On the Surface Properties of High Aspect Ratio β-Ga_2O_3 Fin Structures Formed by I-MacEtch

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To enable 3D β-Ga_2O_3 based high power and high frequency electronics [1], it is imperative to develop device quality high aspect ratio structures. Although traditional dry etch methods have been demonstrated to be somewhat effective, the recently emerged etching approach, metal-assisted chemical etching (MacEtch) [2], has the potential advantage of less damage, more versatile, and much less costly. Here we report on the successful formation of β-Ga_2O_3 fin structures with varied cross-sectional profiles, with aspect ratios > 50:1, by inverse-MacEtch (I-MacEtch) and characterize the surface properties of the etched structures by Schottky barrier diodes and MOS capacitors.

MacEtch [3] is an anisotropic semiconductor etching technique, but does not involve high energy ions or external electrical field as in reactive ion etching (RIE). It uses a chemically stable thin layer of noble metal acting as a catalyst to initiate and define the etch process spatially in a solution that usually consists of an oxidant and an acid. In forward MacEtch, only the semiconductor material directly underneath the metal catalyst gets etched away, leaving the catalyst sinks into the semiconductor and forming a 3D semiconductor structure that is complimentary to the catalyst pattern. I-MacEtch, on the other hand, uses the metal catalyst as a catalytic mask, where etching initiates in-between the catalyst covered the areas before propagating underneath the catalyst, leaving the catalyst sitting at the top of the surface throughout the process. The nature of MacEtch that eliminates high energy ion related damage and subsequent high-temperature annealing thermal budget should ensure high interface quality between the etched surfaces and subsequently deposited layers above including gate dielectric [4] or heterojunctions.

Following our recent report on using Pt I-MacEtch to produce nanoscale groove textured β-Ga2O3 MSM photodiodes with enhanced responsivity [5], we now report the formation of high aspect ratio fin arrays with the fin cross-sectional profile strongly dependent on the orientation of the Pt catalyst strips. Figure 1 and 2 are the SEM and TEM images, respectively, to show the morphology, topography and atomic resolution fin structures. Figure 2 shows the characterization of 3D fin-like Pt/β-Ga_2O_3 Schottky diodes, with the SBHs varied as a function of the fin geometry and all reduced when benchmarking with the un-etched planar surface. Figure 3 shows the characterization of the 3D fin-like Au/Ti/Al_2O_3/β-Ga_2O_3 MOS capacitors, which display lower interface trap density than their planar counterpart. Detailed discussion including XPS analysis will be presented.

Acknowledgement: This work was supported in part by a grant from NSF ECCS #18-09946.

References: [1] Appl. Phys. Lett. 112(6), 060401 (2018). [2] Curr. Opin. Solid State Mater. Sci. 16, 71 (2012). [3] Appl. Phys. Lett. 77, 2572 (2000). [4] IEEE Elec. Dev. Lett. 37, 970 (2016). [5] Appl. Phys. Lett. 113, 222104 (2018).

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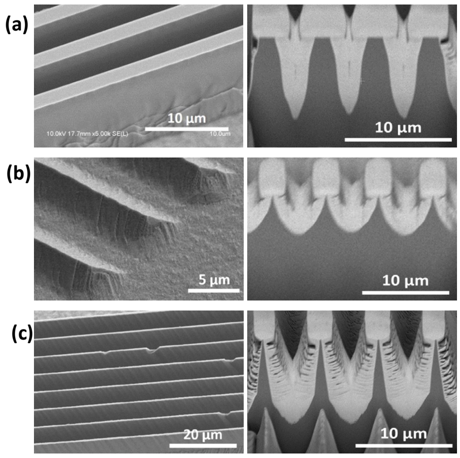
(F1)



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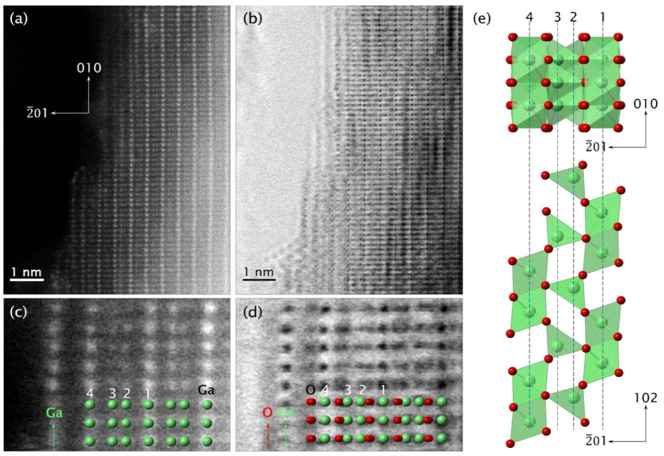

Fig. 1 Tilted (left) and FIB cross-sectional (right) view SEM images of β-Ga2O3 fin arrays formed by I-MacEtch: (a) trapezoidal, (b) pyramidal, and (c) nearly-vertical fin structures. Note tjat in the FIB cross-section images, the bright region covering the vertical structures are Pt protection layers deposited during the FIB process.

Fig. 2 (a) STEM-HAADF image of the β-Ga_2O_3 structure. The zone axis is [102]. (b) Corresponding STEM-ABF image. (c) and (d) Enlarged HAADF and ABF images, respectively, overlapping with projected crystal structure model along [102]. (e) Projected structure model along [102] and [010].

(F3)

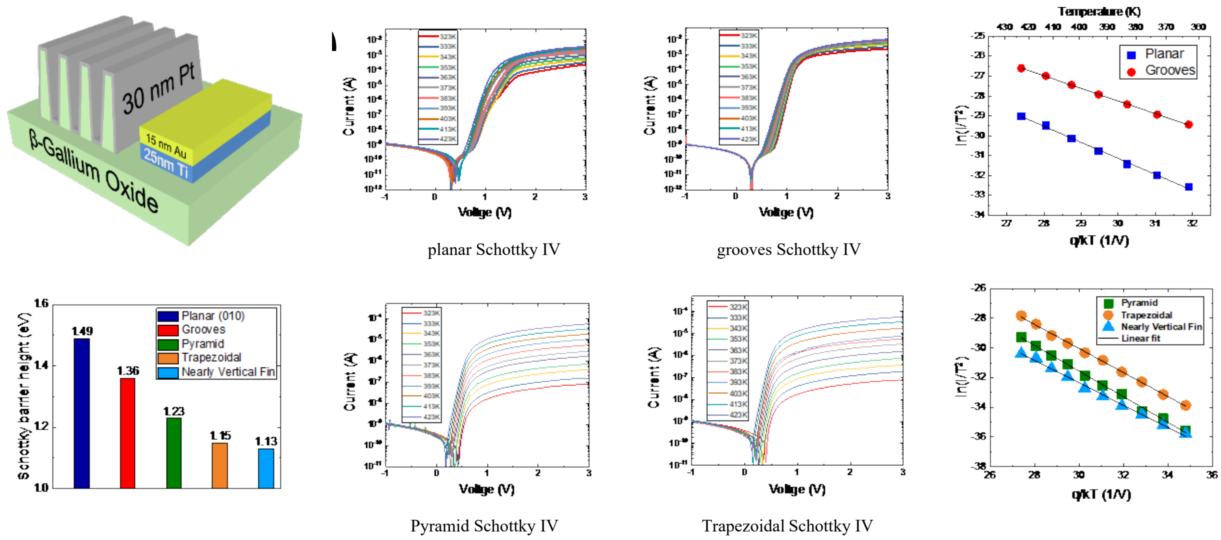

Fig. 3 (**a**) Schematic diagram of Pt/β-Ga_2O_3 Schottky diodes with MacEtch-formed fin structures. (**b-e**) I-V characteristics measured at temperatures from 323K to 423K. (**f-g**) $\ln(I/T^2)$ vs q/kT plots of planar (unetched) and nano-grooved structures (**f**) and pyramidal, trapezoidal and nearly vertical fin structures, with ideality factors of 1.17, 1.09, 1.18, 1.1 and 1.06, respectively. (**h**) The extracted Schottky barrier height values for all structures as labeled.

(F4)

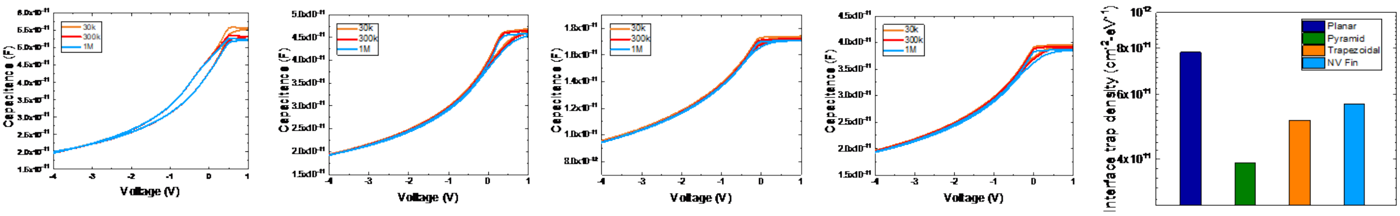

Fig. 4 (**a-d**): Frequency-dependent C-V measurements of Au/Ti/Al_2O_3/β-Ga_2O_3 MOS capacitors with (a) unetched planar, (b) pyramidal, (c) trapezoidal, and (d)nearly-vertical fin structures formed by i-MacEtch. (**e**) Extracted interface trap density values of these structures as labeled.