Silicon Nanomembrane Based Photonic Devices on Foreign Substrates

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Abstract: We demonstrate transferring 2cm x 2cm unpatterned nanomembrane onto glass substrates. A photonic crystal waveguide is patterned together with subwavelength grating couplers on the transferred nanomembrane. Group index up to 26.5 is experimentally demonstrated.

OCIS codes: (350.4238) Nanophotonics and photonic crystals; (050.6624) Subwavelength structure; (050.2770) Gratings

Nanomembrane research has attracted a lot of attention over the last decade, due to the ability to develop light-weight and conformal devices [1-3]. Flexible and conformal electronic devices promise tremendous applications in the areas of medicine, imaging and sensing, which are unthinkable using conventional material systems and processes. Benefits on a similar scale are also foreseeable for photonic components. However, the difficulty in transferring intricate photonic devices, in addition to the unavailability of a suitable light coupling scheme on foreign substrates, has deterred widespread developmental activities. Previous attempts have demonstrated unique transfer schemes, utilizing which, silicon nanomembrane based photonic devices have been developed on flexible as well as on rigid substrates [4-6]. However, light coupling into these devices was based on butt coupling, which is very difficult to realize on different substrates. A universal light coupling scheme is needed that can efficiently package nanomembrane based devices on any substrate.

In this paper, we demonstrate a scheme that satisfactorily addresses both SiNM transfer, and light coupling issues, which can be applicable for developing conformal silicon photonic devices on any substrate. First, a scheme to transfer defect free large area (2cm x 2cm) SiNM on a glass substrate is presented. Next, a 100μm long silicon photonic crystal waveguide (PCW), is patterned on the transferred nanomembrane, together with subwavelength grating couplers [7-8]. We have previously demonstrated high coupling efficiency of up to 37.2% utilizing SWG on transferred SiNM [7]. Furthermore, an integrated Fourier transform interferometer is developed to accurately measure the group index of the transferred PCW, and demonstrate slow-light effect.

A home-made bonding tool is utilized to first bond a 2cm x 2cm SOI (675 μm handle, 3 μm BOX, 250 nm device layer) onto a 1mm thick glass slide with 10 μm SU-8 as an adhesive layer. After bonding, the silicon handle is removed by deep silicon etching (DRIE). To control the thermal budget, the silicon handle is mechanically polished down to ~100 μm prior to DRIE, to shorten the etching time. The ICP and the etching time are carefully tuned to achieve an optimized heat dissipation:etch rate trade-off condition. The silicon etch rate of this recipe is around 2.7 μm/cycle. The 3 μm BOX acts as an etch stop layer, which is later removed by hydrofluoric (HF) acid etching. A picture of the transferred SiNM on glass is shown in Fig. 1. The scanning electron microscope (SEM) cross section in the inset shows the different layers, with the final SU-8 thickness measured to be 9.4μm.

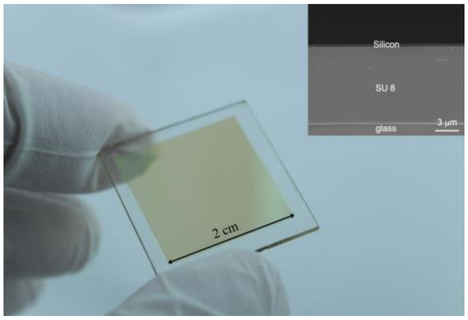

Fig. 1 Microscope image of 2cm x 2cm SiNM transferred on 1mm thick glass substrate. Inset: SEM image of cross section.

The transferred nanomembrane is patterned using conventional electron beam lithography. In this work, a slow-light photonic crystal waveguide (PCW), with a period (L) of 405 nm , and a hole diameter (d) 190 nm is patterned on the transferred SiNM using conventional e-beam lithography. An SEM picture of the fabricated PCW is shown in Fig. 2(a). SWG couplers are utilized to couple light into and out of the waveguides. The SWG couplers are fabricated simultaneously together with the photonic waveguides. An SEM picture of the SWG coupler is shown in Fig. 2(b). A Fourier transform interferometer is designed and fabricated in order to accurately measure the group index of the fabricated PCWs. A microscope image of the interferometer is shown in Fig. 3(c). The interferometer consists of a signal arm (S) consisting of 100 µm of the designed PCW; a reference arm (R) consisting of 5.256 mm of a reference strip waveguide; and an interference arm (I) the combines the R and S signals using a Y-splitter. Using the method outlined in ref [9], we measure the group index of the PCW. Fig. 3(d) shows the measured transmission spectrum from the S (blue), and the I (black) arms. The calculated group index is shown as red data points. Group index up to 28.5 is measured on the SiNM based PCWs. Thus, using our scheme, we have successfully demonstrated the idea of the development and working of intricate photonic devices on foreign substrates. Moreover, SWGs prove to be an ideal packaging tool for such devices.

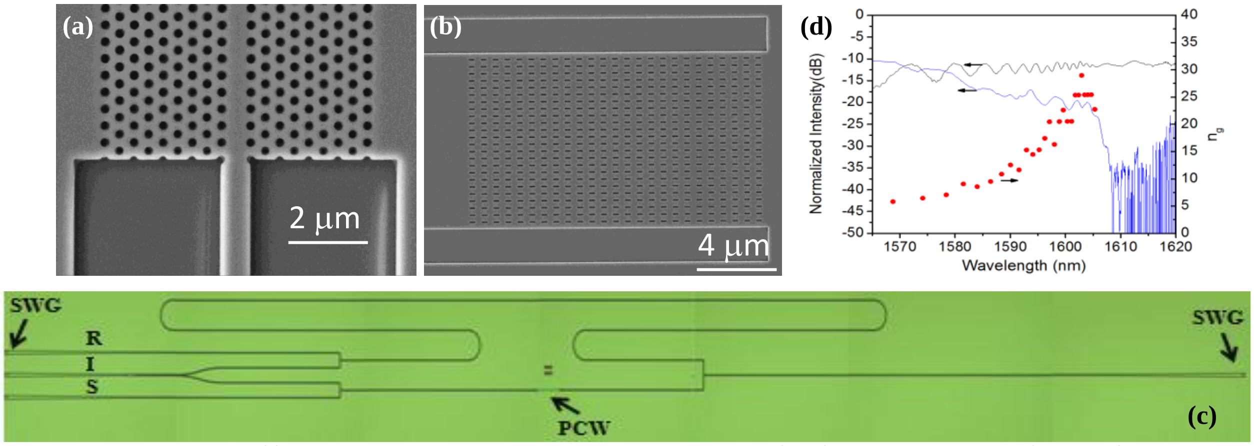

Fig. 2. (a-b) SEM images of fabricated PCW and SWG, (c) Optical microscope image of the fabricated Fourier transform interferometer on SiNM:glass, (d) Measured transmission spectrum from S (blue) and I (black) channels. Calculated group index is shown as red data points.

In conclusion, we have developed a scheme to achieve large area transfer of unpatterned SiNM onto foreign substrates. A light coupling method based on subwavelength grating couplers is utilized to achieve efficient light coupling into the devices. To prove the feasibility, slow-light photonic crystal waveguides are designed and patterned on transferred SiNM. A Fourier transform interferometer is also developed, and group index up to 28.5 is accurately measured for the transferred devices. This demonstration shows great promise for the development of a wide variety of useful photonic devices, and for hybrid integration with other devices, on foreign substrates.

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