Polarization doped AlGaN pn diodes with low on resistance and low ideality factor

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High Al content AlGaN is an attractive material for deep ultraviolet optoelectronics and high-power electronics given its large direct energy bandgap and high critical electric field. However traditional doping methods have proven difficult for ultrawide energy bandgap AlGaN. The challenge with p-type doping is more severe than n-type doping, making the realization of bipolar devices such as p-n diodes (PNDs) and heterojunction bipolar transistors (HBTs) difficult. Polarization induced charges have been used to generate free holes [1] and electrons [2] in polar semiconductors such as AlGaN itself without the use of intentional dopants. This approach has been only recently used to make high Al content AlGaN PNDs [3,4] and deep ultraviolet laser diodes [5]. In this study we demonstrate high Al content AlGaN pn junction with polarization induced charges with desirable electrical characteristics which will enable both new applications and study of fundamental properties of the AlGaN material system.

AlGaN epilayers were grown on metal-polar bulk AlN substrate by molecular beam epitaxy (MBE). A 500 nm AlN buffer layer was grown, followed by a 400 nm Si (target: 8×10^{19} cm^{-3}) doped $Al_{0.7}Ga_{0.3}N$ current spreading ohmic n-contact layer. The pn junction active region consists of a 100 nm AlGaN layer linearly graded in Al composition from $Al_{0.7}Ga_{0.3}N$ to AlN along the growth direction capable of providing free electron slab of density $\rho_\pi = 5\times10^{18}$cm^{-3}, followed by a 100 nm linearly graded AlGaN layer from AlN to $Al_{0.7}Ga_{0.3}N$ providing the free holes of similar density thus forming a p-n junction. The Al content is further rapidly graded down in another 30 nm to reduce the valence band offset between the AlGaN device layers and the p-GaN contact layer, thus potentially reducing the diode resistance. Then a 10 nm Mg doped p^+GaN layer is grown, followed by a thin 5 nm Mg doped $p^+In_{0.05}Ga_{0.95}N$ contact layer [6].

The vertical mesas were defined by low damage Cl_2-based inductively coupled reactive ion etching. The n-electrode V/Al/Ni/Au was deposited and annealed at 850 °C for 10 s in N_2 ambient and Ni/Au p-electrode was deposited and annealed at 450 °C for 210 s in O_2 ambient. High current densities up to 20 kA/cm^2 at 10 V is achieved in the diodes. Low differential on-resistance dV/dJ of 4.5×10^{-4} Ω.cm^2 is extracted at 6 V. These are the lowest on-resistance high Al content AlGaN diodes with average Al composition of 85% in the active region reported in literature. The low on-resistance of the diode is enabled by low resistance contacts to etched n-AlGaN ~ 10^{-5} Ω.cm^2 and p-InGaN ~ 10^{-4} Ω.cm^2 at the current densities of interest. An ideality factor of 1.7 is achieved during diode turn-on close to 5 V, among the lowest reported for AlGaN pn diodes. These results pave way for making functional devices with polarization doped layers, overcoming the shortcomings of traditional doping in ultrawide bandgap AlGaN.

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[1] *Science* 327.5961 (2010): 60-64. [2] *Appl. Phys. Lett.* 81.23 (2002): 4395-4397. [3] *IEEE TED* 71.5 (2024): 3396-3402. [4] *Appl. Phys. Lett.* 124.10 (2024). [5] *Appl. Phys. Exp.* 12.12 (2019): 124003. [6] *DRC* (IEEE, 2019), pp. 171–172.

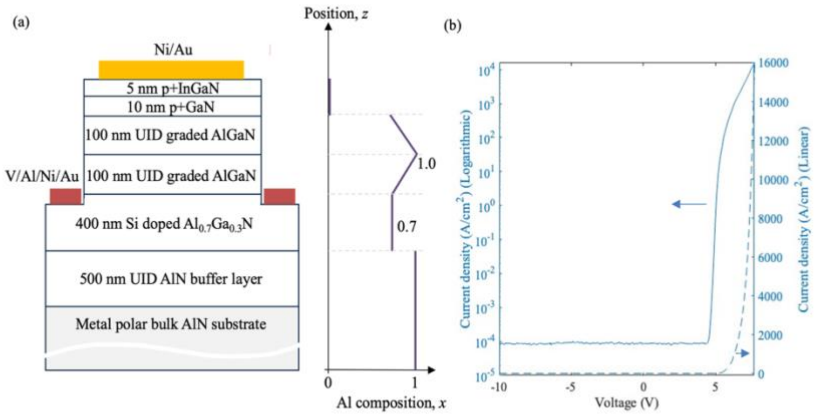

Figure 1. (a) Cross-sectional device schematic along with Al composition profile along the c-axis. (b) Room temperature JV characteristics of a 30 μm diameter device.