ABSTRACT

DC reactive magnetron sputtering is a powerful, most commercially practiced technique for deposition of thin films because of its various advantages like high deposition rates on larger substrates, control of film composition, films with better adhesion and thickness uniformity.

Refractory transition metal-nitride thin films of Zirconium nitride have received widespread attention owing to its unique application in the field of optics, microelectronics, Solid-State Physics, VLSI and ULSI etc. The aim of the present investigation is to deposit and characterize ZrN thin films (including annealing effects), to fabricate and characterize metal-semiconductor, metal-oxide-semiconductor and metal-insulator-metal structures using ZrN as electrode.

Zirconium nitride films were prepared by DC reactive magnetron sputtering from a pure Zirconium (99.9%) disk of 100 mm diameter target, onto cleaned glass and p-type silicon substrate. Nitrogen (99.99%) and argon (99.99%) have been used as reactive and sputtering gasses, respectively. Nitrogen partial pressures were varied from $4 \times 10^{-5}$ mbar to $10 \times 10^{-5}$ mbar and the effect on the structural, electrical and optical properties of the films was systematically studied. Electrical resistivity of the ZrN films was varied from $1.72 \times 10^3$ to $48.28 \times 10^3 \ \Omega \text{cm}$ with increase in nitrogen partial pressure from $6-8 \times 10^{-5}$ mbar. In order to obtain good metallic ZrN films with less resistivity, we fixed nitrogen partial pressure for our further study at $6 \times 10^{-5}$ mbar. The deposited films were found to be crystalline with refractive index and extinction coefficient 1.95 and 0.43, respectively.

In order to study the annealing effects of ZrN films, films deposited at room temperature were subjected to post annealing in a muffle furnace at 350 °C and 550 °C for 1 hour in air ambient. Electrical resistivity was found to increase to $6.21 \times 10^3 \ \Omega \text{cm}$ for annealed films. Variation in refractive index and extinction coefficient was observed in the range of 1.95-1.80 and 0.43-0.15 at 350 nm for the annealed films. The grain size for the films annealed at 350°C was 7.2 nm and it increased to 11.1 nm in case of films annealed at 550°C. Poly-crystalline nature has been observed with
(111) and (201) orientations. Scanning electron microscopy (SEM) and energy dispersive analysis of X-rays (EDAX) showed alloy penetration pits. Extent of penetration was greater in the films, which were annealed at higher temperature (550 °C).

Further, we have fabricated and characterized ZrN metal-semiconductor contact on p-type silicon, n-type germanium and p-type gallium nitride using current–voltage and capacitance-voltage techniques at room temperature. Two different ZrN/Si structures have been fabricated on p-type silicon substrate at two different conditions at room temperature. Rectifying behavior was observed from I-V characteristics with a knee voltage of 0.7 and 0.55 volts, reverse saturation current of 0.2µA and 0.1µA. Barrier height was found to be 0.81eV and 0.83eV with a depletion capacitance in 43-59 pF and 1-2.6nF range.

ZrN/Ge structures exhibited Schottky nature. However, ZrN/GaN showed linear I-V characteristics with high resistance. ZrN/Ge structure exhibited Schottky nature. However, ZrN/GaN showed linear I-V characteristics with high resistance. For ZrN/Ge Schottky structure, barrier height was found to be 0.61eV with reverse saturation current of 0.3mA. Depletion capacitance is found to be in the range of 7-17 pF for ZrN/Ge Schottky structure.

Later, the work was on fabrication and characterization of ZrN/TiO$_2$/p-Si metal-oxide-semiconductor structures. The flat band capacitance was found to be 2.86pF, which correspond to flat band voltage of -1.7V. Fixed oxide charged density and interface state density were found to be $1.63 \times 10^{10}$ cm$^{-2}$ and $6.3 \times 10^{11}$ cm$^{-2}$ eV$^{-1}$. I-V characteristics revealed that the leakage current density was of 0.5mA/cm$^2$ in accumulation mode and 2mA/cm$^2$ in inversion mode at a field of 0.12 MV/cm, respectively. Dielectric breakdown of ZrN/TiO$_2$/p-Si structure was found to be 0.12 MV/cm in accumulation mode. To compare ZrN electrode MOS structure with standard metallized MOS capacitor, Al/TiO$_2$/p-Si MOS structure was fabricated and characterized. Finally, ZrN/TiO$_2$/ZrN metal-insulator-metal device was fabricated and characterized by capacitance-voltage and current-voltage measurements.