CERAMIC TECH CHAT

Episode 43

Title – “Fostering pathways for ceramic engineers: Geoff Brennecka (E43)”

INTRO

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

Ceramics are unique among material classes because they are defined largely by what they are not. These inorganic, crystalline solids are neither metals nor polymers, and this definition means some surprising substances are technically classified as ceramics.”

Brennecka: “So living in Colorado, of course my favorite ceramic is snow because that’s something that we can all relate to. Next time you have a snowfall, as you’re driving along, you can look out at a field and you can tell how old the snow is by how big the sparkles are. If it’s old snow, you get these big flashes as you’re driving along from the sunshine. And if it’s new snow, it’s a much more matte reflection. And that’s because of Ostwald ripening, where those grains are growing. So the bigger flashes, those are larger grains. It’s sintering.”

McDonald: “That’s Geoff Brennecka, the Herman F. Coors Distinguished Professor of Ceramic Engineering at Colorado School of Mines. Geoff’s research focuses on ceramics for electronic applications, but he is also actively involved in ceramics education and outreach, helping to establish ACerS President’s Council of Student Advisors and Young Professionals Network as well as serving on the Ceramic and Glass Industry Foundation Board of Trustees.

In today’s episode, Geoff will walk us through ways to support and train the next generation of ceramicists, from providing students themselves with learning opportunities to training K–12 teachers on the basics of materials science.”

(music)

SECTION 1

McDonald: “So, how is it that you became interested in ceramic materials, and then how did you get interested specifically in the electronic properties of ceramics?”

Brennecka: “I was in high school when high temperature superconductivity was a really big deal, and that caught my attention. I don’t remember if it was a news report or what it was, but for some reason I heard about these cool things called superconductors, and that got me excited about ceramics in the first place.

And then at some point, happened to be I lived in the middle of nowhere, in rural Missouri, and we had come across a downed power line and just found the insulators that were where the power line attached to the pole. And that simple little thing made me think, 'Oh, wow! There's a lot of thought that goes into even the simplest, the boring things that we never think about, that we see every day.' That got me thinking about electrical properties even beyond the superconductors. And this is still when I was in high school, trying to figure out what I was going to do.

And as I said, I grew up in rural Missouri. So, Rolla [Missouri University of Science and Technology] happens to be also in Missouri. And as I was looking at schools, found out that Rolla had a ceramics program. And when I got down there and met the faculty that that also had a passion around this, I was just hooked."

McDonald: "So after graduation, you originally worked at Sandia National Laboratories for quite a few years before transitioning to academia. So, can you tell us about that pathway and why you decided to make the transition?"

Brennecka: "Sure. So, my intersections with Sandia actually started even before I graduated. I was fortunate enough to get an opportunity to do a co-op at Sandia. As an undergrad, I attended one of the department seminars, and Jill Glass was giving a seminar. And as our faculty encouraged us to do, I went up afterwards and handed her my resume and said, 'Hey, I would really love to come work with you.' And six months later, I got a call from someone else at Sandia. She had passed these resumes around, and Paul Clem hired me to work there as a summer and then as a co-op student over semesters. And I was just hooked. I loved everything about the groups that I worked with and the kinds of problems that we were able to work on.

And it was also a really valuable break for me. So, I was funding my own way through college, and so being able to take a semester off and actually go make real money at the national lab, that helped me afford going back to school. It also was really valuable to have a mental break. So you're taking, you know, 20-plus credit hours and just working yourself to death, and then you get to relax and work a 40-hour week for a while and actually enjoy life, then go back to the craziness. And so I think the co-op experience, I ended up doing three co-ops at Sandia, and that was really valuable for me from a financial perspective, from a technical perspective, from a networking perspective, and from a mental health perspective.

And it was while I was at Sandia, everyone that I worked with there, so Paul Clem and Bruce Tuttle and Pin Yang and all of these people, they had all worked for the same person for their Ph.D., David Payne at the University of Illinois. And so these were all the people that I wanted to be like and, of course, because of that, I'm gonna go and work for the same advisor. And so that helped me transition to grad school at the University of Illinois and work for Professor Payne, and he was nice enough to let me continue to go back to Sandia, off and on, to keep my clearance active and keep my network active. And then, when I graduated, I had a job ready and waiting for me."

McDonald: "That's just fabulous. And it really does demonstrate the importance sometimes of taking a break when you're able because I know many students go right from the undergrad, right through the master's, right through Ph.D. And by the end of it, you can just be completely burned out. You might not even like that topic anymore."

Brennecka: "Absolutely. Yeah. And so I did that from a degree perspective. But because I had those co-ops along the way, I was able to take a break and still continue to enjoy what I was doing without so much of the burnout that you mentioned. So, yeah, I highly encourage anyone to take summer internships, co-ops whenever they can."

McDonald: "Yes, definitely. So, let's jump a little bit into the research that you're doing. Because when people hear the word electronic devices, they might think their laptops, their cellphones, but they might not be aware of what it's meant by electronic properties. You know, what goes into these materials and the different properties that they have that allowed the electronic device to work. So can you give us a little bit of an idea of what we mean by electronic properties and some of the main types of electronic properties?"

Brennecka: "Oh, man, we could spend hours on this. So, yeah, you're right. People think of laptops and phones and all that. And that's because it's all the electronic behaviors that allow this magic that we get to carry around in our pocket all the time. It really is everything from the silicon semiconductors and integrated circuits to the capacitors and inductors all the way up to the displays and the screens and the transparent conductors and all of this fun stuff in there.

The specific stuff that I work on, that my group works on primarily, they're the hidden components that you don't actually see. So, for example, we've got a project where we're working on making nonvolatile memory that can operate at high temperatures. So ferroelectric memory has been around for a long time. We're working with collaborators at the Army Research Lab, showing that the materials can function at at least 800°C, which is really just stupid hot. But if you're flying really fast or if you want to send a probe to Venus where it's you know 473°C, you need to be able to operate at really high temperatures. And so, there are a lot of applications where the current technologies just can't do it.

Closer to existing consumer devices, we're also working with some collaborators at a handful of different companies on the next generation of the kinds of materials that go into the resonators in your cellphone. So, you may not think that your phone has a resonator. Well, actually, it's got a couple of 100 of them because they are the filters that help two people in the same room be talking on the cellphone and communicating with the same tower but not overhearing each other's conversations.

And so, these are all of the little components that are hidden away that nobody realizes that they're there, but without them we wouldn't have all those fun cat videos that everyone wants to watch on their phone."

McDonald: “So what are the types of ceramics that are often used in these applications? Oxides, nonoxides, are there specific groups of ceramics that are used a lot for these?”

Brennecka: “They’re all over the place. So I like to say that I grew up on PZT. So, lead zirconium titanate, PZT, is sort of the godfather of piezoelectric materials. Most of my time in Sandia was spent learning how to make and integrate and improve upon PZT-based materials, either as thin films or as bulk ceramics. And then, as I moved to Mines, just because of collaborations that I had with people here at NREL, so the National Renewable Energy Lab, which is a Department of Energy lab right next to me here in at Mines. Working with different collaborators, they have a lot of expertise and a lot of capabilities in nitrides. And so, I started looking into piezoelectric nitrides and ferroelectric nitrides. And so that’s where a lot of a lot of our group’s work has been over the last 10 years.”

McDonald: “So I heard you say the words piezoelectric and ferroelectric. Can you give us some definitions of what those mean?

Brennecka: “Sure. So piezoelectric comes from the Greek ‘pressure electric,’ and it just means that if you squeeze on the material, then you can get charge out of it. Or if you apply an electric field, then you can get it to change shape. And so the example that I gave earlier of the resonators is one way that we do this. So, for example, you’ve got the electric magnetic wave that’s communicating between your cellphone and the tower. It comes in, and if you had that resonating in your cellphone, you would need a big block of a cellphone like those from 25 years ago. But by converting that electromagnetic wave into an acoustic wave through the piezoelectric effect, then we can make it much, much smaller. And so that’s how those filters work, is converting between electrical and mechanical energies.

Other materials like PZT and even some of the aluminum nitrides that we’re working on now can also be ferroelectric. So in addition to that mechanical plus electrical coupling, we can switch the direction of an internal, built-in polarization. And so that means you can change properties just by applying a field. So you don’t need to grow a brand new film. You don’t need to make a brand-new material. You can change its properties right there on the fly by switching the direction of its polarization with a field. And so that opens up all sorts of other activities as well. That’s what I find exciting about it, is that it gives you the opportunity to make it once and then change the properties later when you want to.”

McDonald: “That’s really cool that it just like naturally has these properties that you can then play with in applications.”

Brennecka: “Yep.”

McDonald: “So from all your time in the lab with the students, do you have a favorite story that’s either funny or serendipitous that you’d like to share?”

Brennecka: "I'll tell you one from my Sandia time. I was working with a single crystal of lithium niobate. And so it's a single crystal wafer with a 3-inch diameter, completely transparent, it looks like a hunk of glass. And we were applying an electric field to switch the polarization because it's a ferroelectric. And I needed to be able to do this without putting metal electrodes on it because we needed it to continue being transparent. And so I was using water, Albuquerque [New Mexico] water has enough miscellaneous other stuff in it that it's conductive enough for DC [direct current] at low frequencies.

And so we were using water as the electrode, applying a large voltage, and I heard a pop when it actually switched, and I looked down and the water electrode had actually turned from a circle into a hexagon because the wetting behavior of the material changed when the polarization changed. And then just watching that, I couldn't understand what had just happened, and it occurred to me, it's like, 'Oh, the crystal structure, it's hexagonal, and it's a single crystal. I'm seeing the symmetry of the actual wafer right here in the wetting.' And I just, it was one of those 'ah-ha' moments. And I had to pull out my phone and take a picture of this, and it was just an incredible [experience].

It should have been obvious, but I wasn't thinking about it, kinds of things. And so, there are those kinds of experiences all over the place. And that's what makes the teaching part fun, that's what makes the research part fun, especially when you'll be working with a colleague and both have the same 'ah-ha' moment at the same time, and that's what gives you the excitement to do the next round of experiments."

McDonald: "That would have been amazing to have seen in person.

So, you have talked quite a bit about your work with people to take these materials, make them, put them into applications. But what are some of the considerations that you need to keep in mind to integrating them into a device so that they can be used commercially?"

Brennecka: "Yes. So that's part of the fun of it. Doing the basic science, there are a lot of really fun questions there, and I enjoy addressing those. But I get even more excited when I have a collaborator who's trying to make a real product out of these things. And I think, 'Oh, five years from now, I'm gonna be able to carry this around in my pocket' or 'I'm gonna see this device launched on a satellite,' or something along those lines.

And so you asked what the challenges are. Cost is always one of them. And associated with that, how you can integrate this fun new material that is being developed that has these properties that you think is the greatest thing since sliced bread, but you have to integrate that with an existing infrastructure in some way. And so that might be, we have an existing process that the chemistry has to be compatible. It may be we're going to integrate this with a much larger supply chain and is that going to be compatible, is it going to be integrable. And there are so many challenges along the way.

I love working with people that deal with those things. It's not my expertise to solve those problems. But acknowledging, 'Oh, we've got another multidimensional challenge here, how can we find the best solution across all these different aspects,' is part of the fun."

(music)

SECTION 2

McDonald: "In recent years, it's been really exciting to see that materials science and engineering has been arising as a more common engineering department that students can take at different universities when they're going in there. But can you talk to us a little bit why it's important to have ceramic and glass engineering programs in addition to these more broader materials."

Brennecka: "So, 40 years ago, there were a lot of metallurgy and ceramics programs across the country and across the world. And as the broader materials science education grew out around this, it's understandable that people would want to merge because there are a lot of overlaps between the fundamental understanding and the fundamental behavior of metals and ceramics and polymers and semiconductors and however you want to slice and dice different material classes. But in that process, we lost a little bit of depth. And so I think there's value in having a population of people that know the breadth and a population of people that know the depth. When you go into an engineering team at a company somewhere, it's going to be valuable to have a diverse set of backgrounds, a diverse set of perspectives.

As people that are listening may or may not know, Mines just recently launched a ceramic engineering degree program. So, we are joining Alfred University and Missouri S&T in Rolla to have degree programs focused in ceramics. This was driven a lot by our interactions with people through The American Ceramic Society, where employers would come to us and say, 'Hey, we really need to hire somebody that knows refractories' or 'We really need to hire somebody that knows how to do mechanical testing of glasses,' or whatever it was. There's just a lot more need for the focus than the current educational system had been providing. And so, we're hoping to contribute to that.

And one of my favorite things about this, and something that I always want to point out, is that this has been collaborative with Alfred and with Rolla. And so, we're all in this together trying to grow the pie. It's not a competitive thing. We really see this as growing the ceramic footprints from an educational perspective and from an industrial perspective down the road."

McDonald: "Can you tell us a little bit about how that program is structured to help facilitate that learning environment?"

Brennecka: "Sure. So, this is within our metallurgical and materials engineering department here at Mines, and that department has always had a very strong tradition in hands-on metallurgy with recently a sprinkling of additional ceramics engagement. And so we're building from that base. We're keeping the metallurgical materials engineering degree as an option. And in parallel we now have an option for ceramic engineering. And that ceramic option, we basically built that around what we learned from our colleagues at

Alfred and at Rolla and then found the best way to integrate it with what we have in the MME, the metallurgical materials engineering program, so that these are parallel.

And so yes, we have a lot of labs that are hands on. Every semester, there are a couple of labs. We have a summer course that is called Field Session for our entire department that every program at Mines has this Field Session, which grew out of way back in the old days, when it was just geology and mining and extractive metallurgy, people would go out in the field and actually do work in the field during that time. And that tradition has continued.

So we're now one year away from being a 150-year-old university, and we still have this tradition of Field Session. But we currently use it as a welcome to the field. Take advantage of these longer course times over the summer when we can do those field trips. So we get to visit local industry, so Johns Manville and CoorsTek and Lockheed Martin and Ball Aerospace and other collaborators in the region. Students get to see what life as a materials engineer really looks like, life as a ceramist, life as a metallurgist, and then we come back into the labs and put them to work getting their hands dirty.

And so much like our partner programs at Rolla and Alfred, we have a glass blowing studio, we have a foundry. And so students get to go do these classic types of materials, you know, more visceral experiences where they get to get their hands dirty and make stuff. And then they get to walk over to the next building and looked in the TEM [transmission electron microscope] and the atom probe at individual atoms. And so you can really connect the classic materials behavior with the fundamental, one-atom-at-a-time kind of stuff."

McDonald: "That hands-on participation really is key to being able to absorb that knowledge versus just always sitting in front of a whiteboard."

Brennecka: "Yeah. That's true for any flavor of engineering. I'm a little biased. I think it's even more true for materials. Because it's easy to look at a blackboard and see circles that you are pretending they're atoms. But when you actually get to get your hands on the material and see how this stuff behaves, it just sticks that much better."

McDonald: "Yes. So, you've been very involved with The American Ceramic Society, serving as past editor of *Journal of the American Ceramic Society*, past chair of the Electronics Division. But what I'm also really interested in knowing is you also helped launch both the PCSA, which is our President's Council of Student Advisors, and our YPN, which is our Young Professionals Network. So, not only are you working heavily in inspiring students at Mines, you've also really helped to inspire students within The American Ceramic Society. So, can you tell us about how your journey started at The American Ceramic Society and a little bit about your involvement with getting our students engaged."

Brennecka: "Sure. I'm not sure that I've actually done any useful inspiration, but I have tried to provide pathways and opportunities for students. So, that's the way I look at it.

Going back to my undergraduate time at Rolla, the entire department was very engaged in ACerS because it was a focused ceramics department and ACerS was our home. And so, as part of that, I got involved with at the time the ACerS–NICE Student Congress, so NICE being National Institute of Ceramic Engineers. ACerS and NICE had a Student Congress, which was very similar to today's PCSA. And I was chair of that when I was a sophomore, junior, something like that.

And so ACerS went through some difficult financial times, and unfortunately, the Student Congress fell apart during that period. A handful of years later, Kathy Faber, who was the president of ACerS at the time, and Bill Fahrenholtz approached me and said, 'Hey, we want to get this Congress thing started again. Can you help?' And I had been one of the last chairs, and still happened to be hanging around, I guess, and so we put together a new version of the Student Congress that we hoped we would have a slightly different model so that it would be a little more robust against financial roller coaster that every professional society goes through. The first few years we've got it up and running and grew from, I think, seven or eight people that first year, and then we got up to 30 or 40. And since then, this PCSA, as we renamed it, has been just, I've been blown away by what the students have done with that. It's been amazing to watch.

So, a lot of ideas that were kind of bouncing around and never really going anywhere back when I was a student, now they are major programs within the CGIF [Ceramic and Glass Industry Foundation] and within ACerS. So, the demo kits [Materials Science Classroom Kits], those were started even before I got in the Student Congress, and they were still something that was evolving, and they had to take a little bit of a break when they got the Congress didn't exist anymore. But then, when we got the PCSA up and running, we started with the demo kits and said, 'Hey, what can we do with this?' And now that is a major aspect of the CGIF programming and outreach activities. And the PCSA just continues to push the boundaries of new opportunities and new engagements. So now a third of their delegates every year are international, which is amazing. And they've launched and shown the rest of the Society how to run a mentorship program well. There are so many examples like that. So, yeah, I helped with the nucleus, but beyond that I just kind of stand back and marvel at what has come next."

McDonald: "The students, I get to work with them on the Deciphering column that we publish in the *Bulletin*, and I'm just blown away by even the undergraduates, their writing skills, their grasp of the science that they're working with it. It's really, I can't wait to see them, you know, prosper and realize what the next generation is able to do in the next coming decade."

Brennecka: "And even more fun, the PCSA has been around long enough now that the alumni from the PCSA are taking over as mentors and are now populating many of the committees around the Society. And it's just nice to sit back as the old guy in the room and see all the new energy."

(music)

BREAK

McDonald: "ACerS President's Council of Student Advisors, or the PCSA, is the student-led committee of ACerS responsible for representing student interests to ACerS and its Committees, Divisions, Sections, and Classes. The PCSA helps engage students as active and long-term leaders in the ceramics community. Learn more about the PCSA at www.ceramics.org/pcsa."

SECTION 3

McDonald: "So, in addition to the PCSA and YPN, you've also mentioned the CGIF, which is the Ceramic and Glass Industry Foundation. That's the foundation arm of ACerS that helps support that interest in materials science starting through the K–12 level. Currently this year, you're serving as the chair of the CGIF. So, how did you become involved with the CGIF's activities and helping support students in that way as well?"

Brennecka: "Sure. So, one big aspect of CGIF is the outreach aspect. So, we're trying to get younger students, high school and below, aware of and engaged in ceramics and glass and materials in general. And so, part of my, I guess, interest in the engagement there came from doing the outreach activities via PCSA and other activities. Marcus Fish, who helps run the Foundation, approached me maybe six, seven years ago and asked if I would be on the Board of Trustees for the Foundation because of that engagement on the outreach perspective. And I was honored but wasn't sure I was a really good fit and reluctantly agreed that I would join in.

After being able to see what kinds of activities and things that the CGIF enables. So, not just handing out the demo kits and those kinds of things. But especially once we got Amanda, who's now moving on and taking on even bigger roles, and Lori is coming into replace. Once we had somebody who is really in charge of programming activities so that we could do bigger, more ambitious types of events. Again, I'm just blown away by the kinds of things that this enables. So everything from demo activities for local communities at glass shops and working with faculty members or just community service kinds of people all over the world that are taking the activities that the PCSA students put together as part of the demo kit, or even parallel activities and using those to engage young students all over the place and just show them what materials are and what they can do. That's the part that I really enjoy about it.

The piece that often gets overlooked about the CGIF that I think is also really important and is gradually becoming a greater and greater focus is it's not just about outreach and awareness; it's also about workforce development. And that goes all the way from letting someone who's now in seventh grade know that there are career opportunities in the materials area but all the way up through bachelor's level, Ph.D. level, and beyond, you've got technicians that are currently working at companies and ongoing education and helping companies that are needing to hire people in some flavor of ceramics and glass, have a clearing house or a central place where they can find the talent that they need. That's another aspect that the CGIF has been really putting more emphasis in lately.

And so with the new Career Center, I think that's a step in the right direction. And that's something that has been needed for a long time. So because we are so focused in materials and ceramics and glass, it's not necessarily just as simple as going on Indeed and here's the perfect job for me, right? It helps to have a more focused network. It helps to have the personal network where you can reach out and see where the opportunities really are.

And so that's one aspect that I really like about the CGIF. Is that it's awareness to young students and to the general public, but it's also workforce development across all scales and all education and employment levels."

McDonald: "It's really great that you brought that up because one of the new programs that the CGIF recently launched is Teacher Training Workshops. And so these are workshops where teachers, the ones that are hopefully going to help inspire the next generation and let them know that materials exist, are able to get some training and learn more about the science that they plan to teach their students. And Mines also just recently hosted one of these Teacher Training Workshops, right?"

Brennecka: "We did, yeah. We were able to get Marcus and Amanda to come out with their team of helpers to run a Teacher Training Workshop here in Golden at Mines. And it was amazing to see this in action.

And so, one of the challenges, for example, the demo kits again, I'll go back to those. One of the challenges has always been having someone to explain to a young student how these materials work. And you've got a kit here that has some demonstrations. And sure, you can do this one on one, but that's not very efficient. If we've got, for example, a faculty member like me, if I wanted to go around to all 870 different elementary schools in the Denver area, or something along those lines, there just wouldn't be enough time. But if we can introduce the junior high and high school teachers to the kinds of content that they can be integrating into their curricula and getting their students excited, that's much easier once we've excited the teachers. And so bringing the teachers in and showing them how these various materials that that they may not think about every day, that are hidden, are impacting their lives and impacting their students' lives and show them how they can make these connections. It helps the teachers with new and exciting information that they can add to their courses, and it helps give them some new ideas, and it helps just educate everyone about what materials are.

And so we took this idea from ASM. So ASM has teacher camps as well, and we had worked with them off and on over the past 10 years. But we had an opportunity to have a ceramics and glass focused one, and so now, again, in parallel with ASM, we're running these teacher camps, and it's working out really well."

McDonald: "I've been hearing really good feedback from some of the teachers that I've run into at ACerS events that they're really enjoying and they're looking forward to more."

Brennecka: “Good. We look forward to continuing these. So, the one in Colorado happened to be the first one that was done outside of Ohio. So, we being CGIF started locally in the Ohio area because it’s always easiest to start in your backyard. Then, hopefully, we can start to have these more and more places and develop that long-term pipeline so that there’s a direct connection for universities and local high schools and then local employers as well, all the way through.”

(music)

CONCLUSION

McDonald: “From students to teachers to employers, preparing the next generation of ceramic engineers is a community project. Finding ways to engage each party in the education process is key to successfully realizing this goal.

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 Geoff Brennecka and the new ceramic engineering program at Colorado School of Mines. 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.”