Plasma Etching of High Aspect ratio Sapphire Antireflection Nanostructures Using Multilayer Etching Mask

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Sapphire has many applications in photonics and optoelectronics due to its high mechanical toughness, thermal and chemical stabilities, and high optical transmittance. However, sapphire is difficult to etch due to its chemical stability, and existing etch processes are limited to low aspect-ratio structures and rough surfaces. To further improve the optical and physical properties of sapphire, taller and higher aspect-ratio nanostructures are needed. For example, inspired by moth eyes, nanostructures can mitigate optical reflection losses and interference effects between the material interfaces [1-2]. In prior work we apply multilayer etching masks for reactive ion etching (RIE) to fabricate increase aspect ratio (AR) of etched sapphire nanostructures. The etching results show that 2-D sapphire nanostructure are with 470 nm width and 230 nm height using Cl_2 RIE. We further examine the AR effect of 2-D subwavelength sapphire nanostructures. The reflectivity is reduced by ~3% near normal incidence and can be further eliminated by 7% at 60º incident angle under TE polarization. It can be observed that the data agree well with the rigorous coupled-wave analysis methods (RCWA) and Fresnel models [3]. However, the aspect ratio is still relatively low at around 0.49.

To achieve better antireflection effect, taller and higher AR sapphire nanostructures are needed. In this work we further optimize the etch process by incorporating HBr RIE to improve etching rate and etching selectivity to pattern nanostructures into the intermediate poly-silicon layer as shown in Figure 1. In this case, taller and higher AR nanostructures can be obtained on the combined masks before etching into silicon nitride. CHF_3 RIE is applied to pattern nanostructure into silicon nitride for better etch selectivity. Then, a combination of silicon oxide, poly-silicon, and silicon nitride high AR masks structure is on top of sapphire substrate. Lastly, BCl_3 ICP-RIE is applied to pattern sapphire nanostructures. HF wet etching is used to remove the remained silicon nitride mask on sapphire. Initial results are shown in Figure 2, which depicts 2-D sapphire nanostructures with 530 nm width and 470 nm height, resulting in an aspect ratio (AR) around 0.89, a near two-fold enhancement over previous work.

We will present the fabrication of periodic sapphire nanostructures using interference lithography to fabricate 2-D orthogonal with shorter period to improve antireflection and transmission enhancement for shorter wavelength range. The multiple etch masks thickness will be optimized to acquire tapered nanostructures with higher aspect ratio, which is expected to further suppress reflection losses. Different gas chemistries such as Cl_2, BCl_3, CF_4 and HBr will be examined to improve etch rate and selectivity vs different mask layer. Lastly, the optical reflectance and transmittance of the fabricated structures will be characterized.

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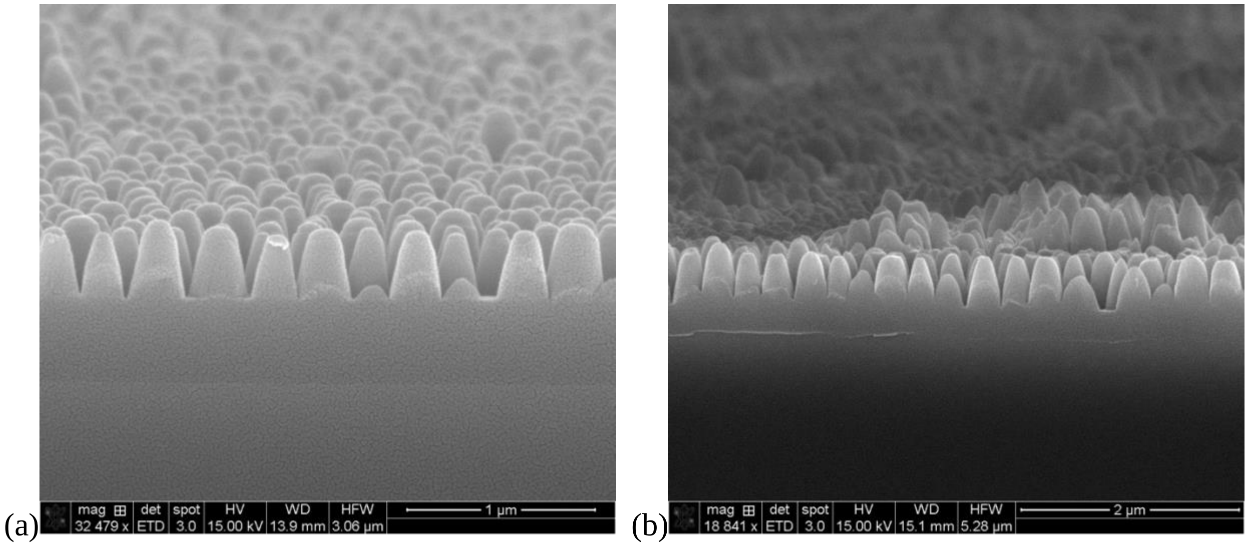

Figure 1. SEM images of silicon oxide, poly-silicon, and silicon nitride masks remained on sapphire substrate (a) after CHF_3 and HBr RIE (b) after CHF_3, HBr, and CHF_3 RIE

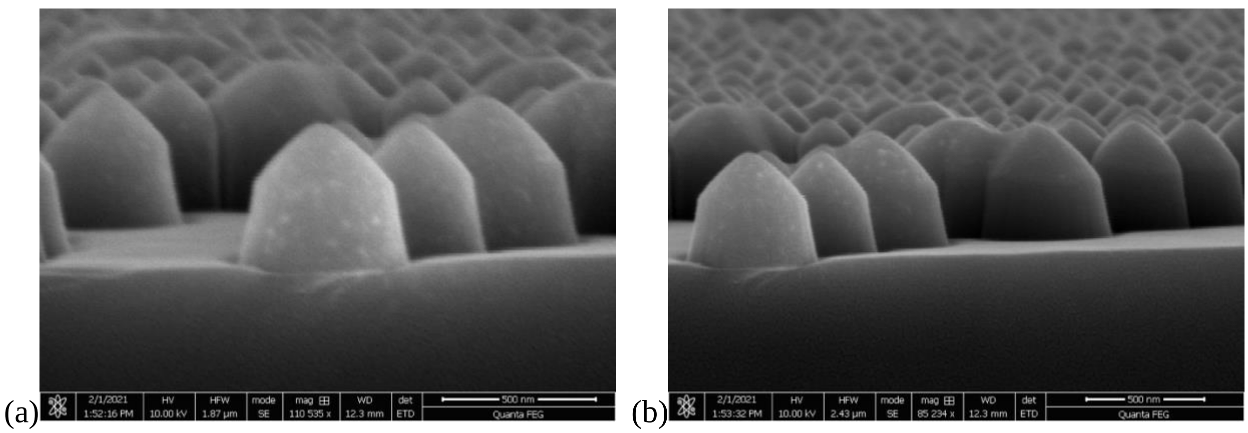

Figure 2. SEM pictures of sapphire nanostructure after CHF_3, HBr, CHF_3, and BCl_3 ICP-RIE

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