Tantalum Pentoxide Slot Waveguides for Waveguide Enhanced Raman Spectroscopy

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Waveguide enhanced Raman spectroscopy (WERS) is a promising technique for the sensing of chemical compounds, thanks to the extended interaction volume and tight confinement of light using photonic waveguides [1]. However, it is sometimes insufficiently sensitive for applications where the relevant concentrations are low. There are different methods to improve the signal intensity, including using high-index-contrast (HIC) waveguides other than Si_3N_4. It has been shown by Raza et al. [2] that the Ta_2O_5 platform is beneficial for WERS, as Ta_2O_5 strip waveguide enhances the signal without introducing more waveguide background than Si_3N_4. The Ta_2O_5 platform still has further potential, as the strip waveguide is not optimal for evanescent sensing compared to the slot waveguide, for which the electric field is mostly confined in the cladding [3]. In this work, we demonstrate a systematic study of Ta_2O_5 slot waveguides for WERS and compare it to Si_3N_4 slot waveguides.

We fabricated 5 mm long, 400 nm high Ta_2O_5 slot waveguides using electron beam lithography, as shown in Figure 1(a). The Stokes signal of the analyte can be estimated as: $P_{Stokes} = P_{pump}\rho L\sigma\eta_0\gamma$, where ρ is the molecular density, L is the waveguide length, σ is the Raman scattering cross-section, γ is the total loss, and η_0 is the specific Raman conversion efficiency. η_0 is uniquely defined by the electric field distribution and the waveguide cross-section [2]. The Raman spectra are measured with a pump wavelength of 785 nm. We numerically estimate the propagation loss of the waveguide using sidewall roughness measured with atomic force microscope as introduced in [4]. Figure 1(b) and (c) show the numerically computed and experimentally measured η_0. The difference between simulation and experiment as well as the large scatter on the experimental data may be induced by waveguide damages (observed under microscope) and associated underestimation of losses. The maximum η_0 in simulation is 1.21 (rail 120 nm, slot 50 nm), while the maximum in experiment is 0.85 (rail 120 nm, slot 90 nm). Figure 1(d) shows the normalized Raman spectra of 50% ethanol on the experimental optimal Ta_2O_5 waveguide and on a common Si_3N_4 slot waveguide (height 300 nm, rail 275 nm, slot 150 nm). The peak intensity at 880 cm^{-1} of the Ta_2O_5 slot waveguide is 450, almost 4x higher than the peak count 120 for the Si_3N_4 slot waveguide. It agrees with simulation, as the η_0 of the Ta_2O_5 and Si_3N_4 waveguides are numerically computed to be 0.98 and 0.24, respectively.

In conclusion, we report the performance of Ta_2O_5 slot waveguides for WERS in simulation and experiment. The optimal waveguide provides 4x better signal intensity than a conventional Si_3N_4 slot waveguide.

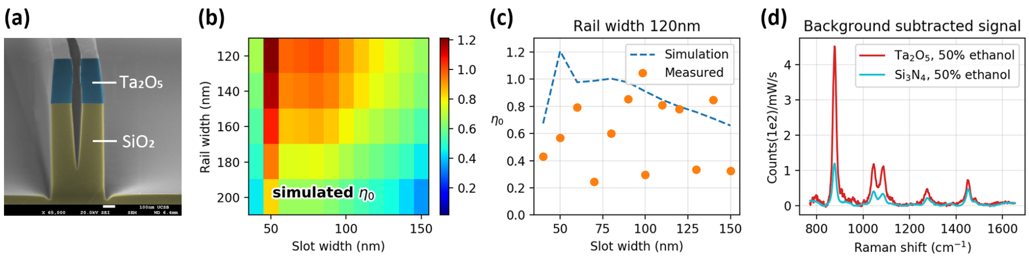

Figure 1: (a) Cross-section of a Ta_2O_5 slot waveguide (b) Simulated η_0 of slot waveguides with varied slot and rail widths (c) Simulated and measured η_0 of waveguides with 120 nm wide rails (d) Raman spectra of 50% ethanol measured on the optimal Ta_2O_5 and Si_3N_4 slot waveguides.

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