Sequential and Parallel Implantation of Al and N into SiO_2

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AlN is a III-V compound that has attracted interest for its possible applications in optoelectronics, high-temperature electronics and as antiwear coatings. Along with many interesting properties such as a large bandgap (6.2 eV), a high thermal conductivity, high acoustic velocity, high stability at high temperature, high hardness and enhanced corrosion resistance, AlN has the potential to be integrated with well- developed silicon microelectronic circuits. However, suitable methods have to be found to produce thin AlN containing films on Si-based substrates. One possibility is ion implantation to allow the formation of nanocrystal precipitates in a host medium. In the case of binary compounds, conventional beamline implantation necessitates the sequential implantation of both constituting elements. This, in turn, will lead to the partial sputtering of the first element during implantation of the second element, especially at low energies and high fluences. Plasma immersion ion implantation (PIII), where the positive ions are extracted from the plasma edge surrounding the substrate, allows the parallel implantation of all present species. However, adjustment of the relative plasma densities and the extraction conditions are more demanding as the incident fluences are only determined by the plasma sheath dynamics. At the same time, lighter ions will dominate during the initial pulse phase with heavier ions being implanted later. Fig. 1 shows the calculated ion depth distributions of Al and N using PIII at 10 kV. Multiple species are present for both ions (90% N2+, 10% N+; 38% Al+, 51% Al2+, 11% Al3+), according to the literature, which lead to a satisfactory overlap of both profiles, despite the highly differing ion masses.

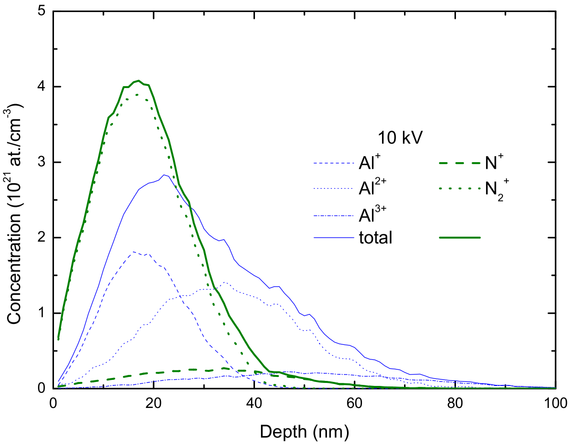

Fig. 1: Calculated depth profiles for an acceleration voltage of 10 kV in plasma immersion ion implantation. The incident fluence is 1016 at./cm2.

Experiments were performed with both, sequential ion implantation and parallel ion implantation using Si wafers with 100 nm thermal oxide on the surface as substrates. The data analysis itself, i.e. the detection of the AlN in the SiO_2 matrix is complicated by the very shallow implantations and the rather low total amount of implanted atoms. Rutherford backscattering spectroscopy is not sensitive enough, whereas data acquisition by SIMS is possible. However, the calibration factors necessary for quantification are not directly accessible. The resulting layers are near the detection limit of optical methods as infrared or Raman spectroscopy, while the resulting information is only about the electronic structure. TEM is another complementary method for the microstructure. ERDA is a suitable method with a dynamic range of about 3.5 orders of magnitude and a depth resolution below 5 nm. Representative ERDA results comparing sequential and parallel implantations are shown in Fig. 2. In the sequential experiment with aluminium implanted after nitrogen (Fig. 2a), the retained nitrogen is already being sputtered away by the impinging aluminium atoms, leading to relative nitrogen deficiency at the surface. At the same time, rather low concentration of Al and N are present.

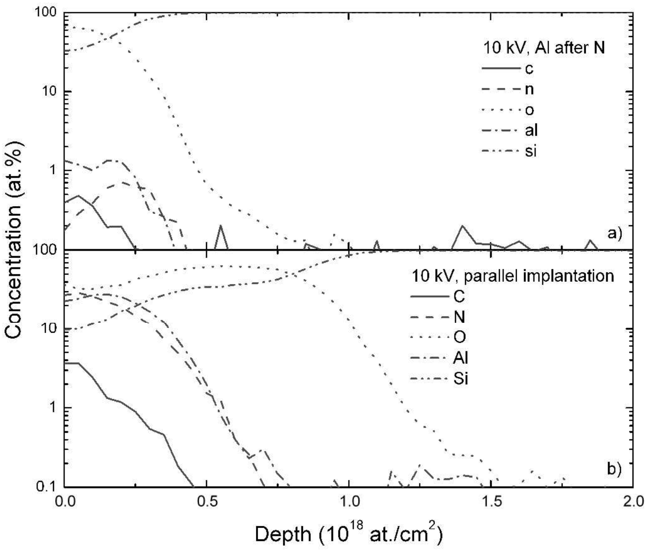

Fig. 2: Resulting ERDA depth profiles after sequential (a) and parallel (b) implantation of Al and N with PIII at 10 kV.

In contrast, Fig. 2b shows nearly identical depth profiles for N and Al, with a retained fluence of 8.5 and 9.8 1016 at./cm2, respectively. Again, a significant fraction of the original SiO_2 is sputtered during the implantation. A combination of a finite pulse rise time in PIII and surface sputtering explains the different surface concentrations in Fig. 1&2. Nevertheless, a ratio of AlN/SiO_2 of about 1:1 is observed in the surface region.

References

[1] E. Valcheva, D. Manova, S. Mndl, S. Alexandrova, J. Lutz, S. Dimitrov, Ion beam synthesis of AlN nanostructured thin films, J. Optoelectr. and Adv. Mater. (2007) (in press)