Development of SiON-based photonic integrated circuits for the blue/near-UV wavelength range

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In this paper, the design of integrated photonics components for blue/near-ultraviolet wavelength range is presented. Optical properties of the silicon oxynitride (SiON) in this spectral range are exploited to develop a complete library of photonic integrated components for operation in blue/near-UV spectral range.
Keywords: *Integrated Optics, Near Ultraviolet, Waveguide, multimode interferometer (MMI)*

INTRODUCTION

NUV (near ultraviolet) photonic devices, like coherent sources and optical functions, may address, in a near future, large domains of applications as for the next generation of biomedical diagnosis tools in particular through Raman spectroscopy as a noninvasive chemical and biological analysis technique of pollutants, medicine, cells...[1,2] They can also address new paradigm in optical frequency metrology, optical functions and sensors in this uncovered wavelength domain [3]. Coherent sources as narrow lasers and optical frequency combs are important tools in fundamental and applied physics [4]. The need of coherent sources in the NUV is also driven by the rich variety of molecular and atomic spectral features to probe [5].

Leveraging from mature microelectronics technologies, Silicon On Insulator (SOI) has emerged, over the past two decades as the preferred technology for photonic integration. However, silicon is not a good candidate for short wavelength operation due to its low bandgap energy preventing efficient transmission for wavelengths shorter than 1.1 µm. Development of new UV-transparent materials platforms is therefore needed. Amongst the possible blue-UV transparent materials candidates, recent years have witnessed the demonstration of different integrated components based on aluminium nitride [6], silicon nitride [7], alumina [8] and silicon oxynitride [9]. These materials have been identified thanks to their transparency and their low propagation loss in blue and violet range that are summarized in Table 1.

Material	AlN (Bulk Single Crystal)	AlN (Film Polycrystalline)	Si_3N_4	Al_2O_3 (Atomic Layer Deposition)	SiON
Propagation loss	350 nm: 43 dB/cm 420 nm: 42 dB/cm	350 nm: 3 dB/cm 420 nm: 1 dB/cm	410 nm: 20 dB/cm 420 nm: 15 dB/cm	370 nm: 4 dB/cm 430 nm: 3 dB/cm	300 nm: 1 dB/cm 400 nm: 0.8 dB/cm
Transmission in near-UV and visible ranges	No transmission	300 to 700 nm	450 to 700 nm	250 to 700 nm	200 to 700 nm

Table. 1. Propagation loss in the near-UV and visible wavelength range for different materials [9,10]

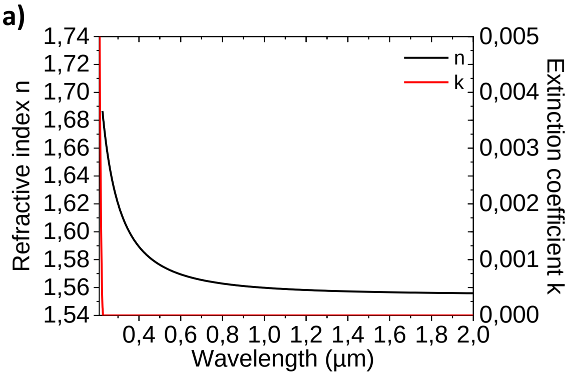
Silicon oxynitride (SiON) can be used for infrared integrated photonics and toroid, microdisks resonators [11] and microring resonators [12] have been demonstrated. Applications in the visible (780 nm) have also been developed taking benefit from the material optical nonlinearities [13]. If the use of SiON has yet been restricted to infrared and red wavelength ranges, SiON platform could also be promising for UV-blue sensing applications. Low propagation losses down to 1 dB/cm in multimode waveguides were demonstrated at 400 nm [9].

This paper presents the simulation and development of photonic integrated components operating at short wavelengths based on silicon oxynitride layers. First, the deposition technique and optical properties of SiON layers are described. Then the optical design of SiON waveguides and multimode interferometers (MMI) are presented.

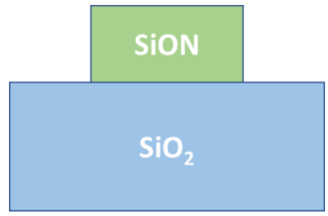
RESULTS

Thin film deposition was performed by Plasma Enhanced Physical Vapor Deposition (PECVD) on thermally oxidized (2-µm thick SiO_2) 3" silicon wafer, placed in the vacuum chamber on a holder set at 280°C. The gas mixture was composed of SiH_4, NH_3, N_2O, Ar, and N_2 with flow rates of 400 sccm, 50 sccm, 200 sccm, 620 sccm and 250 sccm, respectively. Based on preliminary calibrations, the deposition time was adjusted to obtain 300-500 nm thick films. Refractive indices of the SiON thin films were deduced from ellipsometry spectra and show a low material absorption in the blue/near-UV wavelength range (Figure 2).

a)



b)



c)

Wavelength (nm)	405	420	450
SiO_2	1.479	1.474	1.471
SiON	1.588	1.579	1.575

Fig. 2. (a) Refractive index and extinction coefficient of the SiON developed by Foton Institute, (b) Cross-section of the ridge waveguide, (c) Refractive index used for the simulation [14]

To design a SiON/SiO_2 ridge waveguide that would support single-mode propagation, we have to calculate its geometrical dimensions (width and height). Simulations based on the finite difference method were carried out for 3 different wavelengths: 405, 420 and 450 nm. The curves presented in Figures 3 represent the dimensions for which the effective index of a given mode is larger than the silica cladding refractive index. To obtain single mode propagation, geometrical dimensions (width and height) must therefore lie out of the grayed areas.

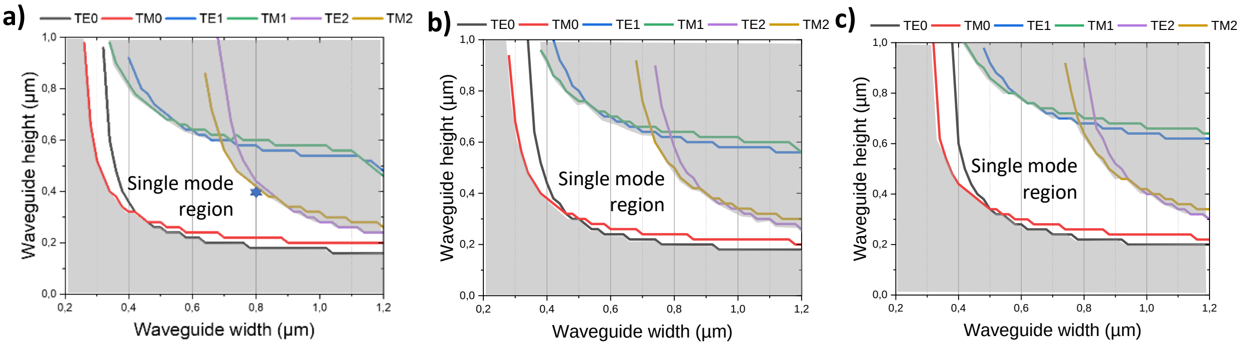


Fig. 3. Modal behavior of the SiON waveguide for different propagation wavelengths: (a) 405 nm, (b) 420 nm, (c) 450 nm.

According to these results and for experimental reasons, a thickness of 0.4 µm was selected for all wavelengths. The width of the waveguide was chosen equal to 0.8 µm for wavelength of 405 nm (see the blue stars in Figures 3). These dimensions can then be used to design more complex passive optical integrated devices such as multimode interferometer (MMI), Bragg resonators, µ-ring resonators.

The FDE solver also calculate the losses associated to the curvature of the waveguide. The mode conversion losses and the radiative losses have been calculated for a 0.8*0.4 µm waveguide at 405 nm. The bend losses become negligeable for radii larger than 1500 µm.

As an example of the various integrated passive building blocks that can be implemented for short wavelength operation, multimode interferometer (MMI) based on SiON design is presented. As a first step, a 1×2 MMI used as a 50-50 splitter was simulated by using an eigenmode expansion solver. To find the optimal MMI dimensions (MMI width, MMI length, separation between output waveguides, width and length of tapers between the input/output waveguides and the multimode section), a circular iterative process is performed to converge towards optimal MMI parameters with respect to the device transmission. Fig. 4a displays the field propagating in the MMI structure optimized for a wavelength of 405 nm and whose dimensions are labelled in Fig. 4b.

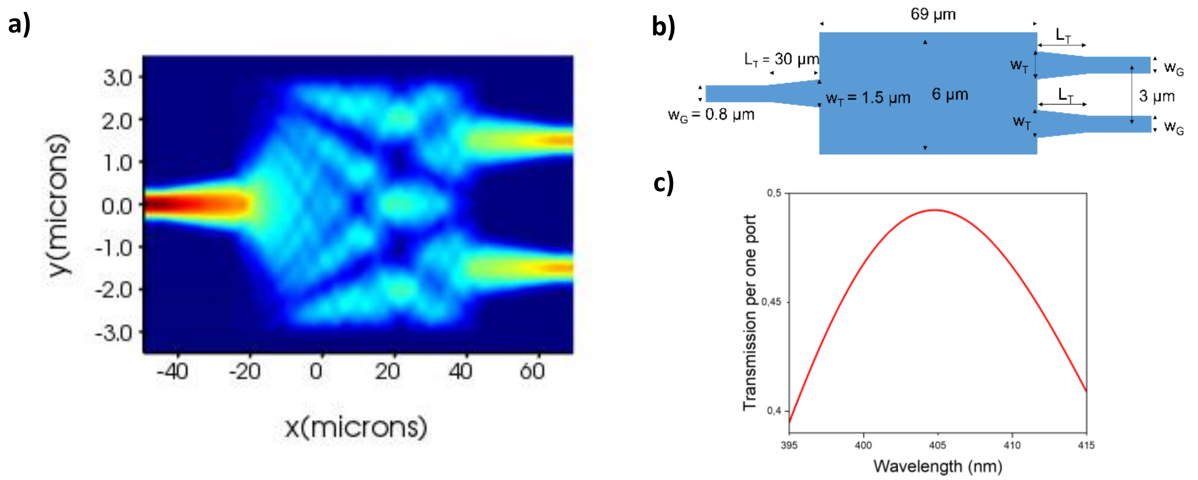


Fig. 4. (a) Simulated E field profile for MMI at 405 nm, (b) Dimensions of the simulated MMI (w_G is the waveguide width, w_T is the taper width and L_T is the taper length), (c) Transmission as a function of the wavelength of the SiON-based multimode interferometer designed for a 405-nm-wavelength propagation

A maximal transmission equal to 49.2% at 405 nm, corresponding to 0.03 dB loss per port, was determined for the component neglecting propagation losses. The same work has been done for the wavelengths of 420 and 450 nm. These components show transmission rates of 49.9% % and 49.8% corresponding to 0.004 and 0.01 dB loss per port at 420 and 450 nm respectively.

In conclusion, waveguides and multimode interferometer were designed by simulation. Optimal dimensions were determined to first fabricate single mode waveguides and more complex passive components. An example of MMI design was presented and demonstrated numerically. Very high transmissions for the two ports could be obtained for three different wavelengths. Additional simulations towards the design of efficient MMI-based multiplexers and demultiplexers with applications in molecular physics [3] are under way to further demonstrate the potential of SiON platform for blue/near-UV integrated photonics.

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