Low-loss single-mode waveguides operating at UV/violet wavelengths and fabricated with contact optical lithography

Student Paper

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ABSTRACT

We demonstrate air-cladding single-mode waveguides operating at ultraviolet (UV) wavelengths with propagation loss of 5 dB/cm at λ =402 nm. The waveguides are fabricated with atomic layer deposition (ALD) of aluminium oxide (AlO_x) on SiO_2/Si substrates and with contact optical lithography. This enables an efficient, cost-effective and fast processing. Our result paves the way for on-chip UV spectroscopy.

Keywords: UV, integrated photonic circuits, low-loss waveguides, AlO_x waveguides, ALD

1. INTRODUCTION

Integrated photonics is an enabling technology in diverse fields of applications, including optical communications and biological sensing. In particular, on-chip bio-sensing arouses great interest, due to its potential in terms of low-cost, compactness and low detection limit. CMOS-compatible silicon nitride (SiN_x), which is currently playing an important role for on-chip spectroscopy, is the material of choice for visible/near infrared (NIR) platforms [1]. However, SiN_x suffers from high absorption loss at blue/UV wavelengths [2]. Much effort has been devoted to investigate waveguides at UV wavelengths, yet the UV platform is still in its infancy. For an ideal photonic platform, both low-loss and single-mode operation are crucial to combine multiple optical components on chip. Recently, X. Liu et.al [3] reported a single crystal AlN platform. Benefiting from the excellent film quality, moderate waveguide-loss of 8 dB/cm at λ =390 nm was reached. Nevertheless, the large waveguide-dimension and high index (n) value of 2.2 lead to multi-mode guidance even using electron-beam lithography. In contrast, aluminium oxide (AlO_x) has a lower refractive index value and high transparency above 220 nm [4]. Using atomic layer deposition (ALD), the uniformity and thickness of AlO_x film can be well controlled. G.N. West et al. demonstrated AlO_x waveguides with an impressive low loss of ~3 dB/cm at λ =371 nm [5]. Stepper lithography was needed to pattern waveguides and then to achieve single mode operation. Besides, their platform implements silicon oxide (SiO_x) as hard mask which is kept as top-cladding afterward. Although this will efficiently decrease the index contrast between the core and cladding and then reduce the scattering loss, the SiO_x-cladding will inevitably inhibit the bio-sensing potentials of the platform. In this paper, we propose air-cladding single-mode AlO_x waveguides fabricated by conventional contact photolithography (Karl Süss MA6 aligner). Prior to implement the expensive and time-consuming stepper lithography, this AlO_x platform makes use of an efficient and cost-effective lithography tool to make research prototypes of devices in UV/violet spectrum. Propagation loss of 5 dB/cm is demonstrated at a wavelength of 402 nm.

2. DESIGN AND CHARACTERIZATION OF ALOX WAVEGUIDES

We have used the simulation tool COMSOL Multiphysics to investigate the range of single-mode operation of the AlO_x waveguides. The AlO_x layer is grown on 3-µm thermal SiO_2 on Si wafers. The thickness of AlO_x layer is designed to be 120 nm for λ =402 nm, while 100 nm is adopted for λ =360 nm to inhibit high-order TE modes. To make sure that the designed waveguide supports only a TE-guided mode, we have simulated the evolution of the modal effective index with respect to the waveguide-width. The results are plotted in Fig. 1(a). With air top-cladding, the cut-off width of the single-mode operation is as large as 1190 nm and 1150 nm for λ=402 nm and 360 nm, respectively. The TE modal profiles of the simulated AlO_x waveguide at λ =402 nm and 360 nm are shown in Fig. 1(b).

To precisely control the thickness and quality of the core layer, AlOx film is deposited on SiO_2/Si wafer via ALD using an Ultratech Savannah 200 instrument (Veeko). AlO_x is deposited at 150°C using trimethylaluminum and water as precursors. Due to the poor etching selectivity between the photoresist and the AlO_x, a layer of SiN_x

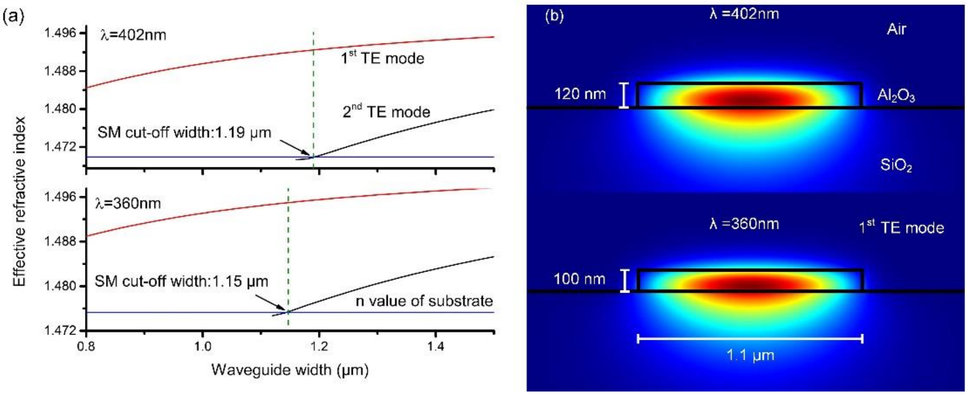

Figure 1. (a) Evolution of 1st and 2nd TE mode effective index with respect to waveguide width at λ =402 nm and 360 nm, respectively. (b) Simulated modal profiles of the designed waveguide for λ=402 nm and 360 nm.

grown by plasma enhanced chemical vapour deposition (PECVD) is used as hard mask to define the AlO_x waveguides. We have used a conventional mercury lamp based contact photolithography system with a band pass filter selecting the 280-350 nm wavelength range to expose the photoresist. The patterns defined by the photoresist are transferred to the SiN_x hard mask by using reactive ion etching (RIE). The AlO_x layer is dry etched in an inductive coupled plasma (ICP)-RIE with a $BCl_3/Cl_2/Ar$ gas mixture. The anisotropy of the etching of both SiN and AlO_x are well controlled, resulting in nearly vertical side walls. Finally, the SiN hard mask is removed by RIE. A typical cross-section of a waveguide is shown in Fig. 2(b). The fabricated waveguide with a width of 1100 nm and height of 120 nm is characterized using a 402 nm diode laser. The top image of the light scattered from a 1.6 cm-long spiral waveguide is shown in Fig. 2(a). The 200 µm bend radius is designed to minimize bend losses. The propagation loss is estimated to be ~5 dB/cm by analysing the intensity decay of scattered light. The intensities of scattering light at input and output are extracted and averaged by 20 lines of pixels, as shown in Fig. 2(c). The total waveguide loss is attributed to material absorption and scattering loss. With the higher deposition temperature of 300 ºC, the material absorption of ALD AlO_x can be further decreased [4]. Meanwhile, waveguides designed to operate at λ =360 nm are under processing.

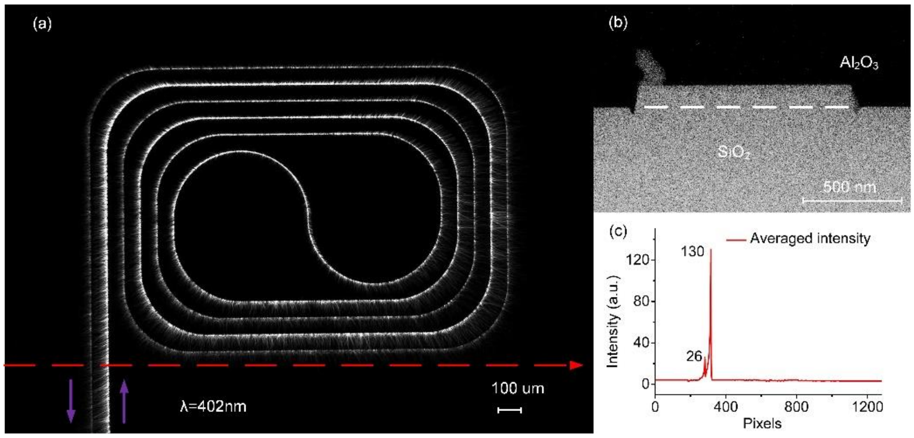

Figure 2. (a) Microscopy images of the scattered light from a spiral waveguide at a wavelength of 402nm, (b) Cross-section of the corresponding AlO_x waveguide imaged by a scanning electron microscope, (c) Averaged intensity profile of the scattered light at the input and output of the spiral. The total length of the spiral equals to 1.6 cm.

3. CONCLUSIONS

This work paves the way for on-chip light-matter interaction in the UV/violet region, and in particular for on-chip UV spectroscopy. Furthermore, being compatible with contact optical lithography, the proposed AlO_x platform exhibits the advantage of fast processing and low-cost. Finally, the achieved 5 dB/cm-loss single-mode waveguides are promising for developing a UV platform with complex on-chip optical components.

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