Optimizing Annealing Temperature for Ohmic Contacts to AlGaN/GaN

CNF Summer Student: Timothy Walsh
Student Affiliation: Chemical Engineering, Cornell University

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Principal Investigator(s): Prof. Huili (Grace) Xing, ECE and MSE, Cornell University

Mentor(s): Aaron Windsor, Cornell NanoScale Science and Technology Facility, Cornell University; Joseph Dill, Applied Engineering Physics, Cornell University; Jimy Encomendero, Electrical and Computer Engineering, Cornell

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Contact: tpw29@cornell.edu, hgx2@cornell.edu, windsor@cnf.cornell.edu, jed296@cornell.edu, jje54@cornell.edu

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Primary CNF Tools Used: GCA AS200 i-line Stepper, Glen 1000 Resist Strip, SC4500 Odd-Hour Evaporator, Rapid Thermal Annealer (RTA), Zeiss Supra SEM, Bruker Energy-dispersive X-ray Spectrometer (EDS), Optical Microscope

Abstract:

As ultra-wide bandgap semiconductor research progresses, the need for reliable, low-resistivity ohmic contacts becomes more essential. To ensure high contact quality and reproducibility, process conditions must be carefully optimized. This project specifically analyzed the impact of various annealing temperatures on a Ta/Al/Ni/Au metal stack to minimize contact resistance. Previously, annealing at 830°C under N_2 ambient showed lateral metal diffusion, known as contact spreading, leading to the transistor short-circuiting and preventing the measurement of contact resistance. GaN pieces were first coated with photoresist, onto which transfer length method patterns were transferred using the GCA AS200 i-line stepper. The SC4500 Odd-Hour evaporator was then used for e-beam evaporation of 20 nm tantalum, 50 nm aluminum, 100 nm nickel, and 40 nm gold. After liftoff, the samples were analyzed and measured under the Zeiss Supra Scanning Electron Microscope (SEM). The samples were then annealed in N_2 ambient at temperatures ranging from 500, 600, 700, 800, and 900°C. Using the SEM and its Energy Dispersive Spectroscopy (EDS), the spreading of the metals was measured. Lastly, using the transfer length method, the optimal annealing conditions for the lowest contact resistance were explored.

Summary of Research:

Silicon Process & Results. The spreading under investigation was seen previously on a 20 nm tantalum, 150 nm aluminum, 50 nm nickel, and 50 nm gold stack on GaN. Thus, the process started by recreating this metal stack onto four 8 × 8 mm Si pieces in order to trial the process. First, each piece was cleaned with sonication in acetone, isopropyl alcohol, and deionized water for five minutes each. Then, to remove any excess moisture, the pieces were placed on a hotplate at 110°C for five minutes. From there, AZ NLOF 2020 negative photoresist was spun onto each piece, with a target width of 1.1 μm, and then they were baked at 115°C for 60 seconds. The GCA AS200 i-line stepper exposed each piece in four spots with an Ohmic contact mask. After baking these pieces again at 115°C for 60 seconds on a hotplate, they developed in 726 MIF for 60 seconds, removing the unexposed

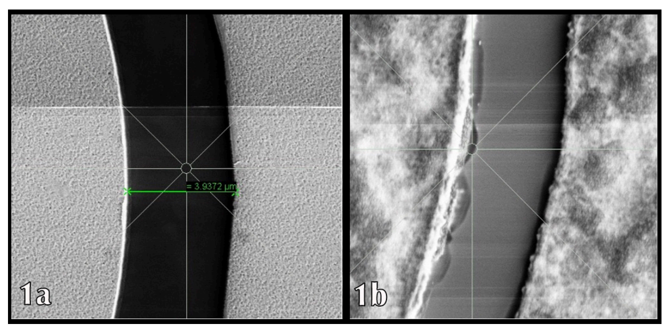

Figure 1: (a) Si Sample 2 µm Gap Pre-anneal. (b) Si Sample 2 µm Gap Annealed at 850°C.

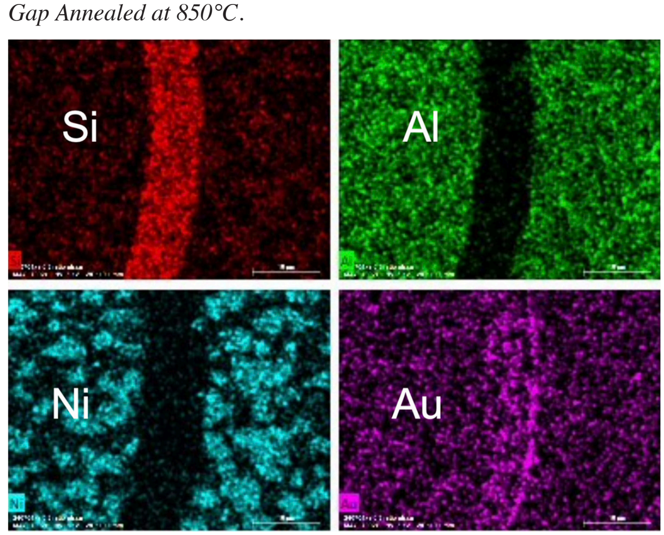

Figure 2: Si Sample 2 µm Gap Annealed at 700°C.

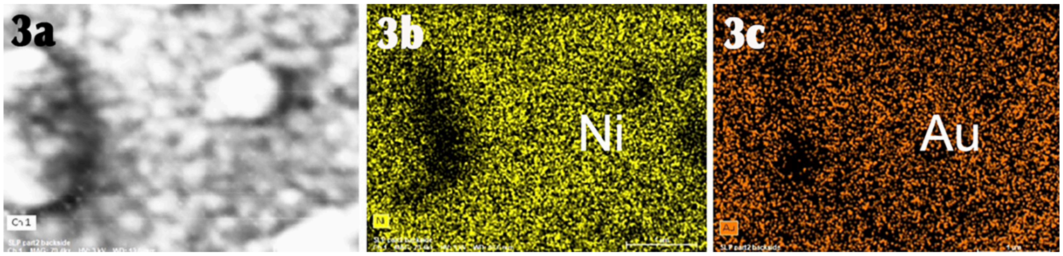

Figure 3: (a) GaN SEM Image. (b): Ni EDS. (c) Au EDS.

photoresist. The Glen 1000 Resist Strip removed any excess organic matter or resist on the pieces. To deposit the metal stack, the SC4500 Odd-Hour electron beam evaporator was used. Liftoff consisted of 10 minutes in Microposit Remover 1165, five minutes isopropyl alcohol, both in sonication, then a rinse with deionized water. Under the Zeiss Supra SEM, the Circular Transfer Length Method (C-TLM) spacings were measured, and EDS baseline images were taken. Then, the four pieces were annealed at 700, 750, 800, and 850°C for 60 seconds under N_2 ambient in the Rapid Thermal Annealer (RTA). Again, the pieces were analyzed under the SEM with EDS to examine any spreading.

Before annealing, the circle lines were crisp, as seen in Figure 1(a). After annealing, visual spreading of aluminum could be seen under both the optical microscope and the SEM, as in Figure 1(b). Additionally, annealing induced nickel clumping. This can be seen in the EDS images in Figure 2. This effect is likely due to the high surface energy of nickel. Since aluminum melts at 660°C, it likely forms a liquid at an annealing temperature above this. Because the nickel sits atop this aluminum liquid, to reduce its surface energy, the nickel obtains a lower surface energy by forming spheres. This causes the clumping effect.

GaN Process and Results. The fabrication process with five 10 × 10 mm GaN pieces was identical to that of the Si pieces, except before the electron beam deposition, the pieces were cleaned in HCl, deionized water, BOE, and deionized water again for 60 seconds each. Additionally, the Ta/Al/Ni/Au metal stack was changed to 20 nm tantalum, 50 nm aluminum, 100 nm nickel, and 40 nm gold. The intention was to reduce the amount of aluminum liquid that the nickel layer sits atop to prevent the nickel clumping. Also, the thickness of nickel was doubled to encourage it to remain flat instead of clumping and forming spheres. The five GaN pieces were annealed at 500, 600, 700, 800, and 900°C, and the 800°C sample was measured on a probe station.

On GaN, there was no visual spreading as there was on the Si, but a "bubbling" effect was observed. This bubbling is evident in Figure 3(a). Figure 3(b) and 3(c) show that these bubbles are actually voids of gold and nickel, so they are different from the nickel clumps seen on Si. Annealing the GaN at 800°C increased the amount of current that could pass through the contact by roughly two orders of magnitude, as shown in Figure 4. Although, the contact is still not Ohmic, as Current vs Voltage is not linear.

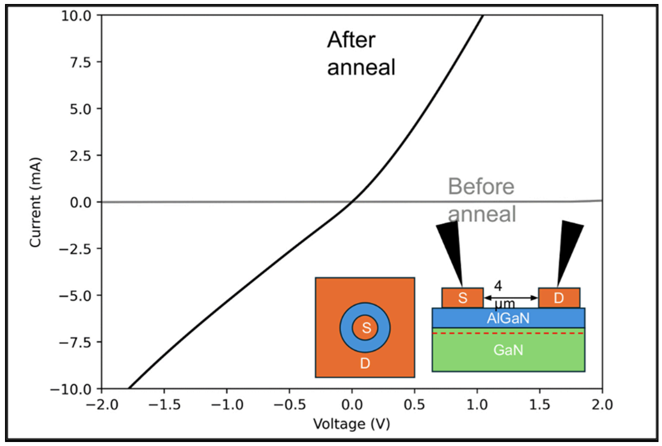

Figure 4: TLM Measurement for 800°C GaN Sample.

Conclusion and Future Steps:

Varying the annealing temperature of the Ta/Al/Ni/Au stack on GaN from 500 to 900°C showed minimal spreading but an increasing "surface bubbling" effect as temperature increases. Nickel clumping as well as spreading on the Si pieces was evident after annealing, and future TLM measurements on the GaN pieces will determine the annealing temperature with the lowest contact resistance.

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