

Low-Power Electro-Optical Switch Based on a III-V Microdisk Cavity on Silicon-on-Insulator Circuit

Liu Liu¹, Günther Roelkens¹, Thijs Spuesens¹, Richard Soref², Philippe Regreny³,
Dries Van Thourhout¹, and Roel Baets¹

¹Photonics Research Group, INTEC Department, Ghent University-IMEC, Sint-Pietersnieuwstraat 41, 9000 Gent, Belgium

²Air Force Research Laboratory, Sensors Directorate, Hanscom AFB, MA 01731, USA

³Université de Lyon; Institut des Nanotechnologies de Lyon INL-UMR5270, CNRS, Ecole Centrale de Lyon, Ecully, F-69134, France
e-mail: liu.liu@intec.ugent.be

Abstract: We introduce a compact, low-power electro-optical switch on silicon-on-insulator circuit through heterogeneous integration. A III-V microdisk cavity with a diameter of 10 μm is employed as the switching element. Switching of a 10Gbps optical signal is demonstrated by sweeping the bias between -1.1V — 0.9V with 15dB extinction ratio and 1.2ns switching speed.

©2009 Optical Society of America

OCIS codes: (130.3120) Integrated optics devices; (130.4815) Optical switching devices

1. Introduction

Silicon-on-Insulator (SOI) structure has been presented as a promising platform for future optical interconnects [1]. In order to realize more complex optical network-on-chip, compact optical switching and routing elements with low power consumption are required. Such a device has been demonstrated by using SOI ring resonators with either optical pumping [2] or electrical pumping [3]. In this paper, we report an alternate approach by using heterogeneous integration of a III-V microdisk cavity on an SOI circuit. The resonant wavelength of the microdisk cavity is shifted through current injection, and the optical signals can then be switched between two output SOI waveguides. Switching of 10Gbps optical signal is demonstrated by sweeping the bias between -1.1V — 0.9V with extinction ratio of 15dB. The switching speed was measured to be within 1.2ns.

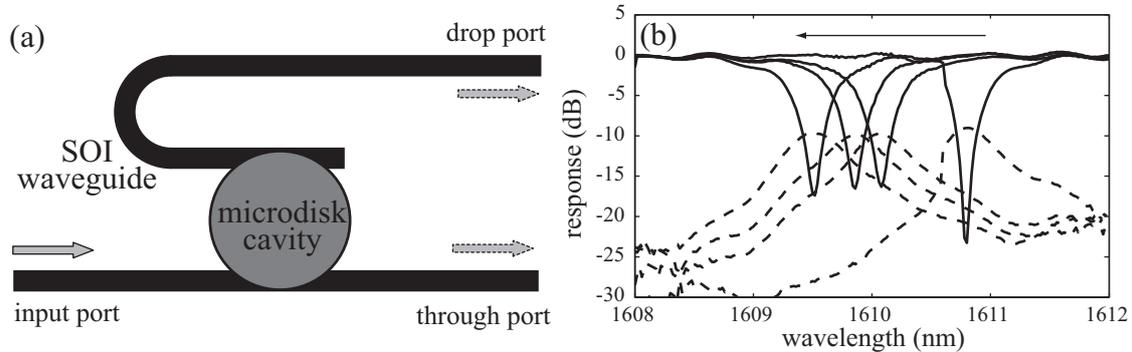


Fig. 1. (a) Schematic drawings of the proposed switch, (b) Measured static transmission spectra at the through port (solid lines) and drop port (dashed lines). Along the arrow direction, the bias currents are 0 μA , 55 $\mu\text{A}/0.9\text{V}$, 100 $\mu\text{A}/1.0\text{V}$, 200 $\mu\text{A}/1.1\text{V}$, respectively.

2. Design and measurement

As shown in Fig. 1, the proposed switching device consists of two SOI wire waveguide (dimension: $500\times 250\text{nm}^2$) and one III-V microdisk cavity with an pin junction in the vertical direction. The III-V/SOI die-to-wafer bonding technology is employed to fabricate the device. Please refer to Ref. [4-6] for the detailed fabrication process and III-V epi layer structure. The microdisk cavity has a diameter of 10 μm . Three compressively-strained InAsP quantum wells are embedded in the cavity. With current injection, the absorption coefficient and the refractive index of the quantum wells will be altered. Correspondingly, the resonance frequency of the microdisk cavity will shift, and the depth of the resonant dip will also change [7]. Therefore, the light at a certain wavelength can be switched between the through port and the drop port by varying the bias. Figure 1(b) shows the static through-port and drop-port spectra of the proposed device under different bias current. One can see that the resonant wavelength blue-shifts as the current increases, due to the increased carrier density. The best working point for drop-port switching was later concluded to be at 55 $\mu\text{A}/0.9\text{V}$, since the extinction ratio exhibits a low optical power dependency at this bias, i.e., the quantum wells reach transparency. The 3-dB bandwidth at 55 $\mu\text{A}/0.9\text{V}$ is about 0.7nm (87.5GHz). The drop port

loss is ~ 10 dB. This high loss is probably due to the unbalanced coupling coefficients of the two SOI waveguides to the microdisk cavity due to the misalignment of the microdisk during the fabrication process. This can be solved by using more accurate lithography system, e.g., E-beam lithography. To demonstrate the dynamic response of the proposed switch, we used a periodic modulated optical signal at 10Gbps (center wavelength at 1610.29nm) as the input light, and the bias of the microdisk was swept from -1.1 V to 0.9 V. The results are shown in Fig. 2. The switching from drop port to through port takes about 70ps. However, in the opposite direction the switching time is about 1.2ns due to the obvious relaxation oscillation in the carrier-injection transient. The dynamic extinction ratio is about 15dB, similar to that of the static case as shown in Fig. 1(b), due to the large bandwidth of the resonance. The eye-diagram of a 10Gbps, 2^{31} -1 non-return-to-zero pseudo random bit stream optical signal, which was switched to either the through port or the drop port, is also plotted in Fig. 2. A clear open eye without significant distortion can be observed.

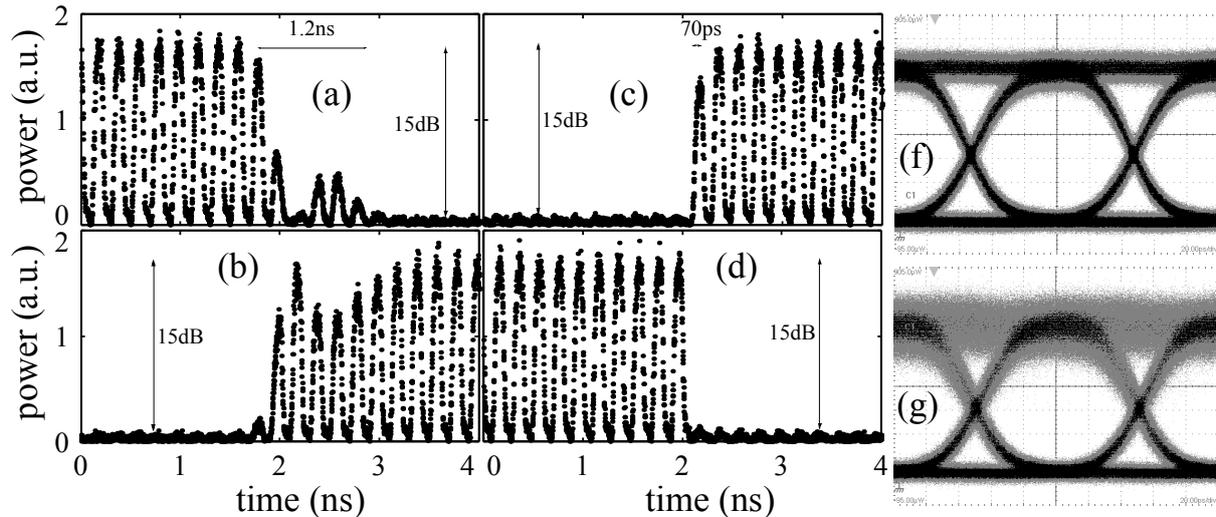


Fig. 2. Dynamic response of the proposed device. (a) and (c) are the off and on transients at the through port, respectively; (d) and (b) are the on and off transients at the drop port, respectively; (f) and (g) are the eye-diagram of a 10Gbps optical signal which were switched to the through port and the drop port, respectively.

3. Conclusion

We have reported a compact electro-optic switch on SOI by using a $10\mu\text{m}$ diameter III-V microdisk cavity. By sweeping the bias of the microdisk cavity from -1.1 V to 0.9 V, a 10Gbps optical signal has been successfully switched between the two output SOI waveguides with extinction ratio of 15dB. The switching time is within 1.2ns.

Acknowledgement

This work was supported partially by the EU-funded FP7-project WADIMOS, and AFOSR.

- [1] W. Bogaerts, R. Baets, P. Dumon, V. Wiaux, S. Beckx, D. Taillaert, B. Luyseart, 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] Y. Vlasov, W. M. J. Green, and F. Xia, "High-throughput silicon nanophotonic wavelength-insensitive switch for on-chip optical networks," *Nature Photon.* **2**, 242-246 (2008).
- [3] M. R. Watts, D. C. Trotter, and R. W. Young, "Maximally Confined High-Speed Second-Order Silicon Microdisk Switches," OFC 2008 PDP14.
- [4] 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).
- [5] 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).
- [6] T. Spuesens, L. Liu, T. de Vries, P. Rojo Romeo, P. Regreny and D. Van Thourhout, "Improved design of an InP-based microdisk laser heterogeneously integrated with SOI," accepted in 6th IEEE International Conference on Group IV Photonics 2009.
- [7] L. Liu, J. Van Campenhout, G. Roelkens, R. Soref, D. Van Thourhout, P. Rojo-Romeo, P. Regreny, C. Seassal, J. Fedeli, 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).