Selective Area Growth of β-Ga_2O_3

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Abstract

Selective area growth (SAG) is emerging as an innovative method to fabricate complex 3D device structures. It has potential to achieve edge termination, faceted structures, to name a few. Here, SAG of β-Ga_2O_3 using metal-organic chemical vapour deposition (MOCVD) on c-plane sapphire followed by HF lift-off was demonstrated. Post-HF etching combined with ultrasonication achieved complete removal of the mask and expose the regrown pattern. An $(Al_xGa_{1-x})_2O_3$ capping layer is found to be highly effective in reducing the etching damage of the surface during the manufacturing process.

Introduction

III-V compound semiconductors have ruled power and radio frequency (RF) applications. With the advent of wide bandgap (WBG) semiconductors, especially GaN, unprecedented, rugged RF amplifiers and power converters have been demonstrated and have opened new application spaces. Owing to the availability of melt growth substrates and its ultrawide band gap, Ga_2O_3 has become the new favourite for next-generation power devices beyond GaN and SiC. Due to the wider bandgap, Ga_2O_3 boasts a theoretical breakdown voltage of 8 MV/cm, almost three times larger than SiC and GaN. Devices with breakdown voltages as high as 8.32 kV were recently reported, well surpassing GaN and SiC [1].

Metal-organic chemical vapor deposition (MOCVD) has established itself as an industry standard for manufacturing thin films with precise doping and thickness. However, to achieve complex 3-D structures, etch techniques such as RIE must be employed with the potential for etch damage, generating trapping, and potentially even degrading mobility dependent on process conditions [2-4]. SAG can play a major role in simplifying fabrication processes e.g. for forming damage-free sidewalls of FINFET-like structures. Hence SAG has the potential to transform device manufacturing.

Recently, halide vapour phase epitaxy (HVPE) for β-Ga_2O_3 [5] and mist-CVD for α-Ga_2O_3 [6] have been reported to successfully achieve SAG layers and epitaxial layer overgrowth (ELO), respectively. The parasitic reaction during the SAG growth of β-Ga_2O_3 using HVPE is usually suppressed by the addition of HCl gas during the growth [7]. The HVPE growth, however, typically includes a high density of impurities. Whereas MOCVD is the industry-preferred growth technique for the active part of a device. This study demonstrates a simple and highly repeatable SAG growth of β-Ga_2O_3 with excellent epitaxial layer quality.

Experimental Details

Patterned dielectric masks, using laser writing and lift-off, of various thicknesses were prepared on c-plane sapphire substrates with PECVD. Growth of β-Ga_2O_3 was performed in an Agnitron Agilis 100 MOCVD system. Growth parameters were adjusted to minimise parasitic growth over various dielectric mask; SiO_2, SiN_x and Al_2O_3 masks were explored.

Results and Discussion

Deposition of β-Ga_2O_3 was performed at 880°C with 60 Torr pressure with a VI/III ratio of 1344. Fig. 1 (a) shows SEM micrographs of the as-grown β-Ga_2O_3. As seen, there is some poly-crystalline deposition over SiO_2-masked surfaces irrespective of growth parameters; similar residual growth was observed for a SiN_x mask with poly-crystalline Ga_2O_3 forming on top of the mask while for an Al_2O_3 mask singe-crystalline Ga_2O_3 was formed on top of the mask. This confirms recent HVPE studies [5] stating that HCl is a key

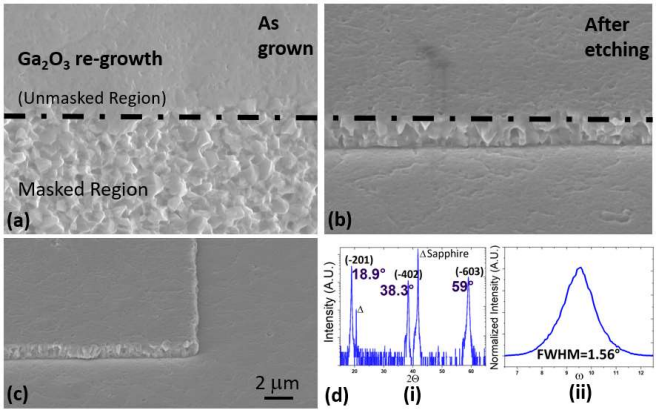

Figure 1. SEM micrographs (a) before, and (b) and (c) after etching of sample in 47% concentrated HF solution for 17 hours. (d) (i) 2Θ–ω XRD scan of the deposited thin film. (ii) Rocking curve of the (-201) peak.

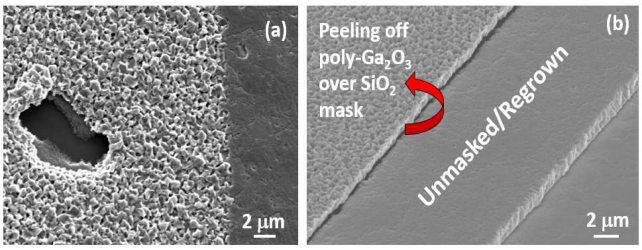

Figure 2. Mechanism of removal of the parasitic growth over mask with HF. (a) Depicts the initial stages of HF finding its way through to the underlying SiO_2 beneath the parasitic growth, while (b) reveals the later stages in which the parasitic grown poly-Ga_2O_3 is being peeled off.

component to suppress residual growth on top of the dielectric mask. As HCl is not an option to use in a standard MCOVD system, use of an HF bath was explored to etch out residual growth over SiO_2 masks, i.e., the parasitic growth regions. The exposed selectively grown areas were then investigated by FE-SEM. Fig. 1 (b) and (c) shows the surfaces after HF removal of the mask and of the residual β-Ga_2O_3 grown area, which in contrast to the material grown in the mask opening, is clearly polycrystalline. XRD scans shown in Fig. 1 (d) confirm β-Ga_2O_3 growth with FWHM of 1.56° of the (-201) peaks illustrating high quality growth [8]. Due to the ease of removing SiO_2 with HF, the SiO_2 masks are preferred over the alternatively explored PECVD-deposited SiN_x, and ALD-deposited Al_2O_3 masks. It should be noted that in-situ plasma-enhanced annealing right before the growth step might assist in improved selectivity. We note that growth variables such as temperature, pressure, VI/III ratio, and time were modified; no significant change was observed on the parasitic deposition. There was a significant change in the exposed/regrown region with the formation of particles and rod-like structures with the decrease in temperature and pressure, respectively. With the increase of growth time and VI/III ratio, the thickness of the regrown region increases as expected.

Fig. 2 shows the FE-SEM image of an intermediate stage of SiO_2 etching and its subsequent peel off. Considering that an adequate amount of time is needed for HF to etch out the SiO_2 mask, etch damage to the as-grown Ga_2O_3 surface needs to be considered. HF is known to etch β-Ga_2O_3 surface if exposed for too long periods of time and this is apparent in Fig 3 (a) as indicated by red circles, for a sample with more than 24 hrs of HF bath. Hence to protect the β-Ga_2O_3 surface, $(Al_xGa_{1-x})_2O_3$ capping was explored. Experiments were performed with uncapped β-Ga_2O_3, and β-Ga_2O_3 capped with $(Al_{0.08}Ga_{0.92})_2O_3$ and $(Al_{0.32}Ga_{0.68})_2O_3$. Each sample was dipped in HF for 24 hrs. The thickness and surface roughness were measured. Increasing Al composition of AlGaO, provides improved resistance against HF etching as illustrated in Fig 3 (c). The etch rate of $(Al_{0.32}Ga_{0.68})_2O_3$ capped thin-film was as low as 3.66 nm/hr, in contrast to 8.43 nm/hr for (-201) β-Ga_2O_3, the latter though significantly

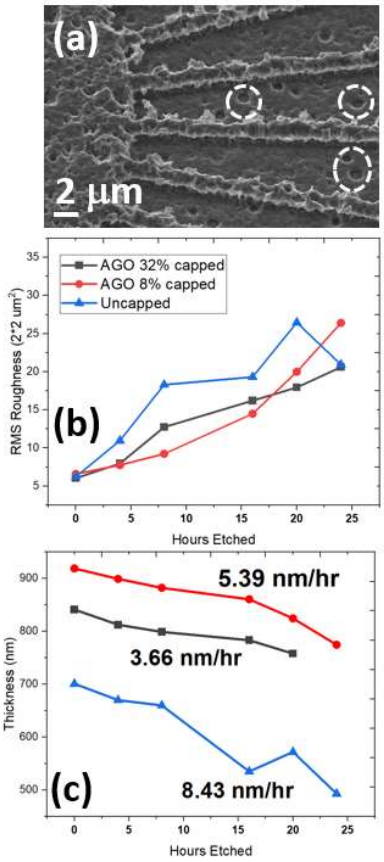

Figure 3. (a) Etch pits formed due to HF damage. (b) Change of surface roughness as measured by RMS across three different regions. (c) Film thickness measured by reflectometry throughout the etching period.

lower than 58.7 and 31.3 nm/hr reported for (100) and (001) β-Ga_2O_3 in the literature [9]. The surface roughness of the capped AlGaO is acceptable at around 20 nm. Effectively, capping with AlGaO protects the underlying thin film in a SAG process.

CONCLUSIONS

HF etching assisted MOCVD SAG of β-Ga_2O_3 on sapphire was demonstrated, though some etch damage of the β-Ga_2O_3 surface by HF was observed. AlGaO was demonstrated to be an effective protectant of the material/device surface, with the lowest etch rate of 3.66 nm/hr. The results further encourage exploration of SAG to fabricate complex device structures to potentially simplify complex manufacturing processes.

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ACRONYMS

SAG: Selective Area Growth
CVD: Chemical Vapor Deposition
HVPE: Halide Vapour Phase Epitaxy
RIE: Reactive Ion Etching
ELO: Epitaxial Layer Overgrowth
PECVD: Plasma Enhanced CVD
ALD: Atomic Layer Deposition
FE-SEM/SEM: Secondary Electron Microscopy
AlGaO/AGO: $(Al_xGa_{1-x})_2O_3$