Materials Science 2100?

Russ R. Chianelli

> The most exciting phrase to hear in science, the one that heralds new discoveries, is not "Eureka!" but "That's funny..."
> —Isaac Asimov

> I like nonsense, it wakes up the brain cells.
> —Dr. Seuss

Now that we materials scientists have survived the "turn of the century" and the Y2K problem—for which we might have been held responsible—perhaps it is a good time to look forward and wonder what the year 2100 might bring us. Usually, when asked to do this, we happily extrapolate our own field into the future with projections typically based on science already at hand. "Only a few more technological and financial hurdles to go and such-and-such a device will be on the market and available to the public." So, we can confidently say that by the year 2100 we will have a booming economy fueled by clean solar power or maybe fusion power. We will be transported by safe hydrogen-powered vehicles and communicate effortlessly any information desired almost instantly. All of this is on the drawing board right now.

There were those who were equally as confident at the "turn of the last century" that the future was quite predictable. Comfortable in the precision of Newtonian mechanics, great coal-powered steam ships would connect nations in trade and commerce. Automobiles would catch on sooner or later, and copper wires would bind the world together. Lighter-than-air craft would be the "breakthrough" of the 20th century to come. Thomas Alva Edison was the man of the hour as he brought light to millions, forever changing the night. The changes that physics and chemistry would bring to the 20th century were unimaginable to most. Only today have some of us—yes, even materials scientists—really begun to comprehend the meaning of relativity and nuclear physics. Of course, the cold facts of the nuclear age have made the consequences of relativity quite clear.

But as I write this, another name is just coming into public view. Very much like Edison, the name of J. Craig Venter, head of Celera Genomics, is not yet a household word, but it will become one as the implications of cracking the genetic code of the human genome enters daily life. Undoubtedly, this result will change the human way of life more than any other previous scientific breakthrough. We can now only imagine some of the implications. Others are, as yet, unimaginable or perhaps unthinkable. Venter, like Edison, ushers in the new century with a discovery and a vision of staggering proportions.

These two scientists hold something else in common. They both proceeded "against the grain" of current scientific orthodoxy to reach rapidly toward practical accomplishment. The so-called "Edisonian" approach to discovery is often derided, but grudgingly admired for its many successes. Edison tried hundreds of materials for his light filaments until he found the right one. Venter used a DNA fragmentation and a brute-force computing approach derided by the establishment to make his discovery in record time. We can be sure that the world has taken note of Venter's methods, and an old lesson is relearned that will be true for materials scientists throughout the 21st century: Innovation requires freedom.

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But in what direction will this innovation take us? What unforeseen events in science will change our forecasts? We must remember that the threats posed by two great wars and the Cold War were the major factors in driving forward our science and technology to where it is today. Equally obvious but often ignored by many, including materials scientists, is that increasing population is a major threat to the envisioned world of clean energy and "ultimate chips." Already we see a revolutionary reaction to the global economy in the protests against the World Trade Organization, reminiscent of the early communist reaction against capitalism. Might Ted Kaczynski become the Karl Marx of the 21st century, fueling the reaction against technology and the global economy that raises some and leaves behind others?

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We materials scientists need to think about this as we move into the next century because much of the focus of materials will be a struggle between extending "the good life" to all on the planet and protecting "the good life" for a minority. How much of "the good life" can be extended to others is difficult to say, but we can be sure that security innovations will be high on the list of products demanded. It is not hard to envision cities completely air-conditioned through necessity, and the air being unbreathable outside. Tokyo is heading in this direction, and it is already very difficult to breathe in cities such as Mexico City. Such cities may be built under the sea for security, with access to fish farms and photosynthetic harvests. For similar reasons, Mars and the moon are likely to have colonies. Imagine the future employment for materials scientists in developing materials for these "secure locations" and their defense technology. Think of the list: self-replicating materials for building cities in extreme environments, implantable microcontrol chips for human behavior modification, and, maybe, force fields!

And what will the people be doing inside their fortified realms? With computers and robots running and producing everything, what is there to do? Have fun, of course! There is absolutely no doubt that the entertainment industry is leading materials science into the 21st century. Moving beyond computer games and virtual reality, polymers and plastics in combination with microchips will give textures to the reality people experience.

Of course, biotechnology will change the world, even the human species itself. Some predict that the ability to manipulate the genetic code will lead to the rapid evolution of an entirely new human species that is free from the defects of the naturally evolved one. Many of our human parts will be replaced with better materials: hearts, lungs, and kidneys that never wear out, only needing a tune-up from time to time. Entertainment or sports may lead the way. I can imagine that the first trillion-dollar quarterback drafted by the New York Giants in 2089 will be required, as part of his contract, to

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have both knees replaced with artificial ones before playing. The materials technology for the player's knees will be of the highest order, perhaps with sensors that allow mechanical parts to fail before muscle or ligaments are torn.

Materials scientists have always taken basic understanding and applied it to practical problems, often adding fundamental knowledge along the way. So, slowly but surely, materials scientists will become facile with the tools of molecular genetics. After all, what are proteins but tiny factories for producing materials necessary for life? In principle, proteins can make anything, and that is just what materials scientists will do with them: make anything that the heart and the market desire. We often struggle in the laboratory for years to learn how to make a material with just the right property for a particular application. But if a living organism needs it, it is produced. For example, magnetobacteria need small magnets to help them stay in the proper feeding zones in the open seas, so they produce small, single-magnetic-domain ferrite crystals, and they align them and put them in "baggies" to boot! This is a neat trick, and we will learn how to do it and apply the technique to any materials we desire.

"Trekkies" remember "room service" in the cabins of the officers on the U.S.S. Enterprise. The Enterprise's computer quickly synthesized any request, whether for a coke or a full-course Italian dinner. The request was provided in minutes in the cabin by the computer. Feasible? Perhaps. Soft drinks and Italian cuisine are really very similar. Both consist mostly of water and carbohydrates, as does most food. A little biotechnology, microcomputerization, and a supply of carbon, hydrogen, and oxygen atoms, and "presto," linguine Alfredo! The "holodeck" on the Enterprise, where any fantasy could be realized, required a lot more machinery, and therefore was centrally located. Here, all the most modern aspects of biotechnology, materials science, miniaturization, and computer technology were combined to keep isolated deep-space adventurers happy. Perhaps by 2100, we will have centrally located "holodecks" run by Disney.

All of the above is fairly predictable, with science fiction leading the way as usual. But where might the really unexpected come from? What about force fields and "tractor beams"? We can imagine very powerful magnetic or electric force fields projected into useful shapes. The possibility of the realization of these things is nicely discussed in *The Physics of Star Trek* by Lawrence M. Krauss. In theory, almost all of the technology envisioned by Gene Roddenberry, the creator of *Star Trek*, is in some manner feasible, waiting for materials scientists to come up with the necessary technology. One notable exception is human teletransportation. Too much energy is required to disassemble and reassemble our molecules. Well, maybe not. Recently, we have been reading about the communication between two photons with opposite spin traveling away from each other at the speed of light. They "know" about each other instantly, even though nothing can travel faster than the speed of light. This is predicted by Bell's theorem: Everything is connected to everything else in the infinite whole. Right now, physics is greatly puzzled by this phenomenon. From such puzzlement the unexpected arises. I am sure physics will give us some surprises here: "warp drive," time travel, and teletransportation?

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In fact, modern physics becomes stranger and stranger as it probes the fundamentals of the universe. However, sometimes it sounds more and more like just plain materials science. When speaking of the origins of the universe, we hear of what is basically a phase diagram of the fundamental particles. As the primordial explosion cools, first the leptons and hadrons phase-separate, creating the "clumpiness" of the universe. Further phase separation occurs with further cooling, until atoms are formed and planets "crystallize" into their orbits. Materials science? Yes, but just in some "extreme environments."

Materials scientists will learn how to operate in these "extreme environments." We are learning how to do this in our accelerators and other equipment here on Earth. I have been intrigued with the "Bose-Einstein" condensates, in which atoms cooled to their lowest quantum states become indistinguishable from one another, creating a superatomic state, the condensate. What can we do with this new material? Think of this state being created in space, where conditions are closer to those needed—maybe a condensate state that covers a required shape. What is this? Basically, it is a single atom of the required shape containing—if it is made from a heavy metal—lots of electrons with no space "wasted" between atoms. This might be a "shield," again envisioned by Roddenberry. But it would now only require a little more work by materials scientists.

Even more intriguing is the idea that matter is constantly being created from "fluctuations" in the vacuum. Something from nothing? We will put aside the philosophical implications of this for a moment. Imagine if we could control the production of these fluctuations. We could create matter anywhere, anytime, for use in any situation. Of course, when we do this, we obtain an approximately equal amount of antimatter, which we must separate from the "normal" matter. Imagine the materials science required to channel and join matter and antimatter—perhaps crystalline materials containing a mixture of matter and antimatter separated by strong local magnetic fields. Dilithium crystals? Presumably, we could use the extra antimatter created for destroying something that we wanted to get rid of, like radioactive material. Actually, this sounds pretty good; I think I'll write a proposal to the Department of Energy: Use of Antimatter to Destroy Radioactive Waste. Anybody interested in joining?

Russ R. Chianelli *received his PhD degree in chemistry from the Polytechnic Institute of Brooklyn in 1974. His PhD thesis concerned* in vitro *modeling of bone calcification. Following this, he joined the Corporate Research Laboratories of Exxon Research and Engineering Co. While at this laboratory, he conducted research in both fundamental and applied areas of interest to the energy industry. This work resulted in more than 170 refereed publications and issued about 50 U.S. patents. During this period, he was active in the Materials Research Society, serving as vice president (1989), president (1990), past president (1991) and councillor (1992–1994). In 1996, he joined the Chemistry Department at the University of Texas at El Paso as Chair and Professor of Chemistry and Materials Sciences. He is currently an active researcher in the areas of catalytic materials, biological materials, synchrotron studies, and art and archeological materials.*