Deposition Processes

Russell Messier, Guest Editor

My introduction in the November MRS BULLETIN to this two-part series on deposition processes discussed the extensive use of thin films in science and technology. That it takes two issues and nine articles to cover this topic—and by no means exhaustively—is testimony to the manifold ways thin films are prepared.

If all deposition processes resulted in the same product, then such extensive coverage would be redundant and unnecessary. Thin films, however, cover a virtual infinity of free energy states—and related crystal structures, microstructures, defects, defect densities, impurities, compositions, composition modulations, etc.—that are sensitive to the particular deposition process and its conditions. It is this richness of choice that makes thin film science and technology both exciting and, at times, frustrating.

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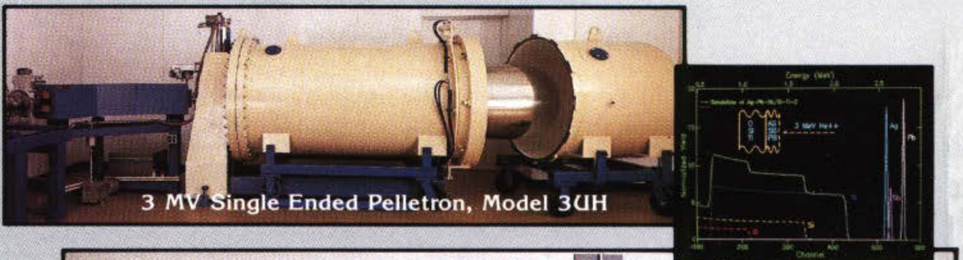
Along with the freedom to extensively vary thin film characteristics, resulting properties and applications comes the difficulty in understanding preparation-characterization-property relations in enough detail to control and reproduce deposition processes.

The November articles covered molecular dynamics computer modeling of nucleation and growth processes, molecular beam epitaxy, organometallic vapor phase epitaxy, and chemical vapor deposition. This month's articles continue the sequence of ways to deposit films, the general direction being toward lower substrate temperatures. Plasmas, which offer both increased flexibility and complexity, are primarily considered. The last article covers thermal plasmas, not to control the vapor deposition but to melt powders which result in a multiple splat-quenched array of particles that form coatings important to industry.

- **R.F. Bunshah and C.V. Deshpandey** (University of California at Los Angeles) consider the broad topic of evaporation processes. They show that, although evaporation is one of the earliest and simplest deposition processes, many variations for thin film preparation are in use. After covering the theory, mechanisms, and approaches to evaporation, they detail the two more technologically important processes involving electron-beam-heated sources and arc evaporation sources. They discuss the wide range of elemental, alloy, and compound materials that can be prepared and show how reactive and activated reactive evaporation (ARE) processes are often used to obtain this wide range of materials. The ARE process, which was pioneered by Bunshah, uses thermal evaporation and plasmas to generate and control gas phase species and the energy of the species during growth. The article is an excellent lead-in to the other plasma-based deposition processes considered in this issue.
- **S.M. Rossnagel and J.J. Cuomo** (IBM T.J. Watson Research Center) review the importance of independent control of ion bombardment by the use of sources such as the extensively used Kaufman-ion source. Using examples from the literature they show how controlled energy and flux of the ion bombardment during deposition can modify film grain size, nucleation density, defects, crystal structure lattice spacing, preferred crystallite orientation, density, and stress. In addition to physical processes at growing film surfaces, ion beams can control surface chemistry through the use of reactive species. Although just several years ago we thought such ion beam sources to be mainly of use in small-scale research deposition systems, the authors indicate that their use in large-scale deposition processing will become more prominent.
- **W.D. Westwood** (Bell Northern Research) points out the long history of sputter deposition processes and notes that the introduction of magnetron sputtering systems in the 1970s was a key turning point in their extensive use in industrial processes. Plasma-created momentum transfer processes are an integral part of both their vaporization and deposition mechanisms. Although the control of ion bombardment in magnetron sputtering is not nearly as well understood and independently controllable as in ion beam processes, the ability to economically scale the process to large areas has made it a mainstay in thin film technology. Magnetron sputtering sources come in a variety of configurations but are based upon a common set of physical principles, which Westwood explains. He goes on to describe ion bombardment and gas phase scattering processes and their relation to alloy compositional control, the control of reactive gas species in the sputtering of metal targets at high rates, and the resulting film properties in terms of the well-known Thornton structure zone model.
- **P.K. Bachmann, G. Gärtner, and H. Lydtin** (Philips Research Laboratories/Aachen) outline the use of plasmas in chemical vapor deposition (CVD) by describing their utility in preparing materials ranging from insulators and semiconductors to metals and from crystalline to amorphous. In particular, they detail various deposition approaches for amorphous hydrogenated silicon for solar cells and other active semiconductor devices, tungsten/thorium free-standing thick films for high power cathodes in electron tubes, ultrapure fused silica for optical fibers, and both diamond and diamondlike carbon for a host of present and potential applications. Using nonequilibrium plasma chemistry to reduce processing temperatures, retain metastable phases, obtain high purity products, and attain high deposition rates makes plasma-assisted CVD an important deposition process approach.

- **H. Herman** (State University of New York-Stony Brook) discusses the concept, history, and utility of thermal plasmas in plasma spray deposition processes, which are used extensively for thick protective coatings and as free-standing forms. Unlike the vapor deposition processes covered in previous articles, the depositing "particles" in thermal plasmas are molten droplets typically 10–30 μm in size and containing approximately 10^5 atoms. Such particles impinge upon a low temperature substrate ($\sim$150°C), are rapidly quenched, and form intricate microstructures that are chemically and mechanically connected. Although the amount of energy required is high, the deposition efficiency and rate are also high making the process commercially viable. In this process, as in many of the vapor deposition processes, the technological advances come faster than the scientific understanding. As Herman points out, plasma chemistry and processing science will be needed increasingly in future developments.

The articles in the November and December issues of the MRS BULLETIN present a capsule view of many of the primary deposition processes used today. They are by no means inclusive, and such processes as electrodeposition are not covered. You will find, however, the necessary scientific background to (1) understand each of the deposition processes, both by itself, and in context with other processes, and (2) realize the connections between the resulting thin film characteristics and a range of applications. My intent is to present a digestible summary of modern thin film science and technology to a broad scientific audience by focusing on particular deposition processes. In this regard I am certain you will find the authors' efforts rewarding. ☐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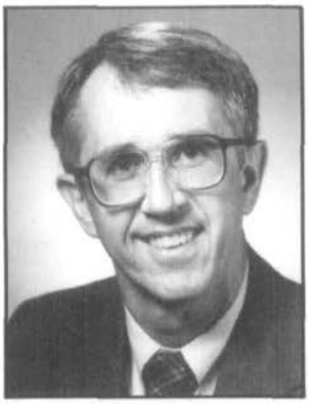

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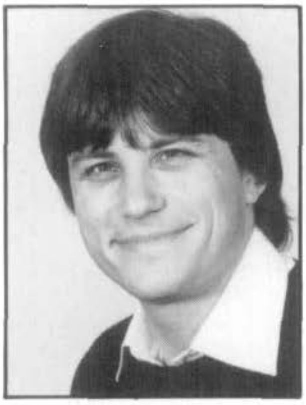

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Russell Messier, Guest Editor for the November and December issues of the MRS BULLETIN, is a staff member at Pennsylvania State University's Materials Research Laboratory and is on the faculty of the university's Department of Engineering Science and Mechanics. His studies have ranged from conventional thin film research, the development of x-ray phosphors, and solar absorbers to theories on the optical behavior of daguerreotypes. During the last decade his research has emphasized the relations among basic sputtering processes, thin film morphology, and resulting film properties. An outcome of that research was the development of a fractal-like void network model which is providing an approach to quantitative preparation-property relations for films prepared under low mobility conditions. He is also involved with a team of scientists in unveiling diamond coating science and technology in the United States. Messier is a member of the Materials Research Society, the American Vacuum Society, IEEE, and SPIE.

Peter K. Bachmann joined the scientific staff of Philips Research Labs in Aachen, West Germany in 1980. For more than six years he has been involved in the design, preparation, and optimization of silica glass optical fibers for telecommunication by plasma chemical vapor deposition (CVD). In December 1986, he was granted a sabbatical year from Philips and joined the Diamond Thin Films group at the Materials Research Laboratory of the Pennsylvania State University. Since returning to Aachen in April 1988, he has continued research in diamond CVD. Bachmann received his MSc and PhD degrees in chemistry from the University of Darmstadt, West Germany. He is a member of the Optical Society of America and the Bunsengesellschaft für Physikalische Chemie.

R.F. Bunshah received a DSc in metallurgy from Carnegie Mellon University in 1952. Since 1969 he has been a professor in Materials Science and Engineering Department at the University of California at Los Angeles. A pioneer in the synthesis of materials by vapor deposition technology for the past 28 years, he is especially known for the development of the activated reactive evaporation process. He has published 135 papers and holds 7 patents. He coauthored a book, *Deposition Technologies and Their Applications,* published in August 1982. Bunshah was the president of the American Vacuum Society in 1971. In 1974 he founded and chaired until 1983 the International Conference on Metallurgical Coatings.

Jerome C. Cuomo is manager of the Materials Processing Laboratory, IBM T.J. Watson Research Center in Yorktown Heights, New York. He has studied thin film preparation and properties and is particularly involved in the study of sputtering, ion beam and plasma processing. He has published extensively and is currently editing books on ion beam and plasma processing. He is the author or coauthor of some 55 patents and about 183 patent publications. Cuomo has made important contributions to the development of LaB_6 electron emitters and Si_3N_4 as dielectric layers. He pioneered work in selective CVD, dendritic solar thermal absorbers, sputtered amorphous silicon, amorphous magnetic bubble domain materials, ion beam modification and synthesis of materials, enhanced plasma processes, and plasma-sprayed high T_c superconductors. Active in the American Vacuum Society, Cuomo was also elected a member of the National Research Council for Superhard Materials 1988-1989.

Chandra Deshpandey is principal development engineer in the Materials Department at the University of California at Los Angeles. He is currently engaged in a variety of research projects related to plasma-assisted processes and synthesis of novel materials. Deshpandey obtained his MS and MTech in solid state physics from IIT Delhi, India and his DPhi in materials science and thin films from the University of Sussex, United Kingdom. He has published over 66 research papers in international journals and holds 3 patents.

Georg Gärtner received the degrees of Dipl.-Physiker in 1973 and Dr.rer.nat. in 1977 from the Johannes Gutenberg University, in Mainz, West Germany. There he was involved with high resolution spectroscopy of stored ions, especially with the direct determination of the proton-electron mass ratio. In 1978 he worked as a research associate in the Atomic Physics group at Texas A&M University in the same field. After a short intermediate stay in Mainz he joined the Philips Research Laboratories in Aachen, West Germany in 1979. His current research focuses on the CVD preparation and characterization of structured materials for high power cathode applications, on metalorganic plasma CVD for the preparation of electrically conducting multicomponent layer structures, and on laser-induced processes.

Herbert Herman is a professor of materials science and engineering at SUNY-Stony Brook, where he has taught since 1968. He received his PhD in materials science from Northwestern University in 1961 and subsequently carried out research on phase transformations at the University of Paris and Argonne National Laboratory before joining the faculty of the University of Pennsylvania. He was a Ford Foundation Professor in Industry and a Liaison Scientist at ONR-London. Herman's principal research is plasma spray surfacing. He is the chairman of the newly formed Thermal Spray Division of ASM International and editor of *Materials Science and Engineering-A.*

Hans Lydtin received his diploma and doctor's degree from the Technical University, Berlin in 1959 and 1961, respectively. During 1962-1963 he worked at the Rheinisch-Westfälische Technische Hochschule in Aachen, West Germany. In 1963 he joined the Philips Research Laboratories, Aachen. Since 1971, he has been in charge of the Solid State Technology Group, which is investigating laser-induced and thermal deposition processes. The PCVD process for manufacturing of optical fibers emerged from these studies. Lydtin was appointed Scientific Advisor to Philips in 1987.

Stephen M. Rossnagel is a research staff member at the IBM T.J. Watson Research Center in Yorktown Heights, New York, working in the Enhanced Plasma Processing Group. He previously held positions at the plasma physics laboratories at Princeton University and the Max Plank Institute in Garching, West Germany and received his PhD in physics from Colorado State University. His current research has been in plasma-based processing, particularly in ion beam and magnetron areas. He has published over 55 papers, 6 patents, and is the editor of two books—*The Handbook of Ion Beam Processing,* and *Plasma-Based Processes,* which will be published early in 1989.

W.D. Westwood graduated from the University of Aberdeen, Scotland in 1962 with a PhD in solid state physics. He joined the solid state research group in the Northern Electric R&D Laboratory (now Bell-Northern Research), Ottawa, Ontario, Canada, to work on magnetic oxide ceramics. He developed sputtering methods for fabricating thin films of these oxides and his research interests have centered on this technique. In addition to spending three years at Flinders University, Australia, on plasma spectroscopy, Westwood has been involved at Bell-Northern Research in thin film deposition and microelectronics. His research covers tantalum hybrids, transparent conductors, integrated optics, high speed electronics and optoelectronics, and he has published over 100 articles on these topics. Westwood is currently manager of Advanced Materials and Devices in the Advanced Technology Lab at BNR. He has been active in the American Vacuum Society for several years and is currently the AVS secretary.