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Professor Dresselhaus' Closing Remarks
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I always find it a challenge to give the concluding summary of what we learned at a day's conference or a week's conference, as I am often asked to do, and this conference was especially challenging, because it covered such a wide range of topics and technologies. So you have to excuse the level of detail in my summary and I hope it will be satisfactory for you.

We gather together and we are very thankful to the JSPS and the corresponding agencies in the US that brought together Japanese researchers, American researchers, and many other researchers in this audience, who have different origins and who all happened to be available for this meeting in Washington, DC. So it was really an international gathering. And the conference topic was frontiers of research in low dimensional systems. What we were trying to do today was to say what was different about these systems and what this particular group of researchers from two countries, some of whom knew each other, some of whom didn't know each other. I believe that most of the people in the audience were not familiar with all of the topics that were covered. They only know a subset of them, as was the case for me.

The first comment I would like to make is that, now nanostructures have reached a different level from what we expected at the time of the previous conference I attended. I was really surprised myself how fast nanostructures became a commercial technology. The first large-impact advance I learned about recently was the use of nanotubes in touch-screen devices. Now that nanotubes are ubiquitous and cheap, everybody will be using them. When nanotubes came in, thanks to Iijima-sensei, a long time ago, that was in the 1990s, 25 years ago. Now we are actually able to do many things about nanotubes that I never dreamed would be possible. For example, separating given chiralities, so we can now do many of the things that we dreamed about, but I didn't think it would happen in my lifetime. So the message here is that science is moving much more rapidly than we had any belief would happen 25 years ago.

The second comment I wanted to make is that today we heard many important advances in science and technology, and a large number of them are involved with US and Japanese collaborations or contributions made independently on similar topics. I think that, in the 1970s, when the US-Japanese interchange of personnel was more frequent, relatively speaking, and there was more money and opportunities relative to the number of workers, there was much

more interaction on a personal level than today. But then again today, we have different modes of communication. We have the internet, and we have magnetic recording as we heard in the last talk of this conference, that enables modes of communications that we didn't have before. So we are able to do much more with much less in this way. So that's another comment I would like to make. That (advances in technology) strongly influences international interactions.

Now I'd like to talk about a vision. For many past years, we have been working on given nanostructures, studying their properties. Maybe we now have many more different interesting materials; that we now have special new materials, or that there is now special physics that we are trying to study. But now we are almost always starting with the materials and studying their properties. Something we have to look forward to, maybe in the next decade, is the reverse of this. In the future, we will think more of properties we would like to study or achieve, and what kind of materials we need to make this all happen. This viewpoint is only becoming possible now. And I imagine that in the next 20 years, we'll see progress bring many new things to us that we have not yet thought about. I remember in the 1960s, no, the 1950s, I heard a lecture by Brian Pippard (he was a great scientist in the 1950s), and what he said was something you'd never guess: we older scientists discovered everything and there's not much more for you young people to do. I was very early in my PhD program when I heard that message, so this was in the early 1950s. We have gone a very long way from there. I believe that we have to, every time, think of looking forward. What are the really big new things happening now?

I think that the new concept of the materials genome project and everything associated with this project, and also the different ways of teaching that we are adopting now due to the ever-presence of computers. So both research and teaching are using big innovation in this time frame. So maybe the next 20 years will be very profitable too, so young people in the audience, whoever you are, don't be discouraged. There are still many new things for you to do. So that was my comment, my third point that I made: let's think now in a different way. What do we want to do now? What can we achieve, and what kind of materials can we make and how do we organize these new materials for the benefit of our people?

Next thing, which we did not talk very much about but there was a little bit of discussion about, relates to what I heard in a lecture last week and this is about manufacturing science. Nano is, intrinsically, a small quantity. So we have to multiply this nano quantity many times to make it macro: 10^{10} or 10^{9}. How are we are going to do this and maybe we need to give more attention to that aspect. There was some discussion of this topic and people from industry are very much concerned. This is what we call scale up, what we can do with nano, that scales. We can then

have coherent devices that work together, not against each other. So we are now giving some attention to such approaches and I think this might be a topic worth looking forward to in the future.

My next comment was about an idea I heard at this conference, about giving some effort to tackling difficult and challenging problems that maybe we didn't think were possible before. I mentioned manufacturing of nanotubes with specific chirality as an example. Now we can detect nanotubes with a given chirality and we can separate them but we can not manufacture a given chirality nanotube in commercial quantity, but we are close enough to doing this that it can happen very soon. We want to make, say, bi-layered graphene, where we have a precise relative orientation of the two planes with each other at a commercial level. We are not there yet, so there are many problems that we could think about, and we discussed some of them at this conference. So, as I was sitting there and thinking about what am I going to say in my summary, I thought that I am surprised that we have advanced both science and product implementation as far as we have. We can now think of what the next steps might be, and that would be making use of the methodology of solving difficult problems. Examples of difficult problems are manufacturing at the beginning stage, and nanotube specification in large quantity. Because one nanotube doesn't do much or twenty or hundred nanotubes are still tiny quantities, we talked about what we need to do next to achieve great success. Such examples are not going to make a really big impact in the world by themselves. So we have to do better than that for large-scale production.

The next comment is, I was fascinated by some of the talks where they were speaking about monitoring growth at the atomic scale, looking at individual atoms and studying exactly how we grow graphene, how we successfully grow nanotubes and how we make nano devices as we grow them. I think that would be a topic and a research direction that would be interesting to do more of, in the future, for generating new ideas. Work on this has already begun.

Spin current was new to me. I was really thankful for the lecture by Professor Maekawa, on spin current. I've heard a few lectures on that topic in very recent months and most of the time I cannot understand what the speakers are talking about. But this talk was really different because it went into the physics. In his talk I could follow what the authors were trying to do and how the process worked. So maybe I can now go and read research papers with more understanding. So I'm very thankful for that. I hope some of other people in the audience had the same experience that I had on that topic. We learned that paying more attention to spin is important, I think magnetic perpendicular recording is a good example of new ideas, and where

a technologically important field might be going.

In the last lecture, I heard about the importance of science to society. I think we are all concerned about this topic. And probably in Japan, when I have been there, and I have visited Japan many times, I feel that there is a great interest in combining science, society, and people. The Americas, North and South America, and probably Europe have a lot to learn from Japan about making science more useful for society and I think that the conversation that we had here on that topic was stimulating to me. So I would like to end by saying I hadn't been to one of the US-Japan or Japan-US meetings, whichever way you want to put it, for some time. However, this is not my first. I've been to one or two before with different sponsorship and location. I personally found the meetings very stimulating, and I hope that these sponsors will find this meeting useful for guiding their research programs, and will continue to support this program appropriately. Having such meetings focus on different fields of science, perhaps including humanities, science, engineering, and whatever else your agencies support, might be a good idea. But it might be interesting for you to consider some cross-cutting meetings that have all the sciences, so that people working in a single room, mostly in physical sciences and engineering, would hear what is happening in other fields, where successful collaborations are going on and what they are finding out, maybe would be very interesting for us. I don't know exactly how to organize that. One thing I was missing at this meeting was what was happening elsewhere in the world with Japanese collaborations, and I would like to maybe have a summary, sometimes, of what great progress is being made between Japan and other countries, as well.

So that's what I came up with by sitting here for a day, and I would welcome some comments by some of the others who agree or disagree or have other things to add, and might be useful to sponsors in closing this conference, thank you.