Small polymer microphotonic integrated devices on silicon substrate

Sailing He, Daoxin Dai, Bo Yang, Qingkun Liu, and Yaocheng Shi

Small SU-8 photoresist-based optical waveguides can be used to realize low-cost, easy-to-fabricate microphotonic integrated devices.

Organic materials are very widely used in photonics because of their ease of fabrication and low cost. The synthesis of a range of organic materials according to the requirements of specific photonic applications is straightforward. Over the past few decades, scientists have developed various passive photonic devices by employing certain low-loss organic materials (e.g., the epoxy-resin photoresist SU-8 or benzocyclobutane). To fabricate organic films, spin coating is usually applied. It is, therefore, convenient to introduce specific dopants into organic materials for realization of active organic photonic devices for light emission, photodetection, and photovoltaic elements.

Because high integration density is usually desirable, we employed a small SU-8 optical waveguide with strong light confinement. This enables the use of a small bending radius. Figure 1(a) shows the waveguide with air cladding and a silicon dioxide insulator on silicon substrate. We used an SU-8 core (width and height of 2.0 and 1.5 μm, respectively) to satisfy the single-mode operation condition. Figure 1(b) shows our small SU-8 bending-waveguide array (for bending radii from 25 to 100 μm). Our results show that the bending radius could be as small as 75 μm, which is one order of magnitude smaller than that of conventional low-index-contrast buried optical waveguides. This helps realize small photonic integrated devices.

Figure 2(a) shows a scanning-electron-microscopy image of our 1×2 Y-branch power splitter, which consists of an input and two S-bend output waveguides (denoted branches 1 and 2). The output waveguide’s S bend has a bending radius of 200 μm to guarantee low bending losses. Figure 2(b) shows the measured spectral responses of the output ports, normalized by the transmission loss of a straight waveguide with the same length. The blue and red curves represent the normalized power from branches 1 and 2, respectively. Because of the limited bandwidth of the superluminescent-diode source, the wavelength span only covers the range from 1450 to 1650 nm. Figure 2(b) shows that the uniformity of our compact power splitter is good. (The relatively large excess loss is mainly caused by scattering losses at the junction.)

Continued on next page
Figure 3. (a) Arrayed-waveguide-grating (de-)multiplexers. Measured spectral responses of (b) all channels and (c) the 19th channel for transverse electric (TE) and transverse magnetic (TM) polarizations.

Figure 3(a) shows our 24-channel arrayed-waveguide-grating (AWG) (de-)multiplexer based on SU-8 optical waveguides. The channel spacing is 400GHz. Figure 3(b) shows the measured transmission spectrum for all channels. The minimal excess loss and channel nonuniformity are approximately 4.3 and 2.2dB, respectively, while the crosstalk is less than -20dB. Figure 3(c) shows the normalized spectral response for the transverse electric and magnetic polarizations of channel 19 of the AWG when light is guided into the central input channel. The polarization-dependent wavelength resolution is 0.02nm (at 1559.6nm), i.e., 0.5% of the channel spacing.

We also realized compact ring resonators based on this small SU-8 waveguide. Figure 4(a) shows our fabricated ring resonator with tapered multimode-interference couplers. With this compact device, we also developed a compact optical sensor by combining it with a microfluidic channel (which covers the micro-ring): see Figure 4(b). We used a liquid mixture of 30ml deionized water and a little alcohol for our experiment. The refractive index, $n$, of the mixture increases almost linearly as the alcohol concentration is increased. When the liquid mixture flows through the micro-ring along the microfluidic channel, the change in ethanol concentration introduces a shift, $\Delta \lambda$, in the resonant wavelength. Figure 4(c) shows the spectral responses of the micro-ring resonator’s through port for alcohol volumes of $V_{\text{alcohol}} = 0, 100, 200, \text{ and } 300\mu\text{l}$. For $\Delta V_{\text{alcohol}} = 100\mu\text{l}$, the resonant wavelength shifts by approximately 0.03nm. Thus, the measured sensitivity $\Delta \lambda / \Delta n$ is approximately 180nm per relative intensity unit.

Since the refractive index of the liquid crystal could be tuned by varying the applied voltage, we also designed and fabricated a tunable filter based on our small SU-8 optical waveguide, combined with a liquid crystal: see Figures 5(a) and (b). The liquid crystal covers the thin poly(methyl methacrylate) cladding.

When the applied voltage is changed, the refractive index of the liquid-crystal cladding changes. Figure 5(c) shows the shift in the ring resonator’s resonance wavelength when increasing the applied voltage from 0 to 10V. The threshold voltage is approximately 3V, and we could achieve a wavelength shift of 0.7nm.
Figure 5. (a) Schematic configuration of a tunable filter using a liquid-crystal (LC)-cladded polymer waveguide. PMMA: Poly(methyl methacrylate). Si: Silicon. (b) Optical microscope image. (c) Resonance-wavelength shift.

at 10V. Our future plans are to continue to develop photonic integrated devices based on SU-8.

Author Information

Sailing He
Joint Research Center of Photonics
Royal Institute of Technology (KTH)
Stockholm, Sweden
and
Zhejiang University
Hangzhou, China

Sailing He received his PhD degree from the KTH in 1992, and has since progressed through the ranks of assistant, associate, and full professor. His research interests include micro/nanophotonics.

Daoxin Dai, Bo Yang, Qingkun Liu, and Yaocheng Shi
Zhejiang University
Hangzhou, China

Daoxin Dai received his BEng degree from Zhejiang University’s Department of Optical Engineering in 2000 and subsequently became a PhD student in the same department. In 2004, he joined the KTH as an exchange student, where he obtained his PhD in 2005. He joined the faculty of Zhejiang University and was promoted to associate professor in 2007. His current research interests include silicon micro/nanophotonics for optical communications, optical interconnections, and optical sensing.

Bo Yang received her BE degree from Zhejiang University in 2007. Since 2007 she has been a Master’s student at the Center for Optical and Electromagnetic Research.

Qingkun Liu received his BE degree in 2007 from the University of Electronic Science and Technology of China in Sichuan. Since 2007 he has been a PhD student at the Center for Optical and Electromagnetic Research.

Yaocheng Shi received his BEng degree from the Department of Optical Engineering of Zhejiang University in 2003, where he is currently a PhD student. His research activities are in design and fabrication of photonic integrated devices.

References