Graphene oxide waveguide and micro-ring resonator polarizers

Yang Qu^a, Jiayang Wu^a, Yunyi Yang^a, Xingyuan Xu^a, Yao Liang^a, Sai T. Chu^b, Brent E. Little^c, Roberto Morandotti^{d,e,f}, Baohua Jia^{a,*} and David J. Moss^{a,*}

^aCentre for Micro-Photonics, Swinburne University of Technology, Hawthorn, VIC 3122, Australia

^bCity University of Hong Kong, Tat Chee Avenue, Hong Kong, China

^cXi'an Institute of Optics and Precision Mechanics Precision Mechanics of CAS, Xi'an, China

^dINRS –Énergie, Matériaux et Télécommunications, 1650 Boulevard Lionel-Boulet, Varennes, Québec, Canada

^eITMO University, St. Petersburg, Russia

^fUniversity of Electronic Science and Technology of China, Chengdu 610054, China.

*E-mail: bjia@swin.edu.au, dmoss@swin.edu.au

ABSTRACT

We experimentally demonstrate integrated waveguide polarizers and polarization-selective micro-ring resonators (MRRs) incorporated with layered graphene oxide (GO) films. We achieve a high polarization dependent loss (PDL) of ~53.8 dB for the GO-coated waveguide and a high polarization extinction ratio of ~8.3 dB for the GO-coated MRR.

Keywords: 2D materials, polarizer, integrated photonics, material anisotropy, graphene oxide

1. INTRODUCTION

Polarization control is a fundamental requirement in many optical technologies [1, 2]. Integrated polarization-selective devices based on complementary metal-oxide-semiconductor (CMOS) compatible integrated platforms [3], offering advantages of compact footprint, high stability, mass producibility and high scalability, are functional building blocks for photonic integrated circuits [2]. In recent years, the huge optical anisotropy and broadband response of two-dimensional (2D) materials such as graphene and transition metal dichalcogenides have been widely recognized and exploited to implement polarization-selective devices [4-7]. Owing to its ease of preparation as well as the tunability of its material properties, graphene oxide (GO) has become a highly promising member of the 2D family [8, 9]. A broadband GO-polymer waveguide polarizer with a high PDL of ~40 dB was demonstrated, where the GO films were introduced onto an SU8 polymer waveguide using drop-casting methods. The GO film thickness for each drop-casting step was ~0.5 μm and the drop coating diameter was ~1.3 mm, neither being ideal for achieving precise control of the placement, thickness, and length of the GO films.

Recently [10-16], we reported large-area, transfer-free, and high-quality GO film coating on integrated waveguides using a solution-based method with layer-by-layer deposition of GO films. Here, we use these techniques to demonstrate GO-coated integrated waveguide polarizers and polarization-selective micro-ring resonators (MRRs) on a CMOS compatible doped silica platform. We achieve highly precise control of the placement, thickness, and length of the GO films coated on integrated photonic devices by using our layer-by-layer GO coating method followed by photolithography and lift-off processes. We measure the performance of the waveguide polarizer for different GO film thicknesses and lengths versus polarization, wavelength, and power, achieving a very high polarization dependent loss (PDL) of ~53.8 dB. For GO-coated integrated MRRs, we achieve an 8.3-dB polarization extinction ratio between the TE and TM resonances. These results confirm the high-performance of integrated polarization selective devices incorporated with GO films.

2. DEVICE FABRICATION AND EXPERIMENTAL RESULTS

The integrated waveguides were fabricated from high-index doped silica glass core (~2 μm $\times$ ~1.5 μm) surrounded by silica via CMOS compatible process, with chemical mechanical polishing used to remove the upper cladding to enable GO film coating on the top surface of the waveguide. GO coating was achieved with a solution-based method that yielded layer-by-layer GO film deposition, as reported previously [10, 11]. Our solution-based GO coating approach, unlike for example, the sophisticated transfer processes employed for coating 2D materials such as graphene [12], is capable of coating large areas (e.g., a 4 inch wafer) on dielectric substrates (e.g., silicon and silica wafers) with relatively few defects. Figure 1 (a) shows the measured Raman spectra of the waveguides without GO and with 2 layers of GO. Figure 1(b) shows

Figure 1. (a) Raman spectra of integrated chip without GO and with 2 layers of GO. Insets show the corresponding microscope images. (b) Measured GO film thickness versus GO layer number. Insets show the images of a silica substrate coated with 1 and 10 layers of GO. (c)–(d) Microscope images of the MRR uniformly coated with 5 layers of GO and patterned with 50 layers of GO, respectively.

Figure 2 (a) Measured TE and TM polarized insertion loss. (b) Extracted PDL and EIL. In (a) and (b), (i) shows the results for 1.5-cm-long uniformly coated waveguides (0, 1, 2, ..., 10 layers of GO) and (ii) shows the results for 1.5-cm-long waveguides with 2-mm-long patterned GO (0, 10, 20, ..., 100 layers of GO). The input CW power and wavelength in (a) are 0 dBm and 1550 nm.

the thickness of GO films versus the layer number characterized by atomic force microscopy. In addition to the uniformly coated devices, we selectively patterned areas of GO films using lithography and lift-off processes, which allows precise control of the size and placement of the GO films, Figure 1(c) and (d) show microscope images of the integrated MRR uniformly coated with 5 layers of GO and patterned with 50 layers of GO, respectively. Note that although a number of concentric rings are shown, only the center ring was coupled with the through/drop bus waveguides to form a MRR.

Figure 2 shows the polarization dependent performance for both the 1.5-cm-long uniformly coated waveguides (0–10 layers, (i)) and the patterned 2-mm-long devices (10–100 layers, (ii)). The TE insertion loss increases much more strongly than TM with layer number, thus yielding a large PDL with low EIL (defined as the insertion loss induced by the GO film over the uncoated waveguide). The PDL reached a maximum of ~37.4 dB for a 10 layer uniformly coated device and ~53.8 dB for a 100 layer patterned device, with a modest maximum EIL of ~5.0 dB and ~7.5 dB for the two devices, respectively.

The measured TE and TM polarized transmission spectra of the uniformly GO-coated MRR are shown in Fig. 3(a), while the transmission spectra of the patterned (50 μm in length) MRR are shown in Fig. 3(b). For the patterned MRR with 50 layers of GO, a maximum polarization extinction ratio (defined as the difference between the extinction ratios of the TE and TM polarized resonances) of ~8.3 dB was achieved. These devices would be useful for silicon based photonic chips [17, 18], and this concept would also be applicable to other 2D materials as well [19, 20].

Figure 3. Measured transmission spectra of the MRR (a) uniformly coated with 0–5 layers and (b) patterned with 0–100 layers of GO.

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