

# Optimization of Ohmic Contacts to III-N Semiconductor Material

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## Abstract:

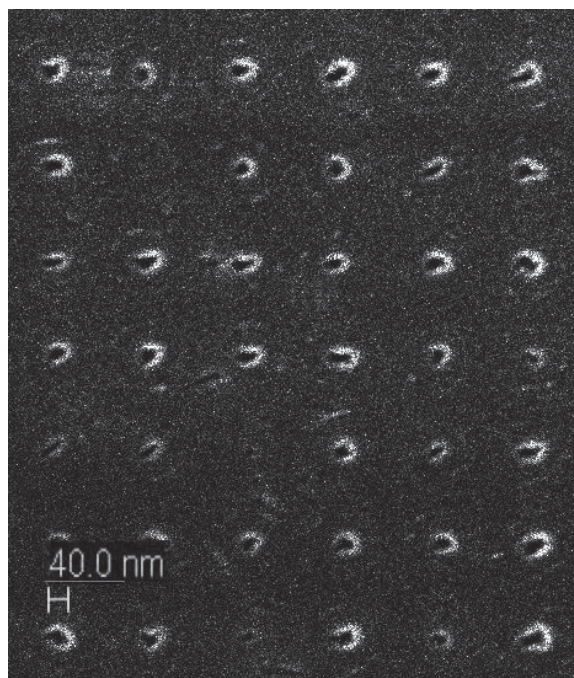
High electron mobility transistors (HEMTs) are a class of material which yield higher power and higher frequency devices than on traditional silicon [1]. In the aluminum gallium nitride (AlGaN) and indium aluminum nitride (InAlN) devices studied, electric current flowed through a thin conductive plane 10-20 nm below the surface of the material; this property made the problem of contacting this plane from outside the device a nontrivial one. Traditional approaches rely on depositing and then annealing stacks of metal to make ohmic contacts. In this process, metal diffused into the material, and donor sites were created by the out-diffusion of nitrogen, both increasing conductivity in the barrier layer. Novel metal stacks were studied at a range of thicknesses and anneal conditions. In addition, because in this process edge acuity can be negatively affected, an alternate approach was tried in which the material was etched in discrete places below the conductive plane prior to metal deposition to create nanoporations. We demonstrate that ohmic contacts can be achieved as deposited using this technique.

## Introduction and Material:

The material studied consists of AlGaN- and AlInN-GaN grown by molecular beam epitaxy on substrates of silicon (Si) and silicon carbide (SiC), respectively. This materials geometry resulted in a potential well forming at the interface of the top epilayer and the GaN in which free electrons from the lattice tend to congregate. This two dimensional electron gas (2DEG) was highly conductive and formed without any doping of the material. The absence of impeding ions allowed the electrons in the 2DEG to have a very high mobility. The quality of metal contacts to this material was a function of the metals used and their thicknesses, as well as the annealing conditions. In particular, metal solid solubility and reaction rates with the material, as well as conductance and band structure of the resulting alloys and states were all considerations for choosing optimal metal contacts.

## Methodology:

To measure contact resistance for the various metal stacks tested, transfer length measurement (TLM) structures were fabricated. First the material was etched below the 2DEG to create electrically isolated mesas 200  $\mu\text{m}$  in width. Nanoporations, if applicable, were created using electron beam lithography. Since this process was expensive to run, only 50  $\mu\text{m}$  of the contact width and 2.5  $\mu\text{m}$  of length was perforated, and the perforations were roughly 40 nm in diameter with 200 nm spacing from center to center (Figure 1). Small perforations were used so that a large total surface



*Figure 1: Scanning electron micrograph of nanoporations before metal deposition.*

contact area was achieved, as several small holes closely spaced provide more contact area with the 2DEG than larger holes further apart. An oxygen plasma descum and buffered oxide etch were both performed to effect a clean surface immediately prior to metal evaporation. Then, on each of the mesas, metal was evaporated in nine rectangles spanning the mesa width and  $50\ \mu\text{m}$  in length, spaced so that between adjacent rectangles, there were 5, 10, 15, 20, 25, 30, 35, and  $40\ \mu\text{m}$  gaps. The resistance of adjacent contacts was measured by the four-point-probe technique. We used these values to work out  $R_c$  [ohm-mm], the contact resistance.

### Traditional Approach Results:

Six novel metal stacks were tested. V-Al-Si-Cu (15 nm, 60 nm, 40 nm, 50 nm), Ti-Cu-Mo-Au (12.5 nm, 60 nm, 45 nm, 55 nm), V-Ti-Au (12.5 nm, 15 nm, 50 nm), and V-Al-V-Au (10 nm, 40 nm, 40 nm, 50 nm) resulted in non-conductive alloys. V-Ti-Al-Mo-Au (10 nm, 12.5 nm, 75 nm, 45 nm, 55 nm), and Ti-Al-Ti-Al-Mo-Au (7.5 nm, 45 nm, 7.5 nm, 45 nm, 45 nm, 55 nm) were ohmic, but did not surpass previously achieved results in the literature.

In addition, stacks of Ta-Ti-Al-Mo-Au (X, 12.5 nm, 60 nm, 40 nm, 50 nm) where X is 7.5 nm, 10 nm, 12.5 nm, 15 nm, 17.5 nm, were tested at a constant annealing condition of  $700^\circ\text{C}$  for 60s and  $800^\circ\text{C}$  for 20s (Figure 2).

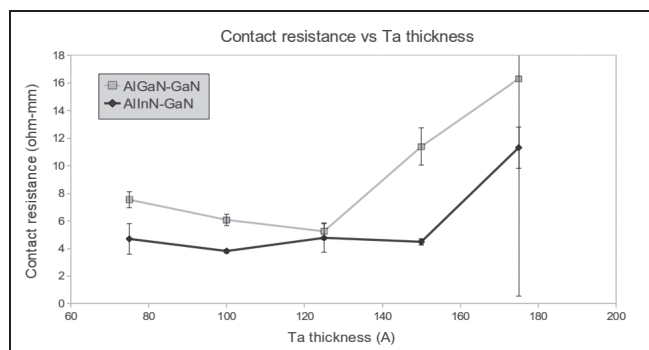


Figure 2: Contact resistance of Ta-Ti-Al-Mo-Au, as a function of Ta thickness.

These values were an order of magnitude worse than what was previously been achieved with this metal stack, which suggests an issue with either the material or the surface preparation for these experiments.

Nevertheless, it is interesting to note that the AlInN performed better than the AlGaIn in these tests, whereas traditionally AlInN has been more difficult to contact than AlGaIn. Further tests on different epilayers are needed.

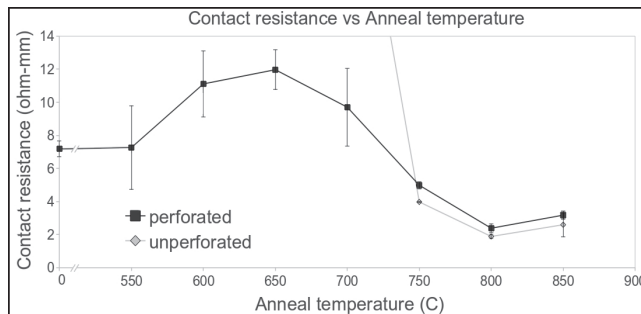


Figure 3: Contact resistance of nanoporations as a function of anneal temperature.

### Nanoporation Results:

Three stacks were tested on the perforated material and its unperforated equivalent: Ti-Al-Mo-Au (15 nm, 90 nm, 45 nm, 55 nm), Sc-Au (10 nm, 55 nm), and Ti-Au (15 nm, 40 nm). Neither the Ti-Au nor the Sc-Au formed ohmic contacts at any anneal temperature, but the Ti-Al-Mo-Au was ohmic as deposited and at every annealing temperature tested (Figure 3). The perforated contact seemed to degrade at low anneal temperatures, but then approached the performance of the unperforated contact at high anneal temperatures. Even though the perforated contact was not optimal as deposited, this was a rough first effort, and only a fraction of the contact area was patterned.

In the future, we will test alternate methods for creating the nanoporations, such as polymer self-assembly, which allows for cheaper fabrication over a larger area.

### Acknowledgments:

Special thanks to Prof. Lester Eastman and his research group, especially Quentin Diduck, Jonathan Felbinger, and Kristopher Matthews; the National Nanotechnology Infrastructure Network Research Experience for Undergraduates (NNIN REU) Program; The National Science Foundation (NSF); the Cornell NanoScale Science and Technology Facility (CNF); the CNF staff, especially Melanie-Claire Mallison and Rob Ilıc.

### References:

- [1] Quay, R. (2008). Gallium nitride electronics. Berlin: Springer.