Robert W Keyes

ROBERT W. KEYES

1921–2010

Elected in 1976

"For systematic development of a definitive theory of the fundamental limits of digital computer devices."

BY MARSHALL I. NATHAN

ROBERT W. KEYES, a condensed matter physicist and major contributor in the areas of the physics of computation and semiconductor physics, died on April 5, 2010, after an accidental fall.

Bob was born on December 2, 1921, in Chicago. He grew up there, attending Parker and Calumet high schools and graduating from the latter in 1939. He attended the University of Chicago and received his bachelor's degree in physics in 1942. His education was then interrupted during the remainder of World War II by a stint in the U.S. Navy, where he served as an electronics technician. After the war in 1946 he started work at Argonne National Laboratory. In 1950 he returned to the University of Chicago for graduate study. He got his Ph.D. in physics in 1953, under the direction of Andy Lawson. For his research he measured the electrical conductivity of liquid germanium and studied the electrical properties of black phosphorus under hydrostatic pressure.

After receiving his Ph.D., Bob joined the newly formed Westinghouse Research Laboratory in suburban Pittsburgh. There he built a high-pressure laboratory of the Bridgman type, working to 12 kilobars. He and other researchers used this facility to study the electrical properties of silicon and germanium group and III-V (from the Periodic Table)

semiconductors, for example, gallium arsenide. Some of these studies constituted the Ph.D. theses of two graduate students at the University of Pittsburgh. Bob expanded these studies to include uniaxial stress experiments. His work and that of others elucidated the energy band structure of germanium and silicon. He showed that, because of the multivalley nature of the conduction band structure in silicon and germanium, the free energy can be lowered by strain that reduces the electron energy due to transfer among the valleys. This causes a reduction in some of the elastic constants in heavily doped n-type silicon and germanium. He experimentally verified the existence and magnitude of the predicted effect several years later.

While at Westinghouse, Bob worked in several other areas of semiconductors, including thermal conductivity, thermoelectric power, and the effects of strain. He and his colleagues observed a very large magnetoresistence in n-type (electrons carry the current as opposed to holes) indium antimonide, which amounted to a metal-insulator transition. He spent the fall quarter of 1957 at the University of Chicago as a visiting scientist on leave from the Westinghouse Research Laboratory. Bob spent his time there studying interpretations of measurements of atomic diffusion in solids at high pressure. His work showed that simple models by and large explain the pressure effects.

In 1960, Bob resigned from Westinghouse to join the new and rapidly expanding IBM Research Laboratory in Yorktown Heights, Westchester County, New York. He spent the remainder of his career there, first as a research manager, then as a research staff member, and finally as a research staff member emeritus. Bob actively engaged in research right up to the time of his death. His last paper was published posthumously.

His first assignment at IBM was to manage a small group involved at various times in work on novel devices, including transistor engineering, the physical basis of the Gunn effect, solar cells, process instrumentation and gas panel displays, and ion-implanted superconducting devices. The group included

Bill Dumke, Al Michel, Frank Stern, Edward J. Walker, me, and others. Under Bob's leadership, some members of the group started work aimed at finding a semiconductor diode laser. Bob sought and got partial support for this work from the U.S. Army Signal Corps in 1962. In the proposal that he wrote to get this support, he made the bold promise to construct the laser before the end of the year. In retrospect it is difficult to realize how audacious that promise was in view of the fact that the semiconductor laser has been around for almost 50 years. His group and those at other laboratories fulfilled that promise and successfully made semiconductor lasers toward the end of 1962.

It was shortly after this time that Bob met his wife to be, Sophie, while hiking in the nearby hills. They were married in 1966. Their children, Andrew and Claire, were born in 1969 and 1971, respectively.

Bob's work at IBM, especially his interactions with his group, led him to become more interested in semiconductor devices and the applications of semiconductor physics to computers. Semiconductor devices were being made smaller and smaller, with increasing numbers of them on a chip. The questions were: Where is this leading? How small a device can work? Why is so much energy being used to execute logic? What can we do about the heat that more and more devices are creating in a small space? He discussed these issues in the Institute of Electrical and Electronics Engineers (IEEE) *Spectrum* in 1969 in a paper that attracted widespread attention and brought him several invitations to speak at conferences and institutions throughout the United States. He had become one of the leading practitioners of the subdiscipline known as "Limits." Other questions that he became interested in were: What voltage to use? Does fundamental physics require energy dissipation to switch? From consideration of these questions he concluded that silicon transistors were the best of the contending logic devices.

Eventually, Bob summarized his views of limits in the *Proceedings of the IEEE* in 1975. This paper was recognized in 1976 with the IEEE's W. R. G. Baker Prize for an outstanding

paper in an IEEE publication that year. Widespread interest in limits continued to garner invitations for Bob to write or speak on the subject in other venues for many years.

Bob Keyes was a very productive scientist. During his lifetime he published over 200 papers, for almost all of which he was the sole author. He wrote one book, *The Physics of VLSI Systems* (Addison-Wesley, 1987), and he made contributions to several others.

Bob was well thought of for generously reaching out and helping his fellow scientists, including several just starting out, whenever he could. His colleagues and many friends will remember him for his quick wit and wry sense of humor. He was an avid hiker and a bird watcher. He is survived by his wife Sophie and their children Andrew and Claire Ames.