Si_3N_4 PLATFORM FOR VISIBLE RANGE APPLICATIONS

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Abstract

We report on the realization of optical waveguides and basic photonic building blocks on a Si_3N_4 *platform for applications in the visible light range. Details are provided on the characterization of the* Si_3N_4 *film and on the design and fabrication of single-mode waveguides and devices operating at RGB wavelengths, namely 450 nm, 520 nm and 660 nm. Preliminary results on optical characterization show propagation loss of 5.7 dB/cm at 660 nm.*

Index Terms – Photonics, Visible, Waveguides, Integrated

I. INTRODUCTION

The visible range of the electromagnetic spectrum is being investigated for many emerging applications, including visible light communication high resolution imaging, metrology and (bio)sensing. This requires the development of integrated photonic platforms where the light can be efficiently generated, manipulated and detected on small chips. Because of its large wavelength range of transparency, silicon nitride (Si_3N_4) is a well-established photonic platform, which has been used for more than two decades in the near-IR range [1] and more recently in the mid-IR range [2]. Now, visible range is the new frontier of Si_3N_4 photonics [3][4].

In this work we report on the realization of optical waveguides and basic photonic building blocks on a Si_3N_4 platform for applications in the visible light range. We discuss the main design and fabrication issues for single-mode waveguides and devices operating at RGB wavelengths, namely 450 nm, 520 nm and 660 nm. Preliminary experimental results are reported on first generation devices operating at 660 nm.

II. MATERIAL CHARACTERIZATION AND BUILDING BLOCK DESIGN

The platform employed for the waveguide realization consists of a low-pressure chemical vapor deposition (LPCVD) Si_3N_4 film deposited on top of a SiO_2 substrate. The table in Figure 1 shows the refractive index of the materials at RGB wavelengths, which where used in the design of the optical waveguide. These data where measured by spectroscopic ellipsometry on 200 nm thick films, and the Si_3N_4 dispersion curve is shown in the figure from the UV (200 nm) to the mid-IR (2000 nm) range. The significant change of the Si_3N_4 refractive index at low wavelength needs to be taken into account accurately for a proper design of optical waveguide working in this wavelength range.

Wavelength	Material	Refractive index
450 nm	SiO_2 Si_3N_4	1.478 2.05
520 nm	SiO_2 Si_3N_4	1.476 2.03
660 nm	SiO_2 Si_3N_4	1.471 2.007

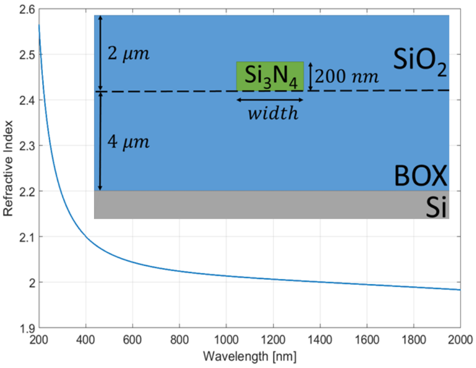
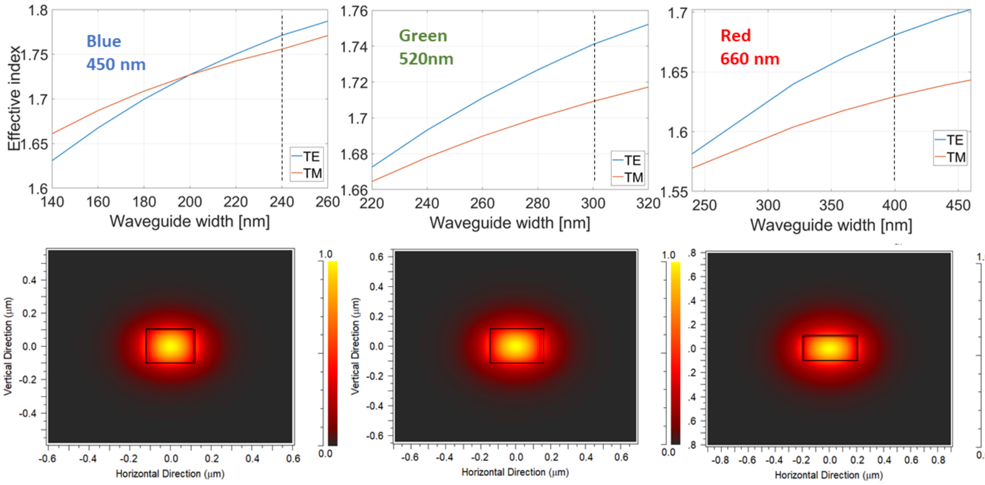


FIG. 1 – At left, the refractive indexes used for the simulations. At the right the Si_3N_4 dispersion curve from 200 to 2000 nm [1] with an inset containing the schematic of the platform.

The designed optical waveguide are buried under a SiO2 upper-cladding layer and have the channel structure shown in the inset. The thickness of the SieN4 film is 200 nm. Mode analysis as well as device designs were performed by using a full-vectorial beam propagation method (BPM). Figure 2 shows the effective indexes of the fundamental TE (blue line) and TM (red line) modes versus the width of the waveguide when the optical wavelength is 450 nm, 530 nm, and 660 nm, respectively. The vertical dashed line indicates the cut-off width of the higher order mode. Results show that the maximum width to have single mode propagation is 240 nm (B), 300 nm (G) and 400 nm (R), respectively. The intensity profile of the fundamental TE mode for these R-G-B single-mode waveguides is shown in the bottom panels.

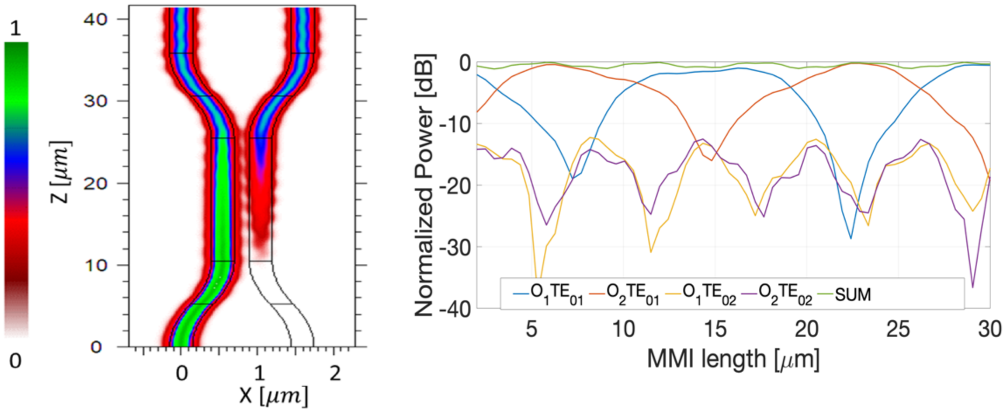


a) b) c)

FIG. 2 – (top) Simulated effective index vs waveguide width of the fundamental TE and TM modes mode at a wavelength of a) 450 nm, b) 520 nm, c) 660 nm. (bottom) Cross-sectional intensity profile of the fundamental TE mode of the considered waveguides.

Both directional couplers and multimode interference couplers (MMI) were designed at the three wavelengths. For directional couplers, the minimum gap distance achievable with available fabrication process is about 100 nm. This sets the minimum length to achieve a given power splitting ratio. For instance, in the example reported in Fig 3a, the total length of the device, including bent-waveguide transition regions, for a 3dB directional coupler at 520 nm is about 30 mm. Field beating in the output waveguides reveals that the higher order mode in weakly guided, but it can be not excited or radiated away by optimizing the curvature profile of the bend.

MMI couplers don’t require long and narrow gaps between the waveguides and in principle could be fabricated more easily. The numerical simulation of Fig. 3b shows the power of the fundamental mode TE_{01} at the output ports of am MMI coupler (O_1 and O_2) and the power of the higher order mode TE_{02} at the same output ports the MMI for increasing length of the MMI. The multimode waveguide of the MMI is 1.15 μm wide. Results show that the optimum length to have 3dB split ratio is about 10.7 μm, where the overall loss is less than 0.3 dB and the higher order mode at the output port 14.6 dB less than the fundamental mode.

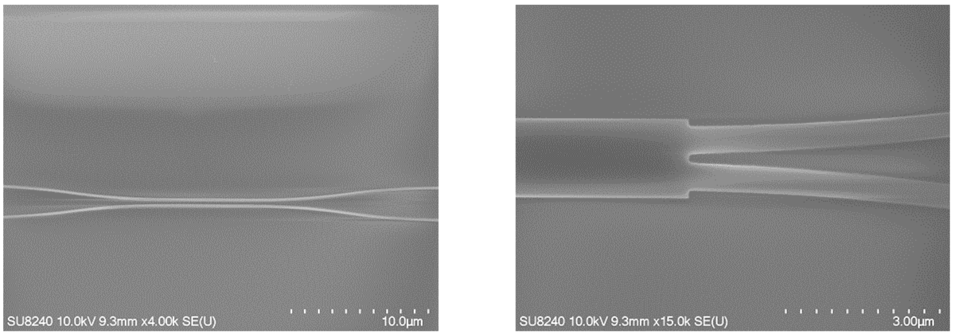


a) b)

FIG. 3 – a) BPM numerical simulation of a 3dB directional coupler operating at a wavelength of 520 nm. b) MMI optimization through the analysis of the mode intensity in the output waveguides. O_1 and O_2 are the two output branches of the MMI.

III. WAVEGUIDE FABRICATION AND PRELIMINARY CHARACTERIZATION

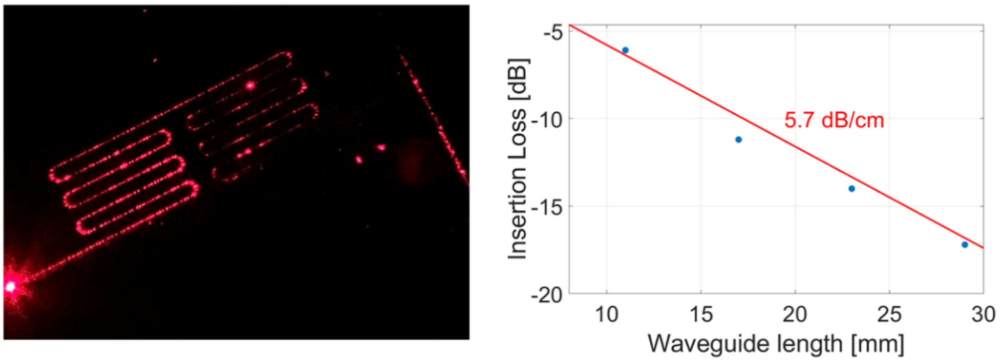
The Si_3N_4 was grown on Si carrier wafer with 4 μm thermal oxide as bottom oxide layer (BOX) using LPCVD. The device pattern was defined using electron beam lithography on Hydrogen Silsequioxane (HSQ). The patterns were transferred to the silicon nitride core with the use of Reactive Ion Etching. The devices were coated with a 2 μm thick plasma enhanced chemical vapor deposition (PECVD) SiO2 as a buffer layer. Two SEM images of the resulting integrated devices are provided in figure 4.



a) b)

FIG. 4 – SEM images of a directional coupler (a) and MMI (b)

Preliminary optical characterizations were performed on 400 nm wide waveguides operating at a wavelength of 660 nm. Figure 5a shows a top view microscope picture of one of the measured waveguides. By measuring the insertion loss of waveguides of different lengths (11 mm, 17 mm, 23 mm and 29 mm), we estimated a propagation of about of 5.7 dB/cm. Optical characterizations at lower wavelengths are in progress.



a) b)

FIG. 5– a) 29 mm length spirals guiding a light signal in the red wavelength. b) Insertion loss measurements for λ = 660 nm. The blue dots represent the measured IL for each specific spirals.

IV. CONCLUSION

In this work we presented the fundamental steps in the development of a Si_3N_4 photonic platform operating in the visible range. Basic building block, including single mode straight and bend waveguides, and power splitters were designed and fabricated for operation at 450 nm, 520 nm and 660 nm. Preliminary results show propagation loss of 5.7 dB/cm at 660 nm, which are close to the state of the art in the field. Further steps will require the realization of a more complex photonic building block and circuits for advanced manipulation and processing of visible light beams.

ACKNOWLEDGEMENT

This work is supported by European Commission through H2020 grant number 829116 (Super-Pixels)

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