Silicon Oxycarbide Waveguides for Photonic Applications

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Abstract. Silicon oxycarbide thin films deposited with rf reactive magnetron sputtering a SiC target are exploited to demonstrate photonic waveguides with a high refractive index of 1.82 yielding an index contrast of 18% with silica glass. The propagation losses of the photonic waveguides are measured at the telecom wavelength of 1.55 $\mu$m by cut-back technique. The results demonstrate the potential of silicon oxycarbide for photonic applications.

1. Introduction

Integrated photonics has progressed significantly over the past decades. Photonics is capable of providing reliable and low-cost high-speed communications. Though different materials have been exploited to fulfill the needs of the integrated photonics industry, however the well-established platforms such as SiO$_2$, SiN, Si, and InP are limited in their refractive index tunability. Silicon oxynitride has been demonstrated to show the flexibility of refractive index tuning between silica glass and SiN. First, SiON exhibits absorption peak around 1500 nm, and secondly cracks are observed when refractive index becomes larger than 1.5 that confines its use to low index [1]. Silicon oxycarbide (SiOC), on the other hand, has a possibility of wide refractive index tunability ranging from silica glass to amorphous silicon carbide [2]. The tunability in refractive index is useful for the large integration scale of photonic devices on a single chip. The light mode can be confined tightly in high contrast waveguide core that enables smaller bending radii and reduces device footprint [3]. The overall picture of the state-of-the art of optical materials with SiOC being a promising platform is represented by Figure 1.

Silicon oxycarbide has received considerable attention in the scientific community. Showing material versatility, SiOC is applied in various important applications ranging from photoluminescence, multilayer structures for bloch surface waves to inter-layer dielectric. Despite possessing excellent material properties, silicon oxycarbide is yet not established as a platform for integrated photonics.

In this work, silicon oxycarbide thin films are deposited with rf reactive magnetron sputter technique. The thin films are characterized with several tools to better understand the structure and optical properties. Then the films of SiOC are exploited as core layer material to demonstrate waveguides for integrated photonics with high refractive index of 1.82 that is surrounded by silica glass.
glass cladding. The losses of the SiOC waveguides were estimated by butt-coupling with optical fibers using a controlled optical setup.

![Figure 1. State-of-the-art of photonic integration technology with silicon oxycarbide (SiOC) as a promising platform.](image)

2. Experimental Details

Silicon oxycarbide (SiOC) thin films were produced by sputtering a 99.9% pure SiC target in a rf reactive magnetron sputter chamber in the presence of argon (Ar) and oxygen (O2) gases. The SiC target material placed on cathode was negatively biased by suppling rf power and the plasma (Ar) and reactive (O2) gases were inlet in the chamber and controlled with mass flow controllers. SiOC thin films with varying refractive index were produced by increasing sputtering power from 150 to 450 watts while keeping Ar and O2 gases at a constant ratio. The SiOC films were deposited on Si (100) and Si (100) with SiO2 layer substrates. The SiOC films deposited on Si substrates with SiO2 layer were used to fabricate photonic channel waveguides.

The deposited SiOC films were characterized to investigate the effect of sputtering parameters and attain the favourable properties. Surface roughness being one of the important parameter was quantified with atomic force microscope (5600LS Keysight AFM system) by scanning the film in tapping mode. The cross section of SiOC waveguides and films were analysed with scanning electron microscopy (SEM-LEO 1525) for morphology and determine the thickness. The optical properties (index of refraction n and coefficient of extinction k) of SiOC films were studied with variable angle spectroscopic ellipsometer (Woollam Inc., US) from UV to near-infrared spectral range.

The photonic waveguides in SiOC films with n = 1.82 were fabricated by UV photo-lithography and reaction of ion etching (R.I.E) techniques. The fabricated waveguides were covered by a thicker PECVD SiO2 (n = 1.444) top layer to attain symmetric guided modes. The SiOC waveguides were characterized for propagation losses with small-core fibers (MFD = 3.6 μm) on a polarization controlled optical bench.

3. Results and Discussion

The surface roughness of the deposited SiOC films was quantified with AFM by scanning in tapping mode over a surface area of 100 μm². The rms roughness as low as 0.9 nm was evaluated from AFM measurements for a film thickness of 400 nm, that is atomically flat to realize photonic waveguides. The film surface roughness is important as it acts as source of scattering for propagating light along the waveguide and contributes to the losses.
The optical properties (n and k spectra) of SiOC thin films deposited under varying sputtering conditions are shown in Figure 2. The refractive index n increases as rf power gains from 150 to 450 watts. The increase in n indicates a change in the chemical composition of SiOC films. The n of SiOC ranges from 1.45 to ∼1.82 demonstrating the wider tunability as shown in Figure 2(a). The extinction coefficient k of SiOC thin films shown in Figure 2(b) is negligible, that is below the detection limit of ellipsometer in the near-infrared spectrum. The lower material absorption coefficient enables the fabrication of photonic waveguides in SiOC thin films. The tunable refractive index and low absorption are ideal for the realization of a range of photonic devices in a single material platform [4].

![Figure 2](image_url)

**Figure 2.** (a) Index of refraction n (b) coefficient of extinction k spectra of SiOC films deposited under changing sputtering conditions.

Figure 3 shows the photonic waveguide fabricated with SiOC core. The image in Figure 3 was captured with SEM. The SiOC waveguide thickness was around 400 nm and refractive index n = 1.82. To achieve single mode operation, the width of SiOC waveguides is 1.8 μm that is patterned with UV photo-lithography and reactive ion etching as shown in Figure 3.
Figure 3. SiOC photonic waveguide with width = 1.8 μm, height = 400 nm and n = 1.82.

The propagation loss of the SiOC core waveguide were characterized on a polarization controlled optical bench. The losses of propagation as low as 0.8 dB/mm were measured for SiOC waveguides with n = 1.82 for both TE and TM polarizations.

4. Conclusion
SiOC photonic waveguides with high refractive index of 1.82 are demonstrated for the first time. The propagation losses of the waveguides are characterized and presented. The results show the significance of SiOC material and imply its suitability for photonic integration applications.

References
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