From R&D to products: Innovation with Fraunhofer

Prof. Dr. Alexander Michaelis

Energy and environmental technology at IKTS.

Membranes

PV / Batteries

Fuel Cells
Fraunhofer is the largest organization for applied research in Europe → your partner for Innovation

7 alliances
- microelectronics
- production
- information and communication
- materials and components
- life sciences
- surface technology and photonics
- defence research and technology

59 Institutes at 40 Locations  18,000 staff  1,7 Bill. € Budget
Joseph von Fraunhofer (1787-1826)

**Researcher**
- Discovery of the “Fraunhofer lines” in the solar spectrum

**Inventor**
- New methods for processing lenses
- mp3 music format, white LED, high-resolution thermal camera

**Entrepreneur**
- Director and partner in a glassworks
- Research volume: approx. 1.7 billion € annually of which 1.4 billion € is generated through contract research

The Fraunhofer-Gesellschaft, Headquarter Munich

Research and development on behalf of industry and state
From a small association to the leading organization for applied research in Europe

**Number of institutes**

- 49: 1
- 54: 19
- 59: 27
- 64: 33
- 69: 37
- 74: 47
- 79: 58
- 84: 60
- 89: 59

**Staff**

- 49: 3
- 54: 20
- 59: 20
- 64: 135
- 69: 700
- 74: 1,250
- 79: 1,675
- 84: 2,213
- 89: 3,477
- 94: 6,390
- 99: 7,980
- 04: 9,200
- 09: 12,800
- 10: 17,150

**Budget in € (millions)**

- 49: 710
- 54: 8,170
- 59: 16,900
- 64: 28,700
- 69: 52,950
- 74: 106,980
- 79: 161,670
- 84: 165,670
- 89: 1,657,160
- 94: 17,150,000
- 99: 18,130,000

© Fraunhofer IKTS
Fraunhofer worldwide
Fraunhofer USA, Inc.
first overseas subsidiary, est. 1994

Fraunhofer USA Headquarters

Laser Technology
CLT

Manufacturing
Innovation
CMI

Heinrich Hertz
Institute (HHI) USA

Sustainable Energy
Systems
CSE

Molecular
Biotechnology
CMB

Digital Media
Technologies
DMT

Coatings and Laser
Applications
CCL

Experimental Software
Engineering
CESE

San José

East Lansing

Plymouth

Cambridge

Newark

Boston

Maryland

© Fraunhofer IKTS
## International Revenues 2010 by Countries – Top 20
(without EU-Commission) in million €

<table>
<thead>
<tr>
<th>Country</th>
<th>Revenue (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA*</td>
<td>30,2</td>
</tr>
<tr>
<td>Austria</td>
<td>10,0</td>
</tr>
<tr>
<td>Switzerland</td>
<td>7,9</td>
</tr>
<tr>
<td>France</td>
<td>6,2</td>
</tr>
<tr>
<td>Japan</td>
<td>5,9</td>
</tr>
<tr>
<td>Belgium without EU</td>
<td>5,5</td>
</tr>
<tr>
<td>Netherlands</td>
<td>4,0</td>
</tr>
<tr>
<td>Great Britain</td>
<td>3,7</td>
</tr>
<tr>
<td>Italy</td>
<td>3,4</td>
</tr>
<tr>
<td>China</td>
<td>3,2</td>
</tr>
<tr>
<td>Sweden</td>
<td>3,0</td>
</tr>
<tr>
<td>Spain</td>
<td>2,8</td>
</tr>
<tr>
<td>South Korea</td>
<td>2,8</td>
</tr>
<tr>
<td>Norway</td>
<td>2,3</td>
</tr>
<tr>
<td>Israel</td>
<td>1,5</td>
</tr>
<tr>
<td>Mexico</td>
<td>1,3</td>
</tr>
<tr>
<td>Poland</td>
<td>1,2</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>1,1</td>
</tr>
<tr>
<td>India</td>
<td>1,0</td>
</tr>
<tr>
<td>Finland</td>
<td>0,9</td>
</tr>
</tbody>
</table>

*USA: of which €19.6 million Fh-USA
Österreich: of which €1.2 million Fh-Austria
Fraunhofer Institute of Ceramic Technologies and Systems, IKTS

→ IKTS belongs to the top 5 Fraunhofer Institutes
→ Main market of IKTS: Energy and environmental technology

Sites         Dresden and Hermsdorf
Staff: 420
Budget: 32 Mio € w/o invest
cia 80 % revenue from contract research
(50 % directly from industry)
Environmental Engineering and Bioenergy at IKTS

1. CO₂-reduction in combustion plants / CCS gas filtration (O₂-production)
2. Water technology (waste water, potable water)
3. Bioenergy (Biogas, Bioethanol, Biobuthanol, Biodiesel)
4. Diesel particle filter
5. Catalysis and membrane reactors
Examples for membrane-materials used at IKTS

1. Nano-porous membranes
   (Zeolite, carbon, CNTs, MOFs, amorphous oxides, …)

2. Dense mixed conducting membranes
   (Perovskites, ZrO₂, Tungstenates, …)

3. Metallic membranes
   (Pd, Ag/Pd, Cu/Pd, …)

4. Composite membranes
   (Zeolite/Polymer, CNT/Polymer, …)

5. Catalysts on ceramic porous substrates
   (mixed oxides, precious metals, …)

IKTS develops membranes and catalysts, produces and tests components at application conditions
Formation of structural pores < 1 nm

Crystallographic cages/channels

Lattice plane distances

Crystallographic defects (vacancies)
Formation of structural pores < 1 nm

- Crystallographic cages/channels
- Lattice plane distances
- Crystallographic defects (vacancies)
From materials up to the systems / products

- Cooling water: 30 °C, cold water: 10 °C, 4 °C
- ETOH: 99.5 wt.%, Steam for start: 110 °C, 85 wt.% M
- Rectification: Fusel oils and techn. alcohols up and control column
- Lutter water: Product: 99.5 wt.%, 142 °C

Support, module, system / product, process

© Fraunhofer IKTS
Profile of the Fraunhofer IKTS

Range of Services

Realization of R&D projects
Transfer to pilot scale

I n n o v a t i o n  S t a g e s

<table>
<thead>
<tr>
<th>Development alliance</th>
<th>Research &amp; development</th>
<th>Prototype manufacturing, pilot plant</th>
<th>Mass production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idea, business case</td>
<td></td>
<td>Additional services IKTS</td>
<td>Task of industry</td>
</tr>
</tbody>
</table>

C o n t e x t

© Fraunhofer IKTS
Energy R&D at IKTS: Highlights

eneramic® Energy with ceramics

- Thermoelectrical Generators, TEG
- Bioenergy
- High Temperature-Fuel Cells (SOFC)
- Photovoltaics
- Energy Harvesting (piezoceramics)
- Low Temperature-Fuel Cells (Micro-PEM)
technology platform functional ceramics / thick film (slurry) deposition

1. pastes / slurry
2. tape casting, printing
3. stacking
4. lamination, co-fire

Micro- and Energy Systems

Micro-Fuel Cells

© Fraunhofer IKTS
Thick film technology for function integration

Cost barrier for economic success

Production costs for components

Ceramics

Metals

Polymers

Functions
Screen Printing at IKTS

- Screen Printing of planar and tubular structures
- Automatic positioning
- Cleen Room facilities
Photovoltaics with Focus on BEOL (Contacting)

Materials for Thick Film Contacting / Issues

1. Cost Reduction, less Ag
2. Environmental friendly materials (Pb-free)
3. Higher lateral resolution
4. Better Yield

Production Processes

1. Higher throughput
2. Non contact to improve yield
3. Automatization
Thick Film Technology for Contacting of Solar-cells

Screen printing

Electrical characterization

FRT Microprof (opt. Profilometer)

Fireing 4 zone IR-furnace
IKTS — Printing Technologies

Screen Printing  Inkjet- Printing  Aerosol Printing
Solid Oxide Fuel Cell (SOFC) value chain

- Material
- MEA
- Stack
- System

- Take over of Siemens AG planar SOFC Technology including IP and some assets in 1998
Fuel cell systems at IKTS

1 W 10 W 100 W 1 kW 10 kW
Hand held portable stationary

Hydrogen
PEFC

Tubular
SOFC

LPG
SOFC

Natural gas
SOFC

Biogas
SOFC

© Fraunhofer IKTS
Fuel cell systems at IKTS

1 W mobile
10 W portable
100 W stationary
1 kW stationary
10 kW stationary

Hydrogen PEFC
Tubular SOFC
LPG SOFC
Natural gas SOFC
Biogas SOFC
Bioenergy Application Center at „Pöhl“ in Saxony

Synergy between structural + functional ceramics

Energy Storage:
Redox - Flow Battery
NaS Battery
Environmental Processing Technology at Fraunhofer IKTS

ENERGY/ENVIRONMENT/AGRICULTURE => Project „More biogas at higher energy level – way to efficient power production“
IKTS integrated technology line along complete value chain

- Thick film
- Glass sealing
- Electrochemistry
- CAD + Simulation
- System technology
- Process technology

Test facilities
Storage technology:
Li-Ion Battery → value chain / technology line

- powder-processing
  - Hydro-metallurgy
  - Calzination
  - Milling
  - Granulation

- Thick film-deposition
  - Slurry preparation
  - Casting processing
  - Roll to roll
  - In-line QS/QM

- Cell assembly stacking
  - Tape handling
  - Lamination / Stacking
  - Thermal management
  - In-line QS/QM

- Electrochemical initializing
  - Electrolyte filling
  - Charging
  - Quality check

- System-design
  - Battery management
  - Thermal management
  - Containment
  - Safety

30 %  10 %  10 %  10 %  40 %
Technology platform for battery systems

- chemical synthesis
- calzination
- milling, granulation
- electrochemistry

<table>
<thead>
<tr>
<th>Material</th>
<th>Average discharge voltage, V</th>
<th>Theor. max. capacity, mAh/g</th>
<th>Reversible capacity, mAh/h</th>
<th>Energy density, mWh/g</th>
<th>Safety</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiCoO$_2$ (LC)</td>
<td>3,9</td>
<td>274</td>
<td>150 - 160</td>
<td>580 - 620</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LiNi$<em>{0.8}$Co$</em>{0.15}$Al$_{0.05}$O$_2$ (NCA)</td>
<td>3,8</td>
<td>271,5</td>
<td>180 - 220</td>
<td>580 - 830</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LiNi$<em>{0.8}$Co$</em>{0.15}$Mn$_{0.05}$O$_2$ (NMC)</td>
<td>3,5</td>
<td>278</td>
<td>170</td>
<td>595</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LiMn$_2$O$_4$ (LM)</td>
<td>4,05</td>
<td>148</td>
<td>100 - 120</td>
<td>405 - 485</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LiFePO$_4$</td>
<td>3,4</td>
<td>170</td>
<td>150 - 160</td>
<td>510 - 540</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Powder Processing

- **Objective:** refining and shaping of precursors and product powders
- **Approach:** using pilot-plant scale processing technology at IKTS
- **IKTS scope:**
  - Milling, granulation, shaping and coating using spray dryer / fluidizes bed reactors
  - Developing cost effective, eco-friendly, proprietary processing methods
- **Advantage:**
  - Tight interface to production process, no end-of-pipe innovation
  - Systematic approach to complete powder production process
Powder Processing – Shape control

- **Objective:** generate controlled-shape powders, characterisation of powders
- **Approach:** using IKTS know-how from other powders
- **IKTS scope:**
  - Developing process windows for controlled shapes using state-of-the art machinery
  - Using IKTS high-end characterisation methods
- **Advantage:**
  - Tight link between powder shaping, characterisation and electrochemistry
Electrochemistry at IKTS

- **Objective:** electrochemical performance of cathode powders and electrodes
- **Approach:** using high-end electrochemical and battery research methods
- **IKTS scope:**
  - Electrochemical assessment of performance in short iteration loops
  - Understanding of structure-performance relationships
  - Degradation mechanisms, post-mortem-analysis
- **Advantage:**
  - First hand, independent information on powder performance

Quick-check cell setup

Standard tests

High end micro equipment
partnerships

Project LiFab
- Pilot scale production of Li-Ion-Batteries
- Process- and technology development

ThyssenKrupp System Engineering
ThyssenKrupp Drauz Nothelfer
Welcome to the 10th CMCEE

With your participation we look forward once again to discussing the most important questions in the field of ceramic components and materials for energy and environmental technology, to gaining new knowledge and to identifying future trends in advanced ceramics science and technology.

We cordially invite you to visit Dresden. Besides its landscape beauty, Dresden currently is one of the most important hot spots of research in Germany and Europe with an enormous density of research institutes and scientists. Dresden offers a very pleasant environment for a successful symposium in 2012.

Right after the symposium you also will have the opportunity to visit the CERAMITEC 2012 fair in Munich. We are proud that we were able to win CERAMITEC, one of the most important exhibition fairs on technical ceramics, as an organizer of CMCEE allowing us to offer you a combined program in Dresden and Munich. With a special symposium package we offer organized transfer to Munich, one of the most beautiful cities of Germany.

We look forward to seeing you in Dresden and Munich.

The organizing committee of the 10th CMCEE

Chair: Prof. Dr. Alexander Mau, Fraunhofer Institute for Ceramic Technologies and Systems (IKTS), Dresden, Germany
Co-chair: Prof. Dr. Ramgir Singh, Chief Scientist, NASA Glenn Research Center, Cleveland/OH, USA
Co-chair: Prof. Dr. Tatsuki Uej, Prime Senior Research Scientist, National Institute of Advanced Industrial Science and Technology (AIST), Nagoya, Japan