Two dimensional designed fabrication of subwavelength grating HCG mirror on Silicon-on-insulator

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ABSTRACT

We designed and fabricated a two dimensional high contrast subwavelength grating (HCG) mirrors. The computer-aided software was employed to verify the structural parameters including grating periods and filling factors. From the optimized simulation results, the designed HCG structure has a wide reflection stopband (reflectivity (R) >90%) of over 200 nm, which centered at telecommunication wavelength. The optimized HCG mirrors were fabricated by electron-beam lithography and inductively coupled plasma process technique. The experimental result was almost consistent with calculated data. This achievement should have an impact on numerous photonic devices helpful attribution to the integrated HCG VCSELs in the future.

Keywords: subwavelength grating, HCG, silicon-on-insulator

1. INTRODUCTION

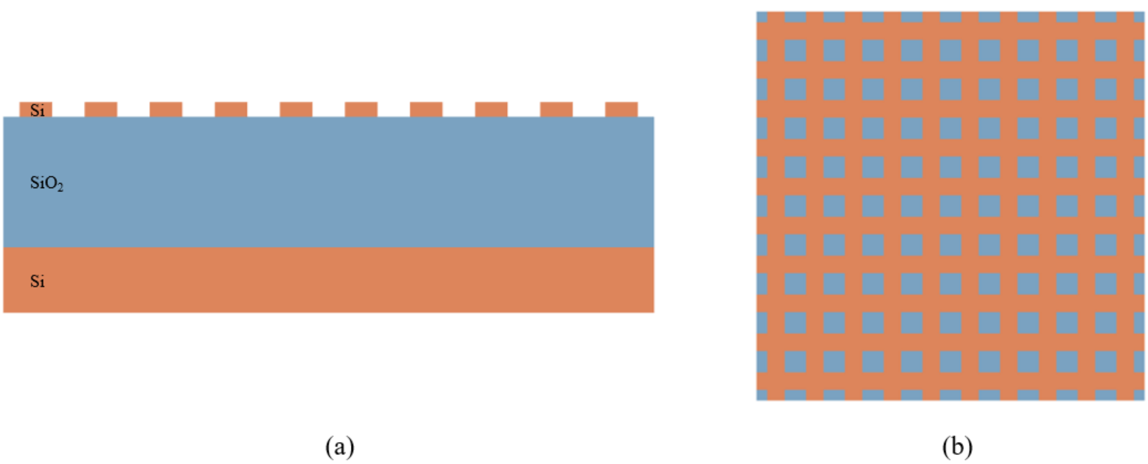

Figure 1. Schematic diagram of a (a) one-dimension and (b) a two-dimension subwavelength gratings on an SOI wafer.

The subwavelength grating structure mentioned as reflective mirrors is composed of a thin planar higher refractive index layer surrounded by distinct lower refractive index substances [1]. In general these high contrast subwavelength gratings are typically one-dimension design which can offer highly reflection spectra and a broadband wavelength range of stopband characterization. These structures are being widely used in several applications, including reflectors [2, 3], filters [4], micro-lens [1], and vertical cavity surface emitting lasers [5]. Moreover, the operating principle of these gratings which behaved as diffractive component are referred to guided-mode resonance effect as a result of surface-normal incident wave coupled with the leaky waveguide modes. The behavior of designed structure also function as superior grating reflectors, leading to out of plane reversed wave totally reflect from the surface structure [6]. The use of various optimal design of geometrical parameters with period, duty cycle, and thickness is obviously suitable for high contrast subwavelength gratings as performance is concerned, leading to the key point to settle the evanescent tail of resonant HCG mode spectral band engineering [7]. In addition, a single layer of grating structure could provide property of two polarized selection, distinct designs of subwavelength grating structure satisfy highly broadband reflective

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characterization for the TE and TM linear polarization respectively. Since the HCG mirror is thinner and will be easier to manufacture, these gratings structure make the superior substitute to conventional quarter wavelength distributed Bragg reflectors of vertical cavity surface emitting lasers. The proposed technic and structural design make the integrated optoelectronic device can be accomplished and keep the cost low. Therefore a lot of subwavelength HCG-based devices have been realized by single mode operation [8], tuning of emission wavelength [9, 10] and mode confinement control [11]. Previous study we have developed a one-dimension HCG membrane mirror [12]. Besides, CMOS-compatible silicon-on-insulator (SOI) for integration is much easier to manufacture, resulting in low-cost thinner nanoscale structure. In this investigated study, the work is organized as follows: first of all we theoretically analyzed both aforementioned one-dimension and two-dimension subwavelength grating designs. Then the important property of polarization independent also experimentally demonstrated a design for highly reflective broadband through two-dimension fabricated structure. Figure 1 displays subwavelength grating HCG mirror on silicon-on-insulator wafer of the one-dimension (1D) and two-dimension (2D) designed structures, which would be used in the following optimized investigation. This accomplishment as the first step in the fabrication of a HCG-based devices in the near future.

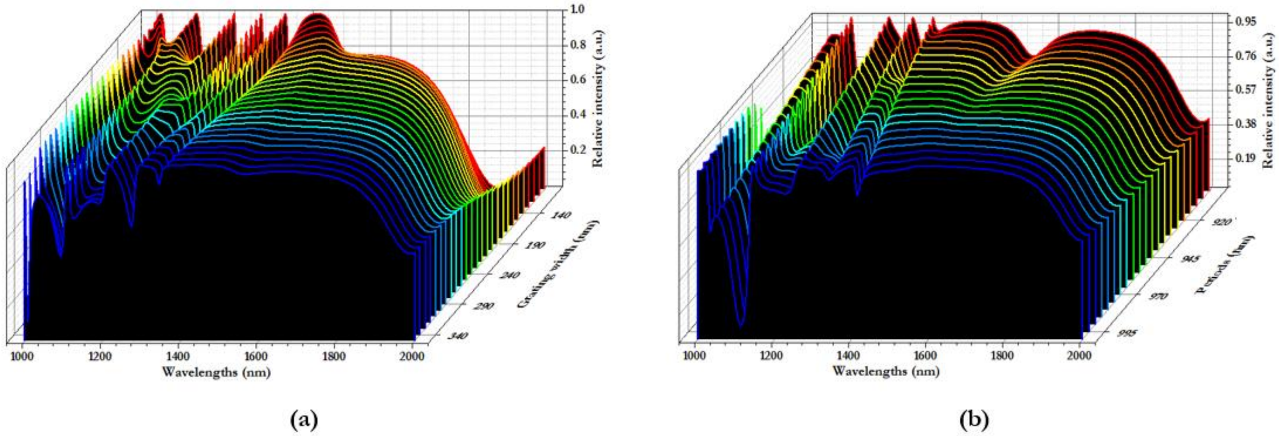

Figure 2. Schematic contour plots of simulated reflectivity versus the gratings (a) widths and (b) periods of a one-dimension subwavelength gratings on an SOI wafer.

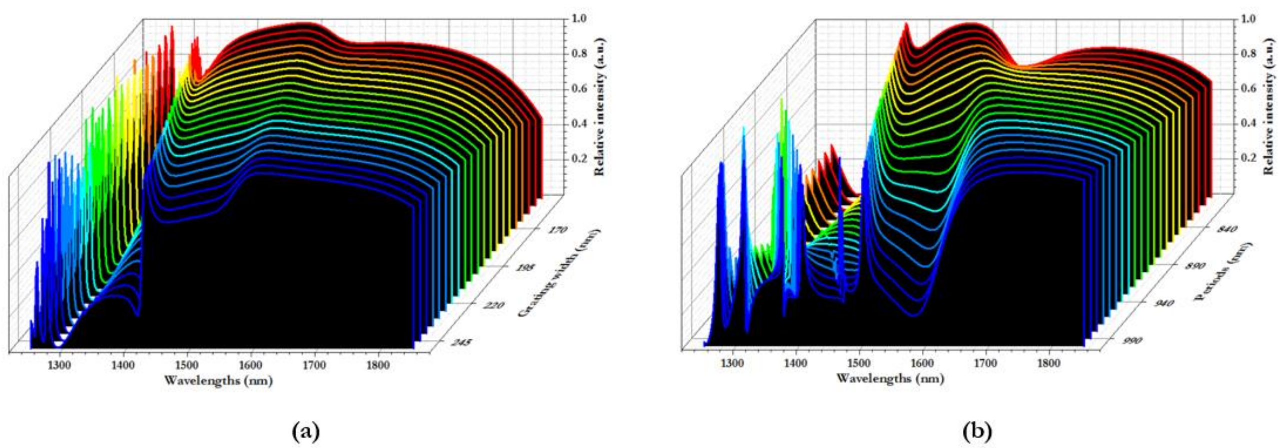

Figure 3. Schematic contour plots of simulated reflectivity versus the gratings (a) widths and (b) periods of a two-dimension subwavelength gratings on an SOI wafer.

2. DEVICE DESIGN

For above mentioned optimized calculations to fabrication tolerances and high-reflectivity stopband in this report, a commercial computer-aided software was employed, which is based upon the finite element methods. As for the one-dimension structure, since the subwavelength gratings structure possessed the specific symmetry of spatial design, the calculation model could be simplified from the two-dimension to one-dimension scheme. We concerned several structural parameters inclusive of grating periods and widths to execute the realization of actual nanoscale fabrication tolerance. As regards the experimental fabrication for two-dimension subwavelength gratings, we select a silicon-on-insulator wafer (SOITEC Inc.) with a 0.22 μm top silicon layer with 2 μm of buried oxide layer with the design wavelength and grating material to be 1.55μm and silicon respectively. Similarly the concepts of other targeted wavelengths and high-index contrast materials also can be valid. A negative resist (ma-N 2403) was utilized as the etching hard mask. The photoresist film was spin-coated onto the wafer surface and then baked on a hot plate to make resist become firm and solid without moisture. Resists were exposed by an electron-beam lithography facility (Raith150 II) at 30KV and developed in a solution ma-D 525. Continuously the designed pattern was transferred to the 0.22 μm-thick below down silicon layer via inductively coupled plasma etching. In order to eliminate the residue, the sample was soaked in 1-Methyl-2-pyrrolidone (NMP) to remove photoresists, then follow-up shaken in ultrasonic cleaner machine with acetone, and after that rinsed in de-ionized (DI) water. Ultimately the sample place into oxygen cleaner to further clean for an hour.

The effects of several parameters on the reflection characterization of HCG-based designed mirror were considered to achieve optimized structure obtaining high-reflectivity and broadband spectra as shown in Figure 2. Based on the contour plots of one-dimension design of HCG-based structural gratings, the largest bandwidth for high reflective stopband above 95% in the range from 1208 to 1758 nm is realized under the design at around width 0.3 μm and period 0.95 μm, respectively. It should be noted that the illuminated light wave started from the normal-incidence direction of top side of the silicon-on-insulator structure in our calculations. And here we set a limit of the grating height for real fabricated condition at 0.22 μm. As for the two-dimension investigated design of subwavelength gratings, we chose the designed value at width 0.195 μm and period 0.9 μm to yield larger than 95% reflectivity in the range from 1476 to 1628 nm. In addition, since the higher average refractive index of two-dimension HCG-based structure with respect to one-dimension case, the stopband of the target wavelength at 1.55μm of two-dimension case is apparently narrower than one-dimension case.

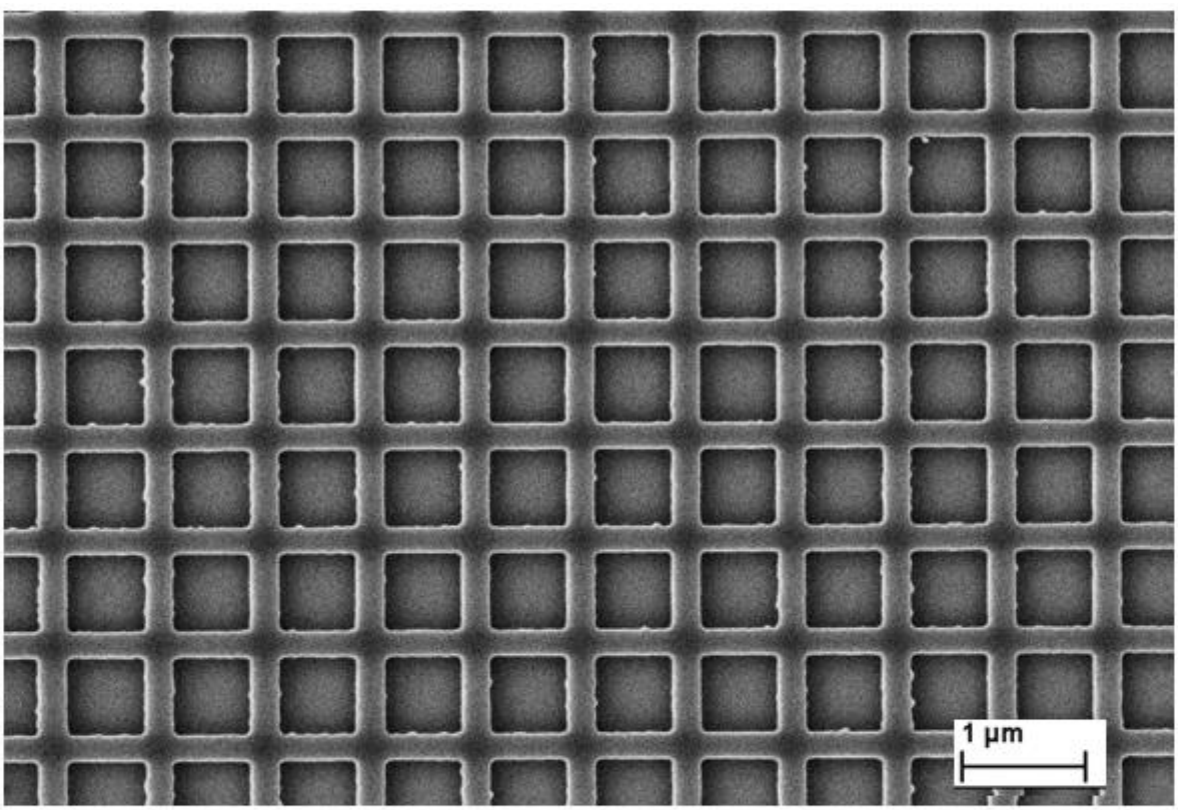

Figure 4. SEM images of the fabricated two-dimension subwavelength gratings on an SOI wafer.

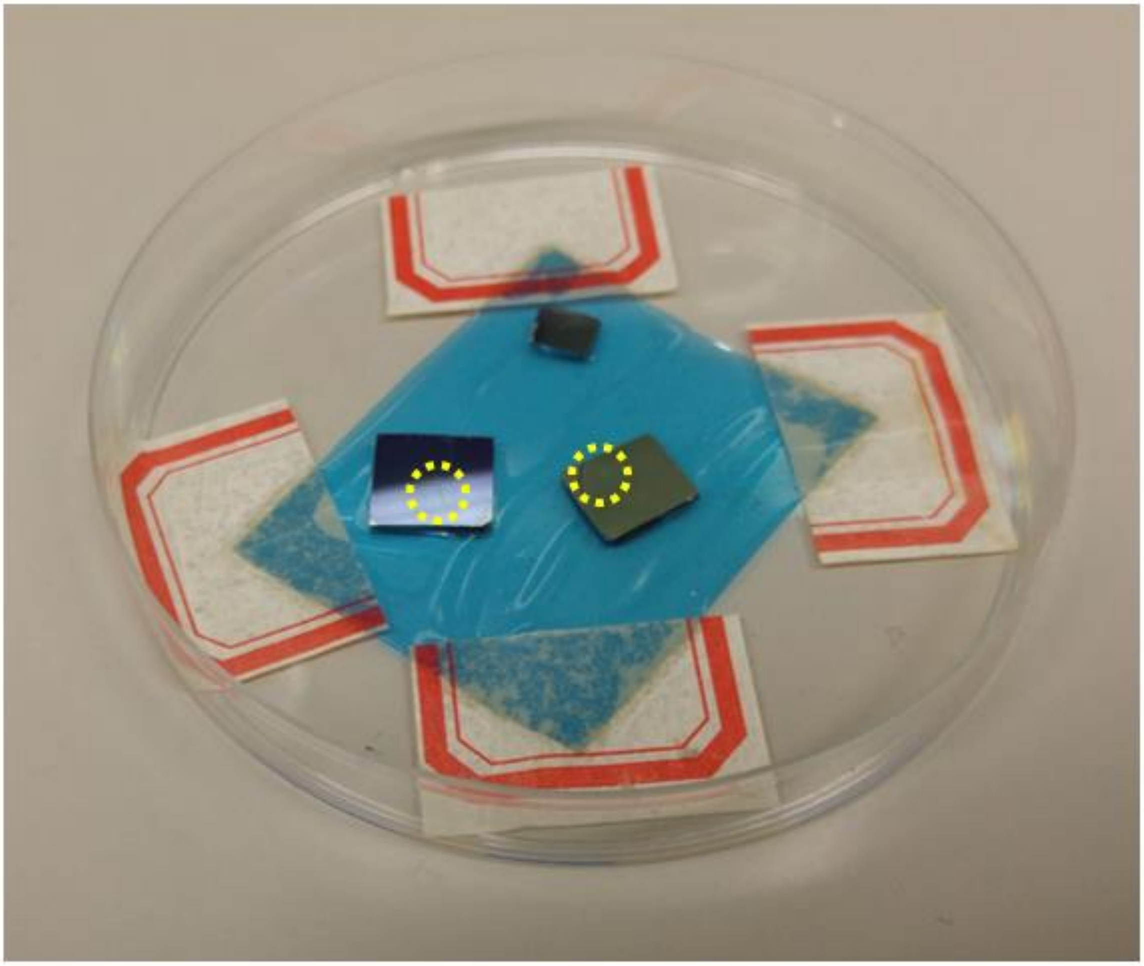

Figure 5. Photograph of the fabricated two-dimension subwavelength gratings on an SOI wafer.

3. RESULTS AND DISCUSSION

Figure 4 shows a top-view scanning electron microscope sketch of the two-dimension fabricated HCG-based mirror. The desired parameters which realized by the SEM images are as followed: grating period ~ 0.84 μm and width ~ 0.24 μm, respectively. Since the ratio between grating widths and periods is the most sensitive value in the fabrication process as result of fluctuations for the duration of common lithography exposure, development, or etching process, resulting in the perturbation of final geometric shapes. Figure 5 also shows the captured photo of the fabricated sample, which the yellow dashed lines indicated the location of HCG-based patterned structure.

For the purpose of further realizing the reflectivity spectra of the experimental subwavelength gratings HCG mirror, the mono-chrometer (Zolix, Omni-λ1509) system involving optical reflectors and lens components, beam splitters, a light source (Zolix LSH-175 Tungsten-Halogen lamp, 6.19A) and a 10X objective lens with a numerical aperture (N.A.) of 0.25 is employed to measure the reflective characterization of the sample as shown in Figure 6. In our measurement, the aluminum mirror (ideaoptics STD-M1UV) was utilized to calibrate as a reference of the reflective property. The reflected light from the sample or aluminum mirror would be collected by the same objective lens and then went through the optical reflector and then was split into two beams via a 50/50 BS. One way is injected into to a charge coupled device in order to observe and make sample alignment with operating 0.01 mm^2 illuminated beam spot size. The other way passes through aperture hole and the rest components to avoid stray light in the measurement system. Hence the reflected illumination from the central sample region is simply propagated and recorded to the spectrometer. For the measurement in the telecommunication wavelengths range, a mono-chrometer and an InGaAs detector are applied to the measured framework and controlled by a computer to do the scanned wavelength.

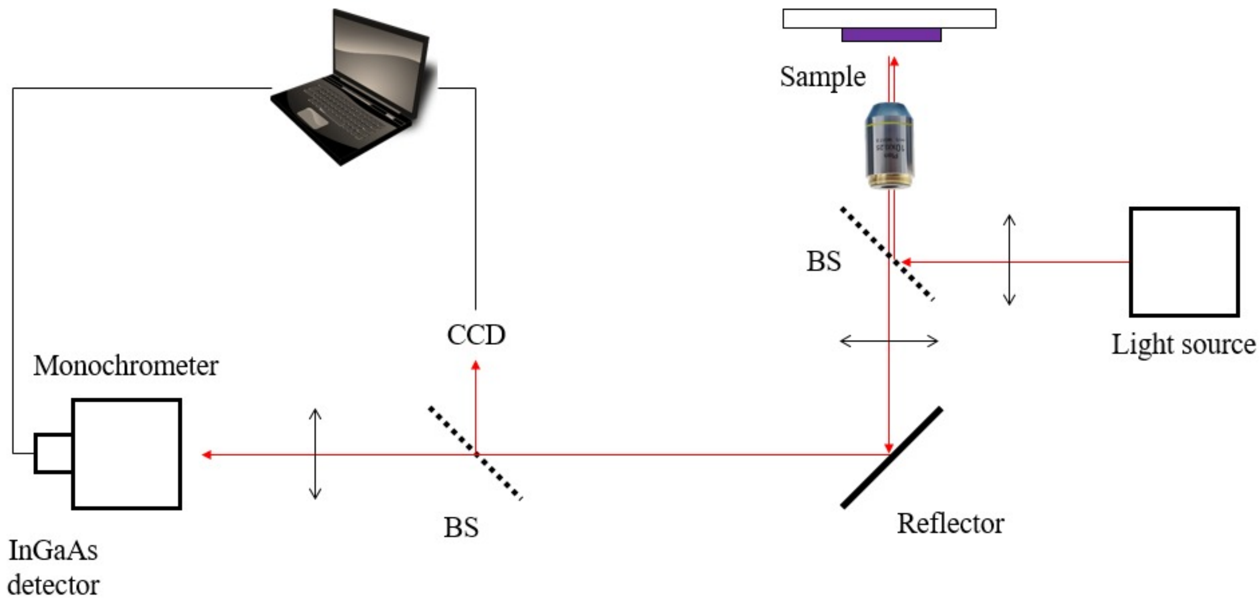

Figure 6. Schematic diagram of spectroscopy to measure the reflection property.

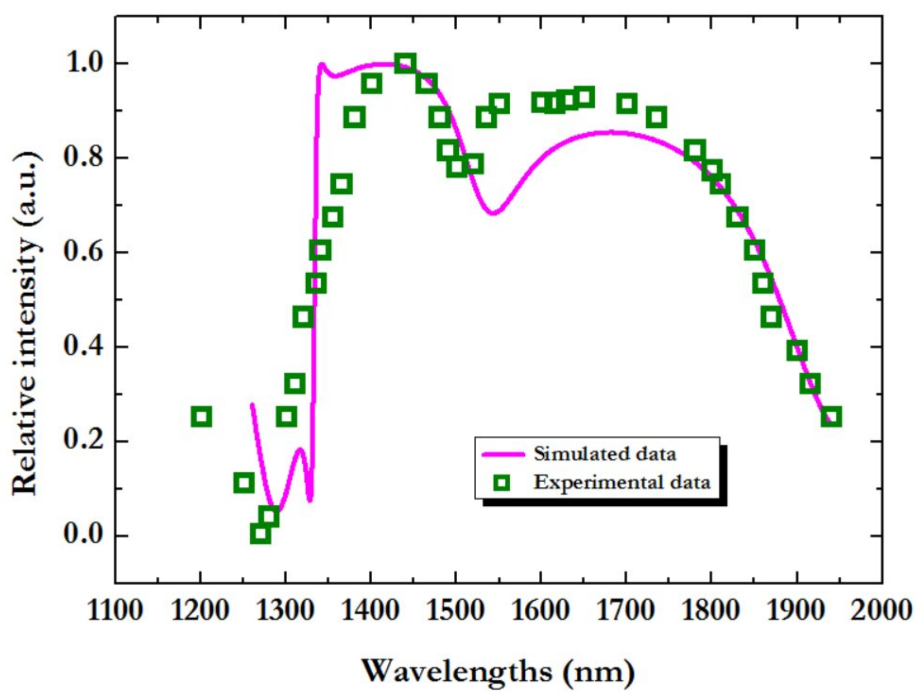

Figure 7. Experimental (green hollow square marks) and numerical (continuous magenta line) reflection spectra for the fabricated two-dimension subwavelength gratings on an SOI wafer.

Figure 7 shows the experimental and numerical reflectivity spectra of the two-dimensional HCG-based mirror. The green hollow square marks and magenta solid line shows the experimental and simulated reflectivity spectrum, respectively. The slightly difference between the measured and calculated results could be the reason of thicker or thinner width variation of subwavelength gratings, resulting in the duty cycle changed simultaneously. Hence, the modified reflectivity was greater than 90% with a stopband larger than 200 nm. The aforementioned results were consistent with the theoretical one and believed to progress the novel HCG-based devices for the future implement platforms.

4. CONCLUSION

In conclusion, we successfully illustrated the two-dimension subwavelength HCG-based mirrors by manipulation on silicon-on-insulator wafers through electron-beam lithography and inductively coupled plasma processing to achieve the fascinating accomplishment of high reflective spectra and broad bandwidth. The experimental results were in good agreement with the simulation realization. Our demonstration potential for the HCG-based photonic application and helpful contribution to the functional arrays implementation in the future.

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