Design of slot waveguide for ultra-violet light based on atomic layer deposition

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Abstract

We unveil parameter sets to achieve a low loss single mode waveguide operating at UV wavelengths. The proposed design that is compatible with atomic layer deposition technology is expected to have potential applications in integrated-photonics based UV sensing.

Keywords: Ultraviolet; Photonic integrated circuits; Guided waves

1. INTRODUCTION

Integrated photonics for sensing applications has been extensively investigated [1]. However, the ultraviolet (UV) range has not yet been explored with integrated photonics due to a lack of low loss single mode waveguides. The requirement of extreme-small waveguide dimensions at shorter wavelengths results in a high scattering loss and currently hampers its development. As many kinds of bio-materials like proteins usually have absorption bands in the UV, a new integrated platform operating in the UV can spark a myriad of applications [2]. In particular, a single mode waveguide at UV wavelengths that can enhance the light-matter interaction and increase the light collection efficiency of surrounding emitters is of paramount importance. Several methods have been reported recently but failed to implement low propagation loss and strong light-matter interaction simultaneously. The propagation loss of silicon nitride (SiN) waveguides increase dramatically below a wavelength of ~460 nm [3]. Although aluminum nitride (AlN) and aluminum oxide (Al_2O_3) waveguides have demonstrated a low loss at wavelengths near 400 nm, operation substantially below a wavelength of 370 nm still needs to be explored [3, 4]. Here, we present a slot waveguide design that can accommodate the single-mode and low-loss constraints up to 260 nm. Importantly, the waveguide design is such that it does not require any etching of the core layer and as a result minimizes the propagation losses. It can be fabricated by the atomic layer deposition (ALD) technique and therefore be promising for achieving ultra-smooth surfaces and low loss propagation at UV wavelengths.

2. STRUCTURE DESIGN AND SIMULATION RESULTS

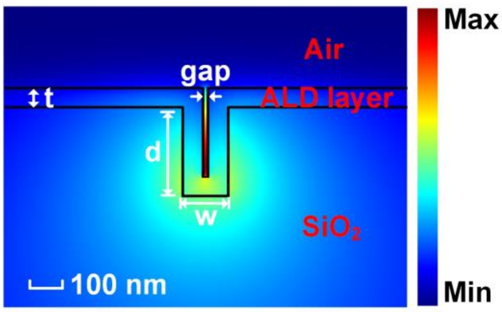

Fig. 1. Cross-section and simulated TE-mode profiles of the slot waveguide

Using COMSOL, the slot waveguide is designed and simulated for three materials used as the waveguide core, namely yttrium oxide (Y_2O_3), hafnium oxide (HfO_2) and Al_2O_3, that all exhibit low absorption at UV wavelengths [5-7]. The TE-mode profile of the slot waveguide is shown in Fig.1, with a SiO_2/Si wafer used as substrate. The waveguide-loss is generally dominated by the material absorption and scattering loss at structure surfaces. At shorter wavelengths, particularly, rough surfaces will result in a large waveguide loss in view of scattering loss proportional to $1/\lambda^4$. Therefore, improving the surface smoothness and further decreasing the scattering loss for a given material plays a crucial role for achieving a low loss waveguide operating in the UV. In this context, the slot waveguides are fabricated on pre-etched SiO_2 to avoid etching the core layer. In addition to reduce waveguide loss, the proposed structure is able to confine light tightly in the slot where the analyte of interest is located. This property can enhance the light-matter interaction dramatically and then contribute to applications in high-sensitive bio-sensing.

Figure 2(a), (b) and (c) summarize the results of the slot waveguide structure simulated at a wavelength of 260 nm, 300 nm and 405 nm, respectively. The refractive indexes of 2.00 and 1.69 are chosen for simulation to match that of Y_2O_3/HfO_2 and Al_2O_3, respectively. The shaded areas show the range where the TE or TM mode are guided and the dotted lines represent the cutoff of the TE, TM and high-order modes. In this structure, many parameters would affect the light confinement such as the depth (d), the width (w), the slot width (gap), the thickness of the ALD layer (t), the working wavelength (λ) and the refractive index value of the ALD layer (n). Note that the cutoff of the high-order modes (orange dotted lines for n=1.69 and red ones for n=2.00) is very close to the cutoff of the fundamental slab mode. To investigate the variables of interest (gap, t, λ and n), the w and d parameters are constrained by the following relationships: aspect ratio = d/w and w=2*t + gap. In this simulation, the aspect ratio is fixed to 2, due to fabrication constraints. The TE mode emerges earlier than the TM mode with increasing the thickness of ALD layer when the gap is narrow, while the TM mode can be guided over a wider thickness range in the case of wider gaps (>10 nm). At λ=260 nm, the single mode behavior for TE and TM ranges over an ALD thickness of 14 nm for n=1.69, which plummets to a range of only ~2 nm for n=2.00. In cases of the same n value, the domain of single mode propagation become narrower at shorter wavelengths. For instance, from a wavelength of 405 nm to 260 nm for n=2.00, the width of single mode area is reduced by more than a half. This result highlights the challenge of fabricating single-mode slot waveguides for λ<300 nm and high index contrast, which can be tackled with the ALD technique.

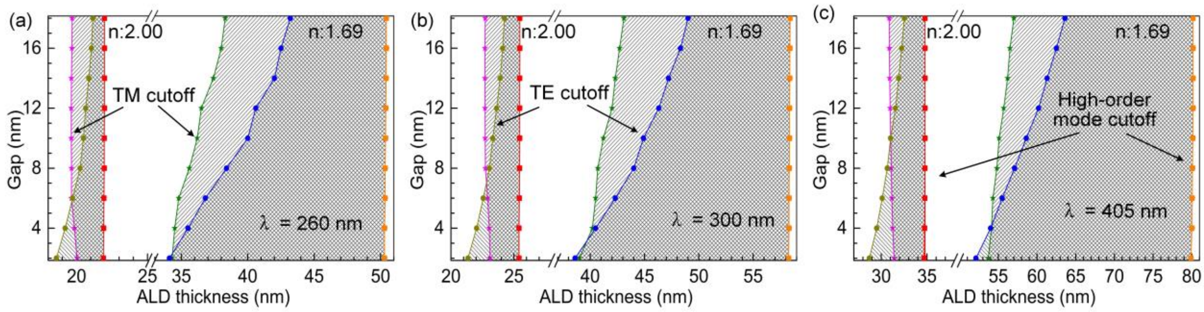

Fig. 2. Simulated mode map for the slot waveguide at a wavelength of (a) 260 nm, (b) 300 nm and (c) 405 nm, respectively. The cutoff of TE and TM modes is compared at both index values of 1.69 and 2.00.

3. CONCLUSIONS

We have proposed a slot waveguide design that is compatible with the ALD technique and we have quantified the typical waveguide dimensions for a single-mode operation at UV wavelength up to λ=260 nm. For a refractive index n=1.69, the thickness range of the core layer is of the order of 10 nm and drops to only 2 nm for n=2.00 and λ=260 nm. This design is promising for simultaneously achieving low-loss single mode waveguides and highly sensitive bio-sensing in the UV. We are currently processing such a waveguide.

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