Materials R&D trends in the United States

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INTRODUCTION

I will present in this lecture a broad overview of materials R&D trends in the United States as I see them, and will present a few examples, mostly from my own experience. Of course, the field is so broad and diverse that only a limited number of examples will have to suffice to illustrate the main points.

Federal funding of materials research in the United States is somewhat over a billion dollars per year. Industrial funding, for materials R&D is known to be considerably larger than the federally sponsored research, perhaps three times as much.

In spite of some reduction in federally sponsored research in recent years, materials R&D in the United States seems to me to be stronger and more productive than it has been at any past time in my experience. This happy state of affairs has been aided by the confluence of a number of factors, including past decades of basic research, global information transfer, increased competitiveness resulting from the global market place, our strong economy, and a strong climate for innovation and entrepreneurship.

NEW MATERIALS

Let me turn first to some few examples of new materials which have emanated from basic research and which are, or promise to be, of industrial significance. Of course, there are famous developments such as the high temperature superconducting materials invented a decade ago, and to which I will return later. But in addition, one can find many dozens of new materials each week or month in physics, chemistry, or materials journals.

As one example, researchers at Pennsylvania State University this year announced development of a new piezo-electric material which has ten times the expansion of the current commercially employed PZT materials. New block copolymers of controlled nanostructure have application as structural materials for opto-electronic applications, and a few months ago Prof. Robert Cohen at MIT showed that nanoparticles of metallic clusters can be caused to form within these polymers. The particles might be arranged for example, to provide a permanent non-erasable magnetic signature or "water mark" to a plastic film. Amorphous ("glassy") metals have been used for some time in thin, rapidly solidified sections. Now, Prof Johnson at Cal Tech has shown that an exceedingly complex metallic alloy can be solidified in the glassy state in sections of some 5 or more mm, and we can expect to see inserts of this material in golf clubs on the circuit this coming spring.

An exciting area of materials R&D in the Untied States today is that of biomaterials. The plastic and metal prostheses used today to repair damage to bones and joints are well known. In time, engineered living structural tissue will replace these, and the living implants will merge seamlessly with the surrounding tissue. Complex customized shapes such as noses and ears will be generated from polymer constructs by computer-aided contour mapping.

The general approach has already been demonstrated in animals by a group led by Prof. Langer at MIT, who engineered artificial heart valves in lambs from cells derived from the animals' blood vessels. Work is underway which should eventually permit designing, and fabricating whole organs such as livers and kidneys, and transfering, these to patients.

NEW PROCESSES

With the end of the cold war and the development of the global marketplace, materials R&D in the United States is increasingly market driven. This is nowhere more evident than in process development. The development of new continuous casting processes and of new magnesium refining processes are two excellent examples of this . The United States has not led in these areas, although it contributed significantly by being the first to adopt European developed thin slab casting technology. Following are some examples of where the United States has led.

Up until about 1960, the high quality "work horse" abrasives were essentially pure alumina, prepared by melting, casting, and then grinding, the product into the desired grit size. In 1962, a new material, an alumina-zirconia alloy, was developed. This was also produced by melting, casting, and grinding to produce the desired grit size. The alloy change alone resulted in an improvement in grinding performance of some 40% over the alumina. This improvement was sufficient for some 15 years to provide a competitive edge for the company that developed the process, Norton Company. Then, a decade later, the company found it was able to extend that competitive edge by a process development. Researchers discovered that they could achieve an additional startling, increase in performance by rapidly solidifying the abrasive. Soon they developed techniques to do so in tonnage quantities, and within 5 years were producing and selling abrasive material with an additional 140% gain in grinding performance. Process developments in that area continue to come. Ten years later, abrasives produced not by melting and casting, but by the sol-gel process provided still an additional 40% edge and most recently ultra-grain refined sol-gel abrasives show another 30% improvement.

In an area close to my own research, conventional die casting of aluminum is being replaced in certain niche areas by semi-solid forming. In this process, the dendritic structure of usual cast metals is broken up by vigorous stirring, so that the semi-solid material behaves as a slurry and can be cast at solid contents well above 50%. Parts produced in this way are being used where the strength, integrity, or leak tightness of conventional die castings are not sufficient. One example of an application is in the front and rear suspension components of the Plymouth Prowler.

Another process of much potential in the United States is one developed by Metal Casting Technologies of Milford, New Hampshire for economic production of titanium aluminide castings. There is much interest today in the automobile industry in pistons of lighter weight and higher temperature capability. Titanium aluminide appears to be an ideal candidate for such an application, except for the cost when made by conventional techniques.

In the Metal Casting Technology casting process, low cost is achieved by carrying out the melting by induction heating, using, inexpensive ceramic crucibles. The essence of the process innovation is that contamination is avoided by achieving an extraordinarily short melting and casting cycle, thus maintaining the impurity pickup below a required minimum. The entire cycle is kept under about 2 seconds. The short melting time is achieved by high power input plus the heat evolved when aluminum reacts with pure titanium. The rapid casting is achieved by counter gravity casting ("drawing" the metal into a ceramic mold).

Another well known example of process development is the silicon chip. Since about 1965 chip performance has tended to follow "Moore's Law", doubling in performance every 18 months or so. This doubling has required continuously decreasing feature size until today off the shelf silicon transistors have length scales between 0.3 and 1 micron, and techniques are in hand to achieve substantially finer spacings. Perhaps not in silicon, but in other materials, physicists see the ability of achieving single molecule transistors with length scales on the order of one nanometer.

ENTREPRENEURSHIP

Today in the United States there is a strong culture of innovation and entrepreneurship among our young people, and it shows no sign of abating. These young people are helped today by a strong economy which provides ample venture capital money and by a climate in both universities and government laboratories that encourages industrial interactions and entrepreneurship.

We are especially proud at MIT of our lone, history of interacting with industry and have been encouraging, our students and faculty to start new companies. A Bank of Boston report published earlier this year summarized the impact that our graduates and faculty have had on formation of new companies in the United States and throughout the world. Our students and faculty have been founders or co-founders of over 4,000 companies. These companies employ 1.1 million people and have an annual world sales of 232 billion dollars. I understand that those revenues would make MIT the 24th largest economy in the world.

One particularly successful recent spinoff from MIT is American Superconductor Company. American Superconductor was formed in 1987, based on research in the Department of Materials Science and Engineering, at MIT. Since that time the company has grown through its own developments and through business partnerships that uniquely position the company to serve a deregulated electric utility industry. In March of this year the company completed the first demonstration of a high temperature superconducting transformer for Brown Bovari. In June of this year they sold their first commercial magnetic energy storage device, based on high temperature superconducting materials. They currently are designing and building motors and cables employing low temperature superconducting materials. The cables are being developed in partnership with Pirelli.

"3D Printing" is a method of building 3 dimensional models, patterns and molds by computer. It is one of a number of methods competing for various niches of the rapid prototyping market. The 3D Printing method developed by Profs. Cima and Sachs at MIT has now been spun off into 3 companies, each with a different focus.

QM Technologies in Albuquerque, New Mexico is a spin-off from Sandia National Laboratory. Technology developed at Sandia for nuclear fusion is being put to use for high energy, large area ion bombardment of materials surfaces. One application of this is for surface melting and rapid solidification of layers a few microns deep on metal surfaces. The process accomplishes much the same structural changes as does laser melting, but can cover much broader areas faster and more economically.

COMPUTERS

The importance of computers in materials R&D cannot be overstated. Computation plays an increasing role in new materials design, in the design of processes and products, and in process control and process improvement. Most of the processes discussed in earlier parts of this talk would not today be technically or economically feasible without computer controls. Process windows are too narrow, and yields required too high to rely on the human hand or eye.

Computers have achieved their position of eminence in our field as a result of their amazing, increase in performance and decrease in cost over time. In 1962 when a student of mine first employed a computer in his doctoral thesis research he used our then state-of-the-art IBM 709 mainframe computer which was built of vacuum tubes, not transistors. It had a memory of about 1/4 MB, a speed of 1 microsecond, and a cost of approximately ten million of today's dollars. In comparison my laptop computer today has 200 times the memory, 5,000 times the speed and costs $4,000 dollars. Following an analogy of Prof. Dertouzos at MIT consider what a family automobile would be like had similar advances been made in that industry. The car would now carry 4,000 passengers, travel at a top speed in excess of 30,000 miles an hour, and would cost $6.

The rate of increase in power of computers and the rate of decrease in cost show no sign of abating, and we can be sure that these will aid in the progress in our materials field in new ways in the years ahead.

CONCLUDING REMARKS

In summary, I have tried to provide some sense of the directions of materials research and development in the United States. New materials and new processes are coming forth at a rate greater than I have seen at any other time in my career. I have referred to a number of factors that have led to this happy circumstance, not the least of these being the global village we all now live in.