

## Subhash Singhal Elected to National Academy of Engineering

SUBHASH C. SINGHAL, an ECS member since 1976, was one of 74 members recently elected to the U.S. National Academy of Engineering (NAE). Dr. Singhal was cited by the NAE for "the development and promotion of solid oxide fuel cells for clean and efficient power generation."

Named an ECS Fellow in 1996, Dr. Singhal has served on many ECS committees including Publication, Ways and Means, Honors and Awards, and Technical Affairs. He was the chair of the ECS High Temperature Materials Division and a member of the ECS Board of Directors (1992-94). Currently, he serves as chair of the Long Range Planning Committee. Singhal received the Outstanding Achievement Award of the ECS High Temperature Materials Division in 1994; and has organized and chaired the highly successful biennial international symposium on Solid Oxide Fuel Cells (SOFC), since its inception in 1989.

Dr. Singhal is a Battelle Fellow and director of fuel cells research at the Department of Energy's Pacific Northwest National Laboratory (PNNL). He is noted for developing high-temperature solid oxide fuel cells, having brought this technology from experimental units that gener-

ated only a few watts to fully integrated, 200 kilowatt power-generation systems.

Singhal leads the technical, managerial, and commercialization efforts for PNNL's extensive fuel cell program, and is recognized internationally as a leader in solid oxide fuel cell technology. He joined the lab's Energy Science and Technology Directorate in 2000 after 29 years with Siemens Westinghouse Power Corp. He has conducted and managed major research, development, and demonstration programs in advanced materials and energy conversion systems, particularly high temperature fuel cells.

Dr. Singhal is the author of more than 70 scientific publications, has edited 12 books, received 13 patents, and given more than 205 invited presentations worldwide. He is a fellow of the American Ceramic Society, of ASM International (formerly known as the American Society for Metals); and he is a member of the Mineral, Metals & Materials Society and the American Association for the Advancement of Science. He serves on numerous national and international advisory committees. Singhal holds a doctorate in materials science and engineering from the University



of Pennsylvania and a master's in business administration from the University of Pittsburgh.

NAE ([www.nae.edu](http://www.nae.edu)) membership is among the highest professional distinctions accorded an engineer. Academy membership honors those who have made outstanding contributions to "engineering research, practice, or education, including, where appropriate, significant contributions to the engineering literature" and to the "pioneering of new and developing fields of technology, making major advancements in traditional fields of engineering, or developing/implementing innovative approaches to engineering education." ■



*In Memoriam*

## Panos Andricacos 1951-2004

The electrodeposition community lost a prominent industrial innovator and an esteemed colleague with the untimely passing of PANAYOTIS (PANOS) ANDRICAÇOS on November 21, 2004. Best known for his pioneering development of the

Damascene copper plating process that transformed the microelectronics industry, Panos made a wide variety of contributions in the field of electrochemical microfabrication over the course of his career and exerted profound influence, directly and indirectly, on many individuals.

Panos was born in 1951 in Athens, Greece. He came to the U.S. in 1970 to study chemical engineering at Columbia University in New York, obtaining the B Eng Sci degree in 1974. He stayed at Columbia to study electrochemical engineering with Professor Huk Yuk Cheh, receiving masters and doctoral degrees in 1977 and 1980. His graduate research topics included pulsed plating and the application of linear sweep voltammetry to electrodeposition. (Later in his career, Panos would return to Columbia as an adjunct associate professor to teach an advanced graduate course in electrochemical engineering.) Panos did postdoctoral research with Phillip Ross at the Lawrence Berkeley Laboratory and University of California at Berkeley, where he published studies of diffusion-controlled cyclic voltammetry, oxygen-reduction kinetics, and underpotential

deposition of Cu on Pt single crystals prepared in a UHV system.

In 1984 Panos joined IBM's T. J. Watson Research Center in Yorktown Heights, New York, as a research staff member in Lubomyr Romankiw's electrochemical technology department. At that time, the Permalloy plating process for magnetic-recording heads needed improvement to meet escalating performance requirements. Panos's early contributions were directed at process monitoring, control, obtaining improved magnetic properties, and quantitative understanding of magnetic-alloy electrodeposition. There was a need for better measurement and understanding of the dependence of NiFe alloy composition on bath composition. Although the phenomenon of "anomalous codeposition" of Ni and Fe had long been recognized,<sup>1</sup> Panos's stripping-voltammetry study of the system<sup>2</sup> revealed the behavior in stark terms with new industrial relevance, and touched off a flurry of ECS talks and papers from academia and industry, all attempting to match Panos's data with mathematical models. The lively exchange ultimately generated new

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## In Memoriam

### Per Bro 1924-2004

PER BRO passed away on August 23, 2004 at his home in Santa Fe, NM, from cancer of the bone marrow.

Per was born on June 30, 1924, to a seafaring family at Horten, an important Norwegian navy base. Per grew up in Norway and, during World War II, he was a member of a resistance group against the Nazis, escaped to Sweden, and later joined the Norwegian Air Force, going to England and Canada. He returned to Norway after the war.

Per came to the United States on a scholarship to Case Western Reserve University in 1948 and met his wife Barbara. He finished his BS in chemistry at Case Western in 1949. He then went to Yale University to do his MS in chemical engineering in 1952 and his PhD in physical chemistry in 1956. He did his postdoctoral work at Princeton University in physics (1956-1957), where he discovered a new short-lived tantalum isotope.

He worked for Socony Mobil Oil Company (1957-1958) as a research scientist investigating physical factors associated with heterogeneous catalysis. After that he worked for AVCO Corporation (1958-1962) in the R&D division and advanced from Senior Scientist to Assistant Section Chief. His work involved experimental studies of heterogeneous reactions at extremely high temperatures in plasma generators and studies of solid-state chemistry and physics related to the development of new high temperature thermoelectric materials.

Per joined the corporate Laboratory for Physical Science (LPS) of P. R. Mallory & Co. Inc., in 1962 as a Group Manager of Batteries. Because the Mallory Company had businesses in areas in addition to batteries, LPS had other groups such as Capacitors, Timers, Metallurgy, and Integrated Circuits. This writer (A. N. Dey) was hired by Per in 1966 to work on high energy density lithium batteries. Mallory's commercial alkaline battery brand name was Duracell. In the 1970s, the Mallory company was acquired by Dart Inc., which then sold off all the other businesses that Mallory had and kept only the battery business; it changed the name of the company to Duracell International Inc. Per's contributions as technical director of the battery R&D group became extremely important to Duracell's enormous success in the battery business. Per had the perfect combination of strong scientific background and interest and managerial skills that



From left to right: A. N. Dey, H. Frank Gibbard, and Per Bro; 7th IMLB, 1994

he used to make his battery R&D division world class. He was a great mentor.

He retired from Duracell in 1980 and established the Southwest Electrochemical Company to provide consulting services in the area of battery technology to industry and other organizations, and he provided consulting services to both domestic and foreign companies. Per Bro is an internationally recognized authority on battery technology and was active in planning and organizing both domestic and international symposia on battery technology. He received the International Meeting on Lithium Batteries Award in 1994 in Boston.

Per Bro authored and co-authored more than 60 papers and lectures and was the co-inventor of more than ten patents on battery technology. He co-authored two books with Sam Levy: *Quality and Reliability Methods for Primary Batteries* (sponsored by ECS) and *Battery Hazards and Accident Prevention*. He contributed chapters on battery technology and environmental aspects to various monographs, also in cooperation with Sam Levy.

Per Bro was a member of The Electrochemical Society (ECS), the American Institute of Chemical Engineers, the American Physical Society, and the American Mathematical Society.

Per had an enduring interest in the science of creating life through chemical reactions, a subject that he pursued on his own for all those years that this writer knew him. His wife Barbara said that he was almost halfway through writing a book on that subject before he passed away.

Per was an Appalachian Club member and led mountain hiking and taught rock climbing, and he passed on that enthusiasm to his children. In Andover, MA, where the family lived for 24 years, they did lots of outdoor activities. About once a year he went back to Norway to keep the family connections strong.

In Barbara's words, "Per had a good life, as I see it, what with his enthusiastic studying and writing and his happy family life. He is much missed by all."

Per is survived by his wife Barbara in Santa Fe, a son Per Bjarne in Chile, a daughter Dandy in Massachusetts, and another son Anders in California, seven grandchildren, and a sister in Norway. ■

*This article was prepared by A. N. Dey (aurobindo@interpac.net) of ARAD Enterprises, with help from Barbara Bro and Anders Bro.*

## In Memoriam

**Daniel F. Downey (1948-2004)**, member since 2001, Electronics.

**James J. Egan (1927-2004)**, member since 1970, Physical Electrochemistry.

**John P. Ryaby (1934-2005)**, member since 1982, Organic and Biological Electrochemistry.

**Tadao Hayashi (1923-2005)**, member since 1952, Electrodeposition.

## Panos Andricacos

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understanding of alloy plating. This was one of several memorable times when Panos's clear and elegant work focused the attention of the electrochemical research community on a compelling process, all the more interesting for its industrial significance, and wound up bringing new richness and vitality to the field. In 1993, ECS honored Panos with the Research Award of the Electrodeposition Division.

In Panos's twenty-year career at IBM he worked on many applications of electrodeposition for electronics, including magnetic recording heads, thin-film packaging, flip-chip solder joints, DRAM electrodes, stack capacitors, RF MEMS structures, and, most notably, plated-copper interconnect structures for integrated circuits. His numerous patents and publications cover such diverse aspects of electrodeposition as bath analysis, process control, plating-cell design, current-distribution modeling, alloy bath formulation, micromagnetics, process optimization, and alloy-plating processes that employ UPD effects. Panos was both an individual contributor and a manager. He led a group of electrochemical researchers at IBM whose members over the years included Vlasta Brusic, Jei-Wei Chang, Emanuel Cooper, Lili Deligianni, John Dukovic, Jerry Frankel, Jean Horkans, Keith Kwietniak, Shahram Mehdizadeh, Milan Paunovic, Alex Schrott, Philippe Vereecken, Keith Wong, and others.

Panos's most significant achievement was the invention of the plating process for making the copper wiring structures on silicon microchips<sup>3</sup>. In the early 1990s there was a growing interest in replacing aluminum wiring with copper, but no viable process for using copper. Few considered plating to be a workable possibility, and those who did were mainly concentrating on through-mask plating. Panos believed that a Damascene plating process could be made to work and he persistently conducted feasibility experiments in his laboratory. He eventually discovered conditions under which submicrometer cavities would fill superconformally (and he coined the term "superfilling" to describe the effect). This development, along with numerous associated inventions and engineering achievements on the part of many contributors, led to the emergence of the first copper chips in 1998. Today, virtually all high-performance logic chips manufactured worldwide contain copper interconnects made with Panos's process. IBM recognized Panos's contributions with an Outstanding Technical Achievement Award (1998), a Corporate Award (1999), and a Research Division Award (2000).

Panos was active in ECS throughout his career, publishing in the *Journal*, chairing the Metropolitan New York Section, and organizing symposia. Characteristically, Panos rallied ECS to the cause of hosting the scientific forum

on the new copper-chip-metallization technology, co-organizing the symposium series, "Electrochemical Processing in ULSI Fabrication." Scores of papers on the subject of superfilling alone have been presented at these symposia. Again, Panos was stirring up new excitement in the electrodeposition field. Not detracting in any way from these scientific exchanges were the restaurants Panos selected for the after-hours discussions!

Panos was an enthusiastic exponent of electrochemical microfabrication. He took pride in seeing electrochemical processes emerge and take hold in the electronics industry. One of his last activities was to serve as guest editor for an issue of the *IBM Journal of Research and Development*<sup>4</sup> with a wide variety of contributions in electrochemical microfabrication.

Panos will be greatly missed by his mentors, co-workers and colleagues. Beyond having great intellectual depth and being full of insight and inventive ideas, he was a good friend with a unique sense of humor and a wise, inspiring presence. Panos's influence lives on, a little bit of it in every copper-plated microchip, and forever in the memories of his family, colleagues, and friends. ■

<sup>1</sup> H. Dhams and I. M. Croll, *J. Electrochem Soc.*, **112**, 771 (1965).

<sup>2</sup> P. C. Andricacos *et al.*, *J. Electrochem Soc.*, **135**, 1172 (1998).

<sup>3</sup> P. C. Andricacos *et al.*, U.S. Pat. 6,709,562 (2004).

<sup>4</sup> *IBM J. Res. & Dev.*, **49**, 1 (2005).

This notice was prepared by John Dukovic (john\_dukovic@amat.com).

## Uhlig Summer Fellowship

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*Journal of The Electrochemical Society*, and edited the very successful monograph, *Uhlig's Corrosion Handbook*. Dr. Uhlig received numerous Society awards and honors. He received the Palladium Medal Award in 1961; was made an Honorary Member in 1973; received the Outstanding Achievement Award of the Corrosion Division in 1985, and received the Society's Edward Goodrich Acheson Award in 1988.

Dr. Uhlig, a professor at the Massachusetts Institute of Technology, was most known as an educator. Over the years, Professor Uhlig taught, inspired, and graduated more than 100 MS students, over 20 PhD students, and an equal number of post-graduate fellows. He and his students published 175 papers.

While ECS will manage the campaign to support the fellowship, the campaign is being spearheaded by a group of former students, associates, and his wife, Greta Uhlig. This group includes Aziz Asphahani, Ronald Latanision, Florian Mansfeld, and R. Winston Revie. The campaign will run through July 2005, and the first fellowship will be awarded in the spring of 2006.

If you have any questions about this important new fellowship, or would like to donate to the Uhlig fellowship campaign, please contact Troy Miller at troy.miller@electrochem.org. ■

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