Robert Rapp Receives 2003 Educator Award

Robert Rapp, professor emeritus of The Ohio State University has received the 2003 Educator Award of The Minerals, Metals & Materials Society. The award recognizes an individual who has made outstanding contributions to education in metallurgical and/or materials science and engineering. He has received many other awards as well as Guggenheim and Fulbright grants to study and teach internationally.

Prof. Rapp is a member of the National Academy of Engineering, and has been named "Chevalier dans l'Ordre des Palmes Academiques." He was awarded Docteur Honoris Causa by the Institut Polytechnique de Toulouse. In 2000, he presented the TMS Institute of Metals Lecture and received the TMS R. F. Mehl Medal. In 2000, Rapp received the ASM Gold Medal. He is a Fellow of TMS, ASM, NACE, British Institute of Corrosion, and Societé Française de Métallurgie et de Matériaux.

Dr. Rapp joined The Electrochemical Society in 1964 and is now an emeritus member. He was named a Fellow in 1993 and received the Society's Henry B. Linford Award in 1998. He received the High Temperature Materials Division Outstanding Achievement Award in 1990. From 1986 to 1988, he was chairman of the ECS Corrosion Division, and he also served on the editorial board for the Society's *Journal*. ■

In Memoriam

Gordon K. Teal 1908-2003

Gordon K. Teal passed away on Jan. 7, 2003 in Dallas at the age of 95 and is survived by his wife of 72 years, Lyda Louise Teal. A memorial service was held subsequent to burial at Hillcrest Memorial Park in Dallas. Dr. Teal had been a member of the First Baptist Church of Dallas and was a member of the Park Cities Baptist Church of Dallas since 1953.

Dr. Teal was truly a seminal figure in the semiconductor electronics industry. After receiving a bachelor's degree in physics and chemistry from Baylor University and his doctorate in physical chemistry from Brown University, he joined the Bell Telephone Laboratories (BTL) in 1930 and worked there in semiconductor research and development until 1952. After the discovery of transistor action in polycrystalline germanium (and subsequently polycrystalline silicon) by John Bardeen and Walter Brattain on December 16, 1947, polycrystalline materials continued to be used for transistor research and development in the late 1940s and early 1950s. The utilization of single crystals of germanium and silicon for the transistor was a very controversial matter at that time, even though the importance of high-purity material to achieve a high rectification current-voltage characteristic was understood. Some researchers were opposed to work on germanium single crystals because they thought that scientific research on transistors could be obtained from small specimens of polycrystalline masses of material. They later realized the shortcomings of their previous assessment of the usefulness and necessity of single crystals.

Teal, however, was a proponent of the importance of single-crystal materials for the electronics era. He recognized that the bipolar junction transistor characteristics in single-crystal germanium and silicon would be substantially better and more reproducible than those of devices built in polycrystalline material. His tenaciousness at BTL in pursuing the growth of single crystals of germanium and silicon in the 1949-1951 timeframe was of critical importance in the technology that led to the microelectronics revolution. The limited capability for the fabrication of single crystal materials in this time period made the developmental research more difficult, requiring Teal and his colleagues to pursue their research in the evenings.

Teal believed the fundamental property of single-crystal semiconductors, which would result in their superior performance, was the easily controllable and spatially variable concentration, type, and mobility of free carriers. Teal reasoned that polycrystalline germanium, with its variations in resistivity and its randomly occurring grain boundaries, twins and crystal defects that acted as uncontrolled resistances, electron or hole emitters and traps would affect transistor operation in uncontrolled ways. Additionally, it seemed to him that use of this material to produce many identical, complex units with close performance tolerances, would be inconsistent with high yields and, therefore, also with low costs. Clearly, Teal was anticipating the industrial importance of his endeavor. When developing complex transistor devices, Teal deemed it essential to have a high-perfection, high-purity controlled composition semiconductor in order to achieve a separation of the various available electron and hole conduction processes. Only by using the single-crystal-material did he believe that the analysis and understanding of device operation could be accomplished and the necessary improvements made. It should be noted, furthermore, that Moore's law (which initially described the doubling of transistors per year and now taken as two years), along with increasing chip size and increasing performance, would not have evolved without the availability of single-crystal silicon materials (currently 300 mm diameter for leading-edge fabs) to produce millions of identical integrated circuits (ICs).

Teal basically proposed to produce a conducting medium in which a high degree of crystal perfection, uniformity of structure and chemical purity was attained. He further proposed to build into this highly perfect medium the required resistivities and electrical boundaries that would produce a large variety of device possibilities as a result of the control of the chemical composition (*i.e.*, donor and acceptor concentration) along the direction of single-crystal growth.

A joint program, initiated in September 1948 between Teal and John Little, was successful in growing several germanium rods with some large single crystals in them by pulling from a container of molten Ge (often referred to as the melt). The technique employed a single-crystal seed (oriented in a <111> or <100> direction) previously cut from a large polycrystalline piece, seed rotation and precise temperature control of the melt-solid interface from which the crystal was pulled. Soon afterwards, Teal and Ed Buehler pulled single crystal silicon crystals. This research was vital in obtaining single crystals in which the essential semiconducting properties were highly controlled. The method is variously referred to as pulling, the Teal-Little process or, somewhat inappropriately, as the Czochralski (CZ) process. Colloquially, the process is simply called the CZ technique, after Jan Czochralski, who in 1918 drew thin single-crystal metal filaments from a melt. Czochralski did not use a single-crystal seed, however, and apparently did not recognize the significance of directly controlling the melt temperature to control the crystal diameter.

In retrospect, it should be noted that Teal's emphasis on the preparation and characterization of single-crystal material additionally facilitated the experimental verification of a number of quantum theoretical concepts developed for electrons and holes in crystalline semiconductors such as effective mass, drift and conductivity mobility, carrier lifetime, tunneling, and subsequent clarification of a number of phenomena in p-n junctions. The single-crystal material indeed exhibited significantly improved characteristics compared with polycrystalline samples. By the early 1950s, all investigators of the semiconducting properties and p-n junction studies of germanium and silicon preferred to use pulled single crystals. Teal filed for a p-n junction patent in single-crystal germanium in 1950. The first bipolar junction transistor (n-p-n) was achieved in single crystal germanium (grown-junction technique) by William Shockley, Morgan Sparks, and Teal in mid-1951 (referred to as the microwatt n-p-n junction transistor), about three and a half years after the initial discovery of transistor action by Bardeen and Brattain. The junction transistor exhibited larger current handling capability and less noise compared with the point-contact transistor.

As a native Texan, Dr. Teal welcomed the opportunity presented by Texas Instruments Inc. in 1952 to organize and develop its Central Research Laboratories. During the May 1954 meeting of the Institute of Radio Engineers in Dayton, Ohio, Teal announced a commercially feasible grown-junction n-p-n silicon transistor. His presentation was the last of the day, after all the previous speakers had noted that a silicon junction transistor would be extremely difficult to fabricate and germanium would remain the dominant transistor material. A literal stampede by the attendees ensued to obtain a copy of his presentation. Willis Adcock, Morton Jones, and colleagues subsequently presented detailed electrical characteristics of these silicon pulled (grown junction) transistors, which exhibited a higher operating temperature, higher output current, and less junction leakage current compared with germanium. Texas Instruments thereby catapulted to the forefront of the fledging electronics industry.

Dr. Teal was an assistant vice-president of Texas Instruments and director of research from 1954 to 1961. He thereafter held a variety of management positions at Texas Instruments both in America and Europe until taking a leave of absence from 1965-1967, to become the first director of the Institute of Materials Research of the National Bureau of Standards (NBS, and now referred to as the National Institute of Standards and Technology or NIST) in Washington, DC. He returned to Texas Instruments in 1967 and served as vice-president and chief scientist for corporate development until he retired in 1972. He continued as a consultant until 1978.

In the world of new semiconductor companies, dominated by brash young engineers, Dr. Teal stood out as a gentleman of the old school. His management style was subdued but nevertheless demanding. In addition to the requisite research and development activities at Texas Instruments, Dr. Teal encouraged the young engineers to participate in external professional activities, both presenting and publishing scientific papers. He also urged the continuing technical development of the research and development staff and one of the contributors (W. R. R.) fondly remembers Dr. Teal coming into his office and placing a photocopy of A. H. Wilson's 1939 *Semi-Conductors & Metals* on his desk, saying, "Everyone should have a copy of this classic." Indeed, this photocopy has continued its photocopying journey to several of the contributors below.

Dr. Teal was the recipient of many scientific honors. These included the 1966 Inventor of the Year award by the Patent Trademark and CopyRight Institute of George Washington University, the 1968 IEEE Medal of Honor, the 1970 American Chemical Society Award for Creative Invention, the National Medal of Science, the IEEE's Third Millennium Award, and selection to membership in the National Academy of Engineering. He was also awarded an honorary LLD degree by Baylor University and received an honorary DSc degree from Brown University. He had been a member of ECS since 1957.

Finally, several contributors to this memoriam (W. R. R., K. E. B., and H. R. H.) had the pleasure of working with Dr. Teal on his last major publication in 1985 entitled "Semiconductor Materials," published in the treatise *Materials and Processes* (3rd edition, edited by J. F. Young and R. S. Shane, Marcel Dekker, Inc.). Dr. Teal's immense technical scope and yet down-to-earth cognizance of the role he played in the onset of the microelectronics revolution, let alone his humor in developing and modifying the manuscript, is a memory that we will cherish and carry forward with us. Dr. Teal's achievement in single-crystal semiconductor technology, its application to the junction transistor, and his early appreciation of the implications of a reproducible material (and the benefit of silicon compared to germanium) to ensure the fabrication of millions of identical transistors and, subsequently, ICs is an achievement that places him in the pantheon of superb 20th century scientists. He led a full life and is sorely missed by his colleagues throughout the world. ■

This notice was contributed by Willis Adcock (retired Texas Instruments, Inc. and the University of Texas), Kenneth E. Bean (retired Texas Instruments, Inc.), Howard R. Huff (International SEMATECH and formerly Texas Instruments, Inc.), Walter R. Runyan (retired Texas Instruments, Inc.), and Frederick J. Strieter (Texas A&M, retired Honeywell, Inc. and formerly Texas Instruments, Inc.). (Several contributed facts, from John Fish and Don Shaw, both retirees of Texas Instruments, Inc., are acknowledged.)

In Memoriam

James R. Black (1921-2002), member since 1959, Electronics.

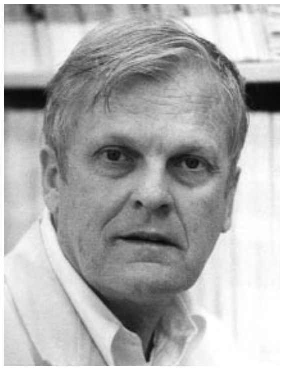
Sergey Gamburzev (1942-2002), member since 1995, Physical Electrochemistry.

Samuel Korman (1910-2003), member since 1953, Electronics.

Harry B. Mark (1934-2003), member since 1976, Organic & Biological Electrochemistry.

Thomas P. May (1908-2002), member since 1943, Corrosion.

Carl E. Swanson (1918-2003), member since 1946, Luminescence and Display Materials.



In Memoriam

James O. McCaldin 1922-2001

James Oeland ("Jim") McCaldin died on November 23, 2001 at the age of 79, after a reappearance of a cancer he had overcome successfully by surgery many years earlier. He was born on April 3, 1922 to an East Coast family, the elder of two sons. He demonstrated an early aptitude for mathematics, obtained a BA degree in that subject in 1944 from the University of Texas, Austin, and a PhD degree in Engineering from the California Institute of Technology ten years later. After two years in Detroit as an engineer at General Motors working on physical metallurgy, he moved to the Hughes Research Laboratories in Southern California in 1956, attracted there by the balmy weather and lured by the exciting developments he saw in the burgeoning semiconductor industry. The move was viewed with reservation by his family, which had deep roots in the eastern establishment; but it was, by his own assessment, the most inspired decision he made in his career. This decision was an expression of his ability to recognize trends, detect connections, and foresee developments with an uncommon astuteness that characterized all his professional and personal pursuits. The move also demonstrated his readiness to act in accordance with his convictions regardless of prevailing opinions. He left Hughes five years later to join the North American Science Center as the leader of the semiconductor activity there, a position he had last held at Hughes Aircraft.

Guided by his insights, McCaldin had the aptitude to single out issues whose solution promised major technological advances. Once defined, he would ponder the problem, reflect, conceive solutions, and then proceed to test their feasibility with simple and telling experiments to which he would contribute with his own hands. At Hughes Aircraft, he showed that by moving the exposed pn junction into the silicon (a process now known as planar), great improvements in the junction characteristics could be achieved. Similar work was going on independently at Fairchild Semiconductor where the idea was developed vigorously, while at Hughes Aircraft its potential went unrecognized. Ion implantation is another technology in which McCaldin was a pioneer. The idea to dope a semiconductor by implantation was originally Shockley's. McCaldin was among the first to apply it by doping silicon with alkali atoms. He did not participate in the ensuing scurry to develop this new technology. He preferred the challenges of untrodden paths to the buzzing activity of trendy R&D.

In 1968 he made his last move and joined the California Institute of Technology (Caltech) as associate professor of materials science and electrical engineering. There he conceived the idea—again independently—of solid-phase epitaxy of silicon and was one of the first to demonstrate it. Together with his Caltech colleague Carver Mead, he founded a company (McCaldin Electronics) to develop light-emitting ZnS diodes, an idea that was well ahead of its time. His attention then turned to compound semiconductors.

His first bout with cancer prompted him to take an early retirement in 1983, after which a long-lasting collaboration ensued with the group of Tom McGill, another Caltech colleague. He became a leading expert in band offsets between semiconductors and in Schottky barriers on semiconductors. He developed a general understanding of how semiconductor electrodes can provide carrier injection, *e.g.*, in polymer light emitters. Topics he dealt with in his last years included, among others, fuel cells, diamond, and field-induced doping.

Jim McCaldin was a private person with multiple talents and interests of which he chose to share all of them with no one. He was a bachelor. He was an astute and very successful investor. He was discharged as a naval lieutenant after service on the cruiser Chauncy in the Pacific Theater. This war experience left profound but rarely expressed marks on his personal beliefs. He had a deep affinity to classical music and an earnest interest in religions, noticeably Buddhism whose emphasis on tolerance resonated with him. He generously supported many charities, foundations, and societies, some over many years and quite liberally. By contrast, his life style was one of refined simplicity. He disliked publicity and shunned the limelight. His self-esteem didn't depend on public recognition, which is something he never pursued. Nor did he miss the recognition he could have expected from his peers for the major contributions he made. He asked that no commemorative service be held at this death. His ashes are buried on his family's burial plot of St. John's Church in Cold Spring Harbor, New York.

McCaldin was editor of the journal *Progress in Solid State Chemistry* from 1969 to 1976. He was a member of the Institute of Electrical and Electronic Engineers; a former chairman of the Southern California Section of the American Institute of Mining, Metallurgical, and Petroleum Engineers; and a Senior Member of the American Physical Society. He joined ECS in 1957 and was a former secretary of the Southern California and Nevada Section. He is survived by his brother, Dr. Roy O. McCaldin of Tucson. ■

This notice was written by Marc-A. Nicolet, Emeritus Professor of Electrical Engineering and Applied Physics at Caltech, a professional colleague of Jim McCaldin, as well as his friend.