Wet Etching of N-Polar AlN on NbN for Novel III-N Device Applications

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Abstract:

Typically, the highest quality thin film heterostructures achieved via epitaxial growth techniques prefer a blanket growth condition, covering the entire substrate. For device applications that demand a buried metallic layer, one must use subtractive fabrication techniques to access the buried metallic layer. In this report, we show that a KOH-based wet etch can be used to selectively etch N-polar AlN thin films with selectivity to a buried, metallic, NbN.

Summary of Research:

Over the past few decades, the III-N material system has developed into a particularly rich family of materials, playing key roles in the photonics [1], electronics [2], MEMs [3] device families — and more recently, the development of ferroelectric, magnetic, and metallic materials [4]. For III-N devices grown via epitaxial techniques, often it is preferred to grow a heterostructure or segments of a heterostructure in a blanket fashion, spanning the entire substrate. In this growth condition, one must define individual device mesas in a subtractive fashion. Recent growth efforts have shown that single crystalline wurtzite AlN can be grown on metallic, superconducting, NBN on 6H-SiC substrate by molecular beam epitaxy (MBE) [5,6]. For high frequency device applications looking to access this buried metallic NbN, but utilize a semi-insulating (SI) SiC substrate, one must etch a via through the top nitride heterostructure or through the entire SiC substrate.

Initial attempts to access the buried NbN layer via ICP-RIE etching revealed poor etch selectivity of AlN to NbN. For instance, a typical Cl- (BCl_3: 10 SCCM, Cl_2: 20 SCCM) and Ar-based (Ar72: 10 SCCM) etch in the PT 770 yielded an etch rate was ~ 1 nm/s, while the epitaxial NbN layer etched at ~ 2-4 nm/s under the same conditions. Over this past year, we have found one can access a buried NbN with relative ease using a two-step ICP-RIE and wet etch, overcoming the difficulty to etch 6H-SiC [7,8]. The process is shown schematically in Figure 1.

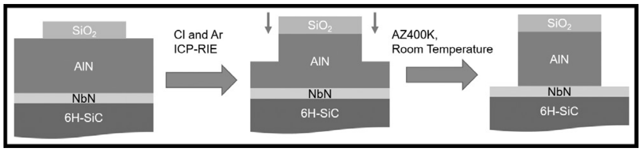

Figure 1: Schematic depiction of the two-step ICP-RIE and wet etch process. To overcome a lack of etch selectivity of AlN to NbN, etch through a small amount of remaining N-polar AlN (<200 nm) with room temperature AZ 400K.

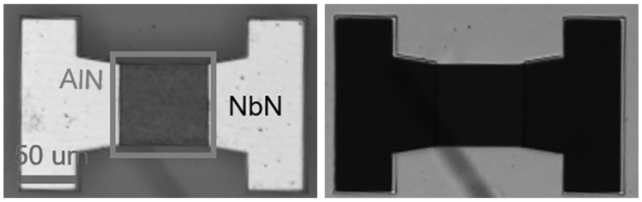

Figure 2: Optical microscope images of exposed NbN with a square AlN mesa (10,000 µm²) post AZ 400K etch. The surrounding region is transparent 6H-SiC substrate. The thickness of the AlN mesa was 330 nm, and the height of the buried NbN was 24 nm. (a) Bright field illumination, and (b) dark field illumination. The NbN is thick enough such that it remains reflective under illumination, and the 6H-SiC substrate is optically transparent. Hence, the exposed NbN is reflective under bright-field illumination, and strongly blocks light under dark-field illumination, showing the buried NbN remains continuous under the AlN mesa.

First, the same ICP-RIE etch was applied to remove a majority of the AlN, with a PECVD SiO_2 etch mas. Then, using the same SiO_2 etch mask from the first step, the remaining (<200nm) AlN was then removed by using a dilute KOH wet etch, in the photolithographic developer AZ400K, at room temperature in under five minutes.

The exposed NbN remains conductive at room temperature, and is continuous underneath an AlN mesa.

Here, we show process results of a 330 nm thick AlN and 24 nm thick NbN heterostructure grown via MBE. Optical microscope images of the exposed NbN surface post-exposure to AZ400K are shown in Figure 2. No visible etching of the exposed NbN layer was detected, as verified by profilometry. Little lateral etching (<1µm) for AlN mesas with areas on order of 10,000 μm^2. The uniformity and speed of the etch in room temperature dilute KOH was attributed to an N-polar AlN surface (also observed by TEM in ref [6]), where KOH simultaneously serves as a catalyst in the oxidation of N-polar AlN and as a solvent for an Al_2O_3 product [8,9].

Conclusions and Future Steps:

Looking forward, we plan to see if the etch translates to N-polar GaN, and eventually more complicated III-N heterostructures. In principle, an etch selective to nitride semiconductors over metallic NbN would provide a potential pathway to dramatically scale various nitride electronics via epitaxial growth techniques. In the high frequency electronics arena, we are using the two-step etch to explore a novel bulk overtone acoustic wave resonator on 6H-SiC10 as well as a means to back-gate AlN-GaN-AlN "quantum well" high electron mobility transistors 11].

References:

[1] Akasaki, I. Nobel Lecture: Fascinated journeys into blue light. Reviews of Modern Physics 87, 1119-1131 (2015).

[2] Eastman, L. F. and Mishra, U. K. The toughest transistor yet [GaN transistors]. IEEE Spectrum 39, 28-33 (2002).

[3] Mahon, S. The 5G Effect on RF Filter Technologies. IEEE Transactions on Semiconductor Manufacturing 30, 494-499 (2017).

[4] Jena, D., et al. The new nitrides: layered, ferroelectric, magnetic, metallic and superconducting nitrides to boost the GaN photonics and electronics eco-system. Japanese Journal of Applied Physics 58, SC0801 (2019).

[5] Meyer, D. J., et al. Epitaxial Lift-Off and Transfer of III-N Materials and Devices from SiC Substrates. IEEE Transactions on Semiconductor Manufacturing 29, 384-389 (2016).

[6] Yan, R., et al. GaN/NbN epitaxial semiconductor/superconductor heterostructures. Nature 555, 183-189 (2018).

[7] Okamoto, N., et al. SiC Backside Via-hole Process for GaN HEMT MMICs Using High Etch Rate ICP Etching. 5 (2009).

[8] Zhuang, D. and Edgar, J. H. Wet etching of GaN, AlN, and SiC: a review. Materials Science and Engineering: R: Reports 48, 1-46 (2005).

[9] Guo, W., et al. KOH based selective wet chemical etching of AlN, Al x Ga 1-x N, and GaN crystals: A way towards substrate removal in deep ultraviolet-light emitting diode. Applied Physics Letters 106, 082110 (2015).

[10] Miller, J., Wright, J., Xing, H. G. and Jena, D. All-Epitaxial Bulk Acoustic Wave Resonators. physica status solidi (a) 217, 1900786 (2020).

[11] Hickman, A., et al. High Breakdown Voltage in RF AlN/GaN/AlN Quantum Well HEMTs. IEEE Electron Device Letters 40, 1293-1296 (2019).