Fabrication of Anti-Resonant Reflecting Optical Waveguides for On-Chip Raman Spectroscopy

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Primary CNF Tools Used: AJA sputter deposition, Woollam spectroscopic ellipsometer, ABM contact aligner, SC4500 evaporator, Oxford PECVD

Abstract:

On-chip gas sensing technology has received extensive attention due to its potential applications in environmental and healthcare monitoring. Herein, we utilize hollow-core anti-resonant reflecting optical waveguides (ARROWs) in the near-infrared wavelength for on-chip Raman scattering for various chemical detections. In this work, we fabricate hollow-core ARROWs with Bragg reflectors made by tantalum oxide (Ta_2O_5) and silicon dioxide (SiO_2) film decks and characterize our device performance. The propagation loss is about 19 dB/cm at 780 nm wavelength, which is an advance for the next-generation integrated on-chip Raman sensors.

Summary of Research:

On-chip sensing technology [1,2] has received extensive attention due to its potential applications in environmental and healthcare monitoring. On-chip spectroscopy methods such as on-chip infrared absorption spectroscopy have high sensitivity and selectivity; however, on-chip infrared devices still face challenges from the component complexity and cost. Herein, we use hollow-core anti-resonant reflecting optical waveguides (ARROWs) [3,4] in the near-infrared wavelength for on-chip Raman scattering for gaseous-molecule detections. The geometry of the hollow-core ARROWs confines the guided light in the air mode, where the optical field can efficiently overlap with the detected molecules. To demonstrate the proof of concept, we fabricate hollow-core ARROWs with alternating layers of Ta_2O_5 and SiO_2, where the fabrication details will be discussed.

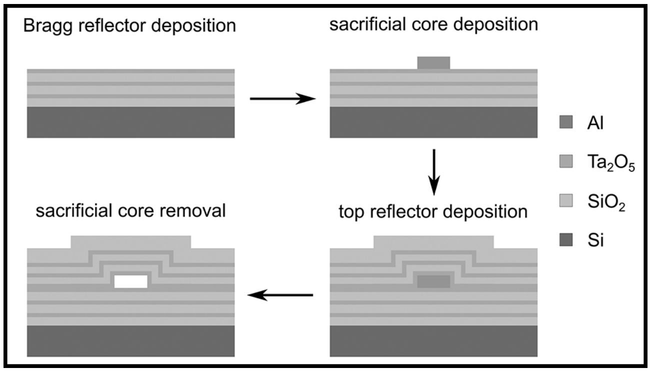

Figure 1: The fabrication process of ARROW waveguides.

We first designed the Bragg reflector by alternating Ta_2O_5 and SiO_2 layers. A period of high index/low index dielectric film decks can provide a desirable reflectance over a certain range. We utilized the transfer matrix method to simulate the film decks with different design parameters. Considering the fabrication difficulty, we limit the Ta_2O_5/SiO_2 period number to be three. We got the actual film thicknesses for each layer by Woollam ellipsometer and measured the reflectance of deposited film decks with UV/Vis/NIR optical spectrophotometer to verify our design (results not shown). The thicknesses used for each layer were optimized to reach the maximum reflection near 800 nm wavelength.

After that, we developed the fabrication process shown in Figure 1 for the ARROWs. We started with a silicon wafer. First, we deposited a stack of Ta_2O_5 and SiO_2 Bragg layers using sputtering (Ta_2O_5 using reactive sputtering

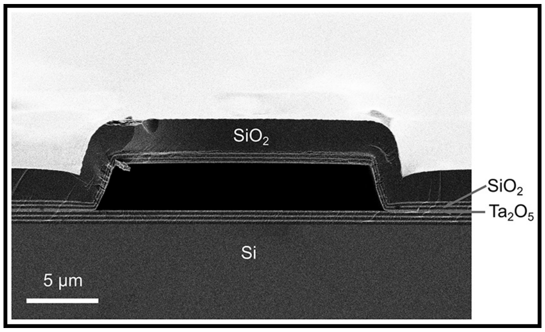

Figure 2: An SEM image of the hollow core structure after aqua regia etching.

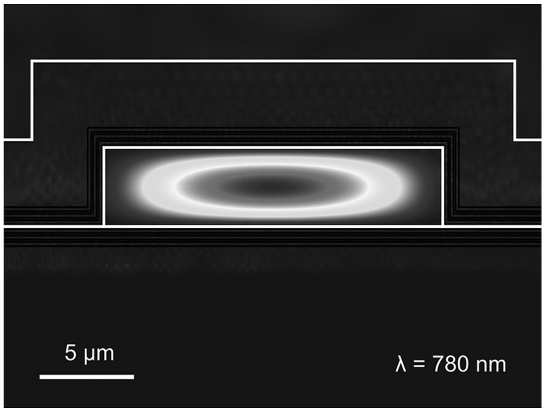

Figure 3: Calculated guiding mode profile of the ARROW waveguide at 780 nm.

and SiO_2 using RF sputtering) based on our calibrated design parameters. Then, we did a contact lithography for waveguide sacrificial core patterning. A 3.5-µm thick aluminum (Al) was evaporated into these patterned channels. Then, we did a lift-off to remove the unwanted Al to form the sacrificial channels. Similarly, a Bragg reflector by Ta_2O_5 and SiO_2 was deposited on top of the Al channels. A 3-µm thick protective oxide cladding was added by PECVD. After a clean facet cleaving, Al sacrificial cores were removed by a two-day heated aqua regia etching in our lab.

Figure 2 shows a representative scanning electron micrograph (SEM) of the fabricated ARROW waveguide after aqua regia etching, which exemplifies a hollow core feature of our device.

We design the ARROWs by calculating the mode profile using the geometry estimated from SEM (Figure 2). The modal behavior was calculated from a commercial mode solver assuming that an air core inside. Figure 3 indicates that our fabricated ARROW waveguide supports a quasi-TE mode inside the air core, which provides the complete mode overlap between the pump mode and Stokes mode. In order to characterize this device's performance, we measured the propagation loss using a top-view camera method around 780 nm wavelength in air. Using the background-corrected signals, we fit the loss data to a regression model. The propagation loss of our device is about 19 dB/cm. To characterize the feasibility of the ARROW as a waveguide-based evanescent Raman sensor for gaseous molecule detection, we are incorporating a flow cell, where external gases can be applied to the device.

In conclusion, we propose a hollow-core ARROW structure by Ta_2O_5 and SiO_2 for on-chip Raman sensing especially for gas detection. We have fabricated the proposed ARROW waveguides with a clear hollow core and the device has been characterized. Future work will focus on the device application for gaseous molecule sensing.

References:

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