CERAMIC TECH CHAT

Episode 54

Title – “Electrospinning of breath-based diagnostics: Perena Gouma”

INTRO

McDonald: “I’m Lisa McDonald, and this is Ceramic Tech Chat.

We live in an era overflowing with information and determining which pieces to include in school curriculum can be challenging. But materials, especially ceramics, offer a fantastic platform on which to hold productive discussions that link many different disciplines together.”

Gouma: “I see a very bright future for ceramic engineering. Ceramic materials, they’ve been used for everything from space exploration to energy to health to everyday life. And so, this is the most important thing: to keep your mind really open and this broad perspective and then merge disciplines, and they’ll learn from each other and then augment the knowledge for everyone.”

McDonald: “That’s Perena Gouma, the Edward Orton Jr., Chair in ceramic engineering at The Ohio State University. Perena uses the nanomanufacturing technique of electrospinning to fabricate ceramics and composites for use in biomedical and environmental applications, including breath and other gas analysis devices.

In today’s episode, Perena describes how she became interested in these lesser-known areas of ceramics research and shares her passion for educating students and the public about these materials and applications.”

(music)

SECTION 1

Gouma: “I studied as a physicist, and there were no materials science departments in Greece where I grew up. So, what happened is in my diploma, the senior thesis, I studied the polymorphism of manganese oxide. So, that was my first exposure to ceramic materials. Then for my Ph.D. in England, I worked on the gas atomization of powders. It was a materials science department. And then I did electron microscopy.

So, when I came to the U.S. for my post-doc, this ceramics exposure followed me in a way because then I started focusing on the polymorphism of titania, TiO_2. And in particular, I studied in-situ the transmission electron microscope, the transformation from anatase to rutile. So, that was it. Once I started again working with metal oxides, then I became so much excited about ceramics research, ceramic science, and ceramic engineering. And that's where I found my purpose in academic life."

McDonald: "That's fantastic. After your post-doc, what was your journey to eventually ending up at The Ohio State University?"

Gouma: "Yeah, so, my journey started as a post-doc at The Ohio State University, then I started my independent academic career at SUNY Stony Brook, the State University of New York. For 16 years, I was there, then I went to The University of Texas at Arlington for a year, and then I moved back to Ohio State, full circle.

And I was very excited because first of all, we're close to The American Ceramic Society. It's the first ceramics engineering department ever at The Ohio State University. Of course, now it's merged materials science and engineering, but still the tradition is there, the ties are there.

And we really have changed since I joined. I believe we have enriched the curriculum of the department. Very strong metallurgical department before, and now students take the ceramics classes, and they love it. And they're like, 'Why didn't we get to learn about this earlier?' So, I'm trying, really striving to introduce more of the ceramics-based courses or course material early on so they can really appreciate.

And that's the other thing that we are seeing now. We are in a revolution for ceramic engineering because this ceramics discipline has become so prevalent and broad. Now you see not only functional materials. We have functional materials everything, from solar cells to electronics and the systems, memristors. You know, neuromorphic computing is going to be utilizing ceramic materials, you're looking at quantum materials. Then we have the structural, you see, the mortar composites, but all the structural ceramics that 25 years ago nobody thought was going to be possible. And then we have the ceramics flying and flying. So, there's so many things."

McDonald: "So, I know as we said, there's so many options in materials that you could do to study, but you particularly have done quite a lot of research on what's known as breath analysis. Some people might recognize breath analyzers, that terminology, from being used during traffic stops to help detect if someone has a certain level of alcohol in their system. But can we talk more broadly about what breath analysis is and how it works?"

Gouma: "Yes. So, breath analysis is, the way that I explain it when people ask me what I'm doing with this, is you have a dog and, you know, people say the dog can smell someone who has diabetes or can smell someone who has Alzheimer's or cancer or even respiratory diseases. The dog can smell the gases that emanate from the body: They are released in the exhaled breath, or they are emitted from the skin. And these gases, these chemicals are called volatile biomarkers. In effect, it's the response of the host of our body to the disease. So every time that we get sick, then our body reacts in many different ways. It has these immune stimuli. And one of the ways that the disease is manifested is by exhaling these biomarkers. Or, these are gases that we normally exhale, but then you find in higher concentration when you are sick. And that's really what I've been doing: I'm making the sensors that really measure the host response of our body to illness."

McDonald: "That is really interesting to think about. Like, when you get sick, you realize you might feel more flushed, you know, you might have body aches. But the fact that there's these chemical biological markers that you can detect to really tell exactly what's going on with the body."

Gouma: "Yeah, that's nothing new. Because, you know, the ancient physicians, Hippocrates, of course, who is supposed to be the first known physician, he will smell the patients, he will smell people and then know what they have. So, he coined several terms, one of them survives today. They use it as a medical term, fetor hepaticus, which is the smell of garlic, the smell of sulfides coming from someone dying from liver disease. So, when some of these gases are in high concentrations, we can smell with our nose.

Some of them are low concentrations, so we need highly sensitive sensors to detect it. And that's where materials science comes in. Because if you don't have good materials that can have high affinity to chemicals and if you don't have good materials that respond fast and recover fast and they have high sensitivity and high selectivity, then you cannot make sensors and then you cannot make these diagnostics. So, materials science at the heart of what is called nanomedicine, the broad field of science and engineering, but it's in the heart of breath analysis too."

McDonald: "How did you become interested in breath analysis originally?"

Gouma: "Yeah, so that's a very good question as well because it sounds counterintuitive: How can you have someone who's working on gas atomization of powders or who's looking at polymorphs of different metal oxides is going to do breath analysis? But I was working for sensors for the automotive exhaust. And this is a selective catalytic reduction process. So, in effect, you have a very, very complex gaseous environment, and you try to test and detect and measure one particular analyte, let's say ammonia. So if you have this complex gas mixture and you look for one gas, you have to make a material that has high affinity and high specificity to that particular gas.

So, I was making highly selective gas sensors for complex environments. Breath is a complex environment, and it was actually one of these alcohol testers that I saw in one of the stores. It was utilizing metal oxide, tin dioxide, the same thing like the carbon monoxide detectors we have at home. And then it struck me, I said, 'If we can use metal oxide sensors to detect gases in the ambience, why don't we use them to detect gases in the breath? Breath is as complex as an automotive exhaust. What will be the difference?' And there are differences, of course. There are concentrations of different gases differs, temperature might be, but same concept. So, I went from selective gas sensors for environmental use to selective gas sensors for medical diagnostics."

McDonald: "So what's the first type of illness or condition that you tried to detect when you first got into this field?"

Gouma: “Yeah, it was the ammonia, typically for H. [Helicobacter] pylori detection, because ammonia sensor was the first and the only gas selective sensor to date, I think. I’m not aware of anybody else having such a selective sensor to detect only ammonia in such a complex environment. And then nitric oxide was the next one because nitric oxide is used in asthma; it’s oxidative state is very important. We actually even use it for COVID.

And then over the years, I’ve done either clinical studies with actual subjects for many different diseases, or the headspace from cell cultures for cancerous diseases, discriminating between lung cancer and breast cancer, for example. And more recently, we work on respiratory panel type of analysis.

So, there’s been a lot of my patents span everything, like I said, from H. pylori to cancer to respiratory diseases to you name it.”

McDonald: “I noticed that you mentioned COVID pandemic, and I am sure many of our listeners have terrible flashbacks to when they had to do the nose swabs to test for themselves back in the early days. So, that sounds fascinating that you’d be able to just breathe and be able to determine if you have COVID that way.”

Gouma: “Yeah, that’s what the subjects participate in the study, they are very, very excited. They say, ‘That’s it? That’s it?’ You know, you talk to clinical coordinators, and they tell you how well received the technology has been by the people who’ve used it. And yes, that’s it because you look for that signature, you look for the constituency of the breath when someone is sick. And we have been able to get a very specific signal for that, yes.”

McDonald: “I noticed you mentioned that you’ve had several patents come out of this research. Can you talk to us a little bit about that process? Because I’m sure that having devices that are intended for human application, that might be a bit more challenging to coordinate than just a device that’s not being used in the human body.”

Gouma: “Yeah, definitely. The good thing about breath- and skin-based diagnostics, because I work on both, they’re benign in that you don’t really have to inhale, it’s noninvasive, it’s nonintrusive. So, you don’t have any real interaction with the person. You just sample their breath or you sample the headspace from their skin. And for that, they are safe devices, okay? Now they are still medical devices, and they undergo scrutiny.

So, the patent is one thing. Certifies that no one else had the same idea, so your invention is unique. But then there is the regulatory pathway, and this is the challenging pathway to bring a new technology, especially medical technology, to market. You need this approval by the FDA, for example, and other agencies worldwide. That has been the challenging part for breath analysis over the years. There are only five tests, and these are clinical tests, that have been approved. That means these tests are administered by physicians in the hospitals. Therefore, to go and disseminate this over the counter, handheld diagnostics, undergoes heavier scrutiny, and that’s what we have been working on for some time now. So, we are working with FDA to get the required approvals to get this as a medical device.

Of course, we have another pathway, another line for doing, for example, breath analysis for metabolic rate monitoring, which doesn't require any regulatory approval. That is a type of technology we are also exploring because there are really no good measures of metabolic rate. And we are working on projects in my group with mechanobiologists, for example, to try to correlate the metabolic cost of different activities to how much acetone changes in your body and making a holistic metabolic rate model for a breath-based monitor and wearable monitor too."

McDonald: "I think that's a great distinction to make, and it really helps our listeners appreciate these pathways that, one's being used maybe for medical diagnosis of illnesses, it has a few more restrictions on it than the ones that are being used just for keeping basically tabs on where your body is at the moment."

Gouma: "Exactly, yes. That's very important, yes. There are different requirements, different specifications, different pathways, and different challenges, yeah."

McDonald: "Well, it'll be really exciting to see if these things stop becoming more popular, start hitting the market. It will really revolutionize how we're able to just keep track of the body, really, just being able to breathe into these devices."

Gouma: "This is my life's dream. So yes, I hope it's going to be sooner rather than later."

McDonald: "Yes, I definitely agree."

(music)

SECTION 2

McDonald: "We've been talking about the application of the devices, the materials you've been working with, like breath analysis to do diagnosis. But then you also have another side of your research, which is how do you create these materials and how do you create these devices. And one of the techniques that you've been really great at pioneering and advancing for the use of with ceramic materials is electrospinning. So, can you tell us what is electrospinning?"

Gouma: "Yes, so electrospinning is really the electrostatic drawing of fibers. You use an electrostatic field and you use a solvent, and then you just create this field and you really try to overcome the surface tension and pull a droplet from the ends of a capillary towards the grounded target. So, in effect you create a jet, a continuous jet, and this jet can be going from the Earth to the moon, a single fiber from just a small vial of a solution. And that's really the process of electrospinning. Very well known to the polymer scientist, less known to ceramic engineers because you really need a carrier polymer. But once you combine soft chemistry, sol gel processing, for example, with a carrier polymer, you have this plant of materials that you can use to make nanowires of ceramics or nanogrids, their connected structures, self-supported photocatalyst, sensors, filtration agents, wound dressings, you name it. So, electrospinning is a very versatile, very affordable technique.

The great thing is you can have it in the lab, and you can try new recipes and new materials and it's an affordable way to do that. The drawback is it takes a long time to draw these fibers and makes it slow and tedious. You have to clean the syringe pump and go back, and that has really limited its growth as a tool for large-scale manufacturing. So, there are either the single-jet or multiple-jet things in the lab. And then there are a couple of enormous machines that they are used to continue deposit coatings on surfaces. But these machines, do they have a problem? You know, change the solvent, you cannot change the material. They are very limited in the specifications, in the precursors.

Therefore, we have been considering in my group for a long time how to meet the challenges and create something in the middle. So we have this desktop turnkey device, which is using self-formation of jets, spontaneous formation of jets on the surface. At the same time, we control the number of jets we allow to cover the collector. So, we avoid the overlap of the jets, we have very controlled fiber size, fiber diameter, fiber length. And therefore, we think we have a tool that small- and medium-sized enterprises can take and utilize and enter into the nanofiber materials market."

McDonald: "How are you planning to or who are you working with to help scale up this technology so that it's available to more people?"

Gouma: "Yes. So, that's the other thing. As a materials scientist and as an academic, of course you can take the technology to a level, but then you cannot really take it, you cannot start making device in the lab. You need to work with someone who has the capability to put things together to assemble the device, the equipment, and to manufacture the equipment in large scale.

So, the Orton Ceramic Foundation, the same Orton who founded The American Ceramic Society, founded this entity, and they have been very supportive to me. They fund my chaired position, they fund students, and they were willing to work with me to create this tool for commercialization. So, the Orton Ceramic Foundation has a long history of making instruments and selling instruments, from furnaces to you name it. And this is a new line for them working with us, and hopefully we'll be able to take this to the market soon."

McDonald: "That is very exciting. And I also know for our listeners who might be inspired by learning about all this, the upcoming December issue of the *Bulletin* that will be here in a few weeks is going to dive into even deeper details on how electrospinning works, how it can be used, and about this new technology that you've been working with the Foundation on."

Gouma: "And thank you so much for this opportunity as well. I look forward to the issue. And we have been working for a long time. Electrospinning has become really a good resource, especially when you start adding biospaces in there and you make biocomposites or then you make these ceramic–organic material composites. So, I think that electrospinning has a long, long way to go. We can use it to make the fibers, for example, for structural ceramics. We can use it for generative medicine. There are so many applications you can use it for, making infrastructure for the habitation of Mars, other theragnostic systems when you sense and you deliver drugs for any type of injury. And now there are handheld electrospinning device emerging. People talk electrospraying repulsion systems for space missions.

So, sky is the limit. There are so many things, and I think we're going to see them happening very soon. It took a long time to fly, but now we're at the point when I think the technique is understood and fully appreciated."

McDonald: "That is very exciting."

Gouma: "And it's nice to be featured in ceramics professional society because, like I said, it's more known into the biotech community, in the biopolymer, biomaterials community. But we [have been making] lot of strides, yeah."

McDonald: "Well, that actually makes a great transition. Like you said, it is more known in the polymer community than the ceramics community. So, how did you learn about this technique in the first place?"

Gouma: "That was, I was at the conference, and it was a specific conference on sensors. And I remember a group from the Army Natick Lab in Massachusetts were representing electrospun fabrics that were meant to incorporate sensors in order to protect the soldier. And I went to them and I said, 'Has anybody tried electrospinning ceramics?' Which I was working on sol gel and I was working on flamespray pyrolysis. I was working on different processes that they had these liquid precursors. So I said, 'If you can spin something that is polymer solution, why can't I spin something that is a sol?' They said, 'Nobody has done it. I mean, you want to try? We will help you set it up.' And that's how it happened.

So, nobody had tried it before, and I think now a lot of people are using it, and they also make these fabrics, smart fabrics, which they used to charge the battery. So, if you want to, you can have everything incorporated on your nonwoven mat, on the textile, and you can charge your electronics, you can have your sensors. Yeah, a lot of different applications."

McDonald: "That's fantastic."

Gouma: "Yeah, I'm very excited. But when I talk about electrospinning, it's one of my favorite topics with polymorphism. These are the two areas that I really enjoy."

McDonald: "And I really enjoy getting to learn about them. I always find the biomedical applications, especially of ceramics, so fascinating."

Gouma: "Yes, they are, and people don't really consider it, but many of the biomaterials are ceramics. Hydroxyapatite is ceramics, and the bone is primarily ceramic composite. And it's only natural to go and use them, yeah."

(music)

BREAK

McDonald: "The American Ceramic Society's Bioceramics Division is dedicated to stimulating the growth and activity of the Society in the areas of the science, engineering, and manufacturing of bioceramics, biocomposites, and biomaterials. Learn more about this Division at www.ceramics.org/bioceramics."

SECTION 3

McDonald: "So, with all of your years of experience in the electrospinning, in the breath analysis, do you have any funny or serendipitous stories of times in the lab that really stand out in your mind?"

Gouma: "Yes, so, I think I have a couple. First is a fun fact. I have this brilliant student, Lisheng Wang. And he was a graduate student, he had got his undergrad in Tsinghua University in China, working with me. And he made this sensor, which was going to be a nitric oxide sensor, the monoclinic phase, using rapid solidification process. But that sensor was very selective to acetone. So, he was trying to figure out why it was doing that. And I said to him, 'You used rapid solidification processing. Can you check if there's a low-temperature phase of tungsten trioxide that's ferroelectric?' Neither he nor I knew if such a thing existed, but it did. So, we're the first to make the ferroelectric epsilon tungsten trioxide and make it available at room temperature and above. Not only is it a brilliant highly selective acetone sensor, we discovered it has a ferrochromic effect, you know, how it changes color in the application of current without needing an electrolyte. So, this is really something that you don't expect is going to happen, but then you have kind of the insight to know why it's happening, and then you discover new things. And that I thought was an exciting time in my lab.

The other time was another student, Jusang Lee, very good student as well. He was working with photocatalysis. So, he had added some blue dye in water, and he was going to use a catalyst to dissolve it. But instead, he put a part of an electrospun mat, it fell into this water, and suddenly it absorbed all the dye. So, he came to me and says, 'Professor, look. This is cellulose acetate. But what is happening? This is floating on water and absorb all the dye. Cellulose acetate is not supposed to float in water. It's supposed to be super hydrophilic.' So, then we looked at if electrospinning had changed the structure, make it super water repellent plus oleophilic. And that created again another avenue. So, that was serendipity that something happened there, but we knew how to recognize it as well.

The last one was when I ask a student to electrospin enzymes and see can we electrospin enzymes. And we were not only were able to electrospin them, we were able to use them as receptors for biosensors, we were able to keep them alive, active, for over six months. And that's another exciting story. So, that led to the National Inventors Competition and a lot of other recognitions.

So yes, there are exciting stories in the lab. Usually, you know, it's just something that catches the eye of the person who's doing the experiment and looks so different, and we have to really find an explanation for that."

McDonald: "And that, I think, is the funnest part about doing research, is sometimes stumbling upon things you're not expecting and then being able to learn more."

Gouma: "Yeah, exactly, yeah, that's why we do that."

McDonald: "And I also know for our listeners, the December *Bulletin* has a few more details on some of these examples that you mentioned. So, they'll have to keep their eye out in the references in the stories there to learn even more about it.

It's so valuable for us that The American Ceramic Society to have members like you who are elevating this knowledge."

Gouma: "But we also need people like you to promote this type of work, and I'm really grateful that you do that because that's how we broaden our horizon as a professional organization. Yes, thank you."

McDonald: "Thank you so much. And how is it that you first came to become a valued member of our Society? How did you learn about ACerS in the beginning?"

Gouma: "When I started as a post-doc, I started working with ceramics, and then I came across The American Ceramic Society, and I really felt attracted to the discipline so much. It gave me a professional identity, but personally as well, I met people who became my mentors or, you know, they helped recognize me for awards. And then I became mentor to other people, and I helped them with getting awards and stuff.

So, I like this idea of this learned society, the academic organization that describes your profession, that describes your academic discipline. That's where you share your ideas, your ideas are understood because you have peers who have the same expertise and they can challenge you. And it has happened. You know, you give talks at ACerS conferences, and someone says, 'No this cannot happen' or 'This can happen,' and then you have these discussions, and that's how the field is evolved. So, I find great value in The American Ceramic Society.

I think it's expected to share your ideas and your research with people in the same discipline. You can go to very generic venues, but then people can get easily impressed, they don't know all the details of the field. I think it's much more powerful when you talk to people within your own community. And also, it's great to talk to others as well, but having the core in your discipline is very important. And it's a privilege to have such a great society to belong to. That's how I feel."

(music)

CONCLUSION

McDonald: "By sharing knowledge both within and between disciplines, as Perena does with her breath analysis and electrospinning research, we are able to advance a very bright future for ceramic engineering.

I'm Lisa McDonald, and this is Ceramic Tech Chat."

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"Visit our website at ceramics.org for this episode's show notes and to learn more about Perena Gouma and her research. Ceramic Tech Chat is produced by Lisa McDonald and copyrighted by The American Ceramic Society.

Until next time, I'm Lisa McDonald, and thank you for joining us."