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Hybrid polymer-titania waveguides for highly integrated circuits

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Abstract. We present an innovative waveguide based on the hybridization of a titanium dioxide nano-waveguide within a polymer strip. Through simulations and design we demonstrate that the waveguide sustains principally the quasi-TM fundamental mode and that even in tight bends (radius smaller than 2 µm) light remains confined in the titania layer. Such a waveguide, in addition of enabling low loss propagation is a way towards efficient evanescent sensing in highly integrated scheme, i.e., small footprint. We also show that the fabrication, here based on electron beam lithography and atomic layer deposition, can be extended easily to large scale manufacturing using nanoimprinting technology.

1 Concept and design

There is a need for efficient sensors with low-cost manufacturing process allowing disposability[1]. Evanescent sensing is based on the probing of the external (to the waveguide) medium by the exponentially decaying tail of the guide mode. The overall interaction of this tail and the outer medium must therefore be maximized. It usually requires either an increase of the optical path length by the implementation of a cavity along the waveguide or a direct increase of the geometrical length of the waveguide. Double spiral waveguides are often used in this case. Unfortunately, it leads to an increase of the footprint of the device in order to minimize the loss due to the smallest radii of the spiral.

In this work we show the development of a nano-waveguide allowing a single mode and low propagation losses together with a high overlap with the outer medium, which can be an analyte for absorption or refractive index sensing. A nano-waveguide can be defined as a strip waveguide with a cross-section of less than 1 × 1 µm^2. Silicon nano-waveguides usually created on silicon-on-insulator waveguides have dimensions of on the order of 200 × 500 nm^2, with the largest dimension being the lateral one. This leads to a predominant quasi-TE mode, which may not be the most suitable for evanescent sensing, due to a lower confinement of the field above the waveguide. We propose here to rotate this nano-waveguide by 90° in order to obtain a predominant quasi-TM mode, i.e., the mode of highest effective index.

The cross section of the waveguide is depicted in Fig. 1. The structure is fabricated on oxidized silicon wafer. It consists of a polymer strip in which a trench is performed and further filled with a high refractive index material, intended to be the core of the nano-waveguide. For our purpose, we chose nLOF AZ 2070 electron beam resist as a polymer (n_P = 1.6 at λ = 1550 nm) and titanium dioxide as high refractive index material (n_H = 2.24). Fabrication constraints are taken into account during the design process. *Filling* the trench requires to deposit the high refractive index material on top of the polymer which means that a layer of it with lays all over the final sample, if we want to limit the fabrication steps. Using atomic layer deposition, the result is a conformal layer of titanium dioxide covering the waveguide[2], as shown in Fig. 1.

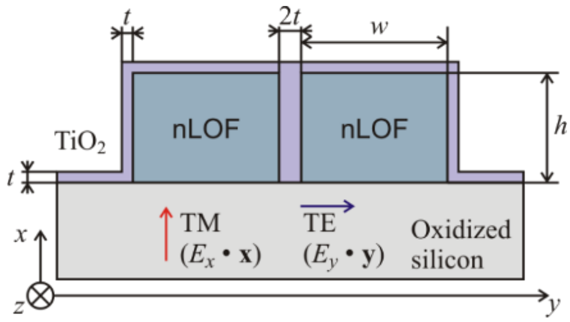

Fig. 1. Cross section of the proposed waveguide

The structure was studied using Lumerical and other mode solvers. The width *w* of each portion of the polymer strip, the thickness *t* and the width of the trench *2t* as well as the thickness *h* of the polymer have been varied. Figure 2a, shows the evolution of the effective index of the TM modes as a function of TiO_2 width *t*. One can see that after 200 nm, the waveguide shows a multi-modal behavior. Similar calculations have been performed to study the light confinement within the waveguide and its interaction with the top medium. The waveguide parameters are t = 200 nm, w = 900 nm, and h = 900 nm. Choosing these parameters allow a single modal operation at λ = 1550 nm, which is used for the demonstration. However, we want to emphasize that all materials are transparent over a large wavelength range enabling operation over a large portion of the electromagnetic spectrum[3].

Figure 2b is the field distribution of the quasi-TM mode in the optimized waveguide. One can remark that

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light is highly confined within the titania core with still a relatively significant portion (~5%) in the top free region. Moreover, and it is one of the main advantages of the waveguide, the lateral (x-direction, see Fig. 1) tails of the mode are within the polymer strip for limited propagation losses.

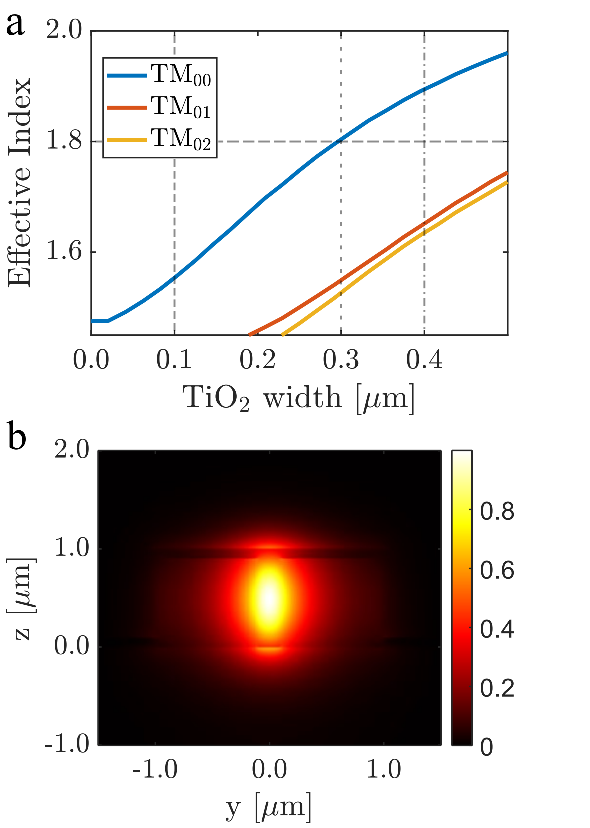

Fig. 2. a) Evolution of the effective index of the few first quasi-TM modes as a function of the titanium dioxide thickness t. **b)** Field distribution of the fundamental quasi TM-mode.

One can remark that the remaining TiO_2 layer has nearly no effect on the lateral tails, and provide an addition increase of the interaction of the field on top of the waveguide.

2 Towards experiments

The fabrication of the waveguide requires a two-steps process. First the polymer waveguide, including the trench, is performed using electron beam lithography by exposure and development of an nLOF layer. Second, a titanium dioxide layer is deposited on top of entire structure. The high conformality of the ALD processes enable the filling of the trench with a smooth and homogenous material. Because we are using a polymer, we set the deposition temperature at 100 °C preventing any degassing or deformation of the polymeric base during the process.

The scanning electron microscope picture in Fig. 3 allows us shows the cross section of the waveguide. One can appreciate the perfect respect of dimensions as well as very horizontal walls despite a slight curvature within the trench. The roughness observable on the top of the waveguide is due to some residues of the conductive layer used for imaging purpose.

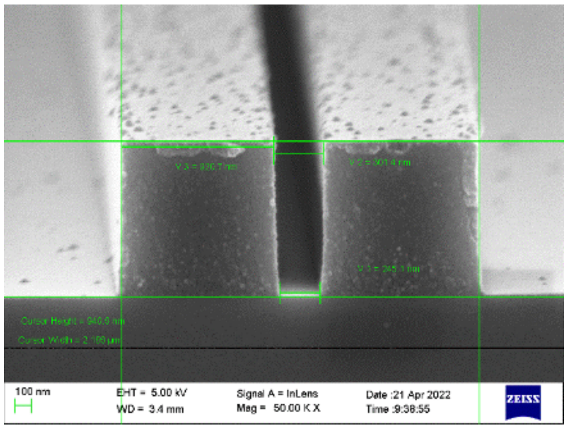

Fig. 3. SEM picture showing a tilted view of the cross section of the waveguide.

The final structure, not shown here, is to be characterized by end-fire coupling method in order to determine the propagation losses (cut-back method). Several patterns have been performed. It includes bends of different radius of curvature as well as long waveguides.

Although we used electron beam lithography in this work, it is to be noted that the polymeric structure can be replicated by means on nanoimprinting. ALD is also a large-scale manufacturing technology[4]. Such a waveguide is therefore one way to enable easier photonics integration with a wider range of materials for a broader field of applications.

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