ABSTRACT

Metal-Insulator-Metal (MIM) capacitors are becoming popular for analog, mixed signal and memory applications. These capacitors are taking more than 50% of circuit area among other passive and active components. Along with scaling of transistors, miniaturization of MIM capacitors is also recommended by International Technology Roadmap for Semiconductors (ITRS). High capacitance and small electrode area can be achieved by introducing high permittivity dielectric materials. ITRS has predicted that MIM capacitors should hold a high capacitance density of $> 5fF/\mu m^2$, low voltage linearity of $< 100ppm/V^2$ and low leakage current density of $< 10nA/cm^2$. In this regard, many works were carried out over the last decade with various high-$k$ dielectrics. However, many of them are facing problems with structural defects, interface traps and poor polarization process due to limitations of fabrication processes. We propose the anodization process for the deposition of high-$k$ dielectrics in MIM capacitors which yields metal oxides with low defects and improved ionic polarization.

This thesis presents the fabrication and characterization of nanostructured barrier type anodic $Al_2O_3$, $TiO_2$ and bilayer stack of $TiO_2/Al_2O_3$ MIM capacitors using potentiostatic anodization on Si wafers. With crystalline properties and improved ionic polarization, many of these capacitors show a high capacitance density of $> 5fF/\mu m^2$ and low leakage current density of $< 10nA/cm^2$ with low voltage linearity at room temperature which are meeting the requirements of ITRS. Frequency dependence of capacitance of all MIM capacitors is studied in detail to understand the defect profile and polarization mechanisms of anodic
oxides. Leakage characteristics of MIM capacitors are measured at various temperatures and analyzed with various tunneling mechanisms of dielectrics. Various electrical properties such as dielectric relaxation, barrier height and trap barrier height are also studied with suitable models. The formation and structural properties of anodic oxides are studied with XRD and SIMS facilities. Effect on the structural and electrical properties of MIM capacitors for the anodization using different electrolytes like borate and sulfuric solutions are studied in detail.

Voltage nonlinearity is a crucial performance parameter of MIM capacitor for RF, analog and mixed signal IC applications. But the origin of the voltage nonlinearity is not clear. A generalized model for voltage linearity is proposed with ionic polarization of induced dipole of dielectrics. The model shows good agreement with experimental results and forms a criteria of material choice and thickness to meet the ITRS recommendations. An analytical model for capacitance-voltage of bilayer capacitors is also derived using Maxwell-Wagner polarization and verified with measured results at various frequencies. From this model, the polarization properties and non-linear capacitance-voltage relation of anodic oxides are studied in detail.