High Aspect Ratio Al-Rich AlGaN Etching Technology for FinFET Fabrication

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Future mm-wave 5G and 6G networks require power amplifiers with unprecedented levels of power density, gain, efficiency, and linearity. Although GaN-based High Electron Mobility Transistors (HEMTs) have demonstrated excellent results, the use of ultra-wideband gap semiconductors such as AlGaN could enable an even higher Johnson figure of merit due to its superior breakdown electric field (> 8 MV/cm), and subsequently higher power densities and efficiencies beyond 30 GHz [1]. New device architectures are however needed to overcome the relatively low mobility of this material system.

Here, we propose a multi-channel epitaxial structure (for higher sheet charge density) combined with a FinFET architecture (for better electrostatic control) to demonstrate Al-rich AlGaN transistors for mm-wave operation. The proposed epitaxial structure consists of five layers of graded $Al_xGa_{1-x}N$ (x = 0.75→0.99) grown by MOCVD on an AlN template. Each of the graded layers contribute to a polarization-induced 3-dimensional electron gas (3DEG) with a density of ~ 1.3×10^{13} cm^{-2}, giving a total electron density of ~ 6.5×10^{13} cm^{-2}. The polarization-induced channel eliminates the need for doping and improves the channel mobility due to the absence of impurity scattering.

Among all the FinFET-related processing steps, the formation of high aspect ratio fin array with smooth and vertical sidewalls is the least studied one. Although high aspect ratio fins have allowed GaN FinFETs [2] to deliver excellent performance, a robust process technology for such fins has not been reported yet, in spite of the increasing attention on high Al-content AlGaN electronics. In this work we used a two-step Inductively Coupled Plasma - Reactive Ion Etching (ICP-RIE) with BCl_3/Ar breakthrough followed by the main Cl_2/Ar (20/20 sccm) etch at a base pressure of 6 Pa. This 1 µm deep etch resulted in relatively smooth sidewalls but not a fully vertical profile. A subsequent wet treatment using 25% tetramethylammonium hydroxide (TMAH) at 85 °C resulted in highly vertical fins, in addition to smoother sidewalls. As with GaN, the TMAH etch was found to be crystallographic orientation-dependent with an etch rate of 42 nm/min on the *m*-plane and 56 nm/min on the *a*-plane. Through process optimization, tall fin arrays with a ~ 16:1 aspect ratio (height =1.5 µm, fin-width = 90 nm) were obtained with smooth sidewalls.

In conclusion, a novel fin-etching technology for Al-rich AlGaN has been demonstrated that enables smooth and vertical fins with a 16:1 aspect ratio (achieving 90 nm fin width). Our current work uses this technology to demonstrate high aspect ratio Al-rich AlGaN FinFETs.

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[1] H. Xue et al., *Appl. Phys. Lett.*, 2019 [2] Y. Zhang et al., *EDL*, 2019.

Supplementary information

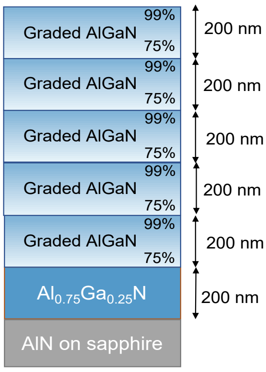


Fig. S1: Epitaxial structure

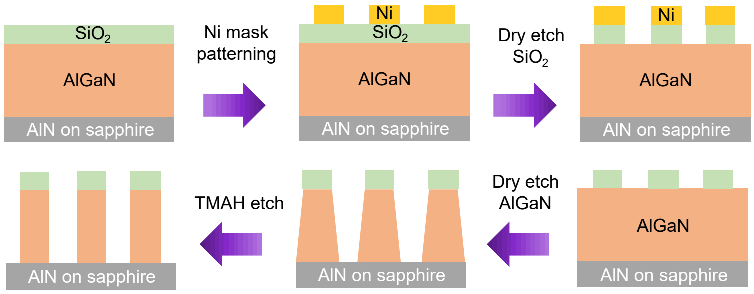


Fig. S2: Schematic of process flow

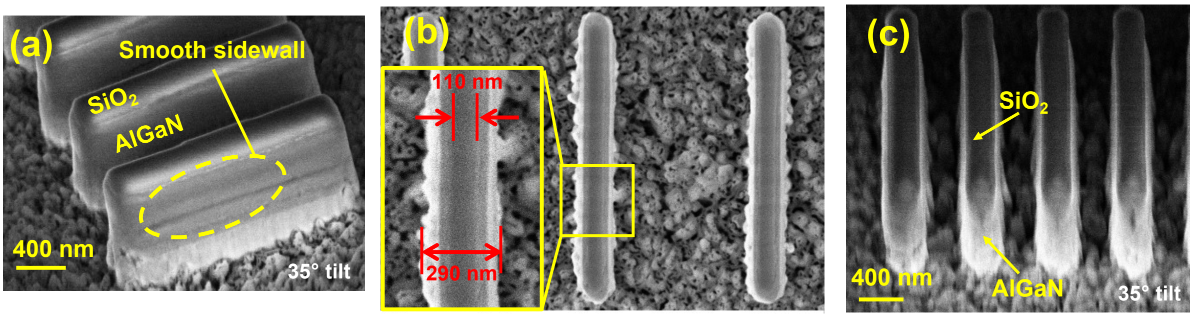


Fig. S3: Formation of AlGaN fin array using dry etching. (a) Smooth sidewall of fin. (b)—(c) Almost vertical sidewall at 88°.

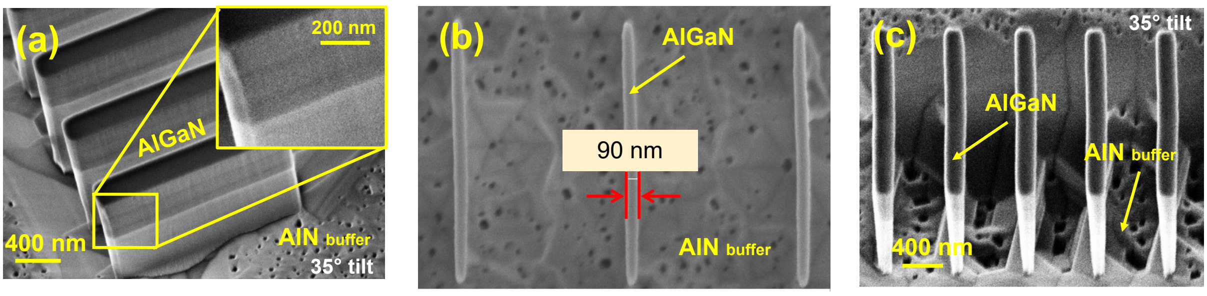
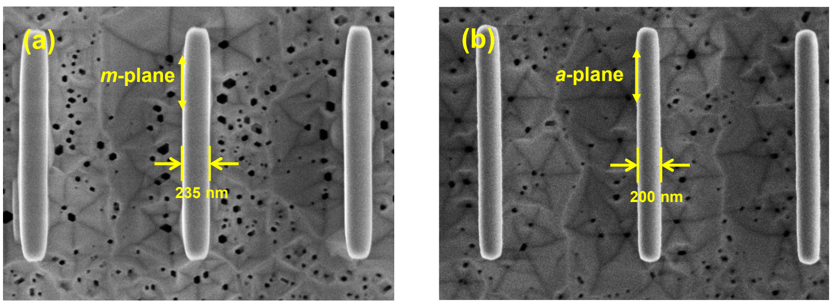


Fig. S4: Further smoothening of sidewall after hot (85°C) 25% TMAH treatment. (a) Smooth sidewall of fin. (b) Ultra-scaled fins achieving width = 90 nm. (c) Completely vertical profile of tall fins (height=1.5 µm). Notice the smoothening of the bottom of the fin as compared to Fig. S3(c).



Plane	*m*	*a*
Fin width (before) (nm)	340	
Fin width (after) (nm)	235	200
Approx. etch rate (nm/min.)	42	56

Fig. S5: Crystallographic orientation-dependence of TMAH etch rate for Al-rich AlGaN fins: (a) Fins aligned along *m*-plane. (b) Fins aligned along *a*-plane. (c) Summary of TMAH etch rate.