Low loss high refractive index niobium oxide waveguide platform for visible light applications

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Abstract: We investigate niobium oxide (NbO) as an alternative waveguide material for applications in the visible spectral range. NbO has a refractive index ranging between 2.3 and 2.35, which is about 25% higher than SiN, the most widely used material for waveguides in the visible spectral range. This increased index contrast between NbO and the cladding material allows to fabricate optical components with much smaller footprint, and consequently to increase the density of photonic integrated circuits substantially. We benchmark this waveguide platform to imec's CMOS compatible PECVD SiN platform and observe fairly similar loss numbers for both materials.

OCIS codes: (230.7370) Waveguides; 230.7390) Waveguides, planar; (250.5300) Photonic integrated circuits;

1. Introduction

Photonic integrated circuits (PICs) have been extensively studied for optical communication (1300/1550 nm) in the near-infrared spectral range with silicon-on-insulator (SOI) based waveguide platforms. In recent years, silicon nitride (SiN) has been extensively studied for waveguiding in the visible spectral range [1], for example in the framework of integrated biological sensing. The footprint of such PICs is typically larger than those realized in SOI platforms, due to the fact that the refractive index of SiN ranges from about 1.85 to 2, depending on the deposition method used. Therefore, we are currently investigating CMOS compatible materials which have an increased refractive index and can be integrated in our 200 mm pilot line. While different research groups [2-5] have studied TiO_2-based compounds, these materials often suffer from instability at elevated processing temperatures, and are therefore less appealing for usage in CMOS compatible fabrication flows. NbO offers an interesting alternative, as its refractive index ranges between 2.3 and 2.35 in the visible spectrum, which is about 25% higher than the commonly used SiN based waveguide platforms. As the device footprint for PICs directly relates to the index contrast between the waveguide core and cladding, the impact of increasing the refractive index by 25% results in an improved confinement and hence reduced device footprints. It also allows to scale bend radii down by a factor larger than 2 at the same bend loss penalty. Here we make a direct comparison between our newly developed NbO waveguide platform and imec's CMOS compatible PECVD SiN platform [1]. We observe similar loss values for the entire visible and NIR wavelength range, paving the way for much more compact PICs at visible wavelengths.

2. Sample fabrication

NbO waveguides were fabricated in a CMOS compatible 200 mm pilot line, using a state-of-the-art fabrication processes. The silicon substrates are first coated with a 70nm SiN anti-reflective coating (ARC) and a 2μm thick SiO_2 bottom cladding by plasma-enhanced chemical vapor deposition (PECVD) at 400°C. Prior to deposition of the NbO waveguide layer, the surface roughness of the bottom cladding layer is reduced by chemical mechanical polishing (CMP). The amorphous 70 / 90 nm NbO waveguide layer itself is deposited by Physical Vapor Deposition (PVD) at room temperature. Subsequently, waveguides (figure 1a) and grating couplers (figure 1b) were patterned using 193 nm lithography and etched using a chlorine based chemistry etch process, and stripped with conventional chemistries. A 1μm SiO_2 top cladding is deposited using PECVD deposition at 400°C..

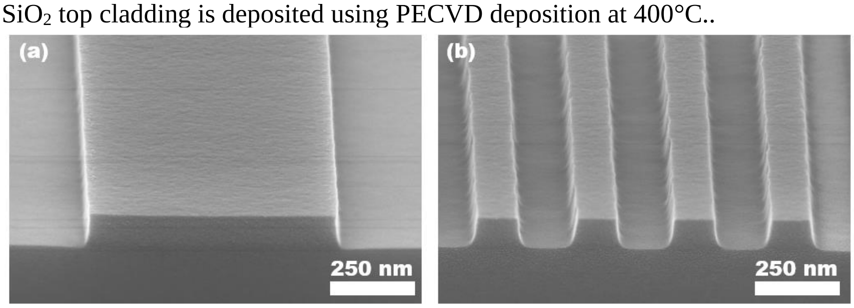

Figure 1: Scanning electron microscope images of the patterned NbO waveguides (a) and graitng couplers (b) after lithography and etch.

The root mean square (RMS) roughness of the amorphous NbO layers is as small as 0.3 nm, resulting in waveguides with very smooth top surfaces after patterning, as can be observed from figure 1.

3. Optical measurements

The optical losses of the patterned waveguides were extracted by means of fiber-to-fiber measurements at different wavelengths throughout the visible spectral range. Grating couplers were designed to couple the fundamental TE mode at an incident angle of 10° in oxide cladding. Waveguide losses were extracted by measuring 5 spiraling waveguides with lengths ranging from about 5 to 20 cm. The spirals were designed in such a way that all bends and routing waveguides had single mode widths, while the waveguide width is varied only in the straight segments that have different lengths for the different spirals, allowing to de-embed all routing and grating coupler losses.

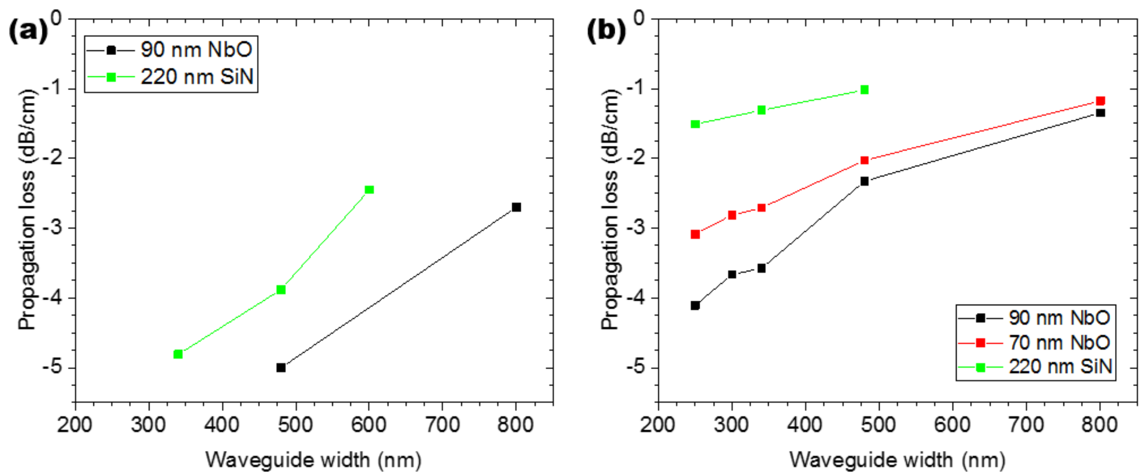

Figure 2: Waveguide losses at 638 nm wavelength before (a) and after (b) top cladding deposition for different NbO strip waveguides and SiN as a reference platform.

When comparing waveguide losses before and after cladding at 638 nm wavelength (figure 2), a clear reduction in the losses is observed due to the decreased index contrast between the waveguide core and cladding, leading to reduced scattering losses due to sidewall and top roughness. With further process tuning, it is likely that we'll be able to further reduce the waveguide losses for our NbO waveguide platform, for example by decreasing sidewall roughness or using conformal ALD coatings that further decrease the index-contrast between waveguide core and cladding.

4. Conclusion and outlook

In summary, we have tested NbO as an alternative waveguide platform for visible light applications. Due to the increased refractive index compared to standard SiN-based waveguide platforms, the footprint of PICs can be scaled down by a factor 2 to 3 without any penalty in losses when comparing with SiN based devices. Therefore, NbO is a very promising candidate for future integrated photonic devices in the visible spectrum, opening up many possibilities for highly integrated sensing devices.

5. References

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