ThB1 (Invited)
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Ultra-Efficient Nano-Photonic Devices using Hybrid Material Systems for Optical Communication and Sensing

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Abstract: We investigated ultra-efficient nano-photonic modulators based on silicon photonic crystal slot waveguides infiltrated with electro-optic polymers. The integration of Si_3N_4 guided mode resonance grating with plasmonic-active nanotubes are also demonstrated for surface enhanced Raman scattering.
OCIS codes: (130.5296) Photonic crystal waveguides; (130.4110) Modulators; (240.6695) Surface Enhanced Raman Scattering; (250.5403) Plasmonics

1. Introduction

With the rapid development of nano-photonic technology, it is becoming increasingly critical to integrate different materials into the same platform to obtain even higher performance and more functionality. In this paper, we focus on periodic dielectric photonic structures, such as slow-light-enhanced photonic crystal waveguides (PCWs) and guided mode resonance (GMR) grating as ultra-compact and highly efficient platforms, with the integration of innovative functional materials such as electro-optic (E-O) polymers, and plasmonic-active silica nanotubes with metallic nanoparticles for power efficient on-chip optical communication and high sensitivity biomolecule detection. Our simulation and experimental results have revealed exclusive advantages of integrating hybrid materials into dielectric nano-photonic devices.

2. E-O Polymer Infiltrated Photonic Crystal Slot Waveguide Modulator

Electro-Optic (E-O) polymer modulators have demonstrated exceptional performances for ultra-high bandwidth [1] and sub-volt half-wave driving voltage (V_π) [2]. However, the E-O efficiency of polymer photonic devices cannot exceed the thin film r_{33} value due to the presence of bottom and top cladding layers. In this paper, we present a design that utilizes strong optical confinement abilities of silicon, superior E-O modulation efficiency of polymers, and slow light enhancement from PCWs. Compared with conventional E-O polymer photonic devices, this hybrid approach requires no cladding polymer layers, which should lead to higher E-O efficiency. The E-O polymer nano-photonic modulator has effective in-device r_{33} to 735 pm/V. To the best of our knowledge, this is the highest E-O efficiency of polymer photonic devices that has ever been reported. Figures 1 (a) shows the scanning electronic microscopy (SEM) image of the transitional region from silicon strip waveguide to photonic crystal slot waveguide using an optical mode converter and photonic impedance taper. The nano-photonic modulator is fabricated on a silicon-on-insulator (SOI) wafer with 230nm thick lightly doped p-type top silicon layer. The input and output waveguides use conventional silicon strip waveguide. The modulation region with slot nanostructures are formed in a hexagonal lattice photonic crystal slab with a lattice constant a=425nm and hole diameter d=297nm. The photonic crystal waveguide is a standard W1.3 waveguide by replacing a line of air holes with a slot of w=320nm. The modulation region consists of 800 periods of photonic crystals, thus the total modulation length is 340μm. The silicon photonic crystal regions including air holes and the slot are fully covered by polymer materials with strong E-O coefficient consisting of a guest host system of 25% weight chromophore AJ-CKL1 into amorphous polycarbonate (APC). The refractive index of the infiltrated polymer is n=1.63 at 1.55μm wavelength. The fabrication procedures of the nano-photonic modulator are described in [3]. After infiltrating AJCKL1/APC, the sample is heated to the glass transition temperature (T_g=145°C) of the guest/host polymer while 100V/μm poling field is applied. In the measurement, the output of the laser source is tuned to 1540 nm wavelength, where maximum modulation response is achieved. The E-O polymer nano-photonic modulator was driven by a 100 KHz triangular wave with a peak-to-peak voltage V_{pp} of 1.7V. The waveform from a digital oscilloscope in Figure 1(b) shows that over modulation occurs at 1.3V, which is the V_π of the E-O polymer nano-photonic modulator. The effective in-device E-O coefficient is calculated as

$$r_{33} = \frac{\lambda w}{n^3 V_\pi \Gamma L} = \frac{1540nm \times 320nm}{1.63^3 \times 1.3V \times 0.35 \times 340\mu m} = 735\, pm/V$$

The nano-photonic modulator also achieves very high modulation efficiency with V_π•L=0.44V•mm. This $V_\pi L$ is the best result for all E-O polymer photonic modulator that has ever been reported. To evaluate the poling efficiency of the E-O materials, we calculated the group index of the photonic crystal slot waveguide to be n_g=36, which gives a slow light enhancement factor of 12.4, so we can conclude that the material r_{33}=59pm/V for 320nm slot.

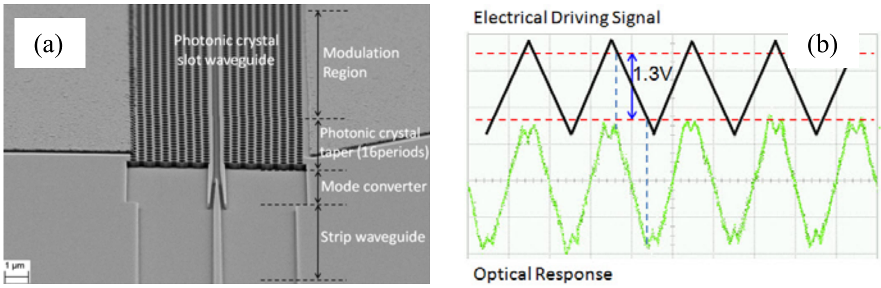

Fig. 1 (a) SEM picture of the 320nm wide silicon photonic crystal slot waveguide; (b) E-O modulation measurements showing a low V_π of 1.3V for the E-O polymer nano-photonic modulator with 340μm modulation arm

3. GMR Grating Coupled Plasmonic-Active Nanotubes for Surface Enhanced Raman Scattering (SERS)

We demonstrate a SERS substrate by integrating plasmonic-active silica nanotubes into Si_3N_4 gratings. First, the dielectric grating that is working under GMR mode [4] provides enhanced electric field for localized surface plasmon polaritons on the surface of metallic nanoparticles. Second, we use silica nanotubes with densely assembled silver nanoparticles to provide a large amount of "hot spots" without significantly damping the GMR mode of the grating. Experimental measurement on Rhodamine-6G shows a constant enhancement factor of 8~10 in addition to the existing SERS effect across the entire surface of the SiO_2 nanotubes. Figure 2 (a) and (b) shows the SEM pictures of the plasmonic-active silica nanotubes with densely assembled silver nanoparticles and the SEM picture of the Si_3N_4 GMR grating, respectively. Rhodamine 6G (R6G), a standard SERS characterization dye, is selected as the detection probe. The R6G molecules are dispersed in ethanol with a concentration of 1 μM, followed by incubation with the nanotube samples for two hours. A confocal Raman microscope equipped with a 532 nm laser is used for SERS measurement. The laser spot size is 2 μm, which can be focused on any specific position of a single nanotube along its longitudinal direction. The integration time is set at 1 second. In each measurement, there is only one plasmonic-active SiO_2 nanotube within the range of the laser spot. Figure 2 (c) shows the measured 1μM R6G SERS signals from a silica nanotube on a flat Si3N4 substrate (blue) and on a silica nanotube on the Si_3N_4 GRM grating (green), respectively. For various signature Raman shift peaks between 500/cm-1 to 1800/cm-1, the absolute intensity of the Raman signals is universally enhanced by 8~10 times. Also, our further characterization shows this enhancement is universal across the whole surface of the plasmonic-active silica nanotube.

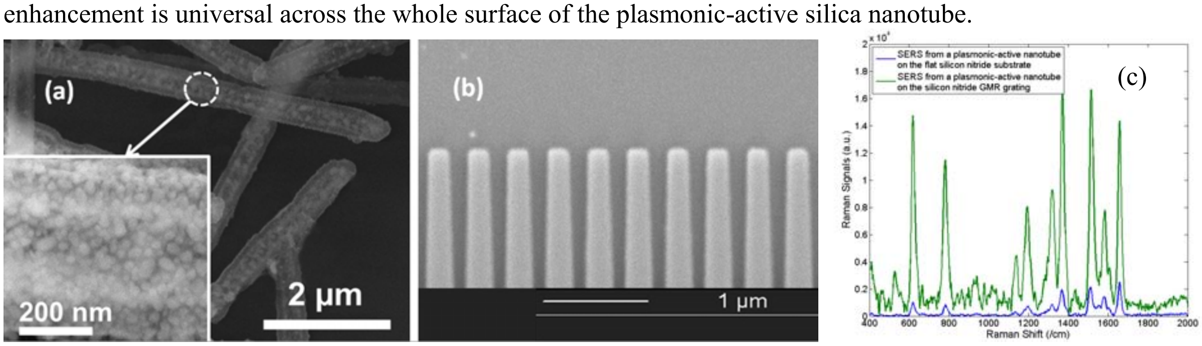

Fig.2 (a) SEM picture of the plasmonic-active silica nanotubes with densely assembled silver nanoparticles (b)SEM picture of the Si_3N_4 GMR grating (c) measured R6G Raman spectrum from the silica nanotube showing 8~10 additional enhancements

4. Conclusion

In summary, we have investigated nano-photonic devices using hybrid materials systems. The silicon photonic crystal modulator infiltrated with electro-optic polymers demonstrated 735pm/V effective in-device r_{33}. The integration of Si_3N_4 GMR grating with plasmonic-active silica nanotubes provides 8~10 additional EFs for SERS sensing, which has significant potentials for biomolecule detections.

5. References

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