Compact, Wavelength-Selective Resonant Photodetector Based on III-V/Silicon-on-Insulator Heterogeneous Integration

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Abstract: We introduce a compact, resonant photodetector based on III-V/silicon-on-insulator heterogeneous integration. Wavelength-selective detection is demonstrated. >10dB extinction ratio is obtained. The responsivity of the detector is ~1.0A/W at the resonance wavelengths.

OCIS codes: (130.3120) Integrated optics devices; (040.5160) photodetectors

1. Introduction

In recent years, silicon-on-insulator (SOI) has been proposed as a promising platform for passive photonic components [1]. However, for some active functionalities, e.g., emission, amplification, and detection, especially at infrared wavelengths, silicon is still outperformed by III-V compound semiconductors. Heterogeneous integration has shown us the ability to combine the advantages of both materials [2, 3]. Based on the III-V/SOI platform, we have successfully demonstrated lasers, detectors, and modulators [3-6], which are critical components for on-chip optical interconnect.

In this paper, we present a resonant photodetector on SOI, which is composed of an InAlAs/InGaAs metal-semiconductor-metal (MSM) detector structure and an SOI ring resonator. By integrating the III-V absorption layer directly inside the SOI ring cavity, the device can provide wavelength-selective detection, and is also compact in size as compared to conventional configurations with the same functionality. The static transmission and the current response are characterized.

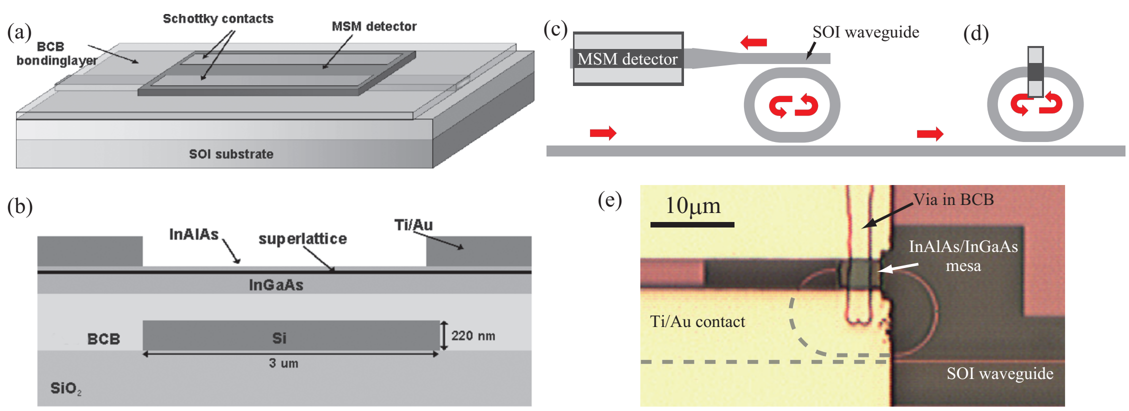

Fig. 1. (a) & (b) sketch of a MSM detector on SOI. (c) Conventional configuration and (d) proposed configuration of wavelength-selective detection. (e) Top view picture of a fabricated device.

2. Design and fabrication

Figure 1(a) and 1(b) show the structure of a MSM detector integrated on an SOI waveguide. By reducing the thickness of the benzocyclobutene (BCB) bonding layer to ~100nm and tapering the waveguide to 3um to achieve phase matching, 25um long III-V layer has been shown to be long enough to absorb nearly all the light in the SOI waveguide over a wide wavelength range [5]. Nonetheless, in future on-chip optical interconnect, wavelength-division-multiplexing is an inevitable technology in order to fully exploit the bandwidth of an SOI waveguide. In this case, a wavelength-selective element has to be included before the detection of light. Figure 1(c) shows one example. In this intuitive configuration, a ring drop filter is inserted, so that the wavelength of interest can be dropped from the bus and brought to, e.g., the aforementioned detector. In this paper, we propose a novel configuration of this ring-based wavelength-selective detection, as shown in Fig. 1(d), where the III-V absorption layer is placed on part of the SOI ring. No drop waveguide is needed in the proposed design. If the absorption loss induced by the III-V layer is equal to the coupling loss to the bus waveguide (assuming the intrinsic loss of the SOI ring cavity itself is negligible), all the light at the resonant wavelength will be dropped. Usually, these coupling and absorption losses are in the range of several percent to tens of percent depending on the required bandwidth. Therefore, the length of the III-V layer can be reduced further or the thickness of the BCB bonding layer can be increased. The latter would improve the yield of the bonding process.

Figure 1(e) presents a fabricated device. The SOI ring resonator has a racetrack shape with the bending radius of 5um and the straight section length of 7um. The InAlAs/InGaAs layer was bonded on the whole chip with BCB, and a 5um long mesa was defined on top of one straight section of the ring. Then, the whole chip was covered by another BCB layer to ensure enough separation between the SOI structure and the metal wires. A via was etched open on top of the III-V. Two metal contacts with a spacing of 3um were then deposited.

3. Measurement results

The normalized transmission spectrum of the present device is shown in Fig. 2(a). Clear resonant dips can be observed. The extinction ratio is at the best of ~25dB around 1505nm, and decreases as the wavelength increases, probably due to the increase of the coupling strength between the ring and the bus waveguide. The free spectral range is ~12nm. Figure 2(b) shows the detected current at different wavelengths. A grating coupler is used to interface with an optical fiber, resulting in a Gaussian coupling spectrum [1]. One can see that the responsivity at the resonant wavelengths is ~1.0A/W, the same as that of the original broadband detector [5]. Off resonance, the detected current drops by more than 10dB. The 3dB bandwidth is ~2nm. Obtaining a sharper resonance is possible through adjusting the coupling strength to both the bus waveguide and the III-V absorption layer.

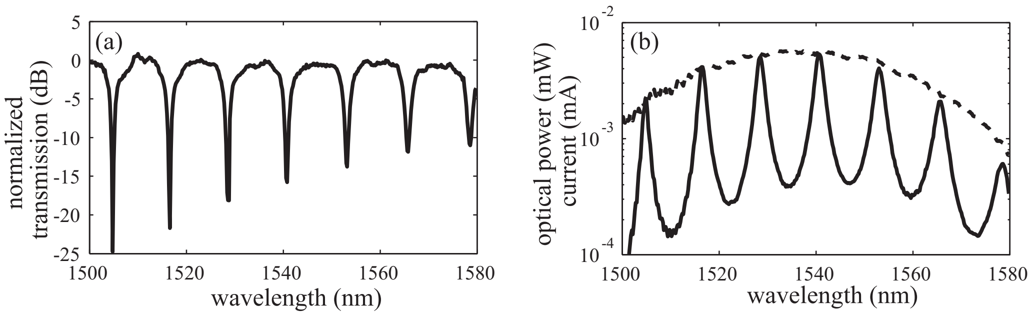

Fig. 2. (a) Transmission spectrum. (b) Detected current (solid line). The dashed line is the input power in the SOI waveguide.

4. Conclusion

We have presented a compact resonant photodetector. The structure consists of an SOI ring resonator and an MSM detector directly on the ring. The wavelength-selective detection has been demonstrated. >10dB extinction ration has been obtained at both the transmission and the current response. The responsivity has reached 1.0A/W at the resonant wavelengths. This device can potentially be used for on-chip optical interconnect and spectroscopy.

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[1] W. Bogaerts, R. Baets, P. Dumon, V. Wiaux, S. Beckx, D. Taillaert, B. Luyssenart, J. Van Campenhout, P. Bienstman, and D. Van Thourhout, “Nanophotonic waveguides in silicon-on-insulator fabricated with CMOS technology,” J. Lightwave Technol. **23**, 401-412 (2005).

[2] A. W. Fang, H. Park, O. Cohen, R. Jones, M. J. Paniccia, and J. E. Bowers, “Electrically pumped hybrid AlGaInAs-silicon evanescent laser,” Opt. Express **14**, 9203-9210 (2006).

[3] G. Roelkens, D. Van Thourhout, R. Baets, R. Notzel, and M. Smit, “Laser emission and photodetection in an InP/InGaAsP layer integrated on and coupled to a Silicon-on-Insulator waveguide circuit,” Opt. Express, **14**, 8154-8159 (2006).

[4] J. Van Campenhout, P. Rojo-Romeo, P. Regreny, C. Seassal, D. Van Thourhout, S. Verstuyft, L. Di Cioccio, J.-M. Fedeli, C. Lagahe, and R. Baets, “Electrically pumped InP-based microdisk lasers integrated with a nanophotonic silicon-on-insulator waveguide circuit,” Opt. Express **15**, 6744-6749 (2007).

[5] J. Brouckaert, G. Roelkens, D. Van Thourhout, and R. Baets, “Compact InAlAs/InGaAs Metal-Semiconductor-Metal Photodetectors Integrated on Silicon-on-Insulator Waveguides,” IEEE Photon. Technol. Lett. **19**, 1484-1486 (2007).

[6] L. Liu, J. Van Campenhout, G. Roelkens, Richard A. Soref, D. Van Thourhout, P. Rojo-Romeo, P. Regreny, C. Seassal, J.-M. Fédéli, and R. Baets, “Carrier-injection-based electro-optic modulator on silicon-on-insulator with a heterogeneously integrated III-V microdisk cavity,” Opt. Lett. **33**, 2518-2520 (2008).