TiO_2 Slot Waveguide for Efficient On-Chip Raman Spectroscopy

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Primary CNF Tools Used: PVD75 sputter deposition, AJA sputter deposition, JEOL 9500, PT770 etcher, Oxford 100 etcher

Abstract:

On-chip integrated Raman spectroscopy offers an attractive route to on-chip sensing, owing to its portability and signal enhancement in comparison to conventional Raman spectroscopy [1-3]. In order to further improve the Raman conversion efficiency over the previous work, we design a titanium dioxide (TiO_2) slot waveguide, which has a stronger overlap with the surrounding molecule and a reduced mode volume, which when combined with the high refractive index of TiO_2, allows the theoretical conversion efficiency to be five times higher than strip waveguides. We fabricate the proposed TiO_2 slot waveguides using a combination of e-beam lithography and chromium (Cr) hard mask. The propagation loss is about 15 dB/cm at 780 nm wavelength, which makes this platform promising for the next-generation integrated on-chip Raman sensors.

Summary of Research:

Fully-integrated on-chip Raman sensors are a critically needed technology for medical diagnostics, threat detection, and environmental-quality monitoring. By utilizing a waveguide design using the evanescent field outside of a dielectric to pump and collect Raman scattering, we have demonstrated an integrated-evanescent Raman sensor on TiO_2 [2]. In order to further improve this on-chip Raman sensing platform, we propose a slot waveguide structure that has an air gap between two parallel bus waveguides to improve the Raman efficiency. In this slot waveguide structure, the electric field discontinuity at the TiO_2/air interface leads to a high confinement of the optical field in the slot region, which makes this structure appealing for sensing applications.

We fabricate the proposed TiO_2 slot waveguides using a combination of e-beam lithography and Cr hard mask. The fabrication flow is shown in Figure 1. Since the design slot width is around 100 nm, which is beyond the resolution of conventional photolithography, we switch to e-beam lithography from our previous work [2].

We start with a silicon substrate with thermal oxide on top and sputter TiO_2 thin film using PVD75 deposition tool. Above TiO_2 thin film, we first sputter a thin layer of Cr as a hard mask and then the e-beam resist for e-beam lithography (Figure 1a). After e-beam exposure and development (Figure 1b), we transfer the slot pattern to Cr layer by dry etching in PT770 ICP (Figure 1c). Then we remove the residual e-beam resist by oxygen plasma (Figure 1d) and transfer the slot pattern to TiO_2 layer by dry

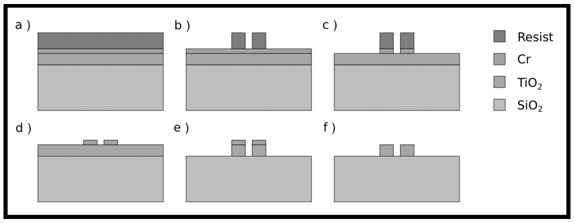

Figure 1: The fabrication process of TiO_2 slot waveguides.

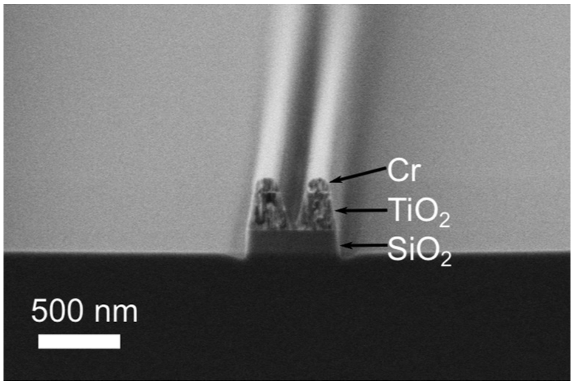

Figure 2: A SEM image of the TiO_2 slot structure after TiO_2 dry etching.

etching in Oxford 100 ICP (Figure 1e). Finally, we remove the Cr hard mask by wet etch (Figure 1f) to form TiO_2 slot waveguides. Figure 2 is a representative scanning electron micrograph (SEM) of the cross section of a fabricated TiO_2 slot waveguide after TiO_2 dry etching step. By utilizing a thin layer of Cr as the hard mask for TiO_2 etch, we are able to define an air gap between two parallel bus waveguides for Raman sensing purpose.

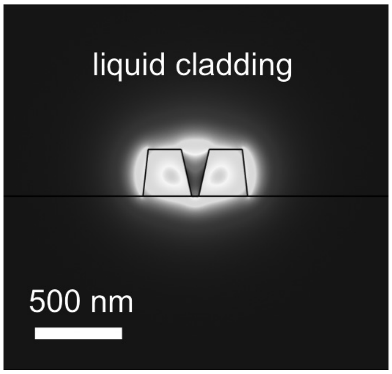

Figure 3: Calculated guiding mode profile of the slot waveguide structure at 780 nm.

In order to characterize this device's performance, we measure the propagation loss using the top-view camera method around 780 nm wavelength in air. We couple a 780 nm laser light into the slot waveguide by an objective lens and capture the waveguide scattering by a camera mounted on the top. We measure the scattering as a function of waveguide length, subtracting the average baseline signal (non-zero dark regions away from the waveguide), and plot the scattering intensity as a function of distance. Then we fit this data to a linear regression model and extract a loss value of about 15 dB/cm. Compared with the previous result by a conformal atomic layer deposition re-coating method to create TiO_2 slot waveguides (767 dB/cm at 664 nm wavelength) [4], our fabrication method has dramatically decreased the device propagation loss, which makes this platform more practical for on-chip Raman sensing application.

We notice that TiO_2 slot etching generates non-vertical sidewalls, so we include those dimension changes and simulate the mode profile in our TiO_2 slot waveguide structure. Figure 3 shows that our fabricated slot structure can support a quasi-TE guiding mode, which is highly confined in the gap region. Based on our previous model of waveguide-based spontaneous Raman scattering conversion efficiency η_0 [2], η_0 is related to the overlap between guiding light and sensing chemistry. This quasi-TE mode in the slot structure has a stronger overlap with the surrounding molecule than that in strip waveguides, which makes the slot waveguide structure more in favor of Raman sensing than a strip waveguide structure. Our calculation reveals that our TiO_2 slot waveguide design has a five-fold η_0 than optimized strip waveguides that were made of TiO_2 as well.

In conclusion, we propose a slot structure on TiO_2 integrated optics platform for efficient on-chip Raman sensing. We fabricate TiO_2 slot waveguides and the low loss (15 dB/cm) of our TiO_2 waveguide puts it as one of the best performing slot waveguide. Future work will focus on the control of the fabrication variation and repeatability and the demonstration of high-performance sensing.

References:

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