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Implantation, Sputtering and Electromigration: Kelvin Probe Microscopy of Focussed Ion Beam Processed SIMOX.

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Scanning Probe Microscopy techniques provide three dimensional nanometer scale spatial resolution information about the structural, mechanical and chemical properties of surfaces and nanoscale materials. Kelvin Probe Microscopy (KPM) is a specialized Atomic Force Microscopy technique in which long-range Coulomb forces between a conductive atomic force probe and a specimen enable the electrical potential at the specimen surface to be characterized.[1] The surface potential may be associated with a charge distribution within the specimen, and information about the spatial extent and relative magnitude of this charge distribution can be deduced from the surface potential data.[2]

The *Separation by IMplantation of OXygen* or SIMOX approach is a popular method for fabricating Silicon-On-Insulator (SOI) wafers for application in high-performance/ low power CMOS and MEMS devices. Oxygen ions are implanted into a silicon substrate which is then annealed at high temperature in an Ar-O_2 atmosphere to form a Buried OXide (BOX) layer. The SIMOX process produces very uniform SOI and BOX layers with reduced defect densities. The SIMOX wafer used in this investigation has a SOI top layer thickness of ~ 220nm and a BOX layer thickness of ~ 400 ± 10 nm on a p-type silicon (100) substrate.[3]

The SIMOX specimen was irradiated with a continuous normal incident 30keV focussed Ga^+ ion beam for increasing exposure times. Focussed ion irradiation of materials used in semiconductor technology is of great importance in fundamental physics (scattering, impurity effects) and practical applications (nano-modification, depth resolved analysis, TEM sample preparation).[4] A *Veeco/ Digital Instruments extended Dimension 3000* Scanning Probe Microscope operating in ambient Kelvin probe mode, has been used to characterize residual potentials associated with the SIMOX specimen as it is processed with a 30keV, 6600pA focussed Ga^+ ion beam in an *FEI* xP200 Focused Ion Beam system. Irradiation induced trapped charge produces electric fields within the implanted SIMOX. The charging processes are localized, dynamic, and are dependent on pre-existing and irradiation induced defect concentrations. The reproducible characteristic surface potentials associated with the Ga^+ irradiated SIMOX have been measured using Kelvin Probe Microscopy. Surface potentials of a few hundred mV are measured and are compared with Electron Microprobe data of the Ga, O and Si concentrations. The high spatial correlation between the measured potential and the oxygen concentration indicates irradiation induced electromigation of oxygen to the periphery of the milled regions of the specimens. The measured characteristic surface potentials are compared with model surface potentials calculated using three-dimensional conformal Finite Element Analysis.[5] The observed potentials are associated with a number of complex competing physical processes including ion neutralisation, positive/secondary ion emission/ sputtering, ion implantation and charge trapping resulting in local electromigration of oxygen. This investigation shows that ion beam processing of SIMOX can result in local modification of the chemical composition of the specimen via implantation and electromigration. This has implications for the processing of semiconductor materials in a Focussed Ion Beam system.

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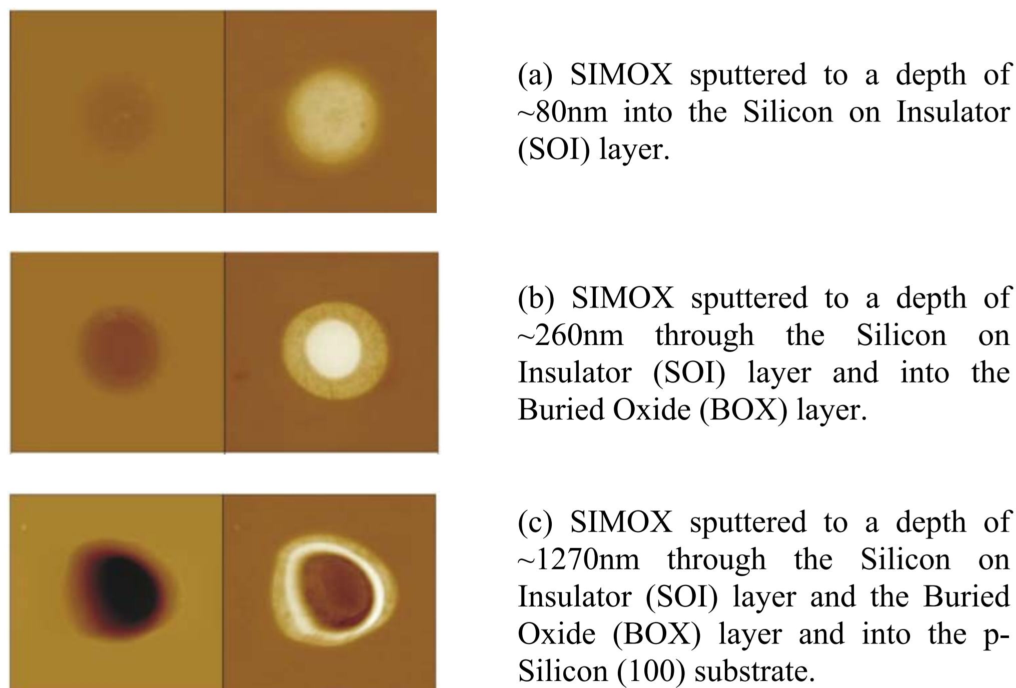

(a) SIMOX sputtered to a depth of ~80nm into the Silicon on Insulator (SOI) layer.

(b) SIMOX sputtered to a depth of ~260nm through the Silicon on Insulator (SOI) layer and into the Buried Oxide (BOX) layer.

(c) SIMOX sputtered to a depth of ~1270nm through the Silicon on Insulator (SOI) layer and the Buried Oxide (BOX) layer and into the p-Silicon (100) substrate.

FIG. 1. Typical 20x20 μm^2 topography and corresponding surface potential images from the SIMOX specimen irradiated with a stationary normal incidence 30keV focussed Ga^+ ion beam for increasing exposure times and therefore increasing sputtered depths of (a) ~80nm, (b) ~260nm and (c) ~1270nm. The SIMOX wafer has a SOI top layer thickness of ~ 220nm and a BOX layer thickness of ~ 400 ± 10 nm on a p-type silicon (100) substrate.

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[5] Programs HiPhi and Metamesh, *Field Precision*, Albuquerque, NM
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