by Eric J. Lerner

Nobel Prizes Honor Innovations in Electronics

The Nobel prizes in physics and chemistry this year honored inventions that paved the way for either present-day electronics and communications or the electronic technology of the near future. Half of the physics prize went to electrical engineer Jack S. Kilby of Texas Instruments (TI) for his part in the invention of the integrated circuit (IC) in 1959 (Figure 1). The other half was shared by physicists Zhores I. Alferov of the A. I. Ioffe Physico-Technical Institute (St. Petersburg, Russia) and Herbert Kroemer (University of California, Santa Barbara) for developing the heterostructures that are now used universally in semiconductor lasers.

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Figure 1. A silicon boule—a single crystal with no lattice defects (center)—is cut into thin wafers on which the electronic components are laid out and cut into identical chips (left). The high-electron-mobility transistor on the right has six gate fingers (at the tips of the white triangles), each 50 µm long; a heterostructure (two or more layers with different energy band gaps) is below each gate.

The chemistry prize went to physicist Alan J. Heeger (also of the University of California, Santa Barbara) and chemists Alan G. MacDiarmid (University of Pennsylvania) and Hideki Shirakawa (University of Tsukuba, Japan), the co-discoverers of electrically conductive polymers. Their work opened up polymer electronics, which will likely find wide application in the coming decade in fields ranging from molecular electronics to foldable electronic newspapers.

It was the first time in years that both physical-science Nobels rewarded work in applied science rather than in the basic science so often highlighted by the Royal Swedish Academy of Sciences, which awards the prizes.

Kilby's honor provoked the most comment and controversy, as it was awarded for an engineering achievement. It was the first prize to honor the work that underlies the present electronics industry since John Bardeen, Walter H. Brattain, and William Shockley won the prize in 1956 for the invention of the transistor. Some physicists were quoted in the media as criticizing the Nobel committee's selection of Kilby. Michael Riordan of the Stanford Linear Accelerator called the innovation of the integrated circuit “an engineering feat, not a scientific one,” and astrophysicist John Learned of the University of Hawaii said the award “had little to do with fundamental science.”

Many other physicists, however, applauded Kilby's selection and this year's emphasis on electronic technology. “This is a return to the roots of the Nobel prizes,” said Marc Brodsky, executive director and chief executive officer of the American Institute of Physics. “Nobel's original intention was to honor those who contributed to human betterment, not just theoretical science. In fact, it's only scientists themselves who make these deep distinctions between science and engineering. To most people, science and technology are intimately linked. This Nobel recognizes key technological advances of the 20th century, which are based on physics-related inventions.”

Nobel's bequest states that the prize in physics shall go to the most important “discovery or invention” that “contributed most materially to the benefit of mankind” in the previous year. In the early years of the prize, awards for technological innovations were relatively common. Only in the past few decades has the physics prize gone almost exclusively to achievements in fundamental physics,such as last year's prize for highly abstract contributions to particle-physics theory.

Kilby co-invented the integrated circuit independently of Robert Noyce of Fairchild Electronics. Noyce died in 1990, so Kilby was honored alone; Nobel prizes are never awarded posthumously.

The invention of the IC was a surprising development at the time because it went against conventional wisdom. “While everyone wanted miniaturization, the idea that you could integrate many components on a single block of silicon was deemed impractical,” recalls Marshall I. Nathan, professor of electrical engineering at the University of Minnesota. “People figured that you could never get a perfect chip with many devices

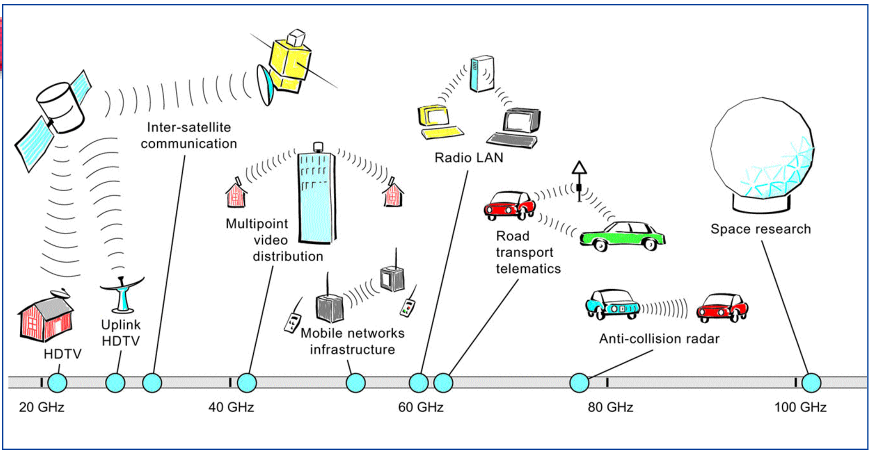

Figure 2. This figure, drawn in 1994, was meant to illustrate applications of heterojunction transistors in the microwave to millimeter-wave spectrum in Europe in 2008. In fact, several of the applications are already on the market, or soon will be.

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on it.” Crosstalk and noise were also thought to be insurmountable.

Thus when Kilby demonstrated in 1958 that the components of a complete circuit could be fabricated on a single piece of germanium, a standard semiconductor material, it was a major step forward. Then a young researcher at TI, Kilby had worked alone through a summer to develop a prototype circuit, using bulk silicon for resistors and p-n junctions for capacitors. He then showed that these separate elements could be integrated using gold lines laid down on the chip as connecting wires.

Noyce’s work, a few months later than Kilby’s, developed an IC that used more of the materials that would eventually become dominant in the field: aluminum, not gold, as the conductor, and silicon dioxide, rather than silicon, as the insulator. Several physicists expressed disappointment that the Nobel committee’s decades-long delay in recognizing the ICs deprived Noyce of his share in the honor.

Honoring heterojunctions

The Nobel committee linked this year’s physics awards to the technology that underlies the Internet. Some physicists have speculated that it was the explosive growth of the worldwide communications system during the past few years that finally spurred the committee to recognize some of the technology that made the modern electronics industry possible (Figure 2). “After all, the Internet is the first way that computers have changed the average person’s life directly,” comments Nathan.

Clearly, the Internet would be impossible without ICs and the tremendous speed of present-day computers that they made possible. At the same time, the Internet, as a fundamentally new means of communication, also relies on the vast carrying capacity of fiber-optic connections. Heterojunction devices, especially heterojunction lasers,are one of the key technologies that made inexpensive, efficient fiber communication possible.

The half of the physics prize that honored Alferov and Kroemer’s inventions caused less controversy than the one for ICs because few questioned that solid-state physics insights were essential to the development of heterojunction semiconductors. When Kroemer was at RCA in 1957, he was the first to analyze in detail and promote the advantages that arise from using a semiconductor material with a smaller-energy bandgap in the base of a transistor or other semiconductor junction. The smaller bandgap between the conduction and valence bands leads to an increase in the electron current. Conversely, with the same current, the base can be made thinner, which leads to a faster junction, among other advantages.

Heterojunctions are used in such basic and common devices as the modulation-doped field-effect transistor (MODFET), which is applied in wireless communication and space telecommunication and other areas. Heterostructures are also essential in the photo receivers of fiber optics, which integrate photodetectors and high-speed electronics on a single chip. “Kroemer was a real visionary, developing the heterostructures idea for his whole career,” says James Merz, Dean of Engineering at Notre Dame University. “In fact, he even had a lecture on ‘Heterostructures for Everything.’”

Kroemer also suggested, in 1963, that a double heterostructure could be used to produce an efficient semiconductor laser, an idea proposed independently by Alferov and his colleague R. F. Kazarinov. In such lasers, charge carriers (electrons and holes) are concentrated in a thin layer between two layers of higher-bandgap material. The heterostructure acts to confine the photons, which allows the stimulated emission to build up into a laser beam. “Alferov took a new idea and applied it in a different field, leading to the first efficient semiconductor lasers,” comments Nathan.

Alferov’s group at Ioffe raced several other research teams to produce the first continuously operating semiconductor laser in 1970. In the process, Alferov contributed the idea of using aluminum gallium arsenide/gallium arsenide as the key material. Today, semiconductor lasers transmit the vast flux of information over optical fibers, without which the Internet could not function. These lasers are also used in millions of common devices, including every compact disk player.

Not everyone was entirely happy with the selection of Kroemer and Alferov. “Why wasn’t Bob Hall, who invented the semiconductor laser in the first place, included?” asks Nick Holonyak of the University of Illinois, who was one of the pioneers of semiconductor lasers. Others pointed to the difficulty of choosing one or two representatives from a “hot” technological field, where improvements often flow in an almost seamless pattern, with many contributing to a single advance. Nobel prizes, however, are limited to a total of three winners each year.

Part of the problem, many agreed, was that the Nobel prizes had long overlooked electronic technologies, despite the fact that electronics has been the most rapidly advancing physics-based technology of the past 30 years. In the past four decades, only four previous Nobel Prizes in Physics have been given for solid-state physics advances—three involving lasers and one for superconductivity theory. Possibly, this year's prize marks the beginning of an effort to catch up, rather than an attempt to reduce the achievements of the electronics revolution to the work of just three scientists.

The physics prize certainly underlined the huge economic and practical impact of supporting research. Alferov, a member of the Russian Duma, or parliament, took the occasion of his prize to speak out forcefully against the gutting of Russian science that has occurred since the collapse of the Soviet Union. He pointed out that the cost of new housing for Duma members was four times the capital budget for all science in Russia, and he warned of the consequences of his government's continuing starvation of research.

Plastic conductors

Perhaps coincidentally, the chemistry prize also was awarded in the field of electronics, but more in the expected Nobel mode. The discovery of conducting polymers in 1977 by Heeger, MacDiarmid, and Shirakawa was a surprising development that unveiled a new and useful feature of nature. And the achievement was honored just when its usefulness in applications is being recognized and applied, not, as with the physics prize, long after the work became the basis of a huge industry. Finally, chemistry makes less of a distinction between theoretical and applied work than physics, so prizes in chemistry rarely can be categorized in this way. As has often been the case with the chemistry prizes in recent years, the prize cut across disciplinary lines—Heeger is a physicist—reflecting the increasing prevalence of interdisciplinary work.

MacDiarmid and Heeger were not looking for conducting organic polymers in the mid-1970s but instead were studying the inorganic polymer polysilicon nitride. Hearing of Shirakawa's work on synthesizing polyacetylene, they used the iodine treatment they had developed for silicon nitride on polyacetylene and succeeded in increasing the conductivity 10 millionfold, which showed that plastics could be conductors.

From this promising start, the three researchers, rapidly joined by many others, expanded the properties of polymers not only to synthesize conductors, but to synthesize semiconductors as well, which opened up the possibility of plastic electronics. At present, the main commercial applications are for conductive polymers—for use as coatings to protect against electromagnetic interference, corrosion, or static, for example.

Many R&D groups are racing to bring to market plastic semiconductors that could have far wider applications. Plastic semiconductors can be used for flexible displays, making possible electronic newspapers that fold the way paper ones do. Equally important, semiconductor polymers can be made water-soluble and literally printed onto surfaces with inkjet printers (see p. 13). This could reduce costs and make possible throwaway electronics that are almost as inexpensive as the paper on which they are printed. Throw-away electronics would be the ultimate step in the process of lowering circuit costs that started with the first IC. Ω