$Al_xGa_{1-x}N$ Layers for Optoelectronic Devices in the Blue and UV Region

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Blue and UV wavelengths are a technologically important region of the electromagnetic spectrum in which efforts to develop semiconductor device technology have been not very successful. At present, semiconductor optical devices routinely operate from the IR to green wavelengths. If this range could be extended into the blue wavelengths, semiconductor components could then emit and detect the three primary colors of the visible spectrum which would have a major impact on imaging and graphics applications [1].

The III–IV nitrides have long been viewed as a promising system for semiconductor device applications in the blue and UV region in much the same manner as their highly successful As– and P–based cousins have been used in the IR, red, and green region. The hexagonal polytypes of GaN, AlN, and InN form a continous alloy system whose direct band gaps range from 1.9 eV for InN, to 3.4 eV for GaN, to 6.2 eV for AlN. Thus, the III–IV nitrides could potentially be fabricated into optical devices which are active at wavelengths ranging from the red well into the UV. Like most wide band gap semiconductors, the nitrides are expected to exhibit superior radiation hardness compared to GaAs and Si, which also makes them attractive as a general material for active electronics for space applications.

A series of $Al_xGa_{1-x}N$ layers with aluminum admixtures X ranging from 0.1 up to 0.9 was grown by molecular beam epitaxy (MBE) on sapphire (Al_2O_3) substrates. In order to obtain the desired value of the band gap between 3.4 eV and 6.2 eV, it is necessary to know the Al content X exactly. The Al content X was determined by two independent techniques. The stoichiometry of the alloyed samples was quantitatively measured by means of elastic recoil detection (ERD). The measurements were performed using the ERD setup at the Q3D magnetic spectrograph. The experimental setup is described elsewere [2,3]. A typical depth profile of a AlGaN sample is shown in fig. 1. The spectrum shows a small decrease with depth of the Ga concentration which is correlated to a small increase of the Al content. The average Al content in the film is 9 at% wich is similar to an Al admixture X of 0.18.

Furthermore, high resolution X–ray diffraction (XRD) was used to measure the lattice constants of the alloy crystals. According to the empirical law of Vegard, the lattice constant of an alloyed crystal results from a summation of the weighted lattice constants of the pure crystals (in this case AlN and GaN) in the isotropic case. The $Al_xGa_{1-x}N$ layers, however, show an unisotropic stress and, therefore, corrections are necessary. Using elasticity theory a transformation of Vegards prediction can be performed to the unisotropic case. Finally, the changes of the lattice constant are corrected for distortions caused by stress due to the lattice mismatch of layer and substrate. Therefore, the Al admixture X is determined from the corrected shift of the lattice constant.

Fig. 2 shows the Al contents X_{ERD} measured with ERD of all investigated samples plotted vs. the Al content X_{XRD} as determined by XRD. The solid line represents a fit of the data points, the relation $X_{ERD} = X_{XRD}$ is plotted as the dashed line. The data obviously follow the expected identity with much higher perfection as expected from the validity of Vegard's Law. However, a small offset towards higher X_{ERD} is obvious.

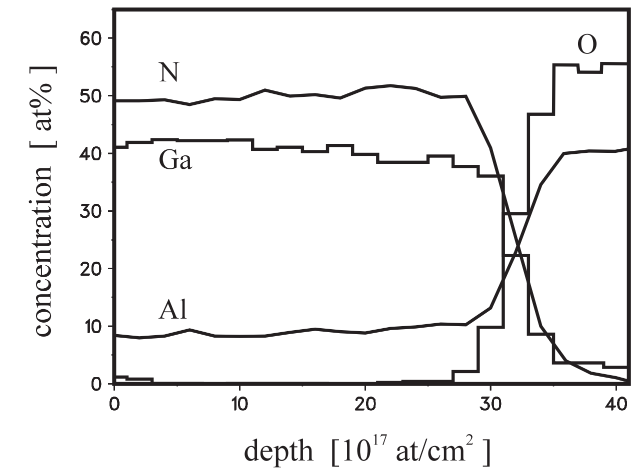

Fig. 1: ERD elemental depth profiles of a $Al_{0.2}Ga_{0.8}N$ film and the underlying sapphire substrate.

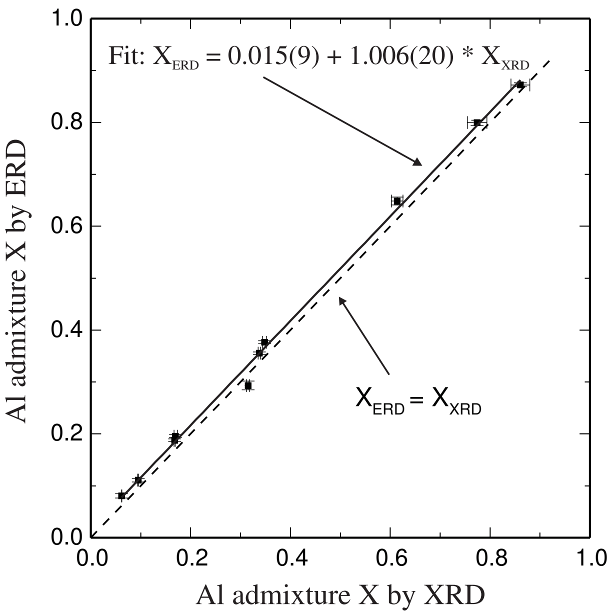

Fig. 2: Al admixture X in $Al_xGa_{1-x}N$ films measured with ERD vs. X determined by XRD.

References

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