Ultra-low contact resistance for Self-aligned HEMT structures on N-polar GaN by MBE regrowth of InGaN-based contact layers

Nidhi[a*], Sansaptak Dasgupta[a], Man Hoi Wong[a], Uttam Singisetti[a], Mark A. Wistey[a,b], Mark J.W. Rodwell[a], James S. Speck[b], Umesh K. Mishra[a]

[a] Department of Electrical and Computer Engineering, University of California, Santa Barbara

[b] Materials Department, University of California, Santa Barbara

AlGaN/GaN based high electron mobility transistors (HEMTs) have been of interest to the semiconductor community[1] because of their high breakdown voltage, high sheet carrier density, and the high saturation velocity of GaN. Owing to these properties GaN based high electron mobility transistors are especially attractive for power devices[2] and with improved device structures[3,4] for millimeter-wave applications. The N-polar orientation of GaN-based HEMTs are particularly suited for ultra-high speed applications because of several advantages associated with them as compared to Ga-polar, such as lower contact resistance,[5] better electron confinement,[6] low gate leakage, low dispersion devices and enhancement mode operation.

In this paper, we demonstrate a pathway towards designing a self-aligned structure to achieve ultra-high speed performance from N-polar GaN HEMTs. The devices use a gate-first methodology with regrown access regions, to achieve very high aspect ratio with low access resistance. Similar device structures have been reported using InGaAs channels[7]. Refractory W gate metal is used such that the gate metal stack can withstand MBE regrowth temperatures. The gate metal stripes are covered with SiO_2 cap and SiO_2 sidewalls (Fig.1d) to avoid contaminating the MBE chamber. Contact layers consisting of InGaN graded from 1% In to higher In compositions (preferably InN) are regrown to achieve ultra-low Ohmic contact resistance.

All MBE regrowths were done on MOCVD GaN templates on sapphire with W gates fabricated on them. InN regrowth was first investigated to study growth morphology and contact resistance from metal to regrown InN. Regrowth was done at various temperatures (570ºC, 525ºC and 475ºC) to optimize the growth of InN. Ti-based non-alloyed Ohmic contacts were deposited on the regrown film. The contact resistance from metal to InN was measured to be between 2-5 Ω-µm. The surface morphology for all three samples is shown in Fig 1. Due to uniform surface morphology without droplets, 475 ºC is chosen as an optimum temperature for regrowth of InN.

Regrowth on graded InGaN doped with 1×10^{19} cm^{-3} Si was then investigated for various temperatures (610ºC, 550ºC and 475ºC). The alloy composition for all samples was measured from high-resolution X-ray diffraction measurements and is shown in Table 1. As shown in Fig. 2, the contact resistance from metal to graded InGaN was observed to increase with ending In composition of the grade which is contrary to the expected trend. It is believed that this could be a result of defects in the regrown films grown at lower temperatures or change in surface pinning position with varying In compositions. However, a relatively low contact resistance of 120 Ω-µm was obtained for InGaN regrown at 610ºC.

To further decrease the contact resistance, a graded InGaN layer capped with 10 nm of InN was regrown at 610ºC on a standard N-polar HEMT structure on SiC. It was confirmed from HR-XRD

* email: nidhi@ece.ucsb.edu   phone: +1-805-893-3812 ext 202

measurements that InGaN was graded from 1-26% and was capped with relaxed InN islands (Fig. 3). The contact resistance to the 2-dimensional electron gas using this contact layer was measured to be as low as **60 Ω-µm**. This is the lowest reported contact resistance to an AlGaN/GaN HEMT structure. It can be projected that lower contact resistances could be obtained by grading to higher In composition InGaN and capping it with a coalesced film of InN.

To summarize, ultra-low Ohmic contact resistance of 60 Ω-µm was obtained for a self-aligned device structure. With the gate-first and regrown access regions technique for making self aligned N-polar HEMT structures, very high frequency performance can be achieved.

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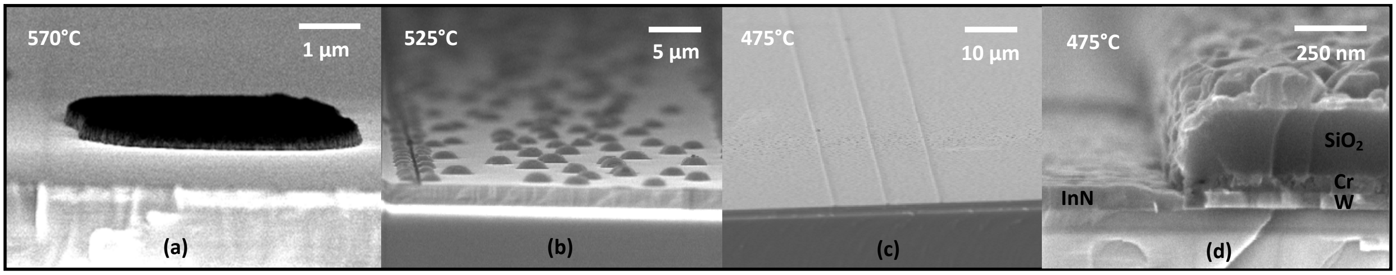

Fig. 1: InN regrowth SEMs showing (a) no growth at 570°C, (b) some growth with In droplets at 525°C, (c) uniform film at 475°C and (d) gate metal stack with the InN regrowth showing full coverage of the regrown layer next to the gate

InGaN Growth Temperature	In composition
475°C	1% to 43%
550°C	1% to 35%
610°C	1% to 26%

Table. 1: The composition of the InGaN grade extracted from the high-resolution X-ray diffraction measurements

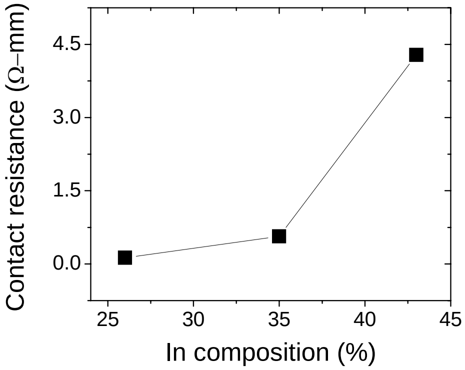

Fig. 2: The variation of the non-alloyed Ohmic contact resistance from the metal to the graded InGaN layers with the final InGaN composition

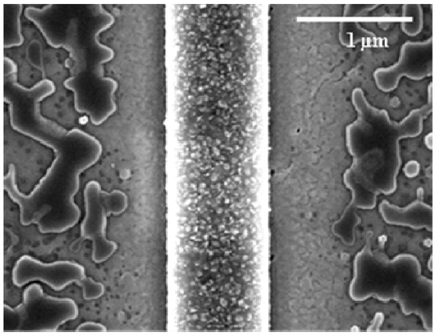

Fig. 3: Scanning electron micrograph of a regrown graded InGaN layer (1% to 26%) capped with 10 nm InN showing that InN forms islands due to relaxation