Milestones in Microelectronics

By George SCALISE

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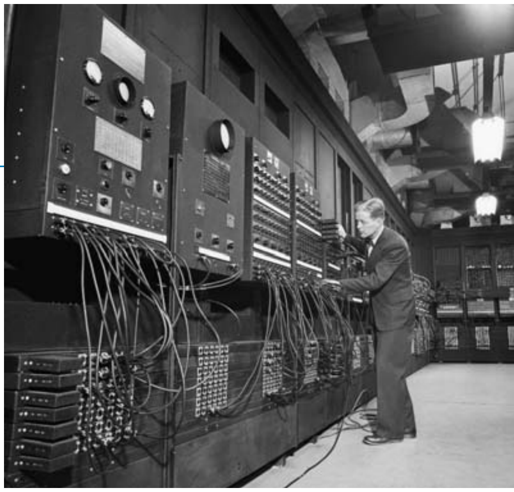


ENIAC (Electrical Numerical Integrator and Calculator), 1946

Nearly 70 years ago, Joseph Schumpeter, a European-born economics professor at Harvard University, published his landmark work, *"Capitalism, Socialism, and Democracy."* In this monumental work, Professor Schumpeter set forth his now-famous concept of "creative destruction."

Creative Destruction – the Real Basis of Competition

Simply put, Schumpeter argued that real competition consists of not merely offering a commodity product at a lower price than a competitor. The real basis of competition is radical innovation based on new technology, new methods of production, and new organizational structures to offer new products that have such compelling advantages that the new products literally kill off older products in a process of creative destruction.

Nowhere has this process been more dramatically demonstrated than in the microelectronics industry. Although Schumpeter lived to see the dawning of the digital age, it is doubtful that even he foresaw the extent of the creative destruction that began in the late 1940s.

The basic building block of electronic systems through the first four decades of the 20th century was the vacuum tube. Invented in the late 1800s, the vacuum tube was itself a great breakthrough that made possible radical new inventions including radio and television broadcasting, telephone networks, radar, and countless other electronic devices. In 1946 the world's first electronic digital computer (named ENIAC for *Electrical Numerical Integrator And Calculator*) was unveiled at the University of Pennsylvania.

ENIAC was both a marvel and a monster. The computer weighed more than 30 tons, occupied 1,800 square feet of floor space, and consumed more than 150 kilowatts to power more than 17,000 vacuum tubes, 10,000 capacitors, and 6,000 manual switches. Switching between different types of calculating operations required manually moving numerous cables and switches. Despite its bulk and unwieldy operations, ENIAC was a very efficient computer: it could do in about 30 seconds a complex calculation that a skilled person with a desk calculator took 20 hours to complete.

A Major Milestone – the Invention of the Transistor in 1947

ENIAC demonstrated not only the potential of electronic computing but also the need for a technological breakthrough that would reduce the size and power requirements while increasing the computational capabilities of future computers. That breakthrough came the following year, in 1947, with the invention of the transistor by William Shockley, John Bardeen, and Walter Brattain at Bell Laboratories in New Jersey. This invention – revealed 60 years ago last December – signaled the onset of a new era and the birth of the microelectronics industry. The three scientists won the 1956 Nobel Prize in Physics for their invention of the transistor.

The process of creative destruction was brutally effective: not one of the US companies that had dominated the manufacture of vacuum tubes made a successful transition to competition in the emerging era of solid-state microelectronics.

The transistor was a huge breakthrough, with enormous advantages over the vacuum tube – especially in size and power consumption. The "portable" radio of the pre-transistor era was approximately the size of a microwave oven and generated enough heat to warm a small room. Vacuum tubes were also rather fragile and frequently burned out. Solid-state circuitry was much more rugged and well suited to new applications that required small size, great endurance, and the ability to operate on battery power. While the transistor radio is widely recognized as the first important product employing transistors in place of vacuum tubes, the aerospace industry was an early driver of demand for lightweight, highly durable, low-power systems built around the transistor.

Even the transistor rather quickly ran up against scaling limits. With a rapidly growing demand for more complex electronic circuitry, the search was on for a new type of device that could further shrink the size of individual transistors while enhancing the performance and reducing the cost of electronic systems.

Another Milestone in Microelectronics – the First Integrated Circuits

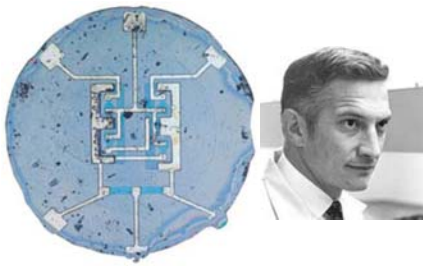
The next major breakthrough came 50 years ago, in 1958, when a young scientist at Texas Instruments, Jack Kilby, invented the integrated circuit – an ungainly-looking device that contained all of the required elements of a circuit on a single piece of semiconducting material, in this case germanium.

Kilby's invention was followed a year later, in 1959, by the invention of the planar integrated circuit by Robert Noyce, then a young engineer with Fairchild Semiconductor. Noyce's contribution was the creation of a system of interconnected transistors on a single, monolithic silicon chip. Noyce's invention provided the breakthrough enabling seemingly unlimited scalability. Today, the most advanced chips contain two billion transistors on a sliver of silicon about the size of a dime.

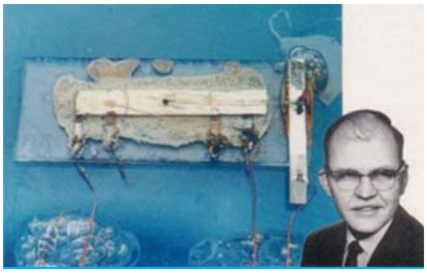
Kilby was awarded the 2000 Nobel Prize in Physics for his invention.

The first integrated circuits (ICs)

Photos: Intel



Bob Noyce's IC, 1959



Jack Kilby's IC, 1958

Nobel prizes are not awarded posthumously, and Noyce had died suddenly in 1990. At the awards ceremony, Kilby graciously stated that he was accepting the prize not only for his own contributions but also in recognition of Noyce as the co-inventor of the integrated circuit.

Smaller, Faster, Cheaper – the Mantra of the Microelectronics Industry

In the nearly half century since the first working silicon integrated circuit was unveiled, "smaller, faster, cheaper" has become the mantra of the microelectronics industry. The pervasiveness of integrated circuits has grown exponentially as microchips have enabled an incredible variety of electronic devices that existed only in science fiction half a century ago. Today it is hard to imagine a world without personal computers, cell phones, the Internet, email, ecommerce, digital cameras, and a host of other products made possible by advances in microchip technology.

The worldwide semiconductor industry is huge – worldwide sales of microchips will be more than $266 billion in 2008 and will surpass $324 billion in 2011. Industry revenues, however, tell only a small part of the story of the growing demand for semiconductors and the ever-more important role chips play in our world. Integrated circuits are unique in that each year these electronic marvels become faster and more powerful, delivering increased performance and functionality in end products – for less money!

The personal computer is an excellent example of how advances in semiconductor technology have dramatically reduced the cost of electronic products while delivering enormous improvements in performance and functionality. The typical desktop computer of 2007 sold for approximately $630 versus $1,833 for a typical desktop system in 1997 – barely more than one-third the cost of a decade ago. The typical PC of 2007, however, was at least 100 times more powerful and included features such as digital video recorders, network interface cards, enhanced graphics, and other features not available a decade ago.

In 2005, for the first time ever, sales of digital cameras surpassed sales of film cameras. In another example of creative destruction at work, the instant film camera has virtually disappeared from the market. While there are a handful of manufacturers still producing typewriters, these remarkable machines first invented in the 19th century have almost disappeared from the modern office, replaced by word processors and laser printers filled with advanced electronic circuitry.

This year the worldwide semiconductor industry will produce nearly 900 million transistors for every man, woman, and child on earth.

Consumers Now Drive Industry Growth

Industry growth is now being driven principally by consumers – approximately 55% of semiconductor industry revenues are from circuits that go into products purchased by individual consumers. This is a major change from just a few years ago when corporate information technology was the major demand driver for semiconductors.

Over the past 10 to 15 years, major economic and political changes throughout the world have brought literally hundreds of millions of new consumers into the marketplace for electronic products. Enormous new markets in China, India, Eastern Europe, Southeast Asia, and Latin America have opened up. China alone now has a middle class of more than 300 million people – roughly equivalent to the entire population of the United States.

To put this rapid expansion of the market for consumer electronic products into perspective, consider this: China added nearly 7.5 million new mobile telephone subscribers in May 2008. AT&T, the largest American cellular phone service provider, added nine million new subscribers in all of 2007!

Moore's Law

In 1965, when the microchip industry was still in its early infancy, another brilliant young engineer at Fairchild Semiconductor, Gordon Moore, made an observation about the pace of technological progress in integrated circuits. Working from only two data points, Moore observed that the number of transistors on a square inch of silicon had doubled every year since the invention of the integrated circuit. Moore, who later went on to co-found Intel Corp. with his colleague Robert Noyce, predicted that this rate of progress could continue for at least another 10 years. The observation, of course, has become known as "Moore's Law" and it has been the benchmark of industry progress for more than four decades. While the pace of technological advance has slowed slightly in recent years – chip density now doubles approximately every 18 months – observers who predicted the imminent end of Moore's Law have been consistently proven wrong.

Photo: Agere

The first transistor, 1947

Innovation allows us to do more with less

Increased functionality and a 66% price drop in only 10 years!

Spec	1997	Q4 2007 (GT5622)
Processor	2nd Gen 32-bit	Intel E2160
Raw Power (Normalized)	1	80-120
Clock Rate	75MHz	1.8 GHz
Memory	9.2MB	3GB
Disk Storage	0.74GB	400GB
Modem	No	56K
Network Interface Card (NIC)	No	Ethernet
Graphics	Add-In	Integrated Chipset
CD ROM	1X	Multi-Format DVD Burner
CD-RW/DVD	No	None
Media Reader	None	15-in-1
Removable Storage	Floppy Disk (1.5MB)	Flash Drive
		4GB
Price	$1,833	$630

Source : *Gateway January 2008*

The Nanoelectronics Era

Moore's Law ultimately must defer to the laws of physics and there is a broad consensus within the industry that the scaling limits of current semiconductor technology (known as CMOS for complementary metal-oxide semiconductor) will be reached within the next 10 to 15 years.

Progress in information technology will not come to a screeching halt once the limits of conventional technology have been reached. Scientists and engineers around the world are engaged in basic research to develop new technologies for nano-scale devices that will enable continued progress well into the 21st century. The challenges are not inconsequential. Creating new devices with features smaller than one nanometer – one one-billionth of a meter – will require the invention of a new switch, use of new materials, and implementation of new assembly methods.

Throughout history, there has typically been a 15-year lag between the beginning of research on any radical new technology and the commercialization of products based on the new technology. By that metric, the true nanoelectronics era is likely to begin around 2020.

Meanwhile the worldwide industry will continue to drive CMOS technology to its ultimate limits.

Challenges and Opportunities

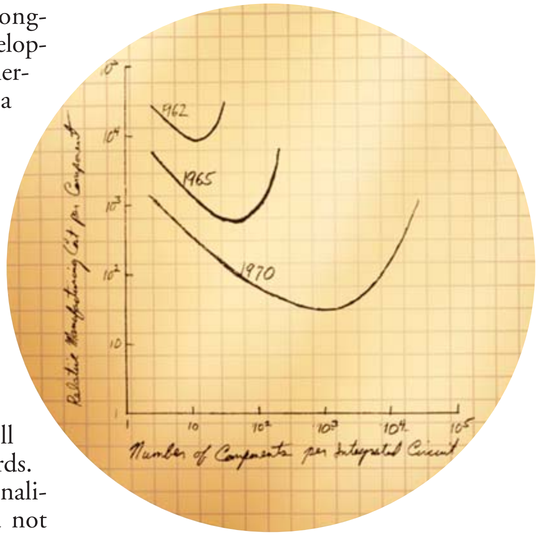
Continued progress in semiconductor technology will require a major ongoing commitment of resources to support both basic research, which has a long-term payback, and research and development, which leads directly to commercialization of new products and has a near-term payback. A question that is frequently posed to industry leaders is: "Why do we need chips that are faster and smaller? How much smaller can you make a cell phone or a personal computer?"

The answer of course is that there will be a never-ending drive to increase the functionality, performance, and ease-of-use of electronic products by increasing the density of microchips. The first cell phones were large by today's standards. The early units had limited functionality, relatively short battery life, and not much storage capacity – and they were more expensive than the typical smart phone of today. Smaller, faster, cheaper microelectronic components account for the difference.

The laptop PC is another beneficiary of technological progress in semiconductors. For well under $1,000 a consumer can buy a lightweight, powerful computer with a high-definition, 15-inch display with performance that exceeds that of a supercomputer of a decade ago.

The reality is that creative engineers and scientists will always find new ways to employ the expanding capabilities of advanced semiconductors. As noted earlier, electronic devices that were the stuff of science fiction only a few years ago are now commodity products affordable even to those in emerging economies.

Photo: Intel



Moore's Law original graph, 1965

Doing More, Using Less

One of the greatest challenges facing the entire world today is meeting the growing demand for energy while minimizing the environmental impact of increased energy production and use.

The microelectronics industry will play a major role in meeting this challenge by enabling people everywhere to do more with less energy. Advanced semiconductors are already achieving dramatic energy savings by reducing energy consumption of the world's largest data centers, enabling more fuel-efficient automobiles, extending the battery life of portable electronic devices, saving energy in home appliances, and helping factories become more productive through the use of variable-speed electric motors. In 1978, computers executed 1,400 instructions per second/watt. That number has increased to 40 million instructions per second/watt this year – an improvement of nearly 3 million percent! Semiconductor technology is also playing a huge role in the creation of more efficient and more effective solar panels, which hold the promise of providing a new and sustainable source of energy.

The pioneers of the microelectronics industry and the engineers and scientists who are at work around the world today to enable the next wave of creative destruction share one common quality: they are incurable optimists who believe that every challenge and every obstacle to continued progress also brings new opportunities. They reject the notion that future generations will have to lower their expectations of a better quality of life.

For more than 60 years, progress in microelectronics has enabled people everywhere to become more productive, to enjoy a higher standard of living, and to believe that their children can expect an even brighter future.

There is little doubt that our best days are yet to come! JS

George Scalise is President of the Semiconductor Industry Association (SIA), a leading voice for the US semiconductor industry that has represented American semiconductor companies since 1977.