On-chip Spectrometer based on Al_2O_3 Arrayed Waveguide Gratings in the UV-blue Range

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Arrayed waveguides gratings (AWGs) are among the most common technologies in wavelength division multiplexing (WDM) and have promising applications in telecommunication and sensing. These devices are typically realized in material platforms such as silicon-on-insulator (SOI) and silicon nitride (SiN). With the emergence of material platforms that support low-loss propagation in the ultraviolet wavelength range, demonstrations of devices operating at these wavelengths are a subject of interest. Al_2O_3 is one of the materials that is studied in the context of integrated photonic circuits that target UV wavelengths. In this paper, we propose based on simulations, promising Al_2O_3-based AWGs for the development of a UV-blue (340-480 nm) spectrometer.

The devices are fully etched and are designed at wavelengths of 369 and 452 nm. Here, 4- and 8-channels AWGs are proposed with corresponding wavelength channel spacing of 2.5 and 5 nm. Insertion losses range from 3 to 6 dB. We believe that these AWGs could pave the way towards potential medical applications in UV-VIS spectroscopy, biosensing and bioimaging.

Introduction

Integrated photonic biosensors in the UV range are becoming promising due to the emergence of on chip lasers in these wavelengths and thus to higher integration density [1]. Aluminum Oxide (Al_2O_3) is a material of choice due to its large transparency window (250-4000 nm) [2] and to its large electronic bandgap [1], allowing hybrid integration of lasers based on Al_2O_3 and InGaN as demonstrated in our previous work in Ref [1].

In addition, photonic biosensors using a spectrometer based on wavelength division multiplexing offer a large bandwidth and a high accuracy [3]. AWGs can be used as a spectrometer [4] due to their compactness and high performance in terms of low insertion loss and low crosstalk. Alternatively, cascaded Mach-Zehnder interferometers are also attractive due to their lower manufacturing complexity, but this would come at the cost of a larger device. Therefore, the AWG was selected for the realization of our spectrometer. AWG spectrometers have been previously demonstrated in the Infrared range [4-5] based on silicon and silicon nitride. In this study, we propose Al_2O_3-AWGs designs for the development of a UV-blue spectrometer.

Designs and simulations

The designed AWGs are based on thin single mode Al_2O_3 waveguides. A holistic approach is necessary to design the entire Al_2O_3 platform, and when it comes to AWGs, low loss is highly preferred. Here, we will focus on the on-chip loss, which includes the bending loss, scattering loss and the mode transition into the free propagation region (FPR) loss. Scattering loss is due to the mode interaction with the waveguide sidewalls due to roughness. Ultra-thin waveguides (50 nm) can reduce the sidewalls-mode interaction and thus the scattering loss [6]. However, due to the lower mode confinement in thin waveguides, this would come at the expanse of larger bending radii and larger AWGs, which is not compatible with dense integration. Therefore, the thickness of the Al_2O_3 platform is set at 100 nm and the width of the waveguides is 400 nm at 369 nm of wavelength. The width slightly increased to 450 nm at the wavelength of 452 nm to further reduce mode interactions with the sidewalls.

The figure shows the waveguide's cross section, the electric field profile of the TE-mode in the 369 and 452 nm designed waveguides. The designed AWGs and their simulated performance are also presented. The Al_2O_3 waveguide is deposited with thermal deposition and is sandwiched between a bottom SiO_2 thermal oxide layer and a top SiO_2 cladding deposited with low-pressure chemical vapor deposition (LPCVD). The refractive indices of the materials were obtained from spectroscopic ellipsometric measurements and using the Sellmeier model. At 369 nm of wavelength, the respective refractive index of thermal SiO_2, LPCVD SiO_2 and thermal Al_2O_3 are 1.47922, 1.47958 and 1.74624.

The AWGs' main parameters such as FPR length, arrayed waveguide length increment, receiver and arrayed waveguide spacing were optimized with Optiwave and the simulations carried out with 2D beam propagation method (BPM). Here, we propose 4- and 8-channels AWGs with respective channel spacing of 2.5 and 5 nm. The 4-channel AWG is based on a rectangular geometry, which limits the spacing between the arrayed waveguides and thus the length increment. Therefore, the 4-channel AWG has a length increment of 6 µm and is designed at 369 nm of wavelength. However, the 8-channel AWGs are based on a single-bend geometry for the array section, which allows much smaller length increment and thus more freedom in the design. We designed single-bend 8-channel AWGs at 369 and 452 nm of wavelength, with respective length increment of 1.6 and 2.6 µm. The 8- and 4-channel AWGs have respectively 64 and 56 arrayed waveguides.

As shown in Figure (h), the input waveguides are tapered to ensure a good mode transition into the FPR to reduce the insertion loss. The bending radii of the curved waveguides are also kept way above 25 µm for the 8-channel AWGs to avoid extra radiation losses. The footprint of the 8-channel AWGs is 600 x 400 µm excluding the input and output waveguides. For the 4-channel AWG however, we set the bending radius of the arrayed waveguides at 25 µm for higher compactness and the resulting device footprint is 270 x 270 µm. In Figure (i) is shown the photonic chip layout containing the AWGs. A gap of 127 µm was inserted between the input waveguides and between the output waveguides for our characterization stage which contains fiber arrays.

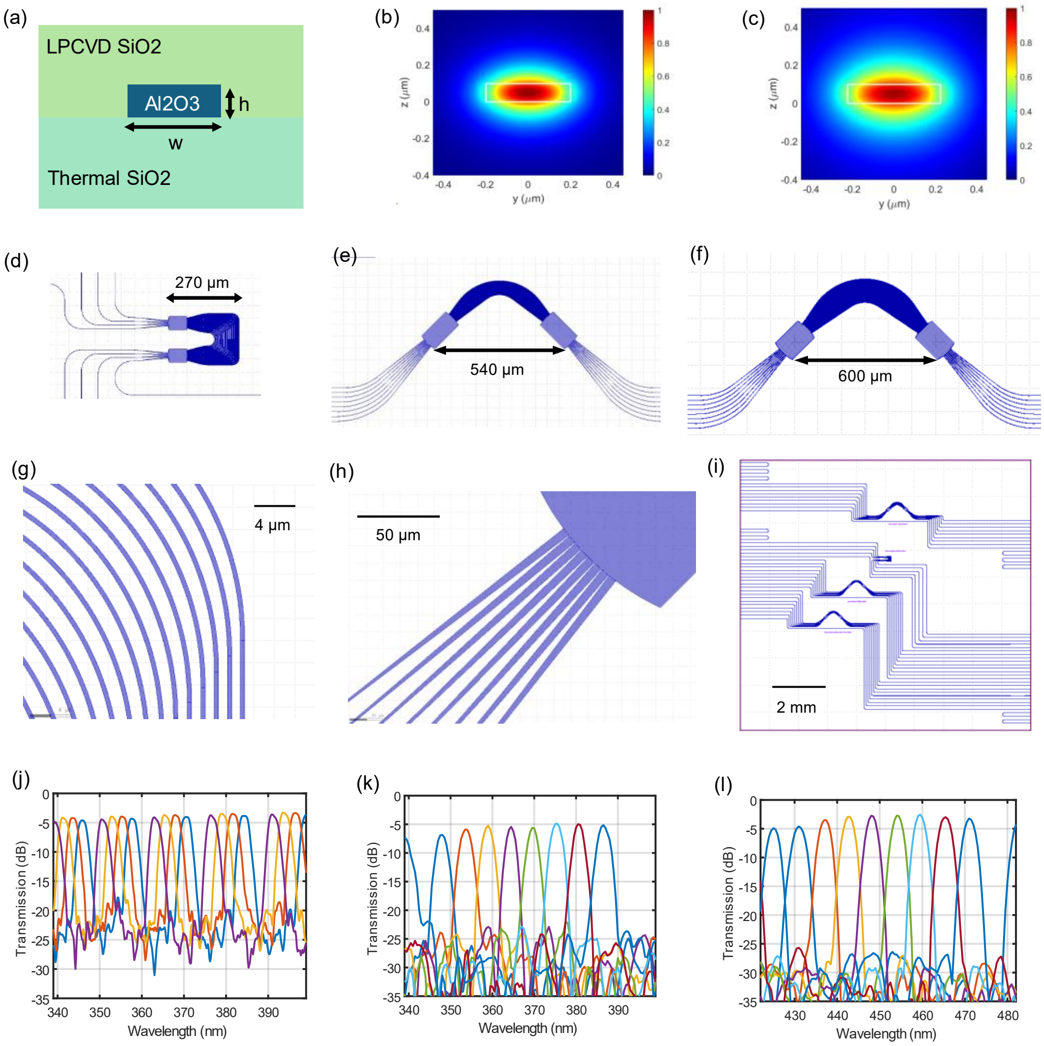

Figure: (a) Waveguide cross section with h = 100 nm, w = 400 nm at λ = 369 nm and 450 nm at λ = 452 nm. Simulated mode distribution of the y-component of the electric field profile for the fundamental TE mode at (b) 369 nm and (c) 452 nm. (d) 4x4 AWG at 369 nm with a length increment ΔL between the arrayed waveguides of 6 µm. (e) 8x8 AWG at 369 nm, (ΔL = 1.6 µm). (f) 8x8 AWG at 452 nm, (ΔL = 2.6 µm). (g) Zoom on the array section of the 4x4 AWG. (h) Input waveguides of the 8x8 AWG. (i) Designed PIC containing all the AWGs. The 8 channel AWG is situated on top is designed at 452 nm and the others are at 369 nm. (j)-(l) Simulated spectra of the 3 AWG designs.

The simulations show insertion losses around 6 dB for the 8-channel AWG at 369 nm and 3 dB at 452 nm. In addition, the crosstalk level is 20 dB at 369 nm and 30 dB at 452 nm. The lower performance of the AWG at 369 nm could explained by the tighter integration of the arrayed waveguides, possibly resulting in mode coupling between them. One way to improve the performance of the AWG at 369 nm would be partially etching the waveguides. Indeed, we simulated the 8-channel AWG at 369 nm based on a two-step etching (50 nm each) and the resulting loss and crosstalk was similar to that of the AWG in Figure (l).

Conclusion

We demonstrate with simulations promising compact AWGs in thin Al_2O_3 platform in the UV-blue range (340-480 nm) for the development of a spectrometer. The simulated on-chip losses range between 3 and 6 dB for a footprint of 600 x 400 µm for the 8-channel devices and 270 x 270 µm for the 4-channel AWG. Additional etching steps could further improve the performance of the devices, which could be implemented in the next fabrication run.

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