Let There Be Light ... Emitting Diodes (LEDs)

Russell Dupuis talks about the development and future of this revolutionary technology.

Russell D. Dupuis is a professor in the School of Electrical and Computer Engineering at the Georgia Institute of Technology. He holds the Steve W. Chaddick Endowed Chair in Electro-Optics and is a Georgia Research Alliance Eminent Scholar. With academic degrees from the University of Illinois at Urbana-Champaign, Dupuis conducts research in the school’s microsystems and optics and photonics groups. Before joining academia, Dupuis worked in several industry positions. Dupuis and two colleagues were awarded the 2002 National Medal of Technologies for inventors and innovators in the light-emitting diode (LED) technology field. Today, LEDs’ myriad applications include digital displays, consumer electronics, automotive lighting, traffic signals and general illumination.

How might the use of LEDs be expanded in coming years?

Right now, people see LEDs as having specialized applications, such as in the side and tail lights of 18-wheeler trucks and buses and as tail lights in high-end cars. LEDs are so reliable. They don’t have to be replaced often, if ever.

LEDs will be used in the headlights of the Audi A8 in 2006, and other car manufacturers will follow.

Indoors, LEDs will eventually replace incandescent lights because the old technology is so inefficient. So much energy is wasted because incandescent lights put out heat. The calculations show we could cut the need for 33 nuclear power plants if LEDs replaced traditional lighting. Edison’s bulb is a wonderful thing, but it’s very wasteful.

With all due respect to Mr. Edison, we’re encroaching on his space. At some point, all incandescent bulbs will be in museums. People will say, “You mean they just ran current through it and heated it up? What kind of wasteful insanity is that?”

There are good physical reasons that LEDs are the ultimate way to create light from electricity. In principle, they are 100 percent efficient internally. You have to argue with Mother Nature about how to get the light out of the crystal and into free space, so you never really get 100 percent out. But there’s no other thing produced with an internal efficiency of 100 percent that can be used so effectively in a compact form. There are competing technologies — primarily diodes made from organic polymers. But they have their own value and problems. For now, the multi-billion dollar LED industry will be the primary source of solid state light for a long time.

LEDs will become the dominant form of lighting in high-end buildings within the next 10 years because designers see energy use as part of the total picture. LEDs will eventually be used in all offices and then in homes. Incandescent and fluorescent lamps are a form factor for these products. LEDs have a different form factor. But for a while, we’re stuck with these bulb-like things.

People are not familiar with LED-designed things that function the same but are different devices to light the room. They need this Edisorian screw-in device that is not very practical for LEDs.

If Thomas Edison was alive today, what do you believe he would think about the advances you and your colleagues have made in LED technology?

I can’t imagine that Tom would be unhappy because he was such an inventive genius. But he was also very competitive, so he might be a little mad, though I think he would appreciate it all. He was a practical guy. He made things humans needed. I think he’d be happy, especially if he owned stock in one of the LED companies. His technology will be supplanted in the next 25
years in a major way. As that happens, it will open new opportunities for jobs and for people to make creative contributions.

What were the major technological challenges in the development of LEDs that you and your colleagues conquered during the past 40 years?

Light-emitting diodes (LEDs) are devices largely invented in the 1960s. The first visible LEDs were made in 1962 by my Ph.D. advisor Nick Holonyak Jr., now of the University of Illinois at Urbana-Champaign, who was at General Electric at the time. A process he developed could grow materials with multiple elemental components. Semiconductor electronic circuits are generally composed of elemental materials like silicon or binary materials like gallium arsenide. The emission from a photo diode made from these materials — by force of nature's plan — is not visible to the human eye. It's in the infrared spectrum.

Professor Holonyak's interest was in visible light emitters because visibility is important to humans for information displays and other devices. Since he created the first visible LEDs, the term has come to refer to visible light-emitting devices of gallium, arsenic and phosphorus origin.

Developing visible LEDs was not just a simple extension of LED technology. It required a lot of perseverance and skill. In the 1960s, materials like alloys — three-element compounds — were thought to likely be unusable because they are crystallographically and chemically random. They are not ordered materials like silicon or diamond or gallium arsenide. But Holonyak pushed the edge into unknown territory and added his own special wrinkles to the process of creating LEDs.

Holonyak's creation of visible LEDs is now called the "Alloy Road" in semiconductor technology. It formed the underpinnings of virtually everything we know today that is not silicon itself.

Today, billions of LEDs are made each month around the world, and those are all made from alloys. The alloys today are more sophisticated than the original ones. They're grown with a different, more complicated process — called metal-organic chemical vapor deposition or MOCVD — that I developed and improved in 1977 while at Rockwell International. Now, MOCVD is the only technology used for the commercial manufacture of all colors of high-brightness LEDs.

The third part of this trio who won the award is George Crabro, who was also one of Holonyak's students. He led the LED development effort at Monsanto and developed the first practical yellow, or amber, LEDs. Crabro is now at Lumileds (previously the Hewlett-Packard Optoelectronics Group), the world's leader in this technology for high-brightness devices.

Over the past 40 years, this technology has gone from low-performance red LEDs to very high-performance, full-color displays like the one at Times Square in New York City. This same technology comes to individuals in the form of cell phone and laptop backlighting, green traffic lights, high-intensity flashlights and specialized architectural lighting in museums.

If you took away MOCVD, the LED world would collapse completely up to this point. There's no other technology in use right now for creating high-brightness LEDs. It would take a huge research investment to bring a competing technology up to the performance level and efficient manufacturing cost that MOCVD provides. MOCVD is the winner for the foreseeable future, and I'm pretty happy about that because I did part of it.

When Holonyak left GE to go to the University of Illinois, Bill Packard wanted him to set up their LED research group at Hewlett-Packard. If he had done that in 1963, he'd have been a multi-millionaire a long time ago. He chose to be a professor, and he says he'd still choose this route again because he's had so much fun doing research and being at the front edge of a lot of things.
“Today, we make LED materials on the microscale level. Next, we want to take semiconductor element atoms and assemble them in a different way using rules that we’re still discovering.”

I came back to academia after working in industry for 15 years because of what I saw Nick Holonyak doing in his career. We like seeing the benefit from our work going into industry. There’s a joy from seeing it go into products.

How did you perfect the process of metal-organic chemical vapor deposition (MOCVD) to grow high-quality semiconductor thin films and devices? And how did it improve LED technology?

In the mid-1970s, Rockwell International was developing the guidance systems for Minuteman missiles. It was necessary to design a system with radiation-hardened circuits so the missiles could go through these nuclear bomb clouds. One key feature of these circuits was the need for stability in the conductivity of the substrate. Silicon was the technology of choice, but it suffered when exposed to large amounts of radiation.

My colleague, Harold Manasevit had the idea of growing silicon on a sapphire substrate, which was an insulator from radiation and inherently stable. So he developed a technology called silicon on sapphire, or SOS, which was used in the Minuteman missiles. He also developed an analogous process for the growth of gallium arsenide on sapphire.

In 1975, I joined Rockwell. At that time, no one had applied this technology to the growth of high-quality materials such as gallium arsenide. I began to work on this and developed my own approach and equipment. By 1976, I had some good devices — solar cells, and in 1977, I created the first semiconductor laser, or LED, made by MOCVD. It was infrared, but it was a high-quality device.

Since joining the faculty of Georgia Tech in 2003, you have begun exploration of nanoscale “self-assembly.” What is that and how will your research affect this nanotechnology work?

To date, we’ve been making semiconductors like we did in the 1960s. Now we’re exploring the possibilities of nanoscale self-assembly to manipulate materials at a fundamental level. Today, we make LED materials on the microscale level. Next, we want to take semiconductor element atoms and assemble them in a different way using rules that we’re still discovering.

We’re forming assemblies of atoms in sets of tens or twenties, not 10 or 20 millions like LEDs are made today. LEDs take a large chunk of real estate today. We’re attempting to build materials on the order of thousands or hundreds of atoms instead of millions or tens of millions. To do that, you can’t use crude tools or chemicals. You must use self-assembly or Mother Nature’s rules such as those for stress, strain and localized physical features. We need to know how to get her to do this for us.

The goals are faster speed, increased efficiency and better ways for processing and storing information. It could result in faster computers and better LEDs.

Why did you choose a career in electrical engineering?

I’m a farm boy, but I didn’t like the farm because I have hay fever. I always liked science and math. I tinkered with things more. I liked taking things apart, like my bike. In high school, my cousin had a boyfriend who was studying electrical engineering at the University of Illinois. So I asked him, “What do you do?”

It seemed more interesting than other types of engineering because there is more physics involved. I never looked back. My fraternal twin brother went into veterinary medicine, and practices near Naperville, Ill.

How did your childhood and teen-age experiences affect your interest in science and technology?

My mother was a teacher. She started her career when she was 18 and taught in a one-room schoolhouse. My dad was a farmer and liked to fix things, and I would help.

There were 130 students in my high school and 36 in my graduating class. My kindergarten through 12th grade academic
training was not that good. 
But my brother and I did 
fine in college. He went to the 
U of I veterinary medical school 
and got his DVM degree. I 
completed my Ph.D. in electrical 
geneering, and we both 
graduated as undergraduates 
with “Highest Honors.”

**How did the influence of your personal and/or pro-

fessional mentors affect your work ethic and 
ultimate achievement?**

Ben Franklin said, “Plow deep 
while sluggards sleep.” I like 
that farm motto. While others 
are goofing off, you work.

My parents were not poor, 
but they always worked hard 
for what they had. My dad was 
a farmer during the 
Depression. He had an eighth 
grade education because he 
had to work on his father’s 
farm instead of going to high 
school. He was the oldest son 
of an Illinois farmer — with his 
origins in a French-Canadian 
farming family that had moved 
from Quebec and settled in 
Illinois in 1853. He had to bor-
row 50 cents from his father to 
take my mother to a dance 
when they were 14. He had 
to work until he was 37 years 
old before he could afford to be 
married.

When my mother was 
39, she had her first child, my 
older brother. Back then, 
teachers had to quit when 
they got pregnant.

So in 1939 or ’40, when 
my parents were offered a 
farm to rent through relatives, 
they did it. The house had no 
electricity or running water. My 
father was used to electricity 
because her family’s farm had 
a diesel generator. So she got 
mixed and then had to go 
back to using kerosene lamps 
and wood and coal cooking 
stoves.

At first, my dad farmed 
with horses. It was not easy. 
Eventually, he bought gaso-
line-powered tractors to 
replace the horses and he 
bought his own farm when 
I started high school.

**What do you enjoy doing 
when you’re not working?**

I have one hobby that I 
occasionally indulge in. It’s 
genealogy. Oh, and I’ve always 
liked to build model airplanes, 
even as an adult.

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