Antireflection Sapphire Nanostructures Fabricated by Low RF Power ICP-RIE

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Bio-inspired nanostructures have drawn significant interest and attention because of their attractive electrical, optical, and mechanical properties. One of those bio-inspired nanostructures is the antireflection (AR) nanostructures that can be applied on planar surfaces to reduce the reflectance and enhance the transmittance, which can be found on the surface of moth eyes.[1] These taper structures gradually match refractive indices of two media across the interface to mitigate Fresnel reflection losses over broad wavelength bands and wide incident angles. As a result, those AR nanostructures have better optical performance than traditional antireflection coatings.[2,3]

Single crystal sapphire has many applications in photonics and optoelectronics due to its high mechanical hardness, thermal tolerance, chemical stability, and high optical transmittance in the infrared range. However, the larger refractive index mismatch between air and sapphire results in higher optical reflection losses. This issue can be mitigated by applying AR nanostructures, especially those with high aspect ratio (HAR), on the sapphire surface. However, the fabrication of HAR sapphire structures is challenging due to the high chemical stability of single crystal sapphire. Our previous work successfully demonstrated that the sapphire nanostructures with a height of 350 nm could be achieved by using a multilayer etching mask.[4] However, its fabrication process includes multiple steps, such as depositions and etching for different materials, including SiO_2, polysilicon, and nitride, which is comparatively complex.

Here, we present a simple technique to fabricate HAR sapphire AR nanostructures to enhance the transmittance of sapphire substrates. This approach utilizes inductively coupled plasma reactive ion etching (ICP-RIE) with low RF power[5] to form HAR polysilicon pillar as an etch mask. The proposed fabrication processes are illustrated in figure 1. First, a thick polysilicon layer is deposited on the sapphire substrate using low pressure chemical vapor deposition. A photoresist (PR) PFI-88 and anti-reflection coating (ARC) i-CON are spin-coated on the polysilicon layer. Then the PR is exposed using Lloyd's mirror interference lithography[6] with a HeCd laser, resulting in 2D nanopillars with a 330 nm period. ICP-RIEs using O_2 and HBr are used to transfer the pattern into the ARC and polysilicon layers, respectively. Finally, the BCl_3/HBr ICP-RIE with 400 W RF power further etches the pattern into the sapphire substrate.

As shown in figure 2, initial fabrication results indicate that the current highest sapphire nanostructures can reach around 500 nm. Here it can be observed that the structure results in a tapered profile, as desirable for AR effects. The broadband transmittance of sapphire nanostructures has been characterized and is shown in figure 3. It can be observed that the transmission has been enhanced to over 90% for wavelengths longer than 600 nm. The best improvement is at 1184 nm, where the transmission increases from 86.2 % to 91.6%. The transmittance of the sample for wavelength shorter than 560 nm decreases due to the diffraction effect, where diffracted orders are trapped in the substrate waveguide mode. This approach demonstrates a simple fabrication process to obtain HAR sapphire AR nanostructures. Initial optical characterization shows promising results, and more details will be presented, including further fabrication results, challenges, and limitations.

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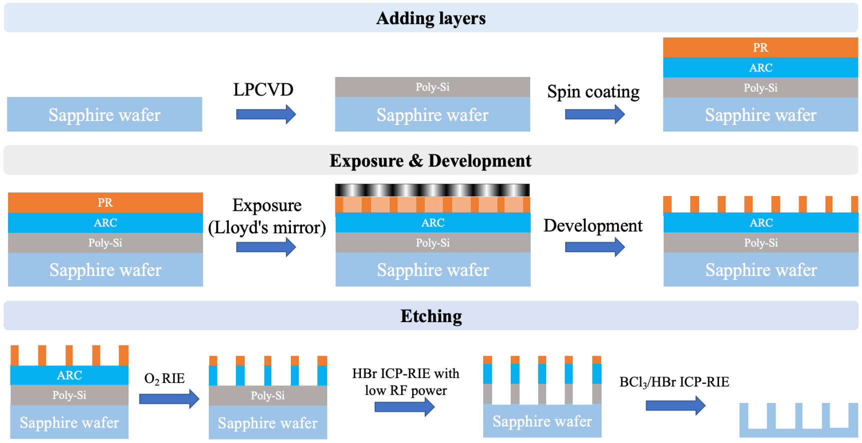

Figure 1. Fabrication processes of proposed technique.

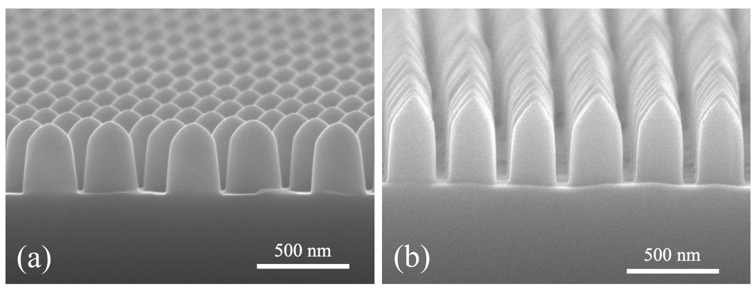

Figure 2. Sapphire nanostructures with the period of 330 nm and the height of (a) 380 nm and (b) 500 nm fabricated by BCl_3/HBr ICP-RIE with 400 W RF power.

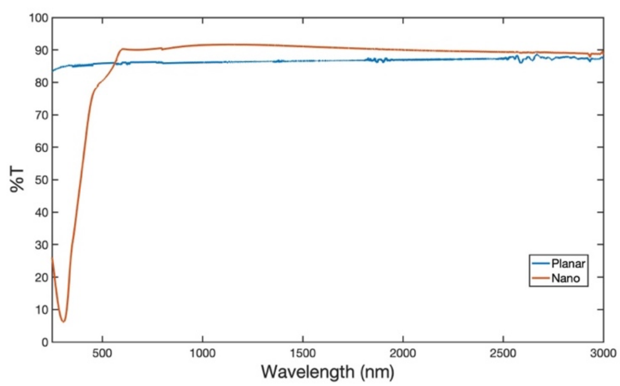

Figure 3. Broadband transmittance of planar sapphire (blue line) and sapphire with 350 nm height of nanostructures (red line).

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