Fabrication of SiC Membrane HCG Blue Reflector Using Nanoimprint Lithography

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ABSTRACT

We designed and fabricated a suspended SiC-based membrane high contrast grating (HCG) reflectors. The rigorous coupled-wave analysis (RCWA) was employed to verify the structural parameters including grating periods, grating height, filling factors and air-gap height. From the optimized simulation results, the designed SiC-based membrane HCG has a wide reflection stopband (reflectivity (R) >90%) of 135 nm for the TE polarization, which centered at 480 nm. The suspended SiC-based membrane HCG reflectors were fabricated by nanoimprint lithography and two-step etching technique. This achievement should have an impact on numerous III-N based photonic devices operating in the blue wavelength or even ultraviolet region.

Keywords: SiC, HCG, Nanoimprint, III-N

1. INTRODUCTION

In recent years, III-N based microcavity (MC) devices such as resonant cavity light emitting diodes (RCLEDs), vertical cavity surface emitting lasers (VCSELs), and polaritonic emitters have aroused much attention in many different applications [1-6]. The high contrast grating (HCG), a high index sub-wavelength grating reflectors surrounded with low index material, has been developed for replacing the distributed Bragg reflector (DBR) in VCSELs due to its high reflectivity, compactness, polarization selectivity, and so on [7]. So far, HCG reflectors have been widely studied in long wavelength VCSELs, modulators, and MC polariton lasers [8-11]. Previously, nitride based blue HCG reflectors have been demonstrated by using focused ion beam milling or e-beam lithography accompany with photo-electro-chemical etching [12,13]. However, the development on short wavelength HCG has been still limited due to difficulties in nitride based membrane structures. Furthermore, making HCG structures on the III-N material also may have a possibility to damage the active layer, which is a tough issue for realizing efficient MC emitter. In this viewpoint, SiC, a wide-bandgap material which has a low absorption at short optical wavelengths and a high etching selectivity against SiO_2 as a sacrificial layer is a good candidate for fabricating a high reflectivity blue HCG reflector.

In this report, we fabricated a high quality membrane SiC blue HCG reflector using nanoimprint lithography followed by two-step etching process. Such membrane SiC HCG provides a functional single layer cavity mirror without damage to the III-N-based active layer, which offers a platform for nitride-based microcavity devices.

2. SIMULATION

Figure 1 shows the schematic of the simulated SiC-based membrane HCG. We assumed that both transverse electric (TE; electric field direction parallel to the grating lines) and transverse magnetic (TM; electric field direction perpendicular to the grating lines) polarized lights would incident from the air side to the HCG structure in the normal direction. Four structural parameters including grating period (Λ), grating height (h_G), filling factor (FF, grating width divided by the period) and air-gap height (h_A) were taken into consideration in our simulation to maximize the reflectivity for TE polarization at blue wavelength as shown in Figs. 2. From Fig. 2(a), it's obviously that the stopband of HCG could be determined by the Λ, which could be precisely fabricated by nanoimprint lithography. At blue wavelength, the h_G has a 50 nm high reflection band (100 nm ~ 150 nm), which provides a wide tolerance while fabrication. There has two reflection peaks at blue wavelength shown in Fig. 2(c), we choose the peak around 50% since its wider tolerance for fabrication. From Fig. 2(d), the HCG has a wide and high reflection band as the h_A exceeds 300 nm. From above

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simulation result, the optimized HCG structure has a 420 nm grating period, a 51% of filling factor, a 130 nm grating height, and a 360 nm air-gap height. The reflection stop band (R>90%) is 135 nm, and the central wavelength is 480 nm.

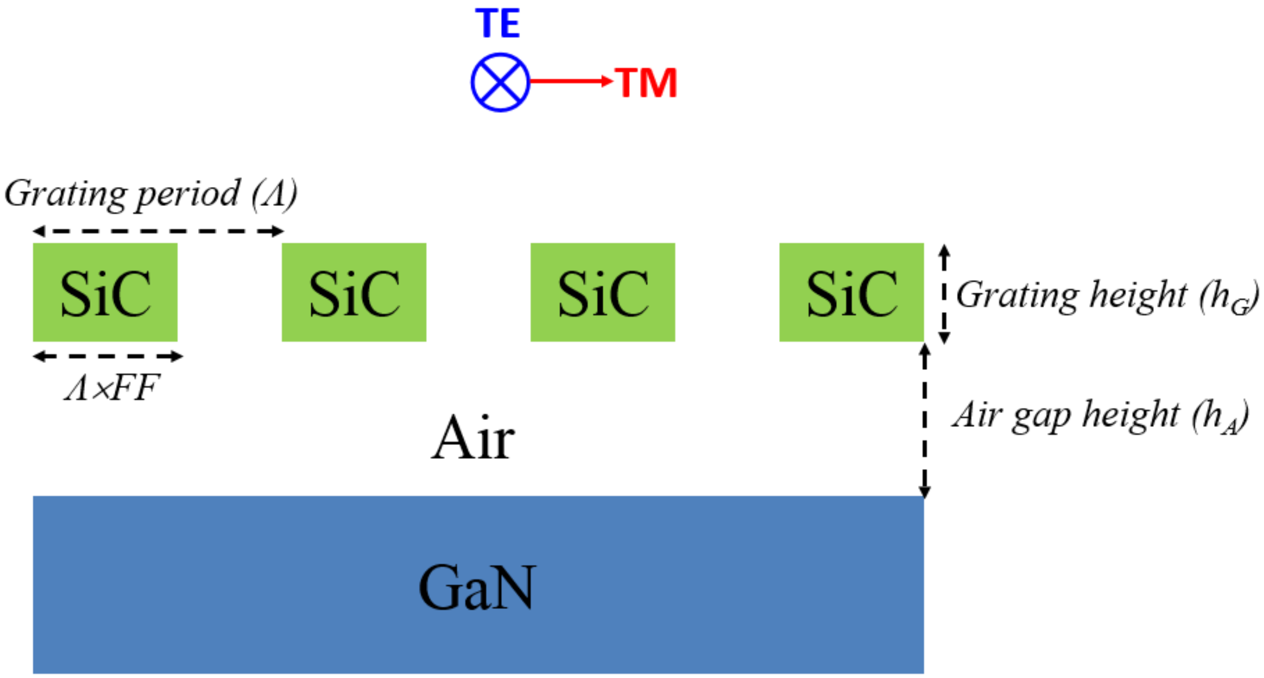

Figure 1. Schematic diagram of simulated SiC-based membrane HCG reflector.

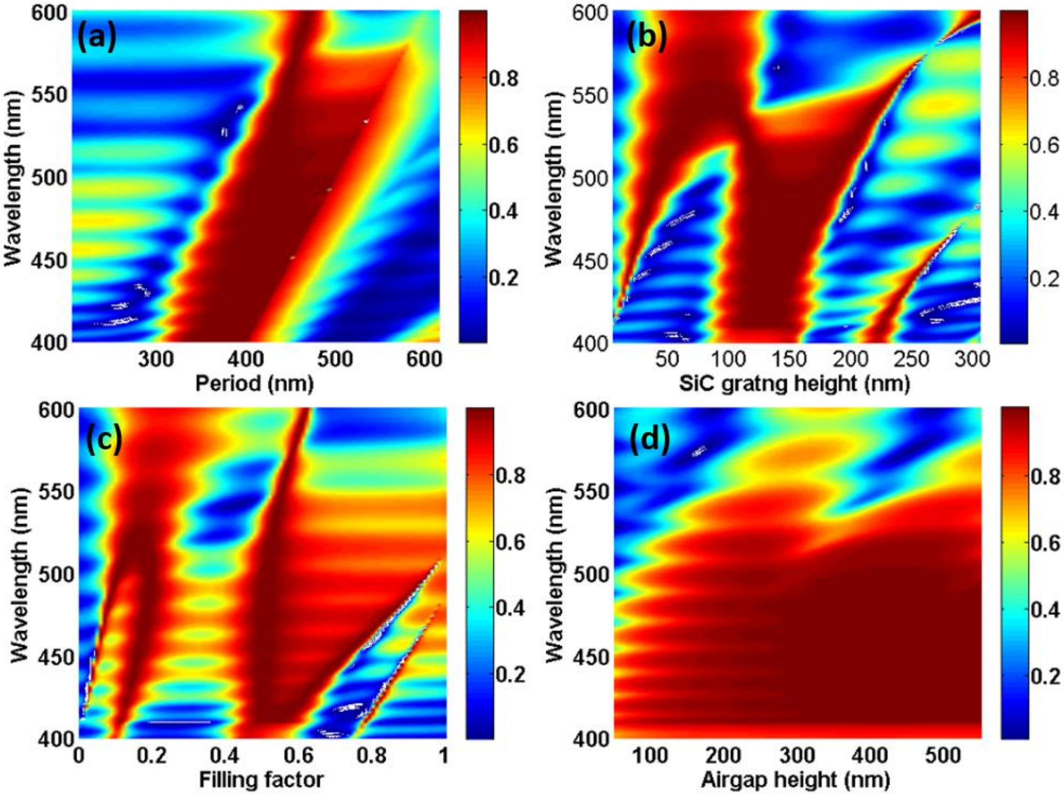

Figure 2. Reflectivity spectra mappings of the SiC-based membrane HCG reflector versus (a) grating period, (b) grating height, (c) filling factor, (d) air-gap height.

3. FABRICATION

The procedure of suspended SiC HCG shown in Fig. 3. The initial sample contains a 360-nm-thick SiO_2 sacrificing layer deposited on Si substrate, and followed a high index SiC layer of 130 nm. First, the HCG pattern was fabricated by temporary Si mold through nanoimprint lithography. Figure 4(a) shows the cross section SEM image of Si mold, which would be used in nanoimprint lithography. First, a thermal nanoimprint resist, named MTR-01 was spin coated on the aforementioned SiC based substrate. Next, the nanoimprint lithography was performed at 170℃ under a pressure of 2.0MPa for 30 minutes [14]. Figure 4(b) shows the photo of the nanoimprinted sample. We can see that a uniform resist grating pattern was formed on the SiC based wafer. From the magnified SEM image shown in Fig. 4(c), the period and the FF are about 420 nm and 50%, respectively.

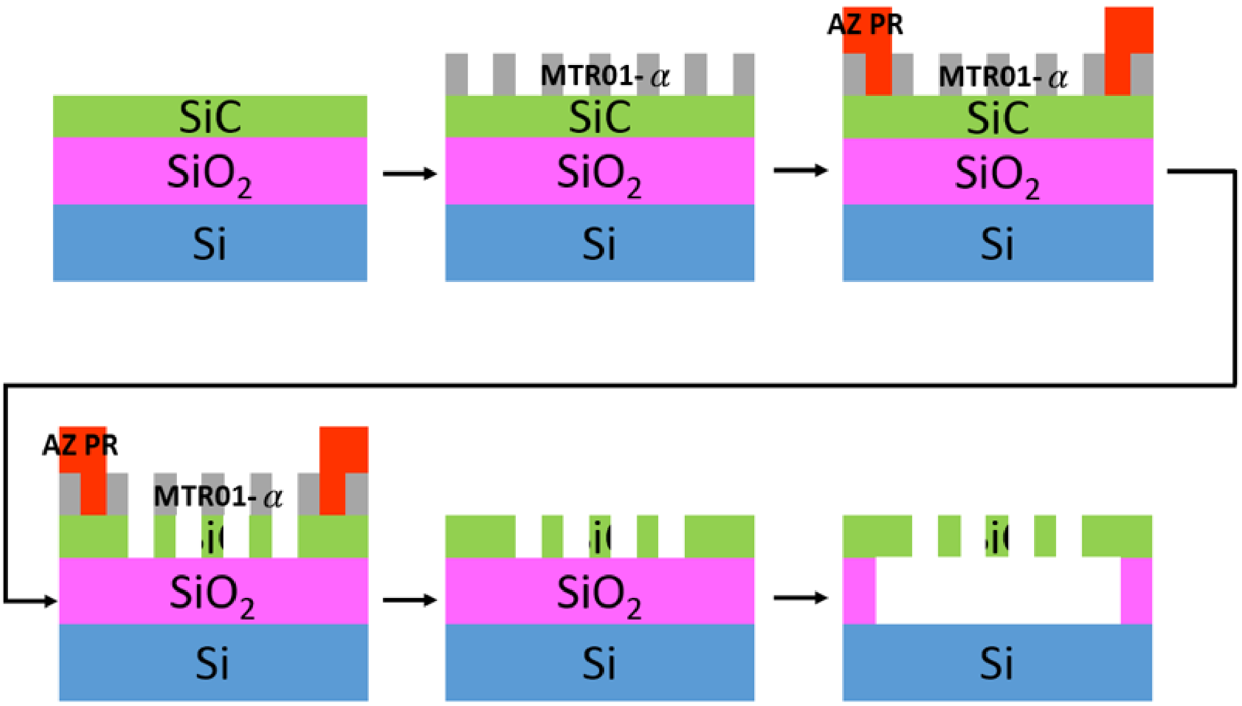

Figure 3. Flow chart of suspended SiC HCG fabrication.

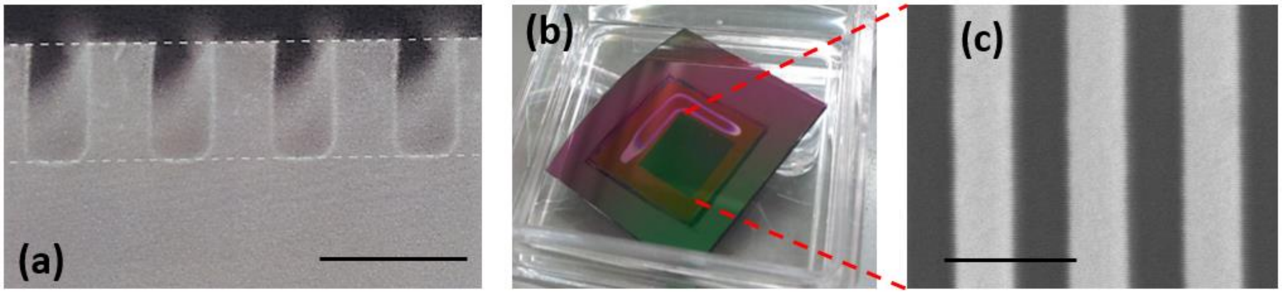

Figure 4. (a) Cross-sectional view of Si mold (b) Photograph of nanoimprinted sample and its (c) magnified SEM image. The scale bars in Figs. 4 are 500 μm.

Then the photoresist (PR) was then spin on the nano-imprinted sample and followed the common photolithography for defining the reflector dimension (70 um in width). From Fig. 5(a), an array of opening windows is formed on the nanoimprinted sample. Figure 5(b) shows the optical microscope (OM) image of PR defined nanoimprinted sample. Inside the central opening rectangular window is the thermal resist grating. After that, the sample was dry etched by Cl_2/Xe for 15 min. After removing the resist, the sample was wet etched by BHF for 15 min to remove the SiO_2 sacrificing layer. Finally, the samples were processed by critical point drying for avoiding undercut SiC grating to stick on the substrate. Figure 6(a) reveals the OM image of the sample after releasing HCG. The green part of Fig. 6(a) shows the undercut SiC membrane. The outside part represents the unsuspended SiC. Figure 6(b) shows the top view of SEM image of the finished suspended SiC HCG. The grating parameters are fit to initial designs.

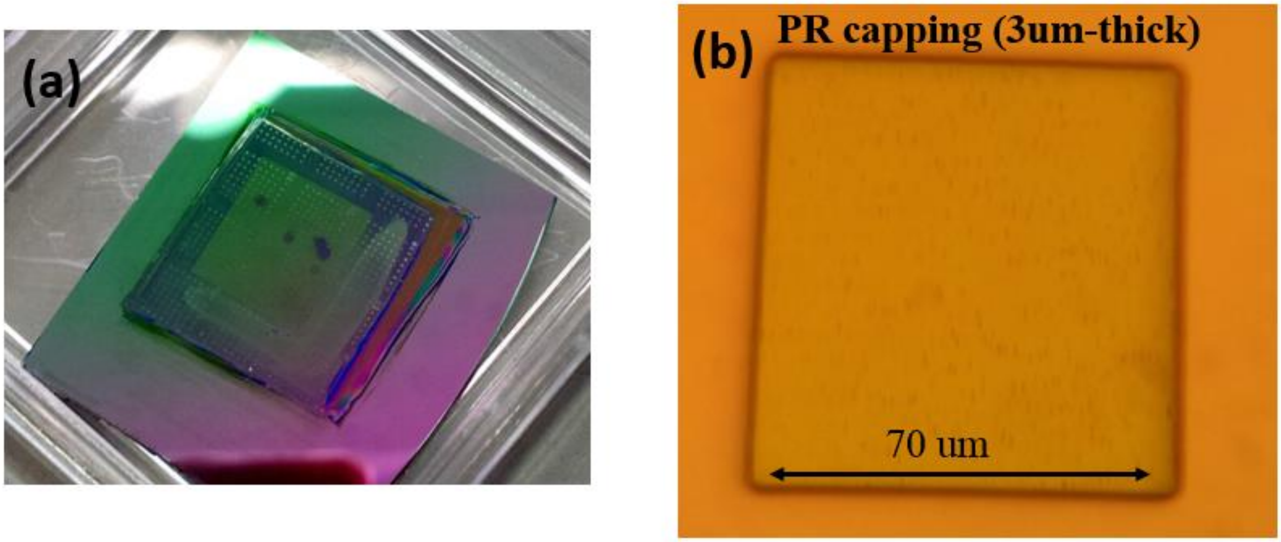

Figure 5. (a) Photograph of PR-defined sample and its (b) OM image.

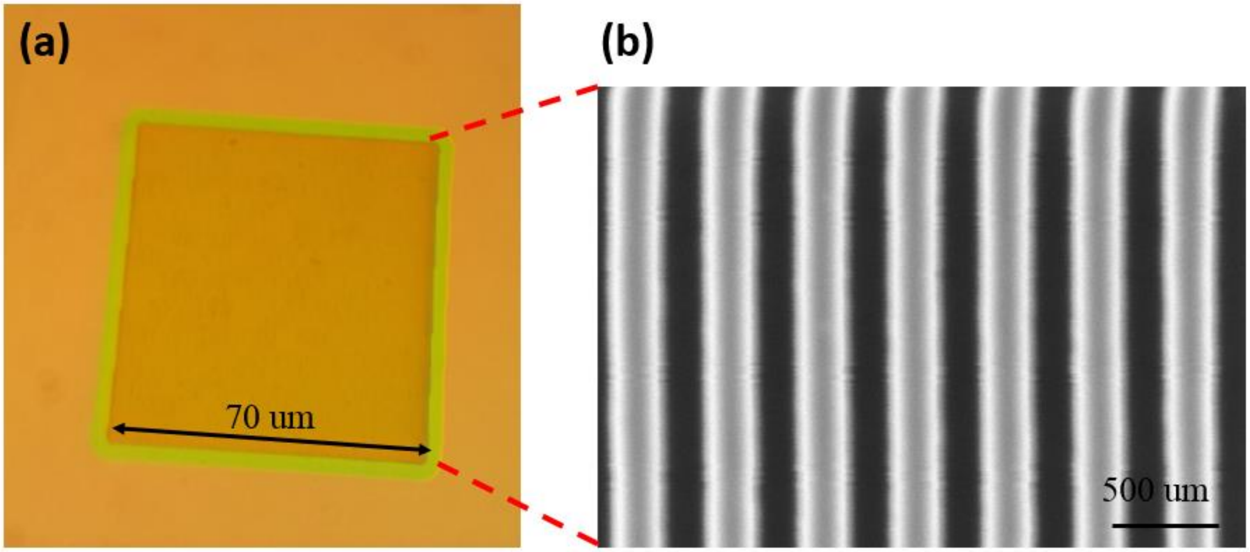

Figure 6. (a) OM image of suspended HCG reflector and its (b) magnified SEM top view.

4. CONCLUSION

We successfully fabricated a SiC-based membrane HCG using nanoimprint lithography and two-step etching process. By using the nanoimprint lithography, a large area membrane HCG could be formed, which is beneficial for future application. This demonstration should have an impact on numerous III-N based photonic devices operating in the blue wavelength or even ultraviolet region.

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