Hyperuniform disordered photonic band gap silicon devices for optical interconnects

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Abstract: We report experimental and simulation results for silicon waveguides and devices in hyperuniform disordered photonic solids. Our results demonstrate the ability of disordered photonic bandgap materials to serve as a platform for optical integrated circuits.

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Recent years have seen an increased interest in hyperuniform disordered solids (HUDS) [1-3] for photonic integrated circuits (PICs) sensor and communications chips. In contrast to traditional bandgap materials, HUDS platform can provide solutions to the challenges associated with the cost-effective application of CMOS-compatible optical filters to optical interconnects: device density per unit chip area and temperature sensitivity. HUDS enables a range of devices to be realised in high-index contrast material systems such as narrow waveguides with arbitrary curvature, splitters at arbitrary angles, new types of athermal resonant filters, and novel active devices.

In this paper we report experimental and simulation results on the design, fabrication and characterisation of silicon-on-insulator (SOI) strip waveguides and devices based on the HUDS platform. Waveguide propagation losses of around 13 dB/cm are estimated, while total insertion losses were improved by 17 dB at around 1550 nm after waveguide optimization. The temperature sensitivity of HUDS resonant defects is predicted to be around 0.15 pm/K which is more than 500 times lower than that of the standard silicon microring resonators [4].

Standard silicon-on-insulator (SOI) wafers with 220 nm crystalline silicon height and 2 μm buried oxide layer were used to fabricate HUDS waveguides and resonant defects using standard electron beam lithography and inductively-coupled plasma reactive ion etching that was originally developed for rapid prototyping of large-scale silicon photonics [5]. The hyperuniform disordered wall-network structure was designed by employing a centroidal tessellation of a hyperuniform point pattern to generate a "relaxed" dual lattice, whose vertices were necessarily trihedrally coordinated by construction. More details about the design can be found in Ref. [1].

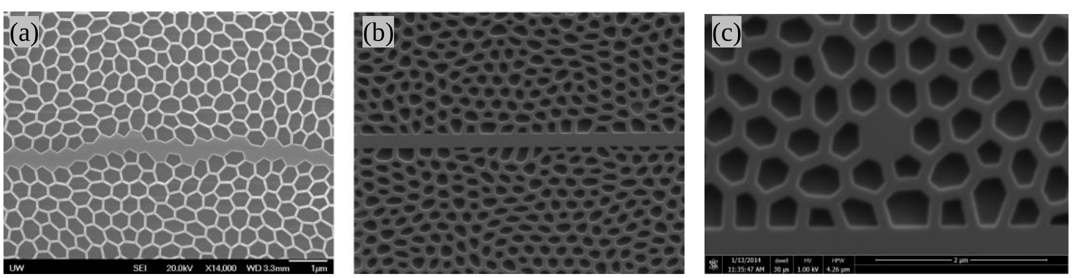

Fig. 1. Scanning electron micrograph image of a fabricated: (a) silicon HUDS waveguide before, and (b) after, the waveguide optimization, and (c) silicon HUDS resonant defect.

The average lattice constant was 499 nm which corresponds to TE polarization photonic band gap (PBG) with zero density-of-state centered around 1.55 μm. The wall thicknesses were varied in the range of 80-150 nm. A fully-etched sub-wavelength grating coupler with 127 μm pitch was used at the input/output of the waveguide to provide efficient coupling of light from/to the single mode optical fibers used for testing [6]. The measurements were performed in the wavelength range of 1.5-1.6 μm using an automated measurement setup as described in Ref. [6].

Figure 1 shows scanning electron micrograph (SEM) images of fabricated devices. Initially, our in-line defects were designed by simply substituting one or two rows of polygon-shape air cells along desired paths with filled silicon (Fig. 1(a)). Waveguide design optimization substantially reduced the initially high backscattering loss of

>30 dB/cm to 13 dB/cm for 500 nm wide waveguides at 1550 nm wavelength (Fig. 1(b)), per simulation analysis using Lumerical software. Both simulations and experiments confirmed that structures exhibit TE photonic band gaps in the 1550±50 nm wavelength range for the chosen wall widths. Figure 2(a) shows transmission spectrum comparing the optical transmission through HUDS having 120 nm thick walls before and after optimization procedure. We measured around 17 dB improvement in total insertion loss at around 1550 nm wavelength compared to the initial waveguide design, and a very flat high transmission profile in the wavelength range of 1.5-1.6 µm. Further systematic optimization and post-fabrication treatments (thermal oxidation and removal of the SiO_2 layer underneath) are planned to reduce propagation losses.

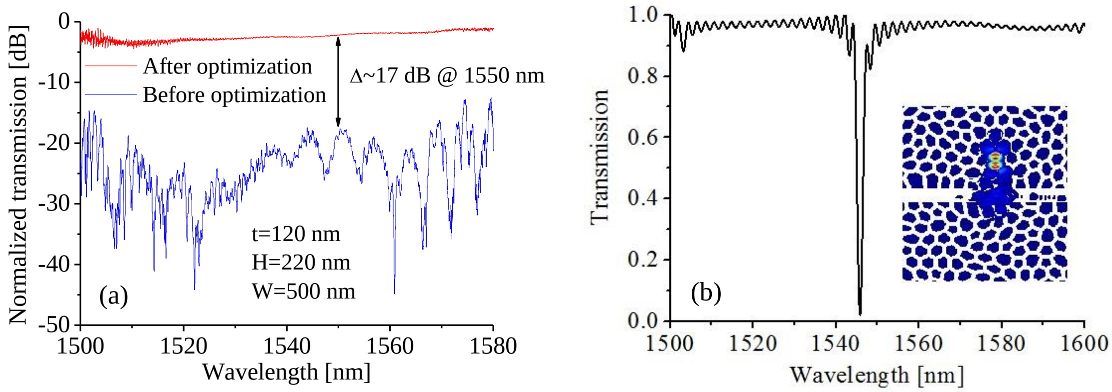

Fig. 2. (a) Insertion loss reduction by 17 dB and a flat transmission spectrum were achieved after waveguide optimization. (b) Transmission spectrum and the field profile (inset) of HUDS resonant defect.

A HUDS resonant filter exhibiting both high extinction ratio and 500 times less temperature sensitivity than a micro-ring resonant filter has been designed and fabricated (Fig.1(c)). Figure 2(b) shows its transmission spectrum. Simulated resonant wavelength shifts as a function of temperature for both HUDS and a ring resonator revealed an improvement of approximately 500 times. The HUDS resonator exhibited a very low temperature dependent resonant wavelength shift of around ~0.15 pm/K, which is 500 times lower than temperature-induced wavelength shift of a ring resonator (~80 pm/K). Temperature dependent resonant wavelength shifts in ring resonators depend on the resonator size and coupling from a straight waveguide [4]. Our results indicated that the reduction in temperature sensitivity is related to the relatively small defect size and lower light interaction with silicon than in the case of ring resonators, as it can be seen from inset Fig. 2(b). Experimental results are being performed to confirm these results.

In conclusion, we have presented our preliminary results on HUDS waveguides and devices at around 1550 nm wavelength. The devices demonstrate an ability to guide light in the infrared regime with low insertion loss associated with predicted propagation loss of ~13 dB/cm. The temperature-induced wavelength shift of a CMOS-compatible HUDS resonator was estimated to be ~0.15 pm/K which is more than 500 times lower than that of the standard silicon microring resonators. Temperature-insensitive and low-loss HUDS devices therefore provide a building block for more complex passive and active devices, together enabling SOI HUDS photonic integrated circuits for wide-ranging applications at optical communication wavelengths.

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