A Tribute to the Transistor at 40: The Tiny I

By Holly Bigelow

Riddle: What 1956 Nobel Prize-winning invention from Bell Labs was no bigger than a walnut, yet has revolutionized the electronics industry and with it, the way we live, work and play?

Answer: The transistor, invented Dec. 23, 1947 at Murray Hill by physicists John Bardeen, Walter Brattain and William Shockley.

The transistor replaced the bulky, power-hungry and short-lived vacuum tube amplifier, providing a tiny, reliable and inexpensive substitute for switching or amplifying electrical signals. The 40th anniversary of the now ubiquitous little device is being celebrated this month.

Think about it. Without the miniaturization of transistors, there would be no personal computers or compact discs. Nobody could phone home from the car, switch channels from the couch, or withdraw cash from an automatic teller. There would be no manned spaceflight or communications satellites. And AT&T could not have developed digital switches, push-button telephones, microwave radio relays and undersea fiber optic cables.

"I think we knew at the time that the transistor was not just a substitute for the vacuum tube, and that it was going to open up a new area of electronics," said Brattain in a 1972 interview. "But I didn't have any idea that the development would come quite as rapidly and go to the great extent that it has today." Brattain died Oct. 13 this year at the age of 85.

According to Bruce Darnall, executive director of the Integrated Circuit Processing Division in Allentown, the success of the transistor is based on its ability to amplify a small signal into a larger signal or use a small signal to control or switch a larger signal. "The small signal might come from a very sensitive microphone, like in the mouthpiece of a telephone," he says. "The voice signal is amplified by transistors in the telephone set to levels where it can be carried over telephone wires and be detected miles away."

"In the past, we used vacuum tubes to switch and amplify signals," continues Darnall. "But vacuum tubes were big, took a lot of power, and were expensive. You couldn't think about having handheld calculators, electric watches or portable, battery powered radios containing thousands of vacuum tubes."

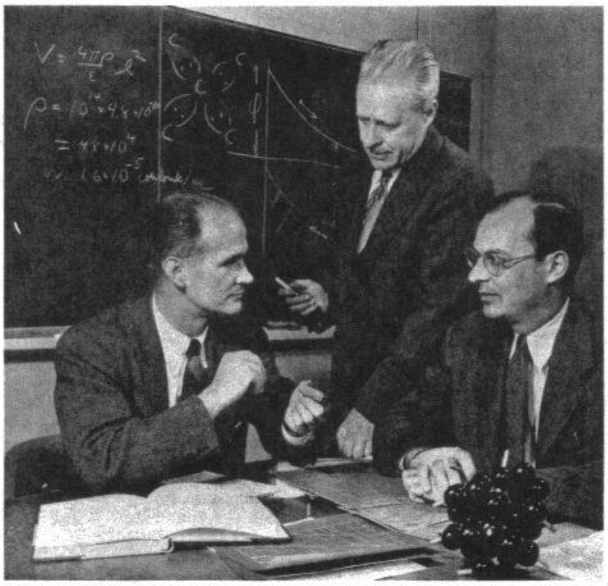
Vacuum tubes consisted of fragile pieces of metal arranged inside an evacuated glass cylinder, each at least the size of a thimble, according to Darnall. Transistors, however, are made of solid state crystalline materials. Today, millions of them can be squeezed onto an integrated circuit "chip" less than 1/2 inch square. Many hundreds of these chips could fit inside a thimble.

The transistor was named by John Pierce, a colleague of its three inventors, who coined the term from the device's ability to transfer resistance from one wire contact to another. The less resistance in the material, the more current can flow.

"This whole technology is centered around how you prepare and apply signals to pieces of semiconductor material so that you can modify the current-carrying behavior of the material by the addition of a small, external control signal," explains Darnall.

"In the first transistors, the semiconductor pieces were made of germanium, with each piece doped differently; that is they contained different amounts of elements such as boron or arsenic, which slightly altered the characteristics of the germanium," Darnall says. Most transistors today are made of silicon, a material that is easier to work with and far more abundant than germanium.

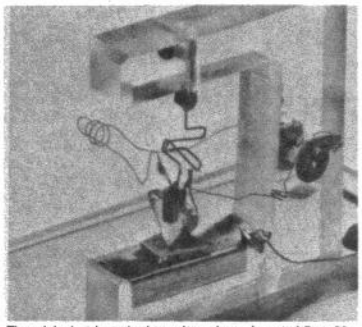
"A lot of work had to follow that first invention before we could start making integrated circuits," continues Darnall. "We had to learn how to create multiple transistors in a single chip of silicon and connect them with wires on the surface of the chip. Once that was done, researchers both here and at other labs around the world, began to find ways of squeezing more of them on a chip." ▶



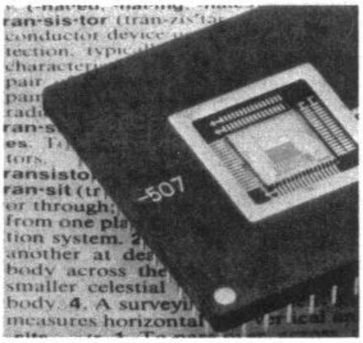
William Shockley, left, Walter Brattain and John Bardeen discovered the transistor effect in 1947 and were awarded the Nobel Prize in Physics for their work in 1956.

Anniversary Memento

R&D community libraries are marking the 40th anniversary of the transistor by providing bookmarks designed to promote AT&T materials science and electronics expertise at trade shows and exhibits. Ask your local librarian for an anniversary bookmark today.



The original walnut-sized transitor, above, invented Dec. 23, Murray Hill. A state-of-the-art custom logic integrated circuit contains the equivalent of 72,000 microscopic transistors.



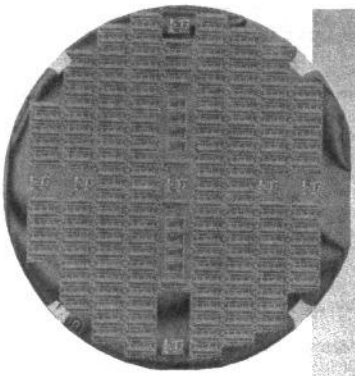
Larry Jackel, head of the Device Structure Research Departme Holmdel, works on new lithographic techniques to produce exp mental electronic neural network chips that may mimic the wa brain cells retrieve stored information.

)evice that Launched the Electronics Era

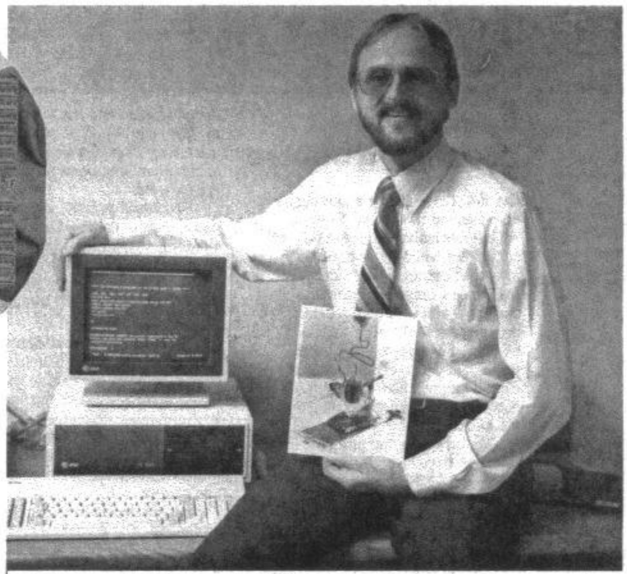
Since the 1960s, the number has been essentially doubled every year. Today, there are ICs containing four million bits of memory on a single chip, each requiring a transistor and a capacitor—a total of 8 million individual devices.

Darnall's division is working on process technology and materials that will allow greater IC complexity by making transistors and interconnects even smaller. "One of the key elements in improving this technology is to make smaller interconnects between the transistors, which you can think of as tiny regions of different kinds of doped silicon within a larger silicon piece," he says. "The interconnect today consists of one-micrometer-wide aluminum lines which are spaced one micrometer apart. By comparison, a human hair is 80 micrometers in diameter.

"We're also talking about making computers on a single chip which will rival the minicomputers made just a few years ago," Darnall says. Other major Bell Labs inventions based on the transistor are listed in the side panel. □



This Charge Coupled Device wafer, three inches in diameter, contains 169 CCDs which are used in video cameras for sensitive imaging applications.



Happy Birthday to You, Too, Mel Harder

Forty years ago, Mel Harder's life and future career began simultaneously. If it weren't for the transistor, born on the same day as Harder, Dec. 23, 1947, the Indian Hill MTS would literally be out of a job. A member of the 5ESS™ Switch ISDN Feature Software Department, Harder is now working on software to provide ISDN Centrex services through the 5ESS switch, which uses digital, all solid state electronics technology made possible by the invention of the transistor.

Transistor Technology Blossoms into Microelectronics Milestones at AT&T

AT&T Bell Laboratories has been responsible for numerous key inventions, developments and milestones in microelectronics technology. Three Bell Labs scientists ushered in the microelectronics era in 1947 with their discovery of the transistor effect. [See related story, page 4.] The transistor, and specifically the MOSFET (metal-oxide semiconductor field-effect transistor) developed later at Bell Labs, laid the foundation for the tiny integrated circuits that are so prevalent today.

Other important devices invented at Bell Labs include:

- **Avalanche Diode (1964).** This device converts light to electrical current and is an essential component of lightwave communications systems.
- **Charged-Coupled Devices (1969).** A class of semiconductors with applications for imaging, digital memory and signal processing. Video cameras using CCD image sensors are much more sensitive than conventional cameras.
- **Semiconductor Lasers (1970).** Smaller than a grain of sand, these inexpensive light sources are a key component of many lightwave communications systems. Bell Labs created the first laser of this type that operates at room temperature.
- **Photonic Switching Chip (1986).** This device may become the primary building block of optical computers in the future. Its components are turned on and off by light beams, in much the same way that electronic transistors are turned on and off by electrical charges.
- **Neural Network Chips (1986).** Highly interconnected networks of many simple components on a chip, all of which function collectively to obtain quick answers. These experimental chips mimic the way some brain cells retrieve stored information and solve problems.

Bell Labs also invented many of the processes widely used today in integrated circuit fabrication. For example, researchers here developed methods of growing single crystals of semiconductor material, refining them to incredible purity to obtain desired electrical characteristics. Another development made it possible to control the precise placement and amount of desired impurities. And in 1974, Bell Labs scientists developed a system for electron-beam lithography that is today widely used to generate integrated circuit masks.

Advances in very-large-scale integrated circuitry permit the SLC® Series 5 carrier to occupy less space and improve performance.

In 1976, Bell Labs announced a technique, called molecular beam epitaxy (MBE), that can control precisely the thickness and composition of a crystal film. Because of its ability to grow one atomic layer at a time, many novel semiconductor structures and devices can be prepared by MBE.

Bell Labs has also developed some of the most sophisticated computer aids for designing circuits that exist anywhere, including an experimental computer program that designs computer chips automatically.

Beginning in the late 1970s, Bell Labs introduced a series of increasingly powerful microprocessors, culminating in 1981 with the introduction of the world's first 32-bit microprocessor.

Today, the company is looking to the future by seeking ways to improve IC performance even further. Bell Labs researchers have developed a radically new way of packaging VLSI chips that potentially could double or triple the speeds of integrated circuits, and reduce packaging costs as well. □