the sets of composite beam layers to get an optimal its configuration to gain the energy harvesting efficiency.

3:20 PM

(EHS-S1-020-2019) Power Amplification through Distributed Forcing at 60 Hz Frequency in Magnetoelectric Energy Harvesters

R. Sriramdas*[1]; M. Kang[1]; S. Priya[1]

1. Pennsylvania State University, Materials Science and Engineering, USA

Magnetoelectric (ME) energy harvesters, designed to resonate at a fixed frequency of 60 Hz, absorb magnetic fields through a composite beam of piezoelectric and magnetostrictive layers, and a magnetic end mass. The end magnet not only affects the power but also the resonance frequency of the harvester. Although the addition of an end magnet can enhance the power generation, the frequency constraint cannot be met with added mass. Here, we show a method of maintaining the resonance frequency of a ME harvester at 60 Hz with added mass that can enhance the power generation. It is observed that by way of distributing the magnetic mass over the beam results in increased distributed forcing along the beam while maintaining the resonant frequency constant. A sensitivity analysis was performed to determine the effect of adding mass at different locations along the beam on both frequency and power. It is observed that the power from a distributed forcing at a fixed frequency can be at least 50% higher depending on the added mass and location. Experiments are performed on an SFC and metglas composite ME harvester designed to resonate at 60 Hz in the two proposed methods. The conventional end mass harvester resonating at 60 Hz generated 2.2 mW at 1 mT ambient field while a distributed forcing on the same harvester developed 4.1 mW indicating an increase of 186% in the power generation.

S2: Integrated Energy Harvesting and Storage Systems for Wearables and IoT

Integrated Energy Harvesting and Storage Systems for Wearables and IoT I

Room: Salon 3
Session Chair: Sebastian Bader, Mid Sweden University

2:30 PM

(EHS-S2-001-2019) Is Energy Wearable? Toward Self-Sustaining Smart Wearable and IoT Devices (Invited)

M. Magno*[1]

1. ETH Zurich, D-ITET, Switzerland

Energy Harvesting (EH) technologies provide promising solutions to overcome the short lifetime of wearable and IoT devices. In the last decade, EH has matured as a technology and found use in many application scenarios, such as smart grid and wireless sensor networks. Recently, advances have been made in miniaturizing EH devices to supply wearable and IoT devices by exploiting ambient energy in the form of motion, thermal gradients, light, and electromagnetic radiation. However, harvesting energy from the body or small size harvesting for powering wearable and IoT devices is more challenging due to strict constraints in terms of size, weight, and cost. This work will present a taxonomy of technologies, architectures and design trade-offs for efficient EH systems suitable for wearable and IoT devices. Additionally, this work will provide implementation details, including the conversion stages for, light, kinetic, thermal EH and RF power transmission, optimized for the human body and small form factors harvesters. This work presents the design guidelines and experimental evaluations we present, with in-field measurement, will be of benefit to designers of future EH wearable and IoT systems, which can be self-sustaining and intelligent.

3:00 PM

(EHS-S2-002-2019) Fabric Power Modules for e-Textiles Applications (Invited)

S. Beeby*[1]

1. University of Southampton, School of Electronics and Computer Science, United Kingdom

Wearable electronic devices are increasingly being developed in textiles (etextiles) but a significant technical challenge for such systems is the supply of energy. At present, etextiles are typically powered by conventional rigid batteries that require frequent charging/replacement and are incompatible with the feel of the textile. Therefore, combining a flexible energy harvester with a flexible energy storage supercapacitor in the same piece of textile is an attractive solution for powering wearable etextile devices. This paper presents investigations at the University of Southampton into a variety of energy harvesting and storage approaches applied to textiles. The energy harvesting techniques include flexible printable polymer piezoelectric films, fabric based ferroelectrets, inductive wireless power transfer and organic and dye sensitised solar cells. The energy storage method is provided by impregnating the fabric with activated carbon to create electrodes that combine to form an electrical double layer supercapacitor. The ferroelectret energy harvesting approach has been combined with the supercapacitor and suitable power conditioning electronics in a single fabric layer to produce a textile power module. This combination demonstrates the feasibility of an integrated power supply that can be power etextiles applications going forward.

3:30 PM

(EHS-S2-003-2019) Power Estimation for Wearable Energy Harvesting Devices

G. Rai*[1]; T. Safwat[1]; C. Rahn[1]; Z. Ounaies[1]

1. The Pennsylavnia State University, Mechanical Engineering, USA

This project develops a network of energy harvesting and storage elements that is used to estimate power harvesting profiles in a real world environment. A framework has been developed to translate human behavioral data, along with environmental data, to meaningful energy inputs for several wearable energy harvesting modalities. The power inputs were then processed in the harvester network which then provides a net output power. The framework developed in this project can be utilized as a design tool for ideal use case analysis. For instance, power profiles for different demographic groups is explored in an effort to understand the variable power dynamics and harvesting intermittency for groups with relatively similar behavior. Moreover, this project provides insight on the feasibility of using multimodal power harvesting, coupled with a storage element, for several low-power applications, where a perennial power supply is needed.

4:00 PM

(EHS-S2-004-2019) Rail trackside energy harvesting devices: Feasibility study, development, tests and future potential (Invited)

Z. Hadas*[1]; O. Rubes[1]; P. Tofel[2]

1. Brno University of Technology, Faculty of Mechanical Engineering, Czechia
2. Brno University of Technologi, Czechia

Railway systems are becoming more complex and railway operators and maintainers need devices known as object controllers which are placed in predesigned areas along the track. Smart object controllers require autonomous electrical power for signalling and communication. The trackside energy harvesters contribute to the reduction of cost, providing an energy harvesting solution for communication of objects that could minimize trackside infrastructure, particularly cabling. A passing train could be used as ambient source of energy for these trackside objects. Ambient energy could be in a form kinetic energy, vibrations, deformations, rail sag, pressure, etc. This contribution will review advanced trackside energy conversion devices with harvesting functionalities. In order to increase the potential of trackside energy harvesting sources and the overall capability of trackside energy harvesting devices, hybrid energy harvesters are under investigation. These hybrid devices are also promising alternatives for harvester-sensor integration on a rail or into smart sleepers. Feasibility assessment of energy harvester systems are introduced, and individual trackside energy harvesting system are presented (vibration electromagnetic harvesters, variable reluctance harvesters, triboelectric nanogenerators, etc.) to achieve the required performance for smart wayside objects.

4:30 PM

(EHS-S2-005-2019) Modelling Validation of Vibration Energy Harvesting for Structural Health Monitoring of Water Pipes (Invited)

V. Pakrashi*[1]; F. O. Okosun[1]

1. University College Dublin, Mechanical and Materials Engineering, Ireland

Vibration energy harvesting as a structural health monitor in its own right is a nascent and challenging topic. In this regard, its potential applications on detection pipelines leakage and damage is of particular relevance. Recent expeirments have indicated that vibration energy harvesting can be an efficient indicator for both damage and leakage detection. This has an immense potential impact since water is a key global resource and both leakage and damage of pipelines is related to substantial losses. However, there exists no numerical benchmarking around this energy harvester based damgae and leakage detection. This paper addresses this gap and presents numerical analyses to put the experimentation into context and also to craete a numerical benchmark around this topic for recreation and repeatbility of the process, The results are expected to be helpful for developing and applying other energy harvesting based sensors as well.

5:00 PM

(EHS-S2-006-2019) Nonlinear vibration energy harvesting systems with a piezoelectric transducer in presence of harmonic excitations and additional noise (Invited)

G. Litak*[1]

1. Lubin University of Technology, Poland

One of the advantage of nonlinear energy harvesting systems with a mechanical resonator is the presence of multiple solutions which can show resonance behaviour in various frequencies. In particular for bistable systems large amplitude solutions with subharmonic character can be found. These solutions showing jumps through a potential barrier are much more effective for energy harvesting than small amplitude oscillations. There is a question: how stable is that solution in the presence of noise. In the lecture we show the effect of noise on such subharmonic solutions and examine their stability.

S3: Multi-functional Energy Conversion Materials and Devices for Energy Harvesting and/or Sensing

Multi-functional Energy Conversion Materials and Devices for Energy Harvesting and/or Sensing III

Room: Salon 2
Session Chair: Evan Reed, Stanford University

2:30 PM

(EHS-S3-013-2019) Roll-to-Roll Slot Die Coated Perovskite for Efficient Flexible Solar Cells

P. Groen*[1]

1. Holst Centre, Netherlands

Metal-halide based perovskites are promising novel materials for thin-film photovoltaics, exhibiting high power conversion efficiencies. A number of challenges still need to be addressed before PSCs can enter the PV market. One of these challenges is the development of industry-relevant technologies for scaling up the perovskite module manufacturing. The feasibility of upscaling the perovskite solar cells technologies to high volume production using Roll-to-Roll (R2R) slot die coating is demonstrated in this talk. Perovskite solar cells were produced by R2R slot die coating on flexible PET/ITO substrates with the width of 30 cm. Roll-to-Roll deposition of electron transport layer (ETL) and perovskite is performed at ambient atmosphere from non-toxic solvents compatible with industrial manufacturing. The average stabilized power conversion efficiency of the devices made from the foils randomly cut from different places was 12%, with the best value of 13.5%. The demonstrated achievement is an important milestone and a big solid step towards future commercialization of perovskite-based solar cells technologies.

2:50 PM

(EHS-S3-014-2019) Treated Perovskite Single Crystals for Solar Cell with Unprecedented Power Conversion Efficiency (Invited)

O. Mohammed*[1]

1. KAUST, Chemistry, Saudi Arabia

Methylammonium lead iodide ($MAPbI_3$) perosvkite single crystals show extremely low trap-state density, high charge carrier diffusion length, long radiative carrier lifetime and high charge carrier mobility, making them outstanding candidates for high efficient solar cells. However, these single crystals still severely suffer from the presence of impurity traces such as triiodide that formed during their growth at high temperature. These traces can act as hole quenching centers on the surface and at the device interface, hindering the further development of the performance of the solar cells based on these crystals. Here, we will first show tremendous impact of the presence of excess triiodide on the charge carrier lifetime and carrier mobility. To take the project one step further, twenty-microns-thick single-crystal methylammonium lead triiodide ($MAPbI_3$) perovskite (as an absorber layer) grown on the charge-selective contact using a solution space-limited inverse-temperature crystal growth method before and after acid treatment of these single crystals yields solar cells with power-conversion efficiencies reaching more than 21% and fill factors of up to 84.3%. These devices set a new record for perovskite single-crystal solar cells, and open an avenue for achieving high fill factors in perovskite solar cells.

3:20 PM

(EHS-S3-015-2019) A solar-powered piezoelectric/pyroelectric sensor containing a single energy conversion/sensing material

Y. Bai*[1]; J. Palosaari[1]; H. M. Jantunen[1]; J. Juuti[1]

1. University of Oulu, Finland

Piezoelectric/pyroelectric materials have succeeded in industries of kinetic/thermal sensors. By contrast, their success as energy harvesters has been hindered by insufficient output energy due to limited energy conversion efficiency and the randomness of input energy. However, there is a considerable demand on autonomous sensors solely powered by energy harvesting because of the rapid development of Internet of Things. Therefore, development of self-powered sensors containing cost-effective energy harvesting components offering an effortless replacement to battery-powered counterparts becomes an urgent task. Solar energy, as a relatively stable input energy, can be used to power piezo-/pyroelectric sensors. However, installing solar cells in those sensors increases costs and structrual complexity. In this talk, a solar-powered piezo-/pyroelectric sensor containing only one functional material is presented. In the sensor, the single photoferroelectric material simultaneously respond to solar, kinetic and thermal stimuli. The DC output from solar energy is used to power the circuits whilst the AC signals from the other sources are used for sensing. This single-mateiral, multi-functional harvesting/sensing concept may significantly decrease the costs and simplify the configuration, and thus stimulate the industrial adoption of self-powered sensors.

3:50 PM

(EHS-S3-016-2019) Development of photothermal chlorophyll thin-films for energy applications

D. Shi*[1]; Y. Zhao[1]

1. University of Cincinnati, Mechanical and Materials Engineering, USA

The photothermal effects have been extensively studied for various metallic materials such as gold and attributed to the localized surface plasmon resonance. Most of photothermal applications have been focused on the madical therapeutics such as tumor ablation. In this presentation, we report a new photothermal material chlorophyll that is highly transparent with strong photothermal effect. The molecular structure of chlorophyll consists of a chlorin ring, whose four nitrogen atoms surround a central magnesium atom, and has several other attached side chains and a hydrocarbon tail. Chlorophyll features a saddle-like spectrum with two peaks respectively at 400 nm (blue-violet) and 700 nm (NIR), which is responsible for its transparency. The thin film coating applied on window surfaces can effectively reduce the heat loss without any insulating gases, making single-pane possible. The experimental results are reported on the synthesis and processing of chlorophyll-based thin films. The fundamental operating mechanism of photothermal heating of chlorophyll is identified.

4:10 PM

(EHS-S3-017-2019) Surface Reaction-Driven Pyroelectric Energy Conversion

B. Hanrahan*[1]; A. Smith[2]; S. Karnani[1]; H. Kareem[1]; L. Mahoney[1]

1. U.S. Army Research Laboratory, USA
2. U.S. Naval Academy, USA

In this work we examine thermal energy conversion on pyroelectric crystals driven by endo- and exo-thermic reactions taking place directly on or adjacent to the material. Since pyroelectric energy conversion requires time-variant heat sources, we examine the system for both pulsed cooling, driven by droplet evaporation, and pulsed heating, driven by catalytic combustion of propane gas. Both experiments we're performed on a platinized single crystal of Z-cut $LiTaO_3$ which was 0.5 mm thick. We performed energy conversion cycles following a charge -> heat -> discharge -> cool protocol by synching the reaction with an applied electric field, where the total energy converted can be calculated by the area encapsulated by the cycle in polarization-electric field space. The combustion-based pyroelectric can be used as a high voltage source for X-ray generation or robotic actuation, or as a portable power source. Using liquid fuel for portable power has the advantage of large starting energy densities, for the example of methanol (22 MJ/kg), the combustion, conversion, and delivery efficiency of a pyroelectric system would only need to be ~3% efficient to match the specific energy of a lithium ion battery. We will discuss the integration of the catalyst into the fabrication, modelling, and testing in both "voltage" and "power" operating modes.

4:30 PM

(EHS-S3-018-2019) Bio-inspired Vitamin Assisted Single-Structured based Self-Powered Piezoelectric/Wind/Acoustic Multi-Energy Harvester with Remarkable Power Density

S. K. Karan*[1]; S. Maiti[1]; B. Khatua[1]

1. Indian Institute of Technology Kharagpur, India, Materials Science Centre, India

Here, bio-inspired vitamin assisted PVDF based multifunctional advanced energy material with high out-of-plane piezoelectric coefficient of ~ −50.3 pC/N, is reported first time for harvesting huge electrical energy from multi-modes of alternative energy sources in a single device. Thus, an entirely organic based fully biocompatible piezoelectric nanogenerator (PNG) having multifunctional energy harvesting capabilities at a time (mechanical/acoustic/wind) has been designed by integrating vitamin B_2 (VB_2) with PVDF. VB_2 is introduced in energy-harvesting family for first time as an effective β-phase (~93%) stabilizer for PVDF and would be better replacement of non-toxic expensive stabilizers. The fabricated nanogenerator reveals high output current (»12.2 mA) and voltage (»61.5 V), theoretically verified with finite element method (FEM) based simulation. The device with fast-charging capability shows remarkable peak power density of »9.3 mW/cm^3 and ultrahigh energy conversion efficiency (»62%) enabling lightening more than 100 LEDs directly and can power up a CD motor/mobile through capacitor charging. Moreover, generation of electricity from various noises allows potentiality of the device as an artificial acoustic ultra-sensor.

4:50 PM

(EHS-S3-019-2019) All- printed magnetic power transformer and power transmission systems for wearable sensors and actuators

V. M. Correia*[1]; N. Pereira[1]; A. C. Lima[2]; P. Martins[2]; N. Perinka[3]; S. Lanceros-Mendez[3]

1. Universidade do Minho, Algoritmi, Portugal
2. Universidade do Minho, Centro de Fisica, Portugal
3. Basque Center for Materials, Applications and Nanostructures, Spain

With the growing demand for alternative low power energy sources for the new paradigms of IOT and industry 4.0 to provide power to a new generation of wearable sensors and actuators, the methods for energy generation and transfer are diversified. Printing technologies applied to the production of microsystems for production, transformation and transmission of energy allow mass production, simple integration and low cost solutions for these new paradigms. In this work, a new generation of fully screen printed planar transformer and planar and flexible RF power transmission system will be presented, based on the printing of concentric coils on various formats, with incorporated magnetic core. A ferromagnetic ink was developed suitable for screen printing allowing improved energy conversion when compared to air core, in particular for low frequency systems. The developed solutions are integrated in wearable actuators and power transformers. The suitability of the solution for energy micro-generation systems will be also demonstrated. Bullet Points: - Full description of printed planar electric transformer process - Development and characterization of magnetic layer development - Application example in remote sensing and actuator devices

5:10 PM

(EHS-S3-020-2019) Low-temperature cofired magnetoelectric voltage tunable inductor (VTIs) with high current saturation

X. Li*[1]; Y. Yan[1]; S. Priya[1]

1. Penn State University, USA

Tunable fundamental circuit elements provide a possibility for the next generation electronics. Tunable magnetic properties under applied electric fields plays a significant role in power electronics, such as adaptive power conversion and tunable multi-band RF communication systems. Voltage tunable inductors (VTIs) enable to control permeability in magnetic components by interfacial stresses induced from piezoelectric components under a voltage. As compared to the conventional magnetic devices, VTIs present larger tunability and lower loss at high frequencies. In this study, ferrite/piezoelectric composites will be investigated by the co firing method. NiZnCu modified with various $CoFe_2O_4$ contents are applied as the ferrite layers due to the tunable saturation and low loss, and <001> textured $Pb(Mg_{1/3}Nb_{2/3})O_3$-$Pb(Zr,Ti)O_3$ is selected as piezoelectric layers based on the large piezoelectric response. A novel E core gradient structure, consisting of two different magnetic layers and one piezoelectric layer without any pure magnetic ferrite part, will be presented. Such gradient design theoretically intensifies the effective saturation of magnetic components and further improves the power capability and tunability over a broaden magnetic field range.

5:30 PM

(EHS-S3-021-2019) Material design of magnetoelectric voltage tunable inductors

Y. Yan*[1]; S. Priya[1]

1. Pennsylvania State University, Materials Science and Engineering, USA

The concept of electric field control of permeability in magnetic materials is driving the development of a new class of magnetoelectric components, namely, voltage tunable inductors (VTI). Inductance with large tunability offers a new paradigm for circuit design, especially for adaptive power conversion. Here we provide foundational analysis on VTIs based on Metglas/PMN-PT composite that exhibit extremely large tunability of up to 1150%. Through combination of analytical models that were validated by experimental results, comprehensive understanding of various anisotropies on the tunability of VTI is provided. Results indicate that inclusion of magnetic materials with low magnetocrystalline anisotropy is one of the most effective ways to achieve high tunability. In order to meet the need for power electronics, we further designed a VTI materials that exhibit remarkable high tunability of over 750% up to 10 MHz, completely covering the frequency range of state-of-the-art power electronics. This breakthroughis achieved based on a concept of magnetocrystalline anisotropy cancellation, predicted in a solid solution of nickel ferrite and cobalt ferrite through first principles calculations. We have employed phase field modeling and simulation to investigate the domain-level strain-mediated coupling between magnetization and polarization which has assisted in elucidating the underlying mechanisms of VTIs' tuning behavior.

S5: Piezoelectric and Triboelectric Energy Harvesting using Low-Dimensional Materials

Piezoelectric and Triboelectric Energy Harvesting using Low-Dimensional Materials I

Room: Salon 1

Session Chair: M. Jasim Uddin, University of Texas Rio Grande Valley

3:50 PM

(EHS-S5-001-2019) New lead-free piezoelectric thin film fabricated using metal-oxide nanosheets for piezoelectric energy harvester (Invited)

M. Im[1]; W. Lee[1]; S. Kweon[2]; S. Nahm*[1]

1. Korea University, Department of Materials Science and Engineering, Republic of Korea
2. Kobe University, Department of Mechanical Engineering, Japan

A new lead-free piezoelectric film consisting of $Sr_2NaNb_4O_{13}^-$ ($SNNO^-$) and $TiNbO_5^-$ (TNO^-) nanosheets was fabricated via electrophoresis. SNNO and TNO films displayed paraelectric polarization versus electric field (P-E) loops. However, a new film composed of mix of $SNNO^-$ and TNO^- (S/T) nanosheets displayed a ferroelectric P-E hysteresis loop with large saturation polarizaton (18.7 $\mu C/cm^2$), remnant polarization (7.7 $\mu C/cm^2$), and a coercive electric field (86 kV/cm). The interfaces formed between the SNNO and TNO layers induced ferroelectric properties in the S/T film through the occurrence of polar distortion and octahedral tilting in the S/T film. Ferroelectric properties were also observed in piezoelectric force microscopy images of the S/T film, which showed 90° domains after the removal of the applied electric field. The dielectric constant of the S/T film was 70, which is higher than those of SNNO and TNO films, indicating that the S/T film is a ferroelectric material. The piezoelectric strain constant of the S/T film was 156 pm/N and promising insulating properties were observed therein. In addition, the piezoelectric energy harvesting properties of this film will be also presented in this work.

4:20 PM

(EHS-S5-002-2019) Neuron-like Energy Harvesting (Invited)

W. Shim*[1]

1. Yonsei University, Department of Materials Science and Engineering, Republic of Korea

A neuron is an electrically excitable cell that communicates with other cells via synapses. These electrical signals are mostly generated by ion movement, referred to the cellular transport, across a cell membrane with exceptional characteristics: high ion selectivity and fast ion diffusion kinetics. In this talk, I will present the implementation of this foregoing concept of neuron-inspired ion transport, using inorganic materials as a fast ion-diffusion channel with high selectivity, to build the electrostatic potential difference between reservoirs. All the chemical energy of chemical compounds can be converted into electrical energy without paying 'Second Law tax', and therefore is comparable to the power generated by human neurons. This work represents a step toward a promising but simple passive power generation design for practical energy harvesting apparatus.

4:50 PM

(EHS-S5-003-2019) Nature driven bio-waste spider silk as high energy conversion efficient biopiezoelectric nanogenerator

S. Maiti*[1]; J. Kim[1]

1. Pohang University of Science and Technology South Korea, Department of Chemical Engineering, Republic of Korea

Spider silk fibers having remarkable protein sequence structure contain nature's most outstanding mechanical properties and unrivalled elasticity along with biocompatibility and biodegradability. Unfortunately, it remains completely unidentified how the mechanical properties of spider silk effectively contribute to the performance and integrity on piezoelectric nanogenerator. Here, using piezoresponse force microscopy (PFM), we report for the first time structure-dependent piezoelectric response of the spider silk at the molecular level and confirm that silk fiber shows vertical (or out of the plane) piezoelectric coefficient of up to ~0.36 pm/V. We also design a mechanically robust piezoelectric nanogenerator (PNG) using nature driven spider silk that exhibits high energy conversion efficiency (≈66%), high output voltage (≈21.3 V) and current (≈0.68 μA) with instantaneous power density of ≈4.56 μW/cm2. The fabricated device is biocompatible and ultra-sensitive towards physiological signal monitoring such as arterial pulse response which can be useful for potential biomedical applications.

5:10 PM

(EHS-S5-004-2019) Flexible electronic skins based on piezoelectric nanogenerators and piezotronics

H. Yuan*[1]

1. Xidian University, China

Electronic skins have received substantial attention in recent years and found great potential in prosthetics, robots, wearable devices, medical equipment, and many other areas. The early electronic skins exhibited low resolution, limited flexibility, and poor sensitivity, which cannot satisfy the need of practical application. It is of great importance to explore new sensing mechanisms to improve the detection capabilities of electronic skins. The development of the emerging field of nanogenerators and piezotronics unveiled new types of flexible electronic skins. These devices demonstrated high sensitivity, rapid response, and self-power capability. This talk gives the research progress of electronic skins based on principles found in nanogenerators and piezotronics. I will discuss the role of the piezoelectric effect and the piezotronic effect in sensors, the materials including inorganic piezoelectric materials, piezopolymer and natural piezoelectric materials used in devices, and the different sensors like piezotronic sensors, piezoelectric sensors, multifunctional sensors and sensor arrays for electronic skins in this talk. I will conclude with an outlook of electronic skins enabled by nanogenerators and piezotronics at the end.

Friday, September 6, 2019

Plenary VI

Room: Salon 4

Session Chair: Yang Bai, University of Oulu

8:05 AM

(EHS-PLEN-006-2019) Symbiosis of energy conversion and system design for efficient energy harvesting solutions

O. Kanoun*[1]; T. Keutel[1]; C. Viehweger[1]; S. Naifar[1]; S. Bradai[1]; G. Bouattour[1]; S. Khriji[1]; D. El Houssaini[1]

1. Chemnitz University of Technology, Chair for Measurement and Sensor Technology, Germany

Wireless sensor networks are becoming increasingly important supported by several trends of digitalization, such as internet of things [1]. The aspects of energy supply become thereby gradually essential, as flexible positioning and easy maintenance are key features for the acceptance of wireless sensors and consequently for their massive use. Recent improvements have revealed interesting possibilities to enhance energy harvesting (EH) efficiency by the choice and design of suitable converters, combination of converters in hybrid solutions and adopting possibilities for wireless energy transmission. Developments of microelectronics enable for significant energy savings, so that energy supply from ambient becomes increasingly practicable. Wake-up receivers allow to fully switch-off unnecessary system parts and also to reduce the energy consumption during sleeping phases. Data aggregation techniques, clustering and intelligent routing realized significant energy savings on network level. Supported by the diversity of individual solutions on different levels, the system design provides nowadays interesting chances to optimize EH based solutions. [1] O. Kanoun et. al.: Next Generation Wireless Energy Aware Sensors for Internet of Things: A Review, Int. Multi-Conf. on Systems Signals and Devices (SSD), DOI: 10.1109/SSD.2018.8570695

S2: Integrated Energy Harvesting and Storage Systems for Wearables and IoT

Integrated Energy Harvesting and Storage Systems for Wearables and IoT II

Room: Salon 2

Session Chair: Zdenek Hadas, Brno University of Technology

9:00 AM

(EHS-S2-007-2019) On-rotor Sensor Systems based on Variable Reluctance Energy Harvesting (Invited)

S. Bader*[1]

1. Mid Sweden University, Department of Electronics Design, Sweden

Rotating parts are commonplace in industrial applications. With the advent of smart industrial machines and components, the need for integrated sensor systems on these rotating parts increases. Providing power to on-rotor sensor systems is inherently difficult, inhibiting their full exploitation. A common solution includes battery-based power supplies, which however impose maintenance costs due to their capacity and lifetime limitations. Consequently, energy harvesting has become a desirable alternative. Variable reluctance energy harvesting (VREH) provides a mechanism that is particularly well-suited to low-speed and large-shaft applications, in which traditional electric generators can be costly and ineffective. In this talk, an introduction to variable reluctance energy harvesters is given based on electromagnetic circuit analysis, and recent research results on these harvesters will be presented. These results include the influence of the transducer's geometrical structure;

optimizations of structural dimensions; investigations of power management solutions; and end-to-end implementations of energy-autonomous, on-rotor sensor systems, powered by VREHs. The presented results demonstrate that VREHs can provide output powers in the mW range already at low rotational speeds.

9:30 AM

(EHS-S2-008-2019) A New Generation of mm-Scale Harvesting Interface Circuits to Enable mW-Scale IoT (Invited)

A. Muhtaroglu*[1]; H. O. Tabrizi[2]; P. Jayaweera[2]

1. METU Northern Cyprus Campus, Electrical-Electronics Engineering, Turkey
2. METU Northern Cyprus Campus, Sustainable Environment and Energy Systems, Turkey

Exponentially increasing population of batteries that occupy the recent living environment creates variety of problems in terms of maintenance costs, environmental issues, and aesthetic (system bulkiness) concerns. Energy harvesting interfaces with high capacity are needed to sustain the growth of machine-to-machine interfaces supporting the modern cities and infrastructures. Overall IoT average power budget after accounting for processor sleep modes, duty cycling in wake up radio technology, and other system level power management features can comfortably fit in a 0.5 – 1 mW envelope. Our research has recently focused on integrated piezoelectric and thermoelectric interface circuits, and their hybridization in batteryless systems. This paper first provides a status overview of our recent research on hybrid energy harvesting interface electronics solutions. It then focuses on our recent research to deliver a novel thermoelectric energy harvesting circuit that has an in-line maximum power point tracking (MPPT) algorithm without open-circuit voltage measurement. Validation of fabricated test-chip in 180nm standard CMOS technology indicates 170 mV start-up voltage with maximum output power capacity of about 0.5 mW, which is the highest noted in the literature for a fully integrated solution.

10:00 AM

(EHS-S2-009-2019) A Single-Stage-Multi-Output Reconfigurable Shared-Inductor Buck-Boost-Converter/Current-Mode Inductive Power Management

H. Sadeghi Gougheri[1]; M. Kiani*[1]

1. Penn State University, EE, USA

Inductive links are used for wireless power transmission (WPT) in various applications, such as biomedical devices, in which depending on operation (e.g., recording, stimulation) different output power/voltage levels are required over time. However, received power by a receiver (Rx) coil (PRx) is often limited due to safety constraints and coils' distance/alignment variations. Conventional IPMs either fail to generate regulated outputs (e.g., VL and VHv) when required output power (PL + PHv) > PRx, or suffer from low power conversion efficiency (PCE) when PRx > PL + PHv due to voltage regulation and protection. To overcome these challenges, we proposed a new IPM with the unique capabilities of 1) generating multiple regulated outputs (VL = 2.6 V, VHv = 3.9 V) directly from the Rx coil with single-stage conversion, 2) efficient current-mode operation with active rectification, enabled by adaptive switching control (ASC), 3) charging a large capacitor (CS) with the purpose of operating as a shared-inductor boost converter, transferring energy from CS to CL, CHv, when PRx < PL + PHv, and 4) efficient voltage-power regulation (VPR). The proposed IPM was fabricated in a 0.35μm 4M2P standard CMOS process. In measurements, the chip extended peak output-power range by 750% and improved power conversion efficiency by 1.3x and 8.1x thanks to ASC and VPR, respectively.

10:30 AM

(EHS-S2-010-2019) Strategies for integrating super and pseudocapapcitor devices (Invited)

O. Pitkänen[1]; H. M. Jantunen[1]; K. Kordas*[1]

1. University of Oulu, Finland

To keep continuing miniaturization of electrical devices, heterogeneous integration of new materials and their components is going to be among the frontiers of future technologies. It means that along with the functional transducer also power management shall be integrated in the very same chip or package. This is particularly important for autonomous operations (e.g. off-grid networks of small sensors and data transmitters) since the energy harvested from the environment either by the means of mechanical, thermal or optical conversion shall be available for extended periods of time. In this work, we demonstrate various approaches to implement on-device energy storage units using tangled networks as well as vertically aligned flilms of carbon nanotubes acting as electrodes of super and pseudocapacitors. The proposed integration protocols are compatible with standard microfabrication processes, offer robust up and downsacalable lightweight energy storage, and thus expected to be an organic part of the future development in this field.

11:00 AM

(EHS-S2-011-2019) Cold sintering process for developement of all-solid-state Li batteries

J. Seo*[3]; E. Gomez[1]; T. Mallouk[2]; C. Randall[3]

1. Penn State University, Chemical Engineering, USA
2. Penn State Univeristy, Chemistry, USA
3. Penn State University, Materials Science and Engineering, USA

All-solid-state lithium batteries have been considered as one of the promising next generation batteries with many advantages such as high safety, stability and energy density. However, fabrication processes of this all solid-state battery usually require very high temperature process to sinter the solid-state electrolytes and integrate the device. Recently, we have developed a low temperature ceramic process, named "cold sintering process", for sintering of ceramics and ceramic-based composites. This process is a very promising process not only to save energy but also to overcome disadvantages of the high temperature sintering process such as any material losses and side reactions. We successfully demonstrated that a highly densified Li-ion cathode and solid-state electrolytes can be fabricated by the cold sintering process at 130 ~ 240 °C. This highly densified electrode and electrolyte layers can be integrated using cold sintering process. It is expected that the not only conductivity of electrolytes, but also energy densities of the solid cell can be improved by densifying the microstructures of each layers and improving the contacts between them. In this presentation, we introduce how to apply the cold sintering process in the fabrication of all solid-state Li batteries. Microstructures, properties and electrochemical performances of cold sintetred all-solid-state betteries will be discussed.

S5: Piezoelectric and Triboelectric Energy Harvesting using Low-Dimensional Materials

Piezoelectric and Triboelectric Energy Harvesting using Low-Dimensional Materials II

Room: Salon 1
Session Chairs: Miso Kim, Korea Research Institute of Standards and Science; Sohini Kar-Narayan, University of Cambridge

9:00 AM

(EHS-S5-008-2019) Design and Energy Application of Piezoelectric Biomaterials (Invited)

R. Yang*[1]

1. Xidian University, School of Advanced Materials and Nanotechnology, China

Multifunctional materials have received increasing attention in recent years. Owing to their inherent biological nature as well as piezoelectric properties, piezoelectric biomaterials are considered as promising candidates for application in fields ranging from electrochemical energy storage to biological systems. Rational material design is important to enhance their piezoelectric and biological activity. Herein, recent advancements to piezoelectric biomaterials like peptide-based micro/nanostructures are provided. Synthetic methods, morphological features, and piezoelectric performance of piezoelectric biomaterials are presented. The effect of growth direction, phase and structure of piezoelectric biomaterials on their piezoelectric activity are discussed. The applications of piezoelectric biomaterials in the field of nanogenerators are provided at the end. H. Yuan, et al., Flexible electronic skins based on nanogenerators and piezotronics, Nano Energy, 59, 84 (2019) V. Nguyen, et al., Piezoelectric peptide-based nanogenerator enhanced by single-electrode triboelectric nanogenerator, APL Materials 5, 074108 (2017) V. Nguyen, et al, Self-assembly of diphenylalanine peptide with controlled polarization for power generation, Nature Communications 7, 13566 (2016) V. Nguyen, et al., Epitaxial growth of vertically aligned piezoelectric diphenylalanine peptide microrods with uniform polarization, Nano Energy 17, 323 (2015)

9:30 AM

(EHS-S5-006-2019) Hybrid nanomanufacturing of hierarchical wearable devices for self-powered user interface (Invited)

W. Wu*[1]

1. Purdue University, School of Industrial Engineering; Birck Nanotechnology Center; Regenstrief Center for Healthcare Engineering, USA

The seamless and adaptive interactions between functional devices and their environment (e.g., the human body) are critical for advancing emerging technologies, e.g., wearable devices and human-machine interface. The state-of-the-art technologies, however, require a complex integration of heterogeneous components to interface the environmental, mechanical stimulus, which is ubiquitous and abundant in the above applications. These limitations have severely hampered the advancement and broader utilization of related technologies. Moreover, all existing technologies require a power source, which complicates the system design and limits operation schemes. I will discuss our recent progress in developing self-powered human-integrated nanodevices through hybrid nanomanufacturing of heterostructured nanodevices with hierarchical architectures. This new class of wearable devices are conformable to human skins and can sustainably perform self-powered, non-invasive functions, e.g., physiological monitoring and gesture recognition, by harvesting the operation power from the human body. Such a scheme is fundamentally hinged on the polarization induced current term in Maxwell's displacement current. This research is expected to have a positive impact and immediate relevance to many societally pervasive areas, e.g., biomedical monitoring, consumer electronics, and intelligent robotics.

10:00 AM

(EHS-S5-007-2019) Nanostructured polymers for piezoelectric and triboelectric energy harvesting applications (Invited)

S. Kar-Narayan*[1]

1. University of Cambridge, United Kingdom

Harvesting energy from ambient mechanical sources in our environment has generated tremendous interest as it offers a fundamental energy solution for 'small-power' applications. In this context, piezoelectric and/or triboelectric materials offer the simplest means of directly converting mechanical vibrations from ambient sources. In particular, nanoscale energy harvesters, or nanogenerators, are capable of converting low-level ambient vibrations into electrical energy. Polymer-based nanogenerators are attractive as they are inherently flexible and robust making them less prone to mechanical failure. They are also lightweight, easy and cheap to fabricate, lead free and biocompatible. My group thus develops scalable nanofabrication techniques for flexible and low-cost polymer-based nanogenerators with improved energy conversion efficiency, by using facile template-assisted nanowire growth techniques. In this talk, I will discuss our recent advances in incorporating polymer nanowires into scalable piezoelectric and triboelectric energy harvesters. In particular, I will focus on the role of crystallinity in determining energy harvesting properties of these nanowires. I will also introduce advanced scanning probe microscopy methods that we use for the characterization of these polymeric nanomaterials and the extraction of relevant materials properties for nanogenerator design.

10:30 AM

(EHS-S5-005-2019) Self-resonant Energy Harvester with a Passively Tuned Sliding Mass (Invited)

H. Kim*[1]

1. Virginia Tech, USA

Passive tuning phenomenon with a sliding mass on a vibrating beam has been observed and studied in the literature. Such a phenomenon can be extended to self-resonant energy harvesting, where the natural frequency can be favorably adjusted to the excitation frequency for enhanced energy harvesting. In this paper, we consider the nonlinear dynamic coupling of a piezoelectric clamped-clamped beam with sliding mass and study experimentally and numerically how these nonlinear interactions affect the performance of the energy harvester. We derive the mathematical model using the extended Hamilton principle. The governing equations of motion are obtained as three coupled nonlinear partial differential equations. The Galerkin method is employed to obtain a reduced order model. Our mathematical formulation is validated via experiments and the results show very good agreement between the simulation and the experiment. Parametric studies are carried out to examine how key parameters affect the performance of the energy harvester. The findings suggest that a passively tuned mechanism with a small sliding mass can increase the power output even when the excitation frequency is far off the original resonance.

11:00 AM

(EHS-S5-009-2019) Compliant triboelectric nanogenerator for human machine interface (Invited)

P. Lee*[1]

1. Nanyang Technological University, School of Materials Science and Engineering, Singapore

Compliant triboelectric nanogenerators are necessary in harvesting mechanical energy from biomechanical motion and serving as an environmental decoder following the changes in external stimuli for human machine interface. Triboelectric nanogenerators (TENGs) are clean energy resources that provide electricity by triboelectrification and electrostatic induction from mechanical sources. Textile-based and cutaneous-based TENGs are attractive options as these compliant devices can be incorporated into garments and highly versatile for portable applications. We developed

textile-TENGs based on the nanomaterials coating that deliver superhydrophobicity for water flow energy harvesting. The cellulose oleoyl ester nanoparticles are nontoxic and low cost for textiles coating to deliver energy harvesting capability. To generate energy from subtle biomechanical motion, an all-textile nanogenerator with the cellulosic particles encapsulated black phosphorus as charge trapping layer was designed to induce higher output voltage to power small electronic gadgets. On the other hand, ionic conductor based on hydrogel has been used as the stretchable electrode in TENGs to achieve stretchable, transparent and self-healable device. Meanwhile, stretchable triboelectric active layer has been realized using a thermoplastic elastomer that can be 3D printable into a patterned device.

11:20 AM

(EHS-S5-010-2019) Surface Modified One-Dimensional Lithium Doped Zinc Oxide in a Piezo-Tribo Hybrid Nanogenerator for Cost Effective Load and Stress Measurement

M. Uddin*[1]; A. Chowdhury[1]; A. Abdullah[2]

1. University of Texas Rio Grande Valley, Chemistry, USA
2. University of Texas Rio Grande Valley, Mechanical Engineering, USA

One dimensional nanomaterial has shown a prominent response in triboelectric and piezoelectric nanogenerators in recent researches. In this work we reported a one-dimensional Lithium doped Zinc Oxide (Li-Zn.O) based Piezo-Tribo Hybrid Nanogenerator (PTENG) which includes Polyvinyledene Fluoride (PVDF) and Multiwalled Carbon Nanotube (MWCNT) in the piezoelectric layer along with Li-ZnO nanowire and a co-polymer including Polydimethylsiloxane (PDMS) and Polytetrafluoroethylene (PTFE) on Aluminium film for the triboelectric layer. Also, the surface of this cost-effective device was modified with Poly Ethylene Glycol (PEG) for higher piezoelectric response. The result provides a linear response of voltage with variable applied stress promoting it for the application of load and stress measurement. Besides, the maximum open circuit voltage and close circuit current was recorded 60.1V and 75μA respectively. Furthermore, Micro stress of high amount was noticed which made contribution in electricity generation. This work demonstrates an application of one-dimensional material in the fabrication of cost effective self-powered pressure transducer and energy harvester.

11:40 AM

(EHS-S5-011-2019) Multi-Beam Shared-Inductor Reconfigurable Voltage/SECE-Mode Piezoelectric Energy Harvesting of Multi-Axial Human Motion

M. Meng[1]; M. Kiani*[1]

1. Penn State University, EE, USA

Energy harvesting from human-body motion is attractive for wearables, however, conventional unidirectional single-cantilever-beam piezoelectric energy harvesters (PEHs) suffer from several challenges in harvesting from body motion, such as multi-axial motion, irregular frequencies, and unpredictable amplitudes with often low power levels. We designed, fabricated (in 0.35μm CMOS process) and tested a PEH chip with the unique capabilities of 1) simultaneously harvesting energy from up to 6 piezoelectric beams in a modular fashion using a single shared off-chip inductor, 2) seamlessly reconfiguring itself between operating as an efficient full-wave active rectifier (voltage mode, VM) or synchronous electrical charge extraction (SECE) to improve overall efficiency, extract maximum energy, and protect the chip against large inputs, eliminating the need for off-chip components or high-voltage processes, 3) adaptive SECE operation (peak and time zero-crossing detection) to address input frequency and beams variations, and 4) cold start with an active voltage doubler. Utilizing all 6 beams, our PEH chip achieved a high figure-of-merit (FoM) of 511%, compared with a full-wave rectifier.

Author Index

*** Denotes Presenter**

Author Index

ANTI HARASSMENT POLICY

The American Ceramic Society
www.ceramics.org

Statement of Policy:

The American Ceramic Society (ACerS) is committed to ensuring that all ACerS activities are free from discrimination, harassment, and/or retaliation of any form. ACerS seeks to foster an environment promoting the free expression and exchange of scientific ideas. ACerS is committed to ensuring equality of treatment and opportunity and freedom from harassment for all members and participants regardless of race, gender, nationality, religious beliefs, gender identity, color, age, marital status, sexual orientation, disabilities, ancestry, personal appearance, or any other basis not relevant to scientific merit. Violators of this policy will be subject to discipline by the Society.

Definition of Harassment:

Harassment includes, but is not limited to, offensive verbal comments related to gender, gender identity and expression, sexual orientation, disability, physical appearance, body size, race, national origin, religion, age, marital status, military status, or any other status protected by law; deliberate intimidation; stalking; following; harassing photography or recording; sustained disruption of talks or other events; and inappropriate physical contact. Attendees asked to stop any harassing behavior are expected to comply immediately.

Definition of Sexual Harassment:

Sexual harassment does not refer to occasional compliments or other generally acceptable social behavior. Sexual harassment refers to verbal, physical, and visual conduct of a sexual nature that is unwelcome and offensive to the recipient. By way of example, sexual harassment may include such conduct as sexual flirtations, advances, or propositions; verbal comments or physical actions of a sexual nature; sexually degrading words used to describe an individual; an unwelcome display of sexually suggestive objects or pictures; sexually explicit jokes; and offensive, unwanted physical contact such as patting, pinching, grabbing, groping, or constant brushing against another's body. Attendees asked to stop any sexually harassing behavior are expected to comply immediately.

Scope of Policy:

This policy applies to all attendees of ACerS meetings, events, and activities, including members, non-members, partnering organizations, volunteers, students, guests, staff, contractors, exhibitors, and all other participants related to ACerS events and activities.

Reporting an Incident:

If you are being harassed, notice that someone else is being harassed, or have any other concerns, please contact an ACerS staff member immediately. ACerS staff can be identified by the official staff badge, their name and title. All complaints will be treated seriously and will be investigated promptly.

Names(s) and Contact Information Onsite to Report an Incident:

1. ACerS Executive Director, **Mark Mecklenborg**, ph 614-794-5829 / email: ExecDirector@ceramics.org
2. ACerS President, **Sylvia Johnson**, ph 510-813-8758 / email: ACerSPresident@ceramics.org

Disciplinary Action:

All reports of harassment will be directed immediately to the ACerS leadership team who may consult with and engage other ACerS staff, leaders and legal counsel as appropriate. Conference security and/or local law enforcement may be involved, as appropriate based on the specific circumstances. In response to a report of harassment, the ACerS leadership team or ACerS staff will take appropriate action. Such actions range from a verbal warning to ejection from the event without a refund. Repeat offenders may be subject to further disciplinary action, such as being banned from participating in future ACerS conferences or events and/or permanently expelled from ACerS membership.

The full policy can be viewed at: https://ceramics.org/antiharassment