Interview with Prof.Kazumi Matsushige

TOWARDS FUTURE MOLECULAR COMPUTER AND VENTURE SPIRITS

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I: Prof. Matsushige, you have been doing research in various fields-most recently in organic molecular structures using SPM, measuring and arranging nanometer-scale objects. But this has not always been the case throughout your career. In fact, you used to be in high-pressure physics at one stage. But now, your work has been in cutting-edge technology in molecular memory and molecular electronics. You have moved from one area of science to another. Perhaps you could start by telling us the motivation behind these changes.

M: Originally I studied physics at undergraduate level, and then I moved into engineering for my masters degree. Then I went to the United States to study macromolecular science as a Ph. D. student, and now I am back in Japan. Because I moved from one place to another, my area of research also changed, depending on what my lab was doing at the time. Perhaps I am easily influenced. But I always seem to have this question of "why" and "how" things work. I feel that I have always been involved in the basic areas of science. If my lab specializes in high-pressure physics, I do that. When high pressure is applied to an organic molecule, the structure changes dramatically because of weak intermolecular force. When a polymer made of carbons is involved, for instance, various things can happen. For example, one of the fun things is that you can create a diamond by applying high pressure and high temperature to such carbon-base molecules. I was also involved in the study of fracture. How and why do materials fracture, and what are their origins? Incidentally, SPM is one of the modern contributions to the study of molecular science and electronics. First, Drs. G. Binnig, and H. Roher won a Nobel prize by this invention. When I first read their paper in a journal, I thought to myself, "Maybe I can do this in my lab-but much more cheaply and simply. So we built the whole thing-software and everything, and it cost us, back then, only one million yen. This was not a lot of money for SPM. So, after we actually constructed the SPM machine, we wrote up a paper about our cheap machine and presented it at a conference. This turned out to be very popular at the time, since an SPM was normally very expensive, perhaps over 10 million yen.

One main philosophy I have kept throughout my work is that if we can build something ourselves, we should. This was what led to us building the inexpensive SPM that I have just mentioned. So equipment development is something we have been involved in-in high pressure physics and in other areas. Anything we can build ourselves, we try to build.

I: Recently, you have been working in the field of molecular memory. Perhaps you could first tell us what that is about.

M: Yes. Molecules contain information themselves. They have energetically different states, and they contain both mechanical and physical information. So, if we could read information from this molecular structure, it would be a great advancement. For instance, if the electric treatment is accomplished in nano-scale, the memory density will be 1 million times that of today's CDs and DVDs. Now, human genomes also contain a lot of information, but the data there is sequential and composed of a group of molecules. With molecular technology, a single molecule can contain far more information than the human genome. Someone who studies nanometer-scale objects knows that one molecule is smaller than one nanometer. Moreover, molecules themselves have several bits of information, so you can multiply the capacity by the number of bits, increasing memory capacity even more. Of course the real question is how do we develop this industrially? This has to do with how technology will advance in the future.

I: And also, the question of how one can use this technology needs to be addressed, right?

M: Yes. Another question is how quickly this works. Of course, not all information needs to be accessed quickly. Slow information can also be useful. It's a matter of preference.

I: Again, molecular memories need some molecular rearrangement and the modification of molecular structures. Would you go into that in more detail ?

M: Yes. Originally I was in the field of physics, as I said before. If there was a need to change some properties of a molecule, chemists could do it, but not physicists. Well, I began to wonder whether or not it was possible to physically change molecular structures. "Isn't there a way to use physics for this?" "Perhaps using an SPM could help." "This microscope can help us touch(?) or arrange molecules." Now, other people had the same idea, but I did not worry too much about what other people were doing.

Last year, Dr. Shirakawa won a Nobel prize for the synthesis of polyacethylene film and its electric application. Well, ten years ago we were doing almost exactly the same thing-by using an SPM to change the chemical structure from paraffin to acethylene and electric characteristics.

I: Using an SPM?

M: Yes, acetylene is a structure where one hydrogen atom is attached to one carbon atom, while in ethylene structure like paraffin molecules there are two hydrogen atoms for each carbon atom. So by some method, if you can get rid of one hydrogen atom, you could end up with acetylene. So using the probe tip of an SPM, you can eliminate one hydrogen atom from molecules with the ethylene structure, dramatically changing the electrical properties of the molecule.

I: Now this isn't as much science as it is engineering.

M: Right. In reality, in science and technology, or physics and engineering, the process is changing. In the past, physicists or scientists would do some basic research, and engineers would use the discoveries or inventions to create something. It used to be like a bucket relay. But, these days, there's a fuzzier boundary between the two. New products for the market-those with significant impact-are very much based on hard science. So the boundary between science and technology is becoming blurred.

I: Of course in the science and engineering fields in Japan, traditionally, chemists would do nothing but chemistry, physicists would do only physics, and engineers would just make things. With you, however, Professor Matsushige, you seem to have all sides of the process down. I think that's great. Do you think this is because of the influence of the United States? Is it "American" in nature?

M: No, I don't think you could call it "American." When I moved from one lab to another, from physics to polymer science, or whatever, the boundaries between different branches of science were not very clear. Take, for instance, medical engineering. In Japan, there are medical researchers and there are engineers. But, in America, there is an area called medical engineering, where these people can do both. Perhaps this has had some influence on me.

I: Yes, and now you are getting more and more into electronics and engineering involving molecules-especially a single molecule. So the question seems to be changing from the why to the how-from physics to engineering and electronics. Could you tell us more about this recent, innovative field, and how this could affect our future lives, for those who are not up to date with this particular field?

M: Single-molecular electronics has a lot to do with the future of computing. Now, computers are basically made of silicon-a semiconductor. We have been making computers smaller and smaller-more compact all the time. But there seems to be a limit to this approach, at the sub-micron level. Another issue is the economic aspect. Making silicon-based computers extremely small will cost manufacturers a lot of money, so they are a little scared, and are hesitating to move in that direction. An alternative method is of course to use an altogether different idea-not to make things smaller but to use smaller items: to change from inorganic silicon crystals to organic molecules. The extreme application of such an approach is to use a single molecule. This would be a target for the future. But ultimately the future goal is to create a molecular computer. For this, we need chemists and physicists. We will also need computer scientists and experts in other fields since this new type of computer may not have the same architecture as today's Von Neumann type. So, different fields must cooperate for the development of these new computers. Indeed, I think this will be more exiting and interesting.

I: Yes, you are referring to inter-disciplinary joint research. It seems, though, that the Japanese are not very good at inter-disciplinary research. Have you started something to this end, systematically building a research structure to make such cooperation a reality?

M: Yes, I like that type of inter-disciplinary study. I know some chemists with whom I've been working. In a sense, we would like to go beyond the boundaries.

I: Do you think this will become more of a norm, to study and cooperate beyond the boundaries of scientific fields?

M: Yes, individually everyone needs to have some foundations, but in the long-run, one needs to have a broader perspective. Historically, the boundary between physics and chemistry, for example, hasn't always been clear. That is a rather recent phenomenon. They both deal with how matters work and what happens in nature. When you think about it, there isn't all that much difference between physics and chemistry.

I: You mean, in terms of history, it is a recent thing to distinguish physics and chemistry as separate fields?

M: Right.

I: Okay, let's discuss something a bit different now. What do you think of the role of Japan, the advantages of the Japanese scientific community, and the leadership of Japan in the world, as far as molecular electronics is concerned?

M: This area, I think, is one where we are still trying to catch up. Now, the reason I am saying this needs to be stated. I think that in individual fields we are at the highest levels. For instance, in synthetic technology, we lead the world. In silicon technology, the same is true in several specific areas. In SPM, the same is again true. But the question is, "Who can bring these ideas and concepts together and come up with innovations?" For example, in America, this is done very efficiently and quickly. People can come up with new ideas and start doing things right away. So in that sense, America and Europe lead Japan in these areas of research.

I: So you mean, academically they can work together jointly?

M: Yes. We need to try to encourage our young researchers to work together-in science and technology. We need to have positive funding, too.

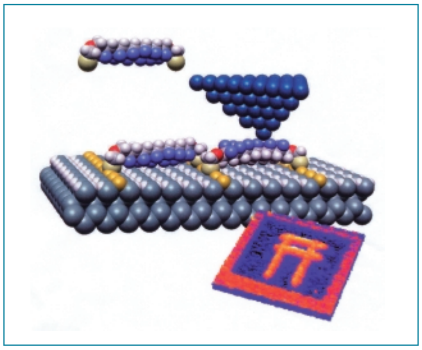
I: You have mentioned molecular computers. When I think about molecules, I have this image of molecules being very fragile-if you touch them, they might disappear. Today's computers-those based on silicon-are robust. They have motherboards, semiconductors, and integrated circuits. They have protective film. If you drop them, they still work. They can be made relatively flat and small. Very versatile. But now we are dealing with molecules. Aren't they too fragile? Do you think you can resolve these issues by working with people in different fields?

M: Yes, when you talk about using organic matters for computers, you are talking about something new. But there are systems like that already. Human brains are like that. Take the human brain and think of it as a computer. It works with a very low level of energy, in ambient temperature, and it is very fast and can deal vast amount of data. It not only handles calculations, but it can also estimate things and think about things. So it should be possible to make such new computers using organic molecules. Of course, we cannot leap too far at one time. Think about the history of silicon and transistors. Then think about how molecules can contain and communicate messages. We need to start with the technology of today and connect it with the technology of tomorrow. Recently, nanometer-scale technology has produced a simple electric device using simple principles with electrodes and molecules.

Another thing is that this whole concept is based on the fact that electrons move back and forth. Well, maybe there is another world where this doesn't have to happen. For instance, pulse signals. The energy is low, but a high speed is obtained. So there are a lot of things to be investigated out there.

I: Certainly. Will these molecular computers become more than just a concept in the near future? What year, approximately, do you think we can expect molecular computers to materialize? When could this dream become a reality?

M: I think perhaps this is too early to predict. The road map for silicon computers is usually based on 5- or 10-year periods. As a target, though, molecular devices, such as molecular displays and memory, could be out in as early as 10 years. It may take 15 to 20 years to assemble these various devices to make a functional unit. So, an actual computer-a molecular computer-may appear in 25 years or so.



I: 1947 saw the arrival of transistors. In 1960, laser technology was invented. But we haven't really seen anything super innovative or drastic for the last few decades. Perhaps something really big is about to emerge-not 30 years from now, but maybe even sooner?

M: Well, silicon computers have been around for about 30 or 40 years. So perhaps a 30- or 40-year period is appropriate when one considers the arrival of a revolutionary device in computing.

I: By the way, speaking of molecular electronics and a future molecular computer, what can we do to promote this new field of study internationally?

M: Molecular electronics and molecular computing require physics, chemistry, applied sciences, computer science and architecture, electronic engineering, as well as other fields. All this knowledge does not have to come from within Japan. There should be international cooperation. We need some creativity and uniqueness. The Japanese may have their own ideas, but the concepts may be uniform. Well, sometimes a person from another country with a different background comes up with very interesting, innovative ideas. Of course, any time we discuss things like that, people talk about national strategies and research strategies. Well, maybe we can look a little further than that. What would be better for the world? For the advancement of the whole world? It's perfectly fine to join hands with foreign researchers.

I: When we think of foreign researchers, we immediately think of walls and barriers. Do you have any good ideas to overcome these barriers and promote international cooperation?

M: Well, one is seen in nano-technology. When we try to bring in experts, we want everyone to come, regardless of their age, field, nationality, race, etc. It would be great to leave the traditional restrictiveness of the scientific community behind and work together beyond these boundaries. Perhaps this would speed up the process.

I: If you want to promote new and innovative research, you need to train young researchers to take this to the next generation. I believe this is important. You used to teach students at a university, and now you are involved in both research and the training of young leaders, as well as being involved in the Venture Business Laboratory (VBL), which we will come back to later. What difficulties do you face while doing all these things?

M: Well, it doesn't matter what the research topics are. I think the basic thing is for each student to understand exactly what he is doing. We of course give guidelines, but the question is what each student wants to do and then how they should do it. We can suggest, for instance, what type of experiment is necessary to find out this or that, and then the student will know exactly what to do next. Developing further questions is also important. I believe that it will be sufficient for master's degree candidates to have experienced this line of thinking and developing process. If students develop this type of research idea, I think it would be great. If they go into a corporation, this type of attitude is of course necessary.

I: Yes, that's true. But a student will probably not realize that unless he/she is taught this type of attitude to research. Do you do anything to help them realize this?

M: Yes, sometimes we hold research meetings where students present their research work. They present their work in detail, but of course we have a much broader view-we ask them questions like, "Why are you doing this? If you found the answer, what would you do with it next ? What is its significance in terms of future technologies ?" Questions like these, I believe, will help them see what they are doing and why they are doing it.

I: Yes, maybe this type of attitude will help us make a transition from laser technology to molecular engineering.

M: Yes, in the conventional electrical science and engineering community, touching molecules(?) is a strange thing. Everyone else is using silicon, compound crystals, opto-electrical devices, and ions-things that are rather well-established. Now, we have no idea what's going to happen with these molecules. But even now students are getting interested in these topics. So I think there is a future here.

I: And when you teach these young people, you also have to worry about their relationship to companies. What I hear is that you have a Venture Business Laboratory at Kyoto University, and that you are the facility director there. Maybe you could tell us more about VBL, how we may transfer these new technologies to corporations, and how venture businesses started by students can play a major and significant role in research in the future.

M: Sure. The VBL is a program established under the Ministry of Education, Culture, Sports, Science and Technology. There are now 35 VBLs nationwide, and the purposes of these centers are very specific: First, to promote and encourage researches for the next generation, and second, to train young researchers to have venture-oriented minds. The first is not so new; we've always tried to encourage researches for the future. But the second purpose is quite unique, and making it happen is easier said than done. In research, they discover or invent something new. Then they take their results to the business and corporate world. We have been doing this for the last few years now. Of course, in the field of molecular electronics for example, the new results are not immediately applicable. What we are hoping is that these results will be useful in the future. Corporations are also looking very carefully at this field. One project is to make organic ELs. In addition to liquid crystal screens, they are interested in creating a totally new type of EL device and display. The field of molecular computers is obviously another application in which companies are interested. In terms of the venture spirit, one thing we are doing is educating researchers to obtain patents. There are many different methods of doing this, but the issue is to ask, "How does the world and the market evaluate this research?" We hold a consulting service for questions regarding patents once a week in our VBL, and we have expert counselors. Some people have actually obtained patents for their inventions and made royalties from them.

I: So when you talk about getting patents, do you actually teach them to write patents, and do these students actually write patents for their inventions?

M: Well, of course, these counselors are experts in the field of patents, and they contact patent attorneys to actually write patents. If you speak to these counselors, they will tell you how to go about getting patents-basically, there is a standard format, and you only have to fill in the blanks in line with the format.

I: So you mean that students are actually saying, "Hey, I want to get a patent for this. I am going to try," and they get patents?

M: Yes.

I: Wow, that's wonderful.

M: For example, we have a student called Kobayashi in our lab. He is credited with the invention of some special electronic circuit that increases the resolution of the SPM. He got a patent for this, and then established a company, named Kyoto Instruments. He has actually made a product out of this, and is now selling it.

I: That's great. Is he a Master's student?

M: No, he was a doctoral candidate at that time.

I: So is it possible for students at doctoral level to get patents and actually make profits from them?

M: Yes. Student venture programs are not all that unusual, but technology-based ventures require the right atmosphere. So I believe that a setting like ours will be very beneficial.

I: I'd heard that many students had started their own ventures with software. But now you're saying that this is becoming true even in the world of hardware. I think this is really encouraging.

Next, I want to ask you about Kyoto-an ancient city. I speak from the standpoint of someone in Tokyo, and I see that there aren't so many big businesses in Kyoto. So if the VBL is trying to work together with local companies, it seems that Kyoto is not an ideal place. Is this a fair evaluation of the city of Kyoto?

M: Well, looking from the outside, Kyoto, as you say, is an ancient capital, and it's also a university town, as well as a tourist town. Perhaps it does not strike you as an industry-oriented city. However, industry is really the biggest business.

I: Do you mean it is the biggest in Japan?

M: No, I don't mean that. In Kyoto, industry is bigger and brings in more money than any other business sector. There are many small and medium sized enterprises in Kyoto. For example, Kyoto has some venture-based companies, such as Kyocera, Rhom, Murata, Omron, and Nintendo. So if you look at Kyoto from the eyes of the world in general, Kyoto is a world-recognized venture town. True, if you are from Tokyo, you may feel that the market is rather limited, and that it's far away. But, on the other hand, the market for Kyoto is not just local; its market is the whole world. So Kyoto has a very healthy atmosphere.

Kyoto University-Venture Buisiness Laboratory

I: Sorry, but I guess I had some misunderstanding of the city. I know that Kyoto University has a rich tradition and history-a very well-respected university, with many intelligent students entering it. But I am under the impression that many of these first-class students would feel more comfortable joining large, secure corporations rather than starting a venture company. What are your students like? Do they really get interested in founding their own companies?

M: Well, there aren't too many students who really want to go into ventures. Sure, it's a nationally funded, reputable school, so if someone wants to go into electronics, they can certainly go into a large firm, especially one of the local ones. However, students are very sensitive to the economy, and they know right away when companies go down. They also know that some major companies have gone bankrupt during the recession. So some of them are actually really interested in venture businesses. As far as I can see, most people do not want to go into ventures. We normally have about 100 people graduating every year from our department, and maybe 2 or 3 people go into venture businesses-that's quite all right. At Kyoto University, there are about 3000 students in total, so 3 % of that is about 100. If we have 100 venture business people every year, that would be great and would change the world. This spring, in addition, Kyoto university has set up a new "International Innovation Center (IIC)" with a faculty staff of 16 to further promote such innovation activities as well as academia-industry collaboration, and I, as a director of the IIC, am going to try several plans.

I: Stanford University also started a venture-business program about 20 years ago. In fact, it took them 20 years to establish this program. If you start with 100 students now, it will be in great shape 20 years from now.

M: Yes, and it doesn't have to be at Kyoto University alone. There are many other schools that can have that foundation. What's important is to maintain support and encouragement. I also think that business itself is going to change. I think that, if the world accepts the system, then anywhere in the world would be a good place for venture business.

I: You know, when I consider these things, it seems that universities are changing, and the roles of students and professors are changing along with them. I represent the Japan Association of Applied Physics, and in this association, the silicon industry used to be a big business. It was an enormous area. But now the fields are changing. When you consider promoting venture businesses in the future, especially in molecular electronics and similar fields, do you have any suggestions for our association?

M: Well, I think applied physics itself is a boundary field. Compared to other fields, I think applied physics can produce more people for venture businesses. But I don't think the association considers that fact all that much. I think there is a great potential, though. I believe the Association should ask itself, "What can we do to promote venture businesses?"

I: And you are heading a sectional group within this Association called something like "molecular and bio-electronics?"

M: Yes, I am. This molecular and bio-electronics (M&BE) section was founded by Prof. Okada about 11 years ago, and it has become more and more popular. Many students have joined this sectional group, now totaling about 540 members. Last year the Japan Association of Applied Physics and the Japan Chemistry Society held a joint symposium on molecular electronics; it was the first one. This year, an international symposium on molecular electronics was held. Among the participants of over 250 from various countries, maybe half or 2/3 of the people were in applied physics. The remaining participants were chemists and others. For chemists in general, physics-oriented conferences are difficult to attend, but they are coming to our meetings. Thus, this field is really an international and inter-disciplinary one.

I: Finally, you have always asked the question "Why." Now, with molecular electronics, perhaps "dream" will be an appropriate word. Maybe you could share with us your dreams in this field.

M: Well, maybe this is not just a dream. This is a research project for the future. I think the most fundamental component of research is the human being. We are the ones developing science and living by science, but there are also environmental and ethical issues. The basis of all these issues is mankind. We need a long, broad view of things so that we can balance what we are doing in the context of the human race.

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