Low loss amorphous silicon photonic wire and ring resonator fabricated by CMOS process

Shankar Kumar Selvaraja (1*), Erik Sleeckx (2), Wim Bogaerts (1), Marc Schaekers (2), Pieter Dumon (1), Dries Van Thourhout (1), Roel Baets (1)
1 Photonic research group-IMEC, University of Gent, Gent, Belgium, 2 IMEC, Leuven, Belgium
* shankar@intec.ugent.be

Abstract *We report low loss amorphous photonic wire loss of 3.5dB/cm. We also report compact racetrack ring resonators with Q factor greater than 20,000. The photonic circuit is fabricated with standard CMOS production tools.*

Introduction

Silicon photonic integrated circuit is a very attractive platform for a wide range of application. High index contrast enables small bending radius subsequently resulting in a much denser circuitry. Crystalline SOI material is used in almost all silicon photonic circuitry [1]. While it typically has exceptional material quality it limits the photonic circuit to a single layer. As an alternative, deposited silicon facilitates multi layer stacking of photonic layers and is CMOS compatible. However, for this the deposited material should have similar quality in terms of optical properties as the crystalline silicon. Various deposited silicon materials have already been explored, such as SiON, SiN, SiC, Poly-Si, a-Si.

Si can be deposited using various deposition processes. The property of the film depends on the process used and process conditions. In this work we explore a low temperature plasma-enhanced CVD process to deposit high-quality amorphous silicon (a-Si). Other groups using similar processes have already demonstrated single-mode waveguides fabricated from hydrogenated a-Si have with a loss of 2 dB/cm (shallow etch) [2] and 6.5dB/cm (deep etch) [3].

Design and fabrication

Single mode operation and strong optical confinement is a prerequisite for high density photonic integrated circuitry. The strong confinement is necessary for making circuits with small (1-5μm) bending radius with low loss [1]. Photonic wires of 220nm height and 500nm width can be used for this purpose [1]. To measure the propagation loss wires of varying length are made by spiraling them with large bending radius (20μm). The length of the photonic wires varies between 0.5cm and 40cm. Along with the spirals all-pass notch filters with race track ring resonators were also added to the design. The bend radius is 4μm and coupling gap is 180nm.

To build a-Si photonic circuitry we start with bare silicon wafers. An overview of the fabrication process is depicted in figure 1. A 2μm silicon dioxide is deposited by high density plasma. The deposition process is followed by chemical mechanical polish (CMP) to prepare the surface for a-Si deposition. The thickness loss due to CMP is compensated by an excess deposition in the first step.

Then 220nm of a-Si is deposited by plasma enhanced CVD process in an Applied Materials PECVD tool. He/ SiH_4 is used as precursor for a-Si deposition. The power is tuned from 300-180W and the He/ SiH_4 gas ratio is tuned between 0 and 9.

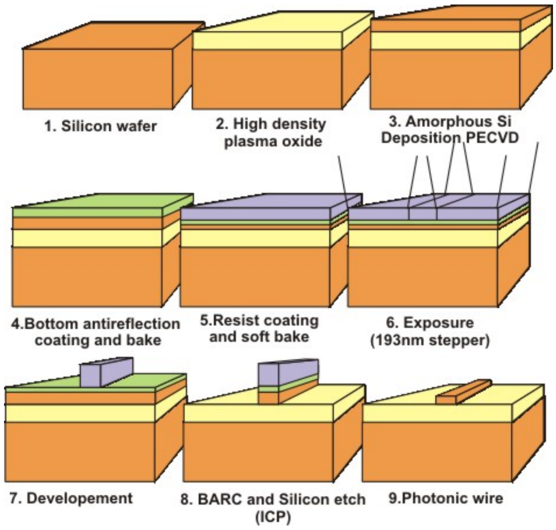

Figure 1.a-Si process flow

The deposition temperature was maintained at 300°C to make the process compatible with backend CMOS process. The low temperature is very important to maintain the amorphous nature of the film. The film defects (dangling bonds) are kept within bounds by finding the optimum deposition parameters. Also, the H content in the film is critical in determining the film quality. Too much H will create H clusters and will cause scattering points while a low H content will leave too much silicon dangling bonds, which cause optical absorption. Therefore an optimum H level is required for low-defect a-Si film.

The deposited film is then patterned by 193nm photolithography [4]. Resist mask is used to etch 220nm of silicon using F and Br chemistry. After dry etch process the remaining photoresist is removed by dry and wet strip process. Finally the waveguides are covered with 1μm of low temperature silicon dioxide. Figure 2 depicts the cross section of fabricated Photonic wire before the final oxide deposition. It is clearly visible that the surface roughness of the deposited film is high but with CMP this roughness can be reduced. In this study we didn't apply this CMP on the a-Si film.

Measurement results

The fabricated photonic wire structures are characterized for propagation loss by coupling in light from a tunable laser (1500nm-1600nm) and the output from the wire is measured with a photo detector.

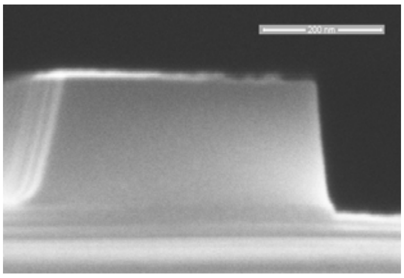

Figure 2. SEM image of an a-Si photonic wire

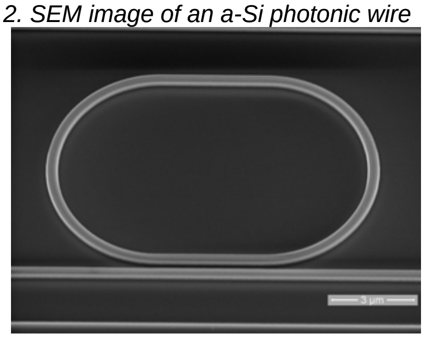

Figure 3. Race track ring resonator

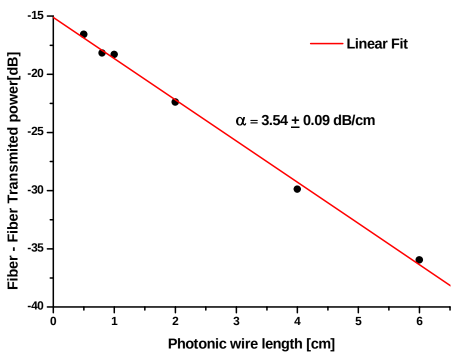

Figure 4.Transmitted power Vs Wire length at 1550nm

Grating fiber couplers [5] are used for in and out coupling of light in the photonic wire. The fiber couplers are polarization dependent; in this work we use the quasi-TE polarization in the photonic wires. The transmitted power through different length of photonic wires is measured in a wavelength range of 1500-1600nm. Figure 4 depicts the measured power for various lengths at 1550nm. The propagation loss is obtained by linear regression of the output power versus the length of the wires.

A propagation loss of 3.5±0.1dB/cm is measured for 480nm wide photonic wire. It is surprising to note that the loss is very close to the crystalline silicon wire loss [4]. This is often true for good quality a-Si film with low defect density [3]. Sidewall roughness and bulk absorption are considered to be the main cause of propagation loss.

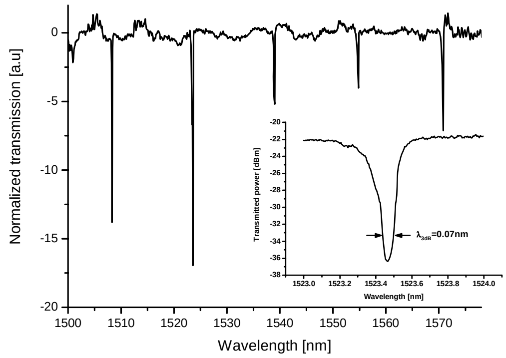

Figure 5.Transmission spectrum of the ring resonator

A rough estimate for bulk loss is ~1dB/cm, which is the difference between the crystalline SOI [4] and a-Si photonic wire loss of same dimension and patterned with the same fabrication process. To verify this estimate we measured the propagation loss in a shallow-etched (70nm) ridge waveguide of a-Si. The shallow etch introduces much less roughness as the deep etch used for photonic wires, so its propagation loss gives a good upper estimate of the bulk material loss. These waveguides show a loss of 1.4±0.01dB/cm, of which the major part of can be attributed to the absorption in an a-Si slab

To demonstrate the good quality of the waveguide, we also implemented resonators in the same process. Figure 5 shows the spectral response of a race track ring resonator. The inset of the figure shows the resonant peak of a high Q factor. The resonator has a free spectral range (FSR) of 15nm and a 3dB bandwidth of 0.07nm, which leads to a finesse of 200 and Q factor over 20,000. Such high Q notch filters can already be used for different practical applications.

Conclusion

We have demonstrated ultra low loss a-Si photonic wire with loss of 3.5dB/cm. To our knowledge this is the lowest loss reported for photonic wire for such dimension. A high Q race track ring resonator shows the devising capability of deposited a-Si. The photonic circuit is fabricated with CMOS industrial tools with a low temperature process.

References

1 P. Dumon et al., *Jap. J. of Applied Physics*, vol. 45, pp. 6589-6602, 2006.

2 A. Harke et al., *Electron. Lett., vol.* 41, pp-1377-1379, 2005

3 D. K. Sparacin et al., Group IV photonics 2006, pp. 255 - 257.

4 S. K. Selvaraja et al, 20th IEEE/LEOS annual meeting 2007, Florida, 2007, to be published.

5 D. Taillaert et al., IEEE J. of Quantum Electron., vol. 38, pp.949-955, 2002.