Development of an atomic layer etch process via repeated cycling of chloride formation in chlorine gas and its argon plasma removal for precision nanometer scale thin layer etch in GaN-based power device fabrications

Xu Li[1], Konstantinos Floros[1], Sung-Jin Cho[1], Ivor Guiney[2], David Moran[1] and Iain G Thayne[1]

[1]*School of Engineering, University of Glasgow, Rankine Building, Oakfield Avenue, Glasgow, G12 8LT, Scotland, UK*

[2]*Department of Materials Science and Metallurgy, University of Cambridge, 27 Charles Babbage Road, Cambridge, CB3 0FS, UK*

phone: +44-141-330-6024, fax: +44-141-330-4907

e-mail: xu.li@glasgow.ac.uk

1. Introduction

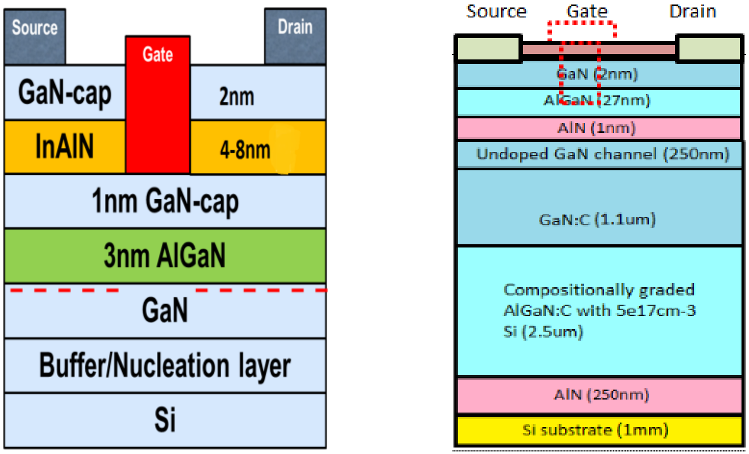
ALE (Atomic Layer Etch) as a technique that removes very thin layers of material precisely using sequential self-limiting reactions has been considered one of the most promising techniques for achieving the low process variability necessary in the atomic-scale era [1]. On the other hand, for last decade around, AlGaN/GaN based HFETs have attracted intensive investigation due to their applications in power electronics [2]. Recent device fabrication, e.g. integrated cascode type device, requires very precisely control for etching only a couple of nanometer materials [3]. In this work, an atomic layer etching process for etching group III nitrides has been developed based on a cycled procedure of Cl_2 chlorination and argon plasma removal of the chlorides, which is suitable for fabricating devices based on III-nitrides, such as materials AlGaN, GaN, AlInN, AlN.

2. Experiment and Results

An Oxford Instrument PlasmaLab Inductively Coupled Plasma (ICP) etching system with repeat loop function has been used in this investigation. The etching chemistry was based on the formation of self-limited Al, Ga and In chlorides on the sample surface in Cl_2 gas or Cl_2 plasma and followed by a removal step using Ar plasma at an optimized RF power level at which the plasma only remove the chlorides on the surface but not the nitrides underneath.

The basic devices could be fabricated by this process have been shown in Fig. 1, where A on the left shows an e-mode device in a dual barrier structure for cascade type devices and B on the right also shows a possible e-mode device fabricated on a normal d-mode structure materials. The materials etched were GaN, AlGaN, AlInN, or AlN based materials on Si wafer grown by MOCVD and patterned by Shipley photo resist S1818.

Etching was investigated under various etching conditions including optimizing chlorination in Cl_2 plasma or Cl_2 gas only, such as time of chlorination, gas flow rate, gas concentration, chamber pressure, and optimizing the Ar plasma removal, such as RF power, chamber pressure, and reaction time. Etched surface, etching depth and etching profile were characterised by AFM, SEM, and TEM. The two figures below showed some typical key parameter optimisations. Fig. 2 shows the effect of Ar plasma power on the etch rate for the chloride removal. Under the optimised condition, Ar plasma would only etch the chlorides but not the underneath III-nitrides. Fig. 3 shows the effect of the flow and the dilution of Cl_2 in Ar on the etch rate to achieve a stable and well controlled atomic layer etch process in the etch tool used here.



A: Dual barrier structures e-mode device   B: Gate recessed for e-mode device

Fig. 1 Scheme of device fabrications requiring precision thin layer etching of III-nitrides

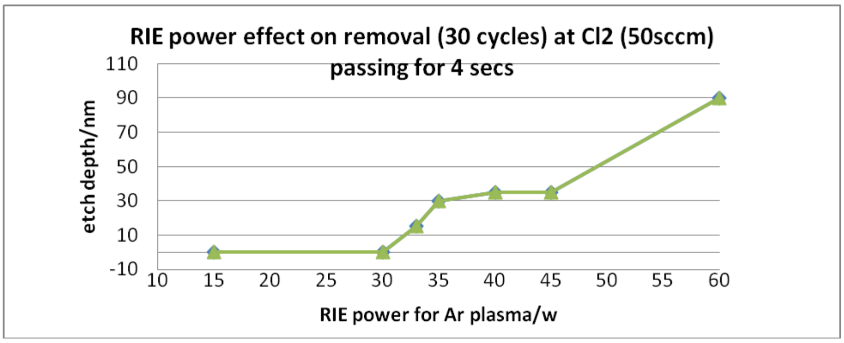


Fig. 2 Effect of RF power on etch depth (fixed 30 cycles) at a fixed chlorination condition

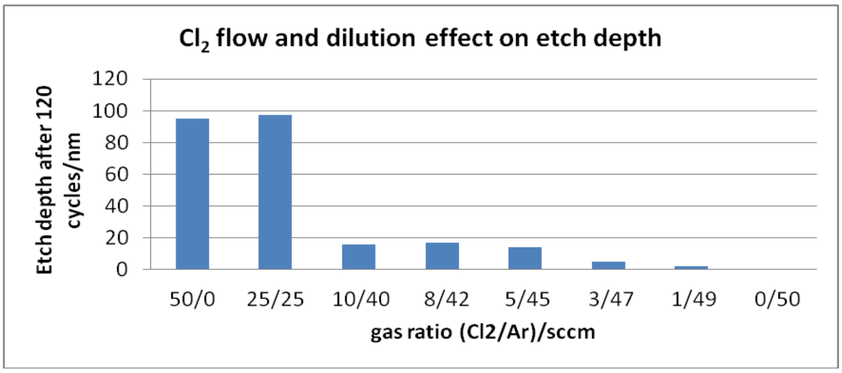


Fig. 3 Effcet of Cl_2 flow and dilution in Ar with passing time of 1 sec (after etching for 120 cycles)

Acknowledgments

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