Oak Ridge National Laboratory helped shape the digital future

(As published in The Oak Ridger's Historically Speaking column on April 12, 2017)

When you drive your car, use your coffee pot, text on your smartphone, wear your Fitbit, look at your digital watch, take a photo with your camera, cook in your microwave, wash clothes in your washer, use your dryer, wash dishes in the dishwasher, or use any and all electronic devices that we use daily without giving a thought to where the technology came from to make these "necessary" things work so faithfully and seemingly without effort, we have the Oak Ridge National Laboratory to thank! Carolyn Krause provides a look back at the beginning and development of computer chips. Enjoy the experience.

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Computer chips are more than the brainy building blocks of computers. These "microcontroller" chips – tiny wafers of semiconducting material (normally silicon implanted with impurities, such as boron and phosphorus ions) that is used to make an integrated electronic circuit – are programmed for tasks in cell phones and coffee pots, in airplanes and autos.

They are found in security systems, children's toys, video games and other entertainment devices. Such microchips embedded in smartphones and tablets enable the devices to function as address books, calculators, cameras, Internet web browsers and more.

Some 99 percent of microchips are used outside supercomputers, desktop computers and laptops. Computer chips have revolutionized the world.

Oak Ridge National Laboratory is known mostly for his contributions to the development of nuclear and non-nuclear energy sources, as well as energy-related environmental and health sciences. But ORNL researchers, especially those involved in developing instruments that monitor and measure energy-related phenomena, have also contributed to the digital revolution.

ORNL researchers provided key information and technologies that sparked the growth and improved the economics of the U.S. semiconductor industry. In 1962 Ordean Oen and Mark Robinson, while conducting theoretical research on radiation damage in crystalline materials, ran computer simulations that revealed the ion channeling effect—the long-range motion of atoms parallel to long rows of atoms in the solid.

This work and energetic ion channeling experiments by Thomas Noggle, Bill Appleton, Charles Moak, Sheldon Datz, Herb Krause and others enabled understanding of channeling phenomena, helping industry produce ion-implanted semiconductor materials with the right properties.

Appleton later became director of the Spallation Neutron Source and hired Thom Mason, who eventually headed the SNS during its construction and is completing his tenth year as director of ORNL. Datz received the prestigious Enrico Fermi Award from the Department of Energy.

The "production of virtually all microelectronic devices involves several ion implantation steps," wrote James B. Roberto, then director of ORNL's Solid State Division, in a 1989 paper. His paper "Ion Implantation Technology in the National Laboratories: Four Decades of Technology Transfer," was published in the journal Nuclear Instruments and Methods in Physics Research B 40/41. Roberto is associate laboratory director for strategic partnerships at ORNL.

Ion implantation technology, he wrote, started with the calutrons at the Oak Ridge Y-12 Plant during the 1940s. Hundreds of these mass separators introduced uranium ions of different masses (U-238 and U-235) and captured them in separate collectors after they were deflected differently in a strong magnetic field. "The calutron ion source remains to this day among the most prolific universal ion sources," he wrote, noting that calutrons at ORNL have provided "much of the free world's supply of stable isotopes."

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Roberto wrote that the "feasibility of electrical junction formation in silicon by direct implantation of boron and phosphorus ions was demonstrated using the calutrons. Thousands of samples were implanted for industry during the early development of integrated circuits." His paper showed an example of an early transistor formed at ORNL by ion implantation technology.

By "doping" blocks of silicon with boron and phosphorus impurities, the material's properties are altered. One application is the "rectifying junction." Current flows in one direction but is blocked in the other. This property enables alternating-current signals to be converted to direct-current signals.

As an aside, ORNL researchers used a reactor to demonstrate another way to dope silicon.

According to the Vol. 36, No. 1, 2003 issue of the ORNL Review magazine, ORNL researchers led by John Cleland used the Bulk Shielding Reactor in the 1960s to demonstrate a neutron transmutation doping (NTD) method for uniformly distributing phosphorus ions in silicon. Nuclei of the isotope Si-30 in a silicon block absorb neutrons from the reactor core and morph into heavier phosphorus. NTD silicon is produced worldwide each year for use in high-end electronic components. But NTD is not as common as ion implantation for doping semiconducting material.

By combining accelerator-based ion implantation doping and laser annealing, Rosa Young, C.W. White, and Greg Clarke introduced boron ions into the near surface of a silicon crystal and incorporated them into electrically active sites, while removing all displacement damage in the silicon lattice. This work in the 1970s provided the foundation for the development of rapid thermal annealing, a process widely used in the semiconductor industry.

In the 1980s ORNL researchers worked with industry in ion implantation through the laboratory's user facility, the Surface Modification and Characterization Collaborative Research Center. In that decade the DOE labs were required by law to devote 0.5 percent of their research budgets to technology transfer. The Stevenson-Wydler Act and the Bayh-Dole Act made technology developed at the government laboratories much more accessible to industry than it had been previously.

ORNL researchers have helped the semiconducting industry in other ways. In 1998 Ken Tobin and associates built two award-winning software tools that helped companies rapidly identify manufacturing problems that cause semiconductor wafer defects, thus reducing defect generation, increasing product yield and cutting costs. These tools were licensed to Applied Materials, IBM, Motorola, Texas Instruments and 20 other companies.

ORNL's award-winning direct-to-digital holography process transferred to nLine rapidly finds small defects in deep-lying contacts and trenches in wafers. Tony Moore and associates invented a sensor-based system to control radiofrequency power that produces plasmas for etching wafer circuit patterns. Use of ORNL's system has saved the industry millions of dollars.

So, the next time you turn on your coffee pot and send email on your smartphone, remember that Oak Ridge National Laboratory played a role in bringing you the conveniences you often take for granted.

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Thanks Carolyn, for yet another excellent insight into the scientific advances from ORNL that we all take for granted each day.

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Bill Appleton works at the Solid State Division's accelerator facility during early experiments with ion implantation in 1975

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Jim Roberto, Associate Oak Ridge National Laboratory Director for Science and Technology Partnerships