

Evolution of Dielectric Science and Technology for Nanoelectronics

by Durga Misra

The term dielectric was first defined by Michael Faraday in the mid-1800s to indicate that something analogous to current flow occurs through a capacitor during the charging process. In other words, dielectric is an electrical insulator that can be polarized by an applied electric field when placed in an electric field such as within a parallel plate capacitor. Electric charges do not flow through the material, as in a conductor, but only slightly shift from their average equilibrium positions causing dielectric polarization. This effect creates an internal electric field, which reduces the overall field within the dielectric itself. In the early days this property had a tremendous impact on both electrical power transmission process and capacitor and transformer design. Recently, the same properties have been seen to play a significant role in nanoelectronic devices, nanoscale interconnects, and nanosystems processing.

The exploration of dielectric science and technology within ECS goes back more than 50 years. In 1945 an Electric Insulation Division was first founded in ECS, primarily due to efforts of F. M. Clark at General Electric, in order to offer an interdisciplinary forum to discuss the science of these materials and applications for electrical insulation. Thomas D. Callinan, the chair of the Electric Insulation Division, wrote in the July 1952 issue of *Journal of The Electrochemical Society* that the Division was formed to promote the attainment and dissemination of knowledge of dielectrics, including the electrical, mechanical, and chemical properties of non-conductors of electricity. The discovery of the transistor changed the focus from power transmission to intelligence transmission and this has been a cornerstone of the Division's development since then. In 1965 the Division changed its name to Dielectrics and Insulation Division. In 1990, it became the Dielectric Science and Technology (DS&T) Division, due to the changed emphasis of electronic processing technology and changes in the interests of its members.

Through the years, the materials and processes of interest to the Division membership have evolved significantly. Prior to the 1960s, the Division addressed the subjects of electrophysics, electrical properties of plastics, wet electrolytic capacitors, wires and cables, inorganic and organic dielectrics, liquid dielectrics, high temperature insulation, pre-fabricated circuitry, and chemical aspects of printed wiring. But in later years, until the late 1980s, the subjects were anodic oxide dielectrics for electrolytic capacitors, silicon nitride and silicon oxide thin insulating films for electronic applications, plasma processing, chemical vapor deposition, and multilevel metallization. In the recent past, the subject list includes diamond and diamond-like carbon films, corrosion and reliability of electronic materials and devices, environmental issues with materials and processes for IC manufacturing, III-V nitride materials and devices, and rapid thermal processing. Then, with the emergence of nanotechnology and nanoelectronics, and the introduction of new materials and processing technologies in the semiconductor industry, many new topics were introduced as the subject interests of the DS&T Division, such as dielectrics in nanosystems, high dielectric constant materials and their deposition on graphene and other high-mobility substrates, ultra low dielectrics for multilayer interconnects, and atomic layer deposition technologies. The science of dielectric materials, where a dielectric is composed of weakly bonded molecule that not only become polarized, but also reorients so that their symmetry axis aligns to the field, remained the focus of all the above subject areas with evolving technologies.

With the exciting evolution of nanoelectronics, in this issue of *Interface* we have focused on reviewing topics that are integral to current and future semiconductor technologies. In the first article by O'Neill et al., the current trends of atomic layer deposition (ALD) technology are reviewed where deposition testing and

molecular modeling studies are used to investigate the performance of various aminosilanes to deposit silicon oxide thin films using ozone as an oxidant. Various precursors like bis(tertiarybutylamino)silane (BTBAS) and bis(diethylamino)silane (BDEAS) were investigated and their superiority over more common precursors like tris(dimethylamino)silane (TDMAS) are being established for the deposition of uniform high purity silicon oxide. The science behind this is the highly endothermic nature of the third amine removal step that results in lower deposition rates and increased carbon impurity in the film. The relative performance of the bis-amine substituted species seems such that BTBAS provides a slightly improved deposition performance relative to BDEAS.

In the second article by Farrell *et al.*, the current research and development of new and advanced silica-based materials with ultra-low dielectric constant (ULK) is reviewed. These mesoporous and microporous materials lead to dielectric constants less than 2 through the introduction of well-defined pore arrangements by controlling of the pore size and pore density. Even though these materials show remarkable electrical breakdown characteristics and leakage currents, which is highly needed by development of modern transistor devices, they suffer from relatively low mechanical strength (compared to dense silica), poor resistance to electrical migration (especially toward copper), their hydrophilicity as well as their sensitivity to onward processing such as reactive ion etching. Continuous improvement of properties such as pore size control, definition of pore alignment (to a surface feature), surface passivation or other novel processing methods is required to make these materials viable for today's requirement of nanoelectronics technologies.

The third article provides an overview of interface defects and their behavior at the high k and high-mobility substrate interface. Interface passivation techniques to optimize the device performance are addressed. The interface characteristics seem to depend on the deposition process, precise selection of deposition parameters, substrate surface orientation, predeposition surface treatments, and subsequent annealing temperatures. Some recent developments of high k /Ge interface and high k /III-V interface and its characterization are also discussed.

The purpose of the Dielectric Science and Technology Division is to stimulate fundamental research of present and future dielectric materials and their synthesis. The Division also strives to exchange and publish information related to all aspects of the science and technology of dielectric materials through its symposia and short courses in current topics. Core areas of the Division include the physics, chemistry, materials science, synthesis, characterization, processing, fabrication, manufacturing, and reliability of materials and related applications. Advances in the science and technology of dielectrics depend on an integrated approach to better develop a fundamental comprehensive understanding of the basic properties of materials and manufacturing processes and their performance and reliability in diverse applications.

About the Author

DURGA MISRA is a professor in the Electrical and Computer Engineering Department at the New Jersey Institute of Technology, Newark, NJ, and is the immediate past Chair of Dielectric Science and Technology Division of ECS. He is a Fellow of ECS and served on the ECS Board during 2008 and 2010. His research interests are in the areas of nanoelectronic/optoelectronic devices and circuits especially high k gate dielectrics for low power nanoscale CMOS devices. He has edited and co-edited more than 25 proceeding volumes and *ECS Transactions* issues. He may be reached at dmisra@njit.edu.