CERAMIC TECH CHAT

Episode 11

Title – "Scanning TEM unlocks grain boundary secrets: Yuichi Ikuhara (E11)"

INTRO

De Guire: "I'm Eileen De Guire, and this is Ceramic Tech Chat.

> Transmission electron microscopy, or TEM, is a well-established and widely used technique for characterizing materials. Since TEM and scanning TEM were developed in the 1930s, the basic technologies have not changed for many decades until around the turn of the century, when aberration-corrected STEM instruments were developed. Now, the resolution capabilities of STEM instruments are beyond what many people may realize."

Ikuhara: "Not so many people know how advanced electron microscopy is developed. We can now directly observe the single atoms. We can directly observe the hydrogen columns, lithium columns if you study lithium-ion battery crystals."

De Guire: "That's Yuichi Ikuhara, professor of engineering innovation at the University of Tokyo. Yuichi specializes in using transmission electron microscopy to study grain boundaries and interfaces in ceramic materials and understand how structure affects mechanical and electrical properties.

> How does someone in Japan, a country that traditionally focuses on more applied research, end up specializing in a basic research field? And what will the recent advances in TEM resolution capabilities mean for the future of microscopy researchers like Yuichi?"
>
> (music)

SECTION 1

De Guire: "Like many guests on our show, Yuichi's interest in science started before college. However, ceramics were not the material he originally specialized in when starting his materials science journey."

Ikuhara: "When I was a senior high school student, I liked physics, mathematics, particularly I liked physics. So then I consider to go to the physics department or engineering department. But at that time my parents suggested me to go to the engineering because it's easy to get a good job. If you go to do the physics, at that time it's very difficult. I selected the engineering department, and particularly I prefer very basic sciences. I think the metallurgy or applied physics and some electric engineering is very basic sciences. I selected materials science at that time, metallurgy at that time. So anyway, I prefer the very basic science since I was a senior high school student."

De Guire: “Okay. So, from about the time you were a teenager, you knew that you liked to answer basic fundamental questions. Very interesting. And how did you get interested in studying ceramic materials?”

Ikuhara: “Yes, yes, that’s an interesting question. So, my major was metallurgy when I was an undergraduate student. And at that time, I was very interested in doing the physical metallurgy. Then I learned dislocation theory, creep phenomena, grain boundary structures, high-temperature plastic deformation and so on in metal. But my Ph.D. thesis was related to silicon nitride, silicon carbide. Then I applied this knowledge to understand silicon nitride, silicon carbide phenomena. So, then I joined Japan Fine Ceramics Center after I obtained the Ph.D. degree. Then I focused on ceramics research. I applied my metallurgical knowledge to research of ceramics field. This was very useful because I think metal and ceramics are not so different from the viewpoint of atoms and electrons. So just the chemical bonding is different. Then I apply the similar approach to understand ceramics. Then, in the field, metal, ceramics, not so big difference. So, then I’m focusing more ceramics materials.”

De Guire: “Okay. All right. At one point, you spent some time in the United States as a research professor. So can you tell me a little bit about the importance of having international collaborations on your career.”

Ikuhara: “Yes, international collaboration. Because when I was young, almost twenty-seven or twenty-eight years ago, I joined Case Western Reserve University, Department of Materials Science, and I worked with Professor Arthur Heuer, and it was very good experience for me. I learned a lot from them about very basic science. As at that time, Japan is, how can I say it, the research approach is more application. But I feel that in the United States, particularly the people in the Case Western Reserve University ceramics group, studied a very basic science. So I learned a lot and for me, this was very good opportunity to learn such research approach. So, I think the international collaboration is therefore very important. Now, we have several foreign people from outside, and we educated such people to approach from the basic science.

But the problem is, how can I say, as you know, the discussion, this also is very important. Because when I was in, I lived in the United States, I can speak English more fluently, but now I don’t. During this time, COVID-19, I didn’t use English for almost one year.

De Guire: “Oh, you’re doing great.”

(music)

SECTION 2

De Guire: “Does your entire group focus on microstructure and electron microscopy studies?”

Ikuhara: “Yes.”

De Guire: “Okay. So how did you get interested in electron microscopy and the study of microstructure?”

Ikuhara: “As you know, so the mechanical properties, functional properties of ceramics strongly dependent on microstructures. Particularly grain boundary, interface is very important. Therefore, we need to characterize grain boundary structures, which are on the atomic scale, in order to obtain the guideline to design good property materials. That’s the reason I’m focusing on transmission microscopy characterization, to investigate the nature of microstructures.”

De Guire: “And how have the TEM tools changed over the course of your career? Do we have better tools for TEM than we used to have, and how has that impacted the kind of research you’re able to do?”

Ikuhara: “Yes. Previously, we are studying conventional transmission electron microscopy. So we can observe the microstructure, but not so high resolution. But in this century, we have a very big revolution, that is spherical aberration corrected scanning transmission electron microscopy. This is very powerful technique, and the resolution of Cs-STEM is now less than 1 angstrom. Actually, we have a very high spatial resolution less than 0.5 angstrom. This means that you can even observe the hydrogen columns or lithium columns in materials. So this is a very big revolution, this is a turning point of transmission electron microscopy. And now, if you use these microscopes, you can reveal the many unknown phenomena which have been in the black box for a long time. So this is a very big step of transmission electron microscopy, and I’m applying this TEM technique to reveal the many unknown phenomena in ceramics field.”

De Guire: “Okay. So the next step, you know, being able to see what is there and characterize the grain boundary, kind of leads to the next idea of can we control the grain boundary and can we engineer activities at the grain boundary. Do you see a day when we’ll be able to engineer grain boundary structure and maybe engineer dopant segregation for certain functionality?”

Ikuhara: “Yeah, I think that’s a main purpose we are doing this kind of research. So, so far, in order to improve the properties of ceramics, we dope various type of dopants to improve the mechanical properties or function properties. But mostly this method is an empirical method. But now we have some very advanced tools. Now we can directly observe the segregation sites at the grain boundaries, and in addition, theoretical calculation field is also developed a lot. Then we can combine such data and theoretical calculation to understand the nature or mechanism of the properties. Then if you understand what kind of dopant is very effective to improve the properties, we can select that dopant reasonably. So, I think then comparing with empirical approach, such kind of theoretical approach is very powerful to design materials.”

De Guire: “And what kinds of materials are you looking at?”

Ikuhara: “I’m studying the very basic science. Therefore, I prefer the alumina, zirconia, zinc oxide, magnesium oxide, very simple materials. This is because this very simple material becomes a very well-defined model system. Then we fabricated many types of grain boundaries by using these crystals and systematically characterized nature of grain boundary atomic structures and chemistry, chemical bounding of the grain boundaries.”

De Guire: “Okay. Do you think some of your work would eventually carry over to nonoxide materials? Like silicon nitride or boron carbide.”

Ikuhara: “I previously studied silicon nitride, silicon carbide, and nonoxide material. So advanced TEM approach can also apply this kind of materials, for example, silicon nitride, many people know there’s IGF, internal glass films, is existed. But this amorphous film, previously we didn’t know the composition of such very narrow amorphous film regions. But if you can apply this technique, you can determine the elemental distribution inside a very narrow amorphous film. So, this is also very important information to design silicon nitride materials.”

De Guire: “Do you ever look at grain boundaries of dissimilar materials? So maybe a zirconia against alumina?”

Ikuhara: “Yeah, we also study dissimilar type of heterointerface, particularly the metal–ceramic interfaces, this is also very traditional or conventional topics, but we also fabricate the joining metal and ceramics. And also, different ceramics is also important to understand the heterointerface structures.”

De Guire: “Right. Because materials are used in combinations of systems. So we need to understand how they interact with each other.”

Ikuhara: “That’s right.”

(music)

BREAK

De Guire: “The Basic Science Division of The American Ceramic Society is dedicated to the development of ceramic science underlying present and future applications of ceramics. The Division co-organizes the Electronic Materials and Applications meeting and also organizes symposia at the ACerS Annual Meeting at MS&T. Learn more about the Basic Science Division at ceramics.org/basic-science-division.”

SECTION 3

De Guire: “Though Yuichi focuses on basic research, the knowledge he gains is useful for immediate real-world applications.”

Ikuhara: “Many industrial people are interested in my work. I’m collaborating with industrial people a lot. I think the industrial people want to know knowledge of very basic science. They are very good at making commercial-like ceramics, but now such approach is almost saturated. Then, to the next step, they want to know the very basic approach. So, this combination is very important.”

De Guire: “Is there a particular segment of industry that is interested, for example, is interest coming mostly from the electronics industry or automotive?”

Ikuhara: “I think electronics also, and particularly structured materials. Very simple structured materials, zirconia company, alumina company, there are many such companies in Japan. But they want to further improve the alumina properties, they want to further improve the properties of zirconia. Such companies sent the people to my laboratory to study such basic thing, not only electronic field, electronic ceramics field. Structural ceramics, very traditional field, also needs such basic science knowledge, I think.”

De Guire: “Great. What advice would you give to somebody young who was thinking about a career in microscopy?”

Ikuhara: “Young people?”

De Guire: “Yes.”

Ikuhara: “Yeah, I always educate how microscopy, how advanced microscopy is very useful to research. But we first should know materials, materials science, not only transmission electron microscopy. Then I think the combination of microscopy and materials science, this is very powerful. So, we have many people who are in the microscopy field, particularly in the physics department. They are not interested in the materials. They just observe silicon always. That’s not so good. So I always push students to combine electron microscopy and materials science, ceramics, to understand the properties of materials. This combination is very important. I always educate like that.”

De Guire: “Okay. So you’ve been a member of The American Ceramic Society for quite a long time, and you are a Fellow. So, can you tell me how being a member has contributed to your career?”

Ikuhara: “I often attend Annual Meeting of The American Ceramic Society. So that is very useful to me to study the new topics, new trends of the ceramics field. Particularly, I remember that *Journal of the American Ceramic Society* previously have a special issue on science of alumina. You remember? It was a very long time ago. I think Peter Lagerlöf first proposed this idea. But this was very impressive. They organized a conference on science of alumina. I also attended that conference, that was supported by The American Ceramic Society. That was very nice and very useful for me to consider my future studies. So then, The American Ceramic Society contribute a lot to my research career.”

De Guire: “Yeah. Where do you see the field of microscopy going in the future?”

Ikuhara: “Now I think we have very big revolution in this century, as I told you, aberration corrected STEM. Spatial resolution is now less than 1 angstrom. You can even see one single atom. You can even see the hydrogen columns, lithium columns; very powerful technique. But next step is to, we can observe the inside atoms. Now our group is doing this. If you can obtain a very fine electron probe, less than 0.5 angstrom—0.5 angstrom is smaller than atom diameter—then we scan the atoms by using these fine probes. And this probe is a little bit deflected because those charge inside atoms, we can image this. Then, for example, we can map the atomic electro-field. And I think in the future, we can observe the electron cloud, chemical bonding directly, by using this very advanced scanning transmission electron microscopy. This is the next futures. Then electric field or magnetic field also will be observed on the atomic scale.”

De Guire: “That’s amazing.”

Ikuhara: “Yeah, yeah.”

(music)

CONCLUSION

De Guire: “Even as scientists develop new techniques and processes to characterize and synthesize materials, sometimes the best option is improving the methods we already have.

I’m Eileen De Guire, 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 Yuichi Ikuhara and his microscopy research. Ceramic Tech Chat is produced by Lisa McDonald and copyrighted by The American Ceramic Society.

Until next time, I’m Eileen De Guire, and thank you for joining us.”