Investigation of Nitridated Al_2O_3 Wafers Using High Resolution ERD

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In recent years the need for optoelectronic devices in the blue and UV wavelength region of the electromagnetic spectrum has led to the development of Group-III-nitride based blue and UV emitting LEDs and lasers. Although LEDs are commercially available and lasers are on the verge of industrial production, presently only one company can supply high quality devices. Therefore, great efforts are made to study the properties and technology of nitride fabrication.

Group-III-nitride films can be grown on Al_2O_3 (0001-sapphire) substrates by molecular beam epitaxy (MBE) or metal organic chemical vapour deposition (MOCVD). Despite of the high lattice mismatch of 16.1 % between film and substrate, the growth of a polycristalline buffer layer prior to the actual film deposition yields highly oriented smooth films. At the beginning of the deposition in the MOCVD process the substrate is heated in a NH_3 atmosphere for surface cleaning. Various papers reported the existence of chemically bound nitrogen on the surface after this cleaning step. Furthermore, the film quality on such pretreated substrates was greatly improved [1–3]. One possible explanation is the formation of a thin AlN-layer at the surface by exchange of oxygen and nitrogen from thermally decomposed ammonia. This layer may act as a first buffer for nucleation.

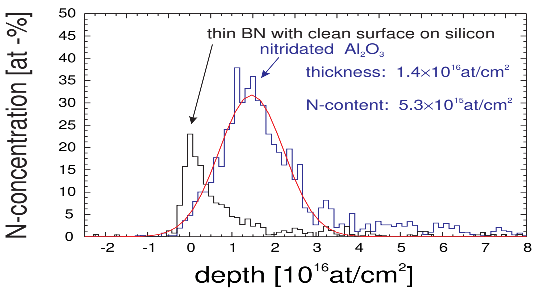

Fig. 1: Nitrogen depth profile of a nitridated sapphire wafer measured with 53 MeV ^{179}Au ions

In order to obtain quantitative results, high resolution ERD-measurements were carried out at the Q3D magnetic spectrograph to get nitrogen depth profiles with a depth resolution of < 1 nm. The samples (0001-sapphire, tempered 1h in 100 mbar NH_3 at 1050 °C, untreated sapphire) were irradiated by a 53 MeV ^{179}Au beam and the recoiled N-ions were detected under 15° in the Q3D. Fig. 1 shows the resulting depth profile, compared to a profile of a sub-nm BN-layer for depth resolution testing. The nitridated layer near the surface of the Al_2O_3 substrate can be approximated by a gaussian distribution. The total content of nitrogen is $(5.3 \pm 0.2) \times 10^{15}$ at/cm^2 distributed over a thickness of 1.4×10^{16} at/cm^2 (FWHM) and has a maximum concentration of 35 to 40 at-% integrated over the beam spot. The depth of the maximum shows that the nitridated layer is covered. This may be due to surface oxidation caused by long term exposure to air between fabrication and measurement (approx. 1/2 year) or by oxygen contaminated gas during the sample cooling in the reactor. No other elements of significant amount except aluminum, oxygen, hydrogen and nitrogen were detected in low resolution ERD-measurements. This means that the only other species than AlN that could have been formed on the surface are oxygen or hydrogen rich phases. Since oxygen rich phases and also NH-bonds are not stable at temperatures of 1000°C, no arguments seem to exist against an (inhomogeneously) AlN covered surface.

A problem in ERD-analysis is strong irradiation damage arising from heavy ion bombardment. During the first measurements [4], carried out with a 60 MeV ^{58}Ni beam, a strong reduction of the detected N-yield with increasing ion fluence was observed, which can be explained with electronically enhanced sputtering (Fig. 2).

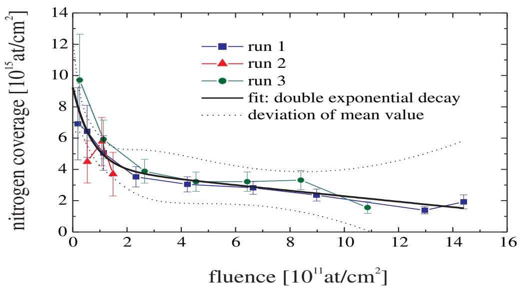

Fig. 2: Decrease of nitrogen yield with ion fluence under 60 MeV ^{58}Ni bombardment

Quantitatively, a sputter yield of $5^{+7}_{-1} \times 10^4$ at/cm^2 was extracted from the data. From this value a track diameter of 5.5 nm can be deduced, which is comparable with a value of 4 nm calculated with a formula for thermal spike approximation given by Tombrello [5]. As the track diameter is bigger than the thickness of the N-rich layer, the complete layer is sputtered away around the track with each ion hit. Every detected N-ion comes therefore from an undisturbed surface area and carries the whole depth information. However, extrapolation is necessary to determine the nitrogen coverage at the beginning. Since this implies a big statistical error, efforts were made to reduce the ratio of irratiation damage to scattering crossection. This led to the employment of the mentioned 53 MeV ^{179}Au beam, which decreases the damage to crossection ratio by a factor of 100 in theory, assuming a power law [5] between sputtering and stopping power. With these settings the samples were investigated and no reduction in N-yield was observed after a ten times better statistics than in the first measurement.

References

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