Polarization-insensitive PECVD SiC waveguides for photonic sensing

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ABSTRACT

Planar silicon carbide (SiC) waveguides are proposed for fabrication on a silicon substrate with a oxide isolation layer. Using post deposition annealing it is possible to achieve low Polarization-Dependent Loss (PDL) within optical SiC waveguides fabricated using a low temperature deposition technique. Those waveguides have been successfully used in power splitters and cantilivers. These first devices open the way for photonic sensing in harsh environment using SiC.

Keywords: Integrated optics, a-SiC, Polarisation Dependency Loss.

1. INTRODUCTION

In recent years Si-based optoelectronics has been intensely investigated with the objective of bridging between the field of photonics and silicon integrated circuit. Like the shrinking of electronic building blocks allowing billions of elements on a single chip nanostructures in photonics opens similar integration perspectives [1]. Because the size of the components decrease, the propagation loss is no longer an obstacle allowing then the use of material never considered in the past. This is even more true in sensor applications where only a readable output signal is required. Among those new considered materials, SU-8 [2] has shown promising results.

The transparent wavelength range of Si is limited to the region of above 1.2 μm, therefore integrated optics applications in the visible range are excluded. PECVD SiC is a wide bandgap optoelectronic material (i.e. high refractive index), transparent above 0.5 μm [3] and therefore suitable for guiding over the visible and near-infrared spectrum range as well as the longer wavelengths. Theoretical analysis [4] of SiC optical waveguide has shown that low loss and good beam confinement in the guiding core is achievable. The mechanical strength of the material makes it attractive for use at high optical power densities [5] like the one provided by Raman sources. Furthermore, the low deposition temperature allows the compatibility with standard CMOS process.

Many of the electronic properties of SiC have been characterized and reviewed, but very little is known about its properties when used as an optical waveguide [6], at least while deposited by low temperature techniques. In the following, we report a technique to produce polarization insensitive PECVD SiC waveguides and their uses as cantilevers and power splitters.

2. FABRICATION AND OPTICAL CHARACTERISTICS OF POLARISATION INSENSITIVE SIC WAVEGUIDES

First a 1μm thick PECVD SiO2 layer is deposited on a standard <100> Si wafer. The oxide serves to optically isolate the circuit from the substrate and reduce the loss due to substrate leakage. Then a 2 μm thick PECVD SiC layer is deposited using silane (SiH4) and methane (CH4) in a Novellus Concept One system. The temperature of deposition is 400^{o}C. Large thicknesses lead to multimode high index contrast planar waveguides but it is fortunate that the quite restrictive slab criterion is not essential for monomode rib waveguide [7]. Wafers were pattern and 3 μm wide singlemode straight waveguides etched down to 1.6 μm in Trikon Omega inductively coupled plasma with: 30 sccm Cl_2, under 9.5 Torr at 25 ^{o}C, and with an ICP RF power of 500 W and a RF platen power of 35 W. As reported in [8], this process allows a etching uniformity over a 4 inch wafer of 210 ±10 nm and a waveguide width uniformity of 3±0.5 μm. The estimate etch rate over the entire wafer is 380 nm/min.

A cross section view with the parameters of the considered waveguide is shown is Figure 1.

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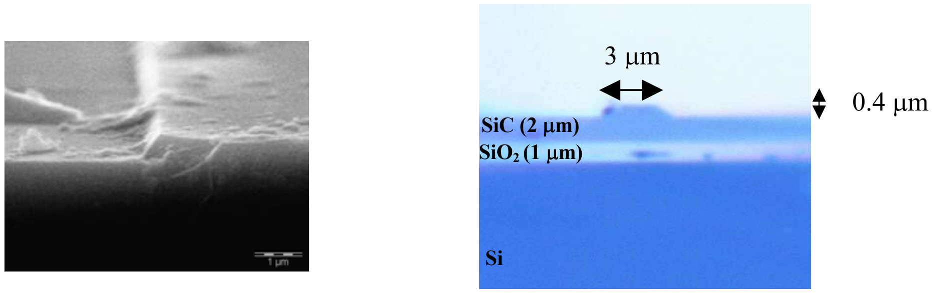

Fig. 1. Cross section view and dimensions of the fabricated waveguides.

Once fabricated the waveguides are annealed. Figure 2 presents the index for three different temperature of annealing, the deposition temperature 400 ^{o} C, 500^o C and 600^o C. During the annealing the temperature increase by 50 ^{o} C every 5 min. until the target temperature. The cooling uses the same steps. The waveguides, shown in figure 1 which were etched down to 1.6 µm remained single mode (despite the change in refractive index) for the three temperatures at 633 nm (the wavelength used to characterize the waveguides).

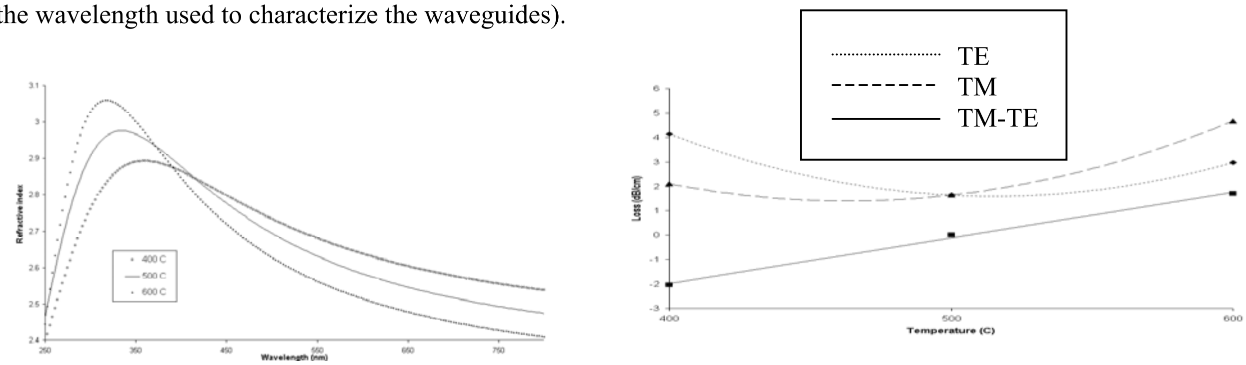

Fig. 2. Refractive index of the SiC films after annealing and PDL evolution according to the annealing temperature.

The absorption measured while estimating the refractive index of the annealed SiC films tells us when the films become transparent. For example, the films annealed at 400^{o}C are transparent for any wavelengths higher than 625 nm, the one annealed at 500^{o}C are transparent from 614 nm and finally the one annealed at 600 ^{o} C are transparent from 589 nm.
To characterise the waveguides, various lengths have been obtained by cleavage. The radiation of a 1mW 633 nm laser diode, was then launched in the different cleaved waveguides using a spot size converter (i.e. an objective lens). It brings the incident beam size down to 3 µm matching then the physical dimensions of the waveguide. A polarization controller is used for adjusting the light polarization for both TE- and TM-guided mode excitations. The output signal at the waveguide end face, is magnified and recorded by a power meter. The advantage of this setup (figure 3) is the ability to change the polarization without changing the mechanical positioning at the input of the waveguide. Both the input and output spot size converter are mounted on precision positioning stages that allow precise control of the alignment with the waveguide input-ouput. The propagation losses have been estimated with the cut-back technique, from a set of four points at least for the three considered temperatures. The results are presented in figure 2 b). The PDL is plotted subtracting the TM propagation loss and the TE one.

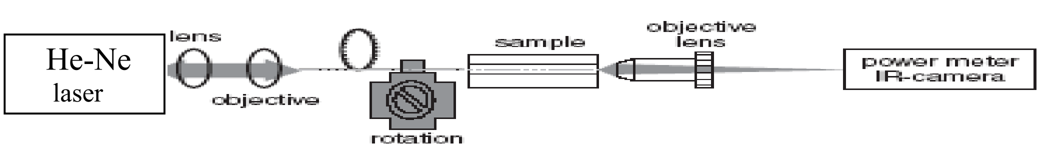

Fig. 3. Optical bench used for the cut back measurements.

3. POLARIZATION INSENSITIVE TRANSDUCER HEAD AND ITS OPTICAL READOUT

To produce optomechanical structure, a second etching step is performed. The SiC is isotropically etched and a wet etching of the oxide (73% HF is used here) makes the mechanical structure to be free standing. To prevent sticking, freeze drying is applied [9]. Figure 4 shows a top view of the fabricated transducer head with the rib waveguide defined on the top. The cantilever presented here is 20 µm wide. The guided mode propagating in the cantilever is confined, so such width will not introduce extra propagation loss. We fabricated cantilevers with several lengths and measured the transmitted power. The results are presented in figure 4. Cantilevers exhibit up to 3 dB loss for the TM polarization while placed on the optical bench shown in figure 3. This loss disappears after annealing at 500 ^{o} C. Fresnel loss extracted from the propagation loss measurements are subtracted here.

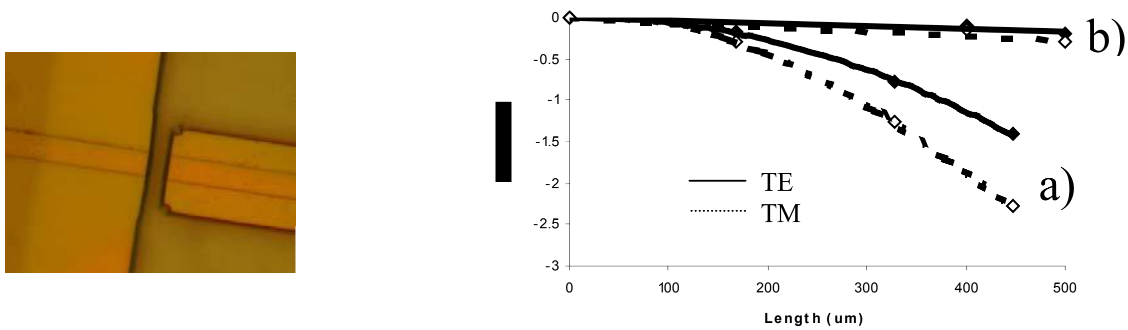

Fig. 4. Top view of the transducer head and its optical transmission before a) and after annealing b).

In the case of vibration sensing (the mechanical sensitivity being fixed by the requirements on the frequency response) the optical circuit should be able to detect displacement as small as 10 nm. This high sensitivity can be reached by using a MMI coupler in the optical detection path (figure 5). The MMI coupler is 11.5µm long and 350 µm large in order to improve the sensitivity and also give a linear response of the differential output signal for a range of displacement between ±1 µm (figure 5). The difference of intensity caused by mechanical displacement along the sensitivity axis is amplified by the MMI whereas a displacement along the transverse axis produces losses but does not affect the difference of intensity between the two output waveguides.

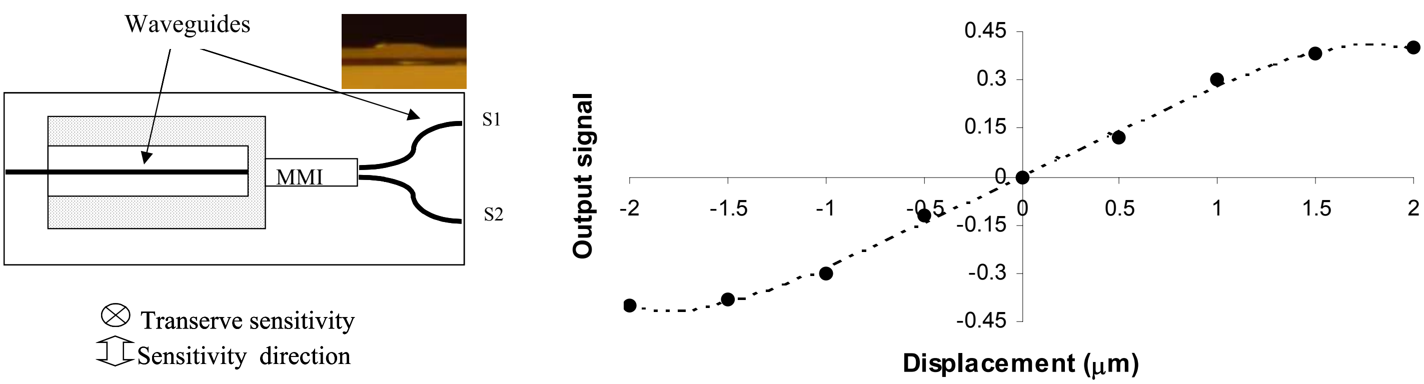

Fig. 5. Schematic of a vibration sensor and the response of the fabricated MMI.

Furthermore the MMI is not dependent on the polarization so the sensitivity is the same for both polarization.

4. OPTICAL POWER SPLITTER

Power splitters are key elements for optical sensing. Recently they have found applications in microfluidic plateform [9] and in four-channel Young interferometers [10]. The insensitivity to the polarization is often required to avoid the use of complex or long polarization controller or canceller. Conventional cheap optical sources are usually not polarised. Optical circuits insensitive to the polarization have then the advantage of being fully compatible with cheap light sources. We designed 1x4 optical power splitters using 1x2 MMI. The MMIs are 425µm long and 12 µm wide and cascaded twice (figure 6).

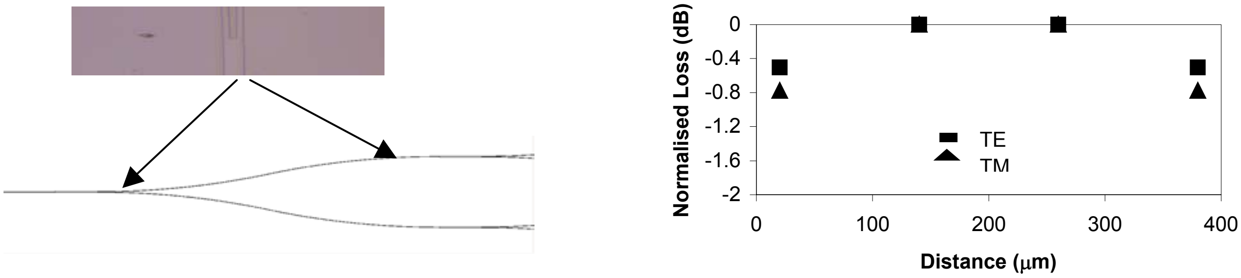

Fig. 6. Schematic of the 1x4 power splitter designed and its transmission according to the polarization.

The waveguides used here have been annealed at 500 ^{o} C to provide PDL free waveguides. The maximum measured PDL on the extreme ports is 0.2 dB. Shorter devices using one 700 μm long and 25 μm wide MMI give the same response.

Beside power splitters and cantilever beams, polarization insensitive waveguides have been be successfully used in pressure sensors [10], or in attenuators [11].

5. CONCLUSION

It has been shown that low loss and low PDL are achievable using PECVD SiC waveguides and that such a waveguide can be used in passive optical devices like power splitters and cantilevers. These results can be used as a benchmark for further development of SiC microphotonic components and circuit for sensor systems in harsh environments.

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