Mg Doping of AlGaN Alloys for Optoelectronic Devices

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Motivation—AlGaN semiconductors have emerged as materials of great technological importance. With direct energy bandgaps that are tunable throughout much of the ultraviolet (UV) region of the spectrum (200-365nm), compact solid-state, solar-blind detectors as well as UV light emitting diodes (LEDs) and laser diodes have been demonstrated in this alloy system. Relevant applications for these devices include fluorescence-based biological agent detection, non-line-of-sight communication, portable water purification, and quantum information processing.

A major challenge of realizing high performance AlGaN optoelectronic devices, especially laser diodes, is the difficulty of achieving low resistivity p-type alloys of even modest Al composition (~10%). Mg is the most effective p-type dopant to date, yet it still exhibits an extremely large acceptor activation energy, which increases with Al composition from ~200meV in GaN to as high as ~400meV in AlN. We have focused on minimizing the p-type resistivity of Mg doped AlGaN alloys by optimizing the metal-organic chemical vapor deposition (MOCVD) process.

Accomplishment—AlGaN films with an Al composition of 30% were grown using bis(cyclopentadienyl)magnesium, trimethyl-aluminum, trimethylgallium and NH_3 at 75torr. Gas flow conditions in the reactor were previously optimized to minimize parasitic, gas-phase chemical reactions that could mask intrinsic effects of growth conditions. Optimal activation of the Mg dopant was achieved using a post growth anneal in a N_2 ambient at 900°C for 2 minutes. Hot probe measurements were used to confirm p-type conductivity, and conventional van der Pauw measurements were used to measure resistivity. The focus of these growth studies was to minimize the resistivity of $Al_{0.3}Ga_{0.7}N$ films by optimizing critical growth parameters such as temperature, and flux of NH_3 and group-III sources.

Figure 1a suggests that the resistivity of $Al_{0.3}Ga_{0.7}N$ films is dominated by the NH_3/group-III ratio when the ratio is less than ~1200. However, the Mg flux dominates when the NH_3/group-III ratio exceeds ~1200 (Fig. 1b). The higher NH_3 flux presumably leads to more effective p-type doping by reducing the density of n-type, compensating nitrogen vacancies. The resistivity is relatively insensitive to changes in growth temperature from 990°C to 1025°C once NH_3, Mg and group-III fluxes are optimized.

Under optimized conditions, a resistivity of 8 ohm-cm is achieved for $Al_{0.3}Ga_{0.7}N$ films which is one of the best results reported for this composition. Figure 2 shows the resistivity measured for AlGaN films with Al compositions from 10% to 30% using optimized conditions developed in this work. P-type AlGaN films at these compositions have been used in our effort to develop laser diodes with emission at UV wavelengths.

Significance—The ability to effectively p-type dope AlGaN films with Al compositions to 30% is a key element in realizing laser diodes with emission near 340nm. With improved performance enabled by more effective p-type doping, AlGaN optoelectronic devices will replace photomultiplier tubes, mercury lamps, and large frame lasers and enable a new generation of compact, robust, and portable systems for sensing and communications.

Sponsors for various phases of this work include: Laboratory Directed Research & Development, and Defense Advanced Research Projects Agency

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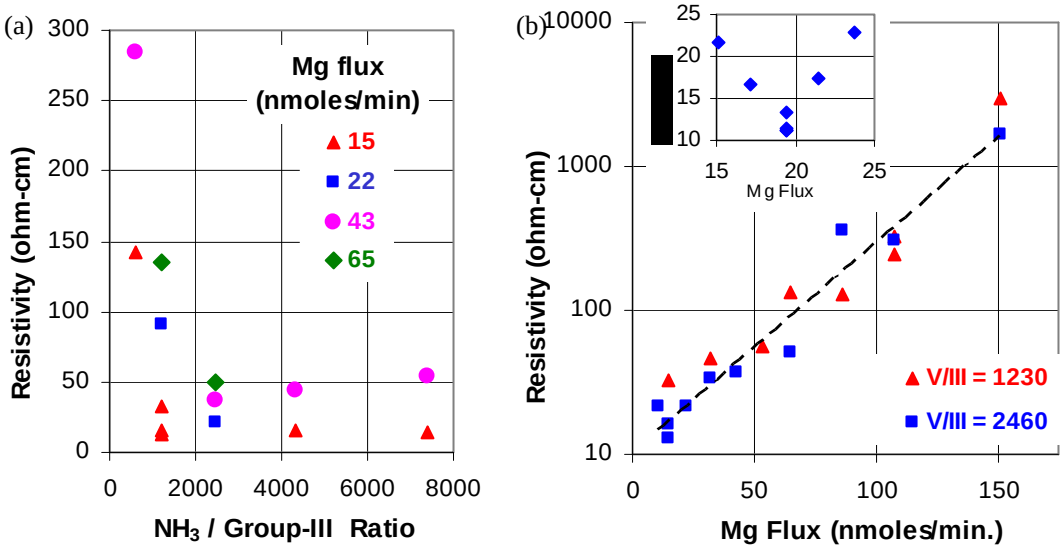

Figure 1. The resistivity of 30% AlGaN films is shown in a) where the resistivity is largely independent of NH_3 flux for NH_3/group-III ratios exceeding ~1200 and in b) where the sensitivity to Mg flux clearly dominates the effects of NH_3/group-III ratios (.i.e. V/III ratio) exceeding ~1200. The dashed line is drawn as an aid to the eye. The inset shows the resistivity eventually increasing for decreasing Mg fluxes, indicating a minimum resistivity is achieved for an optimum Mg flux.

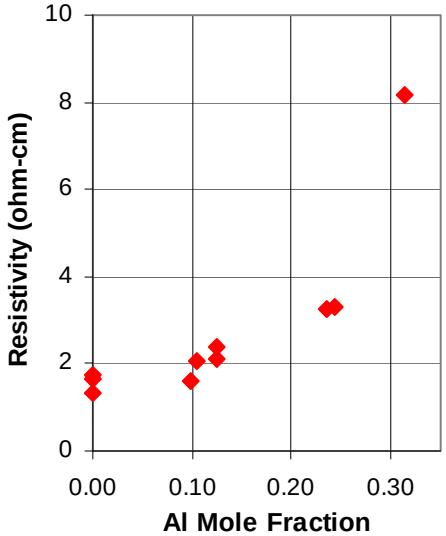

Figure 2. The resistivity of AlGaN films grown under optimized conditions from this work. The sharp rise in resistivity reflects the increase in Mg acceptor activation energy with higher Al mole fraction.