Order in Disorder: Stanford Ovshinsky Talks of His Materials, Methods, and Machines

You may not see Stanford Ovshinsky listed under inventors in the Yellow Pages of Troy, Michigan's telephone directory. But you will find his name at various places in the White Pages listed as chair or president or CEO of companies he founded. But truly, he is an inventor—an inventor of materials. His materials are something special: disordered or amorphous structures, "freed from the tyranny of crystalline periodicity" as he said. He has been developing these materials for over three decades from what has now become a commonplace material—amorphous silicon—to more exotic complex metal hydrides for batteries. He also discovered uses for them: photovoltaics from silicon and powered vehicles from metal hydrides. As though these accomplishments were not enough, he tries to convince the skeptics by building production facilities to turn these materials into products. Stan Ovshinsky with his wife Iris and his scientists form a compact team of inventors. Stan said it is difficult to separate their contributions. But Iris is more forthcoming. "Stan always thinks of the new ideas and new materials," she said. And the ideas keep flowing. Despite their many decades of being in this business, retirement, it looks, is not on their agenda.

We were not sure from where to start our interview. Stan helped us by whisking us away into his research and development and manufacturing facilities. The machines he designed, the products he made, and the colleagues he works with, all spoke for him in their own ways. After the tour, when we still insisted on talking with him, he was surprised. "Wasn't that enough?" he questioned. But we wanted to learn more about what made him enter the field of materials, the challenges he faced, and the friends he made en route. On a sunny and an incredibly beautiful day, Stan, with Iris sitting nearby, spoke to us in the course of an excellent mid-eastern lunch.

Stan, tell us of your earlier years and how you entered the materials field.

I am from Akron, a quintessential industrial town in Ohio. I worked in the farmlands of Ohio and in its factories and was educated in the public libraries of Ohio. I was always interested in all things science then. Nature did not create scientific disciplines, nor divide science, but humankind did. I feel if you can prove your ideas using scientific methods, you can pursue any discipline. I first came to Detroit as an inventor, machine builder, and director of research with a great interest in neurophysiology.

Neurophysiology?

Yes, neurophysiology. I was then interested in machine automation and it was then part of "cybernetics"—a term that has long been forgotten. I thought intelligence was not the usual IQ stuff but an ability to learn, adapt, and change. I wanted to put this logic into machines. To learn more about how human beings think, I started attending meetings in neurophysiology. In one such meeting I heard a speaker making an astounding statement that nerve cells were mere empty bags. I felt there had to be more to it than that. I wondered whether it was the surface of the bags that mattered.

How did disordered materials come into the picture?

The interesting thing about the nerve cells is the disorder on the surface. Surface is a disordered state with dangling uncoordinated and unusual bonding configurations. It was not a fashionable idea then to model nerve cells as disordered materials, as everyone was modeling them in a transistor analogue of a circuit being switched on and off. Iris, with her PhD in biology and biochemistry, understood my interest in the disordered state of the nerve cell surfaces and helped me to model the process. It was then I started getting interested in disordered materials.

We see disorder on the surface of materials because all bonds are not coordinated, but I wondered what would be the properties of a bulk material if it were totally disordered; whole bulk turned into all surface, if you like. In multi-elemental alloys, disorder can also be a compositional one. I came up with the term *intermediate order* to describe some of these materials that are between short- and long-range order. It is difficult to apply quantum mechanical band theory calculations to describe these materials. Perhaps we should describe them more locally on the basis of coordination from the bonding of nearby atoms and configurations they form. The disordered materials thus provide a flexibility unavailable in crystalline

Profiles & Perspectives explores the people behind the profession of materials research.

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materials, where the coordinations are all frozen and neighbors determined.

What were your first disordered materials?

Transition metal oxides and then chalcogenide glass. I invented two types of switching, the Ovonic threshold switch and the Ovonic memory switch. The latter used a reversible structural phase change from amorphous to crystalline. [He points to the oscilloscope on his counter.] After some 30 years, this former switch I fabricated still works well, though I keep replacing the oscilloscope that displays the switching action.

When I wrote a paper about this switching phenomenon in chalcogenide glasses and published it in *Physical Review Letters* in 1968, it evoked its own share of controversy. But 20 years later, this paper became one of the five citation classics in the history of *Physical Review Letters.*

What made you form a company?

You are talking about Energy Conversion Devices, the company I formed with Iris? Our whole company is based on materials. We are really a different kind of company. In 1960, when Iris and I started the company, we wanted to develop device technologies to help solve problems of our society. We were really interested in using materials for effecting energy and information transformation. We felt that they are actually the opposite sides of the same coin, and the coin is made of materials [taking a coin and flipping it on the table in front of us].

When Iris and I formed a company "Energy Conversion Devices," our first product was phase-change materials as a switching device. But commercial development and manufacture of devices from this alloy took almost a decade, and only in 1972 we were able to license optical data storage disk technologies to other companies.

The usual complaint one hears about disordered materials is that they are not stable in a controllable way. Did you have any such problems?

No, these materials have been stable for more than 30 years now. One of our licensees, Matsushita, has been fabricating these devices since 1991. Last year, our licensees introduced CD-RW [read-write] disks of 650 Mbytes capacity and the next product will be a 2.6 Gbyte DVD-RAM disk. The optical memory industry has chosen our materials to be the basis for these very high capacity rewritable disks. Chalcogenide is a mouthful, but phase change is easy to say! Hitachi talks of a growing market of 30 million DVD-RAM in the year 2000.

Have you tried making semiconductor memories from these materials?

Oh yes! We have fabricated semiconductor nonvolatile memories as well. We have been able to achieve multibit data storage in chalcogenides. The thin films can be incorporated in semiconductor silicon using magnetron sputtering and photolithography. I see a great future for these devices as they are miserly in power consumption and can be easily fabricated into multilayer architecture. It offers a dynamic range for data storage. I see applications for these in cryptology.

We hear of a company you have formed with General Motors for manufacturing batteries for cars. How did it come about?

We were in the battery business many years back. Our nickel metal hydride batteries for consumer product applications are a big business. Last year's production was over 600 million batteries and this business is still growing. All significant manufacturers of this battery have our licenses. It was this performance that led us to the development of batteries for electric vehicle applications. Their ruggedness, high energy density, and high power made us enter this challenging development. Instead of using pure metal, we have been successful in developing compositionally disordered alloys that have very large hydrogen storage capacity, and the results are very impressive. The U.S. Advanced Battery Consortium (USABC) chose us to pursue the development of the batteries for electric vehicles. Our battery pack today has achieved a fuel economy equivalent of over 105 miles per gallon of gasoline! We have also fitted the batteries for motor scooters that can go about 70 miles on a single charge. We even have bicycle bat-

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teries to assist pedaling uphill.

If you really want to change the world it is necessary to work with people who have changed the world. Do you remember that tongue-in-cheek quote about what is good for General Motors is good for America? We needed a vehicle for changing the world, and we saw that in General Motors. General Motors has a sincere interest in going to the next century with electric vehicles and hybrid systems. We thought that they would be our ideal partners. But remember we are not a division of General Motors; we are a separate and independent joint venture called GM Ovonic. General Motors recognized from the beginning that our culture was flexible and we could work well with them. For us also it was a challenge. We had to learn to work with a giant organization with its own bureaucracy, work culture, and people who may not be sensitive to our way of thinking. But thanks to Bob Stempel, who was the chair and CEO of General Motors, and is now chair of ECD and our Ovonic Battery Company, we are making the transformation from a research company to a battery manufacturing company. A four-passenger electric car equipped with Ovonic batteries has gone 375 miles on a single charge! Since we have an engineered material, we will be able to go much further than that if necessary.

Don't you think the batteries are still very heavy? And we don't seem to have a Moore's Law-like relationship for batteries?

This is not true. There is so much progress even in batteries. In semiconductors we talk of the density of electronic states and in batteries we talk of density of chemically reactive sites. By developing disordered structures from carefully chosen elements, it is possible to improve the performance of batteries. Remember, we have come a long way from the classic lead acid batteries increasing both the capacity and specific power density. In the next generation of batteries we have achieved specific energy of 95 Wh/kg, and, based upon planned improvements in advanced materials, we believe we can increase the specific energy to as much as 120 Wh/kg.

Will the battery-operated car cost more?

The cost will come down when there is large-scale manufacturing and the demand picks up. Look at the cost of cell phones? They almost give them free now! The social forces are important. If we are concerned with pollution, battery cars will have to come and I guarantee you the price will become affordable.

You talk like an entrepreneur.

I have to be one. I found it difficult to be just a research scientist. Iris and I are practical revolutionaries. If you are working with companies you find they are so compartmentalized. Those in research are separate from those in production. And often they don't even meet. We wanted no barriers, so our inventions should see their fruition in marketed products.

> We have to look into the total efficiency: energy spent in producing single crystals, amount of material, and the area of materials we can use as photovoltaic generator.

How comfortable are you working in the two worlds: pursuit of knowledge and pursuit of wealth?

[Laughs] First of all, I don't know what the pursuit of wealth is. Our wealth is in patents, about several hundred patents. But Wall Street doesn't put value on patents. They value only quarterly earnings! The value of our Ovonic Battery Company has been set at $150 million by several Japanese companies buying a small percentage of its stock. But wealth has not been our driving passion. It's very difficult for anybody who has short-term thinking, as many financial institutions have, to understand what it takes to build new industries. And I want to tell you, we are very serious about building new industries. Building profitable industries and creating employment is what we must all do to our society.

What does it take?

Courage, perseverance, and being right. Any one of them is not enough. We cannot afford failures, as we are not a large company like IBM and Xerox who can afford to gamble on unproven technologies. They spend millions and sometimes can take hits. We have to be successful every time.

[Iris intervenes] People find Stan's conceptualization of a new idea to be so different from others. Innovative people may start with "A" and go to "D," then filling in "B" and "C." Stan leaps from "A" to "P," and then fills in every letter in between. People often said Stan has one foot on the ground and one foot in the air, but when he takes his foot in the air and puts it down, it is on solid ground.

[Stan continues] So when we have new ideas, the company policy is to validate them. Without validation, we don't move forward. This goes for me and for everyone else who works here. Talking is no good, alone. It is this that made us beat 60 large companies who were competing for the automobile battery development contract [USABC].

Will good engineering make a good material?

No. You have to have a scientific base for developing the material. When we chose complex metal hydrides, we knew it would be difficult to model the process with quantum mechanical calculations.

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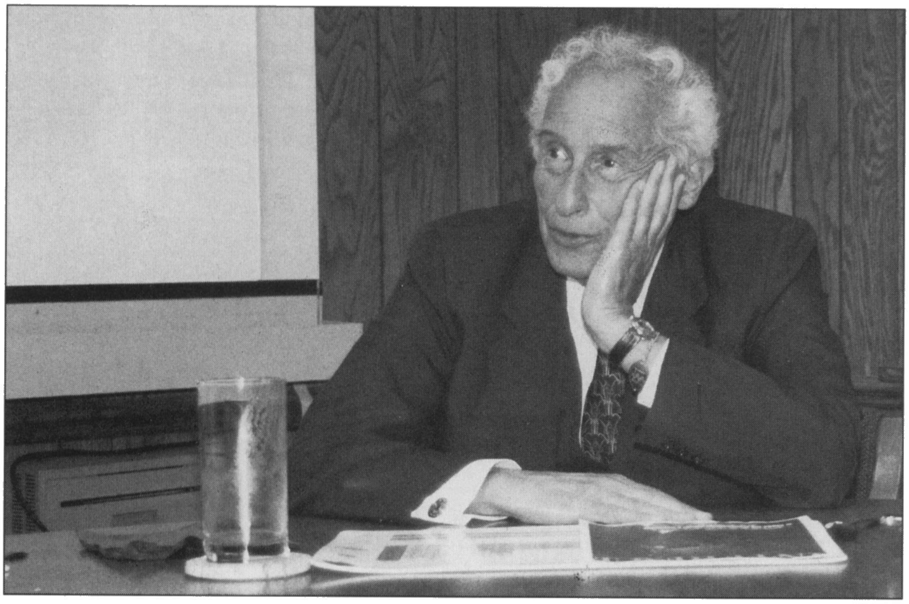

The *d* and *f* orbitals are not easily amenable for such quantum mechanical calculations. Instead we used the periodic table and understanding of orbitals and bonding. Intuition helps, but alone is not adequate. We use the periodic table so fully in our labs that you will see them hanging on the walls of every office. [And we did.]

[After Stan Ovshinsky stops to shake hands with one of his workers who walks by, he tells us]: Do you know that we once counted over 35 nationalities in our workforce? Some learned to speak English on the job. Many came at a young, impressionable age, and excited about being treated as a partner in a firm. All were eager to learn and advance their ideas. Did you notice a large number of women running our factories? We don't limit our talent pool. We are lucky to have the brightest scientists, engineers, and workers. And believe me, the turnover is very small. I tell every one of our people, when they ask for advice about how to represent the company outside, to act as the CEOs of the company. We have 60 or 70 PhDs in the company and they all have to be chemists, physicists, and materials scientists, regardless of their education.

We would like to take you back to your work on the development of disordered materials. Did you feel there was a crisis of confidence in scientific establishments when you first talked of these materials?

Yes, of course. I remember at one time when I talked at a Gordon conference about disordered catalysts. There was a noticeable chill. It was then fashionable to think clean surfaces as necessary for reaction sites—the opposite of what we want. Today we have separate sessions at conferences on disordered catalysts! It takes time, perseverance, and results to bring people to a new way of thinking. That's why we separated ourselves from the idea of being a part of an establishment and not letting that drive us in any way. And we have been fortunate in having wonderful associations with some of the outstanding academics in the field of disordered materials. For example, I really enjoyed working with Hellmut Fritzsche of the University of Chicago, and the late David Adler of MIT [Massachusetts Institute of Technology]. So I can't say we've been persecuted by scientific establishments. Scientific institutions are what I said before, hard to change. I didn't want to waste my time trying to change scientific institutions. In science, either you are going to be proven right or wrong, and that's perfectly okay. Some of our greatest supporters now were our greatest skeptics. Scientific institutions, in time, will respect the truth.

Stan has one foot on the ground and one foot in the air, but when he takes his foot in the air and puts it down, it is on solid ground.

You seem to have had an excellent relationship with Sir Nevill Mott, the Nobel Prize recipient in physics.

I first met Sir Nevill Mott in 1967 in San Francisco when some friends introduced me to him, and said we would get along fine. I then said to Nevill, as I said to you this morning, "let us not talk now, but see the work; and later, we shall discuss." He became very interested in disordered materials then, and I feel happy that later he acknowledged me as responsible for provoking his interest in disordered materials. His later work on the modeling of disordered structures with well-defined mobility edges is really an outstanding contribution. For Mott's Nobel Prize celebration I sent him a bottle of champagne and I recently saw that photograph in a volume. We went to his 90th birthday celebration. He was very generous in his acknowledgment. He gave a wonderful talk there and acknowledged me as the one who influenced him most in his pursuit of disordered materials.

Turning back to your industrial connections, you seem to have sold a number of your patents to Japan and also have a joint venture with Canon?

Yes, we have a number of agreements in both photovoltaics, nickel hydride batteries, and for memory disks. In Japan they respect my work in the science of disordered materials and they are creative in manufacturing products. If there were no Japan, the world would have to invent one. They have an industrial culture of a very high quality and an obsession for creative manufacturing. I am global-oriented in that I want to see manufacturing of useful developments flourish everywhere. Talking about East Asia, I think the problems they face are temporary. I'm sure Korea will rise from its temporary setbacks. Koreans are very, very hard working. I think the world today needs more jobs, in Europe and elsewhere. We can do this only by building new industries, and that is why innovative entrepreneurs are important. Governments don't really build industries.

We saw your photovoltaic plant. It is very impressive, but do you think amorphous materials can be competitive against PV crystalline silicon? Their efficiency seems so much better.

You seem to take photovoltaic efficiency as a single and sole criterion. What about the amount of material? You need a lot of thickness to absorb the sunlight in a single crystal. In amorphous silicon it is possible to absorb the sunlight in a fraction of a micron with multijunctions. We have to look into the total efficiency: energy spent in producing single crystals, amount of material, and the area of materials we can use as photovoltaic generator. We have already set up a manufacturing plant with an annual capacity of 5 MW. What did you think of the plant?

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It seems to us like a continuous casting plant in any metallurgical industry.

Yes, the continuous manufacturing line you saw is based on a proprietary deposition process and gas gate design that prevents contamination by dopants and other impurities down the line. It is so different from silicon chip manufacturing facilities with all of the clean rooms, etc., and still, as efficient. Five megawatts is really nothing. Even a run-of-the-mill coal-fired plant produces 1,000s of megawatts. If we want to make an impact, we must produce at least 100 megawatts of photovoltaic power. If I had money for such a plant, I would build one now. We would then have ushered in a new energy revolution. In 1980, I invented PV shingles, which we are now manufacturing along with metal roofs to make every part of a home receptive to photovoltaic generation [showing us a video of U.S. President Clinton appreciatively examining a photovoltaic shingle]. With larger production and wider dissemination, we should be able to bring down the cost to an ideal $1/W. We would then be seeing many gigawatts of power from solar energy.

Apart from your complaint about the Wall Street and financial institutions not empathizing with the process of innovation and the time it takes, did you face other problems, such as selling your wares?

[Turning to V.S. Arunachalam, who is an Indian citizen] My great regret is not being able to convince my friends in India that solar photovoltaics is the answer to their chronic electric power scarcity and that India should also consider electric-powered scooters and cars. You seem to have inherited the crippling bureaucracy from the British. I would dearly love to see a far wider application of photovoltaics in India and China. And that would bring the economy of scale I am looking for.

You seemed to have moved forward to collaborate with the Russians. How is this collaboration going?

I presented one of my earliest scientific papers in Russia and later in the Ukraine, which was part of the Soviet Union then. I could not then work with the Russian scientists because of their State control and politics. Now we have partnerships with the Russians both for manufacturing materials for batteries and photovoltaics. The Russians' metallurgical competence is outstanding, and we are working closely with them in developing and manufacturing the complex metal hydrides we need for batteries. They have very large economic problems today, but I have great respect for their professional competence.

It was time for us to end the interview. As we shook hands with Stan and Iris, Stan mused of his feelings for science and manufacturing. "Science is a noble profession," he said, "and it is made visible by products we manufacture, by the jobs we create, and the friendships we build."

We left Stan Ovshinsky there, with his dream of yet another invention, and solving another problem for society.

The interviewers were
MRS Bulletin editor Betsy Fleischer and
1998 Visiting Scientist V.S. Arunachalam

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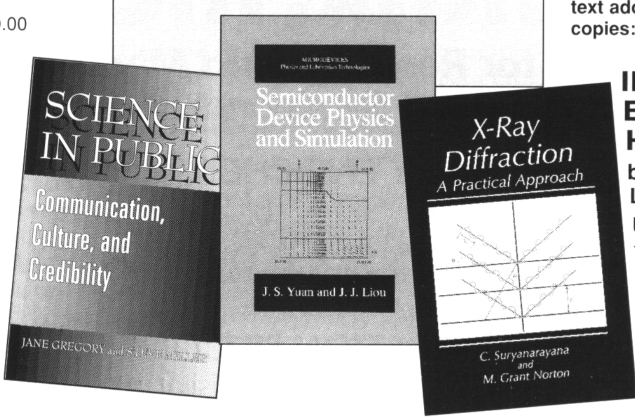

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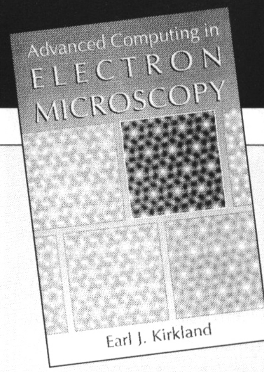

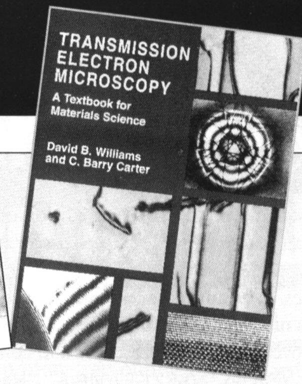

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