Plasma Etching of Sapphire Antireflection Nanostructures

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Sapphire have many applications in photonics and optoelectronics due to its high mechanical toughness, thermal and chemical stabilities, and high optical transmittance. However, the transmittance of sapphire is lower than other transparent materials (eg. fused silica and quartz) due to its relatively higher refractive index [1]. The high index mismatch to air causes large Fresnel reflection losses [2-4]. Sapphire and other alumina-based materials can also be used in multilayer composites for protective armor, which will result in significant reflection losses and interference effects between the material interfaces [5]. These losses may be mitigated considerably if we apply antireflective subwavelength structures inspired from moth eyes [6]. In this manner, the discontinuity in refractive index can be replaced by an effective medium with continuously changing index.

In this work, we report the fabrication of subwavelength structures on sapphire wafer to reduce optical reflection losses and increase transmittance. Initial fabrication result is to demonstrate the proposed concept on structure with height of 80 nm and period of 300 nm. A Lloyd's mirror interference lithography set up is used to create periodic nanostructures in photoresist. Using inductively coupled plasma reactive ion etching (ICP-RIE), the pattern is then transferred to the underlying Si_3N_4 mask and sapphire substrate by using CHF_3 and BCl_3/HBr etch chemistry, respectively. The initial SEM of the 1D subwavelength nanostructure at the middle point of etching is shown in Figure 1(a) and Figure 1(b). We can see that there are some antireflection coating and Si_3N_4 remained in Figure 1(a) and (b). After reactive ion etching, we use HF to remove the remained Si_3N_4. From Figure 2(a) and (b), we can see the fabricated 1D sapphire nanostructures is around 80 nm height, and 300 nm period with high fidelity.

To further increase sapphire nanostructure aspect ratio, we evaluated Cl_2, BCl_3, and HBr etch rates and selectivity. The Cl_2 and BCl_3 selectivity of Si_3N_4 over sapphire and etching rate data is shown in Figure 3. The processing conditions for these experiments are pressure is 10 mTorr, flow rate is 50 sccm, ICP power is 500W, and RIE power is 300W. The data shows that increasing BCl_3 results in better selectivity and higher etching rate. We will investigate the etch mechanism using optical emission spectrometer (OES) to analysis the etch products during sapphire etching. This can also service as a function of etching end point detection to control the etching time better. Preliminary spectrum for Cl_2 RIE is shown in Figure 4, where several elements and components can be identify. We can see that the Al and O elements are detected, which indicates that the sapphire (Al_2O_3) is already etched by Cl_2 plasma.

We will present the detailed fabrication results and analysis of etch by products using OES spectra. We will also explore the use of multilayer masks for combination of RIE processes to fabricate higher nanostructure with ~1 aspect ratio. In this method poly-silicon and SiO_2 masks will be used, which has higher selectivity. We will also evaluate different gas proportion such as Cl_2, BCl_3, CF_4 and HBr to improve etch rate and selectivity. Lastly, the optical reflectance and transmittance of the fabricated structures will be characterized.

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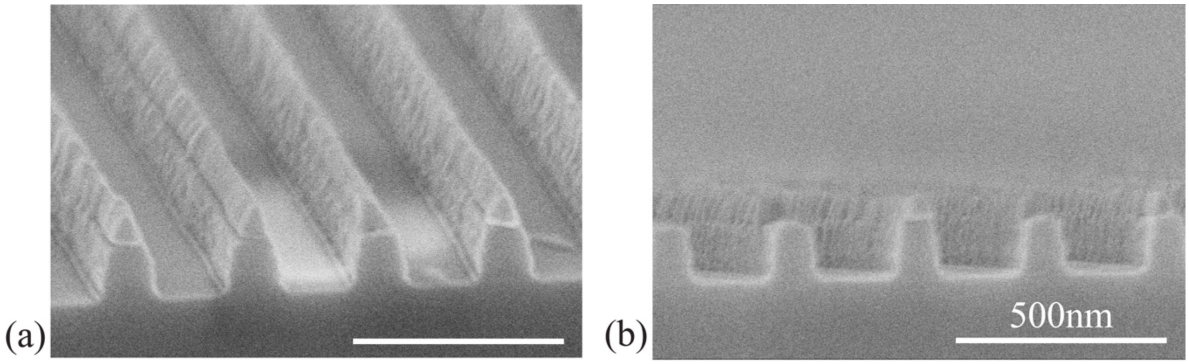

Figure 1. SEM pictures of Si_3N_4 remained at middle point of sapphire etching (a) tilt angle view. (b) cross section view.

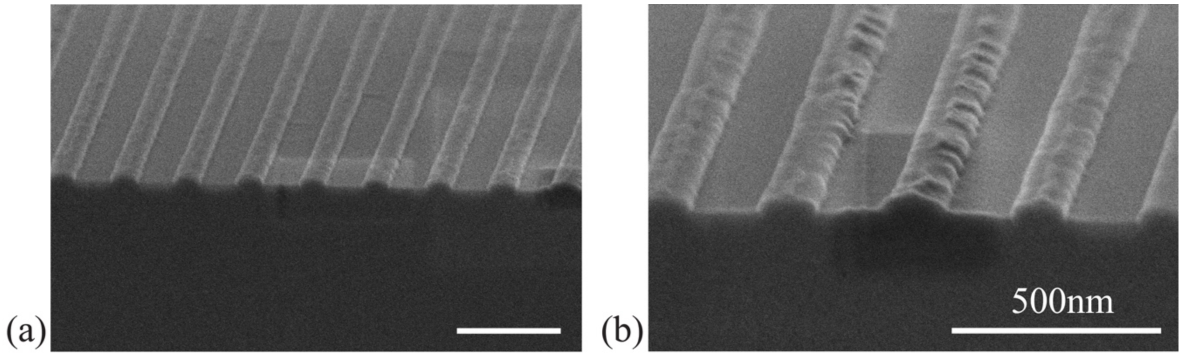

Figure 2. SEM pictures of sapphire nanostructure after HF cleaning (a) zoom out view. (b) zoom in view.

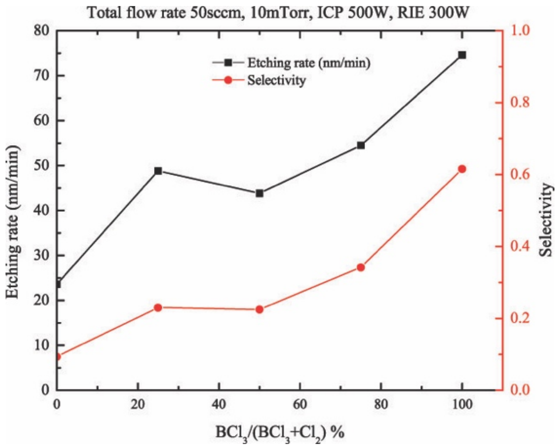

Figure 3. Etch rate and selectivity of sapphire vs Cl_2 and BCl_3.

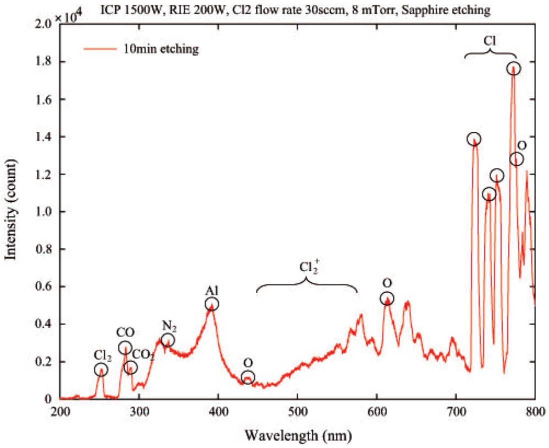

Figure 4. Etch by product from OES during sapphire etching using Cl_2 plasma.

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