Investigating the Lateral Spreading of Vanadium-Based Ohmic Contacts

CNF Summer Student: Fabiana P. Mayol López
Student Affiliation: Department of Natural Sciences, Ana G. Méndez University, Gurabo Campus

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

Mentor(s): Joseph Dill, Department of AEP, Cornell University; Shivali Agrawal Department of CBE, Cornell University; Xianzhi Wei, Department of MSE, Cornell University

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Contact: anapao73@outlook.com, hgx2@cornell.edu, jed296@cornell.edu, sa2368@cornell.edu, xw694@cornell.edu

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Primary CNF Tools Used: SC4500 Odd-Hour Evaporator, Zeiss Supra Scanning Electron Microscope, Bruker Quantax 200 Energy Dispersive X-Ray Spectroscopy (EDS), GCA AS200 i-line Stepper, Glen 1000 Resist Strip, RTA-AG610b

Abstract:

Aluminum gallium nitride (AlGaN) is a material of interest for the development of UV-emitting photonic devices. Vanadium-based metal stacks are a popular means of forming ohmic contacts to n-type AlGaN. However, these metal stacks must be annealed to temperatures above 600°C [6] for VN to form during which the metals in the ohmic contact stack can spread laterally and short patterned devices. The aim of this study is to determine the annealing conditions that minimize the lateral spreading of V/Al/Ni/Au stacks and investigate the behavior of these stacks under annealing. Metal stacks were patterned on 8 × 8 mm silicon (Si) pieces and annealed for different temperatures and times. A "safe zone" of annealing conditions that didn't short the devices was determined. The amount of spreading was determined from scanning electron microscope (SEM) images of C-TLM structures. We also observed a "balling up" of the Ni under annealing, likely due to its high surface energy. This observation motivates switching Ni to a metal with a lower surface energy in future studies.

Summary of Research:

Background. Since the first realization of the GaN blue LED in 1993 [1], research attention has been devoted to AlGaN-based light-emitting devices that would emit invisible UV light. Such devices would enable many novel technologies, including chemical-free sterilization of medical equipment and water purification [2]. One key challenge to this end is the formation of ohmic contacts to n-type AlGaN. Several studies have achieved low resistance contacts using annealed V/Al/X/Au metal stacks [6,7]. When annealed in N_2, V alloys with N to form VN on the surface, which has a work function of 3.55 [5]. The Al helps form donor-like N vacancies in the AlGaN, and Au prevents oxidation and provides a soft surface for electrical probing. X is the "diffusion barrier" metal, usually V or Ni. However, annealing these metal stacks often leads to strange and undesirable metallurgical effects, such as the formation of Ni domains [7].

Methods. Annealed metal pads were fabricated on 8 × 8 mm Si pieces as follows:

1. Si pieces were cleaned in acetone, isopropyl alcohol (IPA), and deionized water for five minutes each with sonication to remove any organic contamination from the surface.
2. Pieces were spin-coated with AZ nLOF 2020 negative photoresist and baked.
3. Circular transmission line method (C-TLM) patterns were exposed using the GCA AS200 i-line Stepper, followed by a post-exposure bake.
4. The pattern was developed in 726 MIF developer for 30 sec.
5. An ozone descum was performed to remove all residual undeveloped photoresist.
6. A metal stack of 20 nm of V, 80 nm of Al, 40 nm of Ni, and 100 nm of Au was deposited by electron-beam evaporation (see Figure 1).
7. Liftoff was performed by immersing the pieces in Microposit Remover 1165 and IPA with sonication.
8. Each sample was annealed in N_2 ambient. The anneal times and temperatures for each sample are shown in Figure 2a.

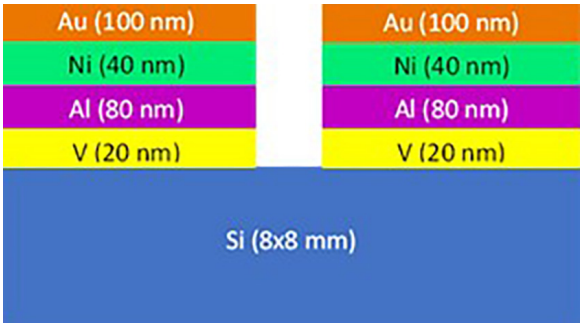

Figure 1: Cross-sectional view of sample.

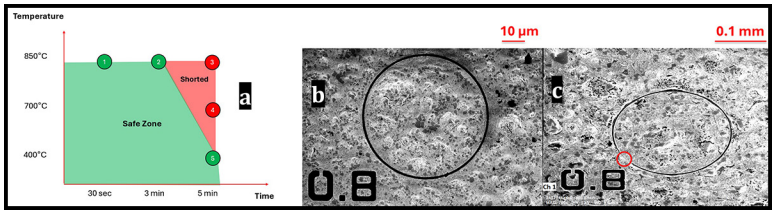

Figure 2: Plot of each annealed sample with temperature vs time annealed in (a). Post-anneal SEM images in (b) sample 1: 850°C, 30 seconds and (c) sample 3: 850°C, five minutes. Red circle indicates shorting the in the C-TLM pattern.

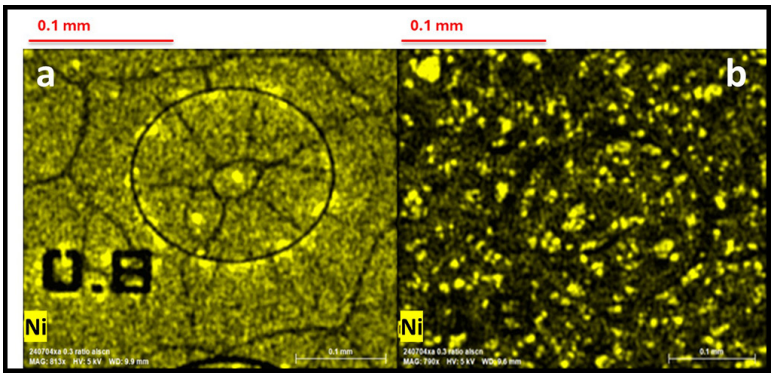

Figure 3: EDS map of Ni in (a) sample 5: 400°C, 5 minutes and (b) sample 3: 850°C, five minutes.

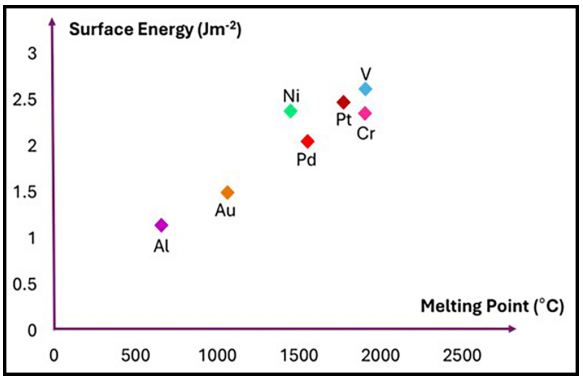

Figure 4: Plot of surface energy vs melting point. Values obtained from [4].

Results. Figures 2b and 2c show SEM images of a C-TLM structure with 0.8 μm spacing on samples 1 and 3, annealed at 850°C for 30 sec and 5 min, respectively. The red circle in 2c indicates a point where the C-TLM pad was shorted due to lateral spreading of the metal during annealing. The annealing conditions that did and didn't result in shorting of the 0.8 μm pattern are summarized in Figure 2a. The annealing conditions for samples 1, 2, and 5 establish a "safe zone" in which annealing didn't cause shorting.

The annealed samples were imaged with Electron Dispersive X-Ray Spectroscopy (EDS) to investigate the motion of the constituent metals in the stack during annealing. As seen in Figure 3, Ni was observed to coalesce, forming domains that decreased in size with increasing anneal temperature. In sample 5, annealed at 400°C for 5 minutes, ~ 40 μm-wide domains formed (see Figure 3a), and in sample 3, annealed at 850°C for 5 minutes, ~ 5 μm-wide domains formed (see Figure 3b). This is likely a result of nickel's high surface energy.

Conclusions and Future Steps:

During annealing, a metal can minimize its surface energy by forming a spherical shape rather than remaining flat. These spheres will be tighter at higher temperatures to minimize the additional thermal free energy. We observe the initial stages of this in Figure 3a wherein the Ni begins forming wide domains, presenting a "cracked" appearance. Ni's tendency to ball up during annealing is *used* by Shi, et al. to form Ni nanoparticles annealing sputtered Ni thin films [3].

Considering these findings, future ohmic contact stacks should utilize a diffusion barrier with a lower surface energy than Ni. The surface energies and melting points of V, Al, Ni, Au, and alternate diffusion barrier metals (Pd, Pt, Cr) are benchmarked in Figure 4. Of the candidate metals, Pd has the lowest surface energy. Future studies should also be conducted on AlGaN, rather than Si, such that the electrical performance of the ohmic contacts can be investigated in parallel with the metallurgical behavior under annealing.

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