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Chalcogenides applied to microring switching

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Abstract**—We show that switching a phase-change material between its two bonding states can be used to shift the resonant wavelength of a ring resonator and change its Q-factor and extinction ratio, in a reversible and non-volatile way.**

Phase-change material; integrated optics; microring resonator.

I. INTRODUCTION

Optical fiber networks have become the backbone of our telecommunication system. These networks rely on, among others, the modulation, switching and multiplexing of optical signals, all of which can be carried out by ring resonators [1]. In this paper, we explore the use of phase-change materials (PCM) as a means of controlling the resonance of a ring resonator, in a way that is both non-volatile and reversible.

PCMs can exist under two stable solid phases (a covalent bonding phase and a resonant one), which exhibit very different absorptions and refractive indices [2]. It is possible to switch such materials between these two phases reversibly in nanosecond, picosecond and femtosecond time scales using light or current pulses [3], with energies typically on the order of 1 nJ/μm^2. These unique properties have been applied to rewritable DVDs [2], and more recently to electrical phase-change RAM [3]. Here, we show that switching a rectangle of PCM deposited on top of a ring resonator between its two bonding phases can also be used to modify the behavior of the ring, a concept that has the potential both to improve the knowledge of the properties of PCMs, and to demonstrate new applications for PCMs in photonics (e.g. switching, tuning, or use in optical memories).

II. SIMULATION RESULTS

In order to design a device sensitive to the switching of a PCM between its two bonding phases, the behavior of the structure depicted in Fig.1 is simulated, using a ring resonator model and a mode solver [4].

A. Ring resonator model

As described elsewhere [5], the power transmission $|S_{21}|^2$ from port 1 (input) to port 2 (throughput) of a ring resonator (see Fig.1) can be expressed analytically as:

$$|S_{21}|^2 = \frac{t_a^2 + t_b^2\tau^2 - 2t_a t_b \tau \cos\phi}{1 + t_a^2 t_b^2 \tau^2 - 2t_a t_b \tau \cos\phi}, \qquad (1)$$

where $t_{a,b}$ are the amplitude transmission coefficients in the two coupling regions (related to the amplitude coupling coefficients $\xi_{a,b}$ through $t_{a,b} = (1 - \xi_{a,b}{}^2)^{1/2}$), and ϕ and τ are respectively the phase difference and the amplitude attenuation induced by one round-trip in the ring. Considering a ring of perimeter L, of which a section of length x has been covered with PCM (see Fig.1b), ϕ and τ can be expressed as follows:

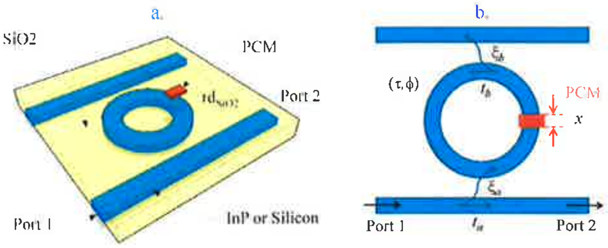

Figure 1. (a.) Aerial and (b.) top view of the proposed microring structure

$$\phi = k_0 n_{eff}(L-x) + k_0 n_{eff_{PCM}} x \ , \qquad (2)$$

$$\tau = e^{-(\alpha(L-x)+\alpha_{PCM}x)/2} \ , \qquad (3)$$

where $k_0 = 2\pi/\lambda_0$ is the propagation constant of the field in vacuum, and n_{eff} and α (n_{effPCM} and α_{PCM}) are the effective index and the attenuation coefficient of the mode propagating in the section of the ring without PCM (with PCM).

B. Mode Solving

Using the dependency of k_0 with wavelength, (1), (2) and (3) allow the theoretical transmission spectrum of the proposed ring structure to be determined. However, in order to do so, t_a, t_b, n_{eff}, α, n_{effPCM} and α_{PCM} need to be determined. The first four of these parameters can be extracted from measurements carried out on fabricated devices [1,6]. But for the parameters of the mode guided in the ring section covered with PCM, there is no experimental data available. Therefore, a mode solving tool is used to calculate these parameters.

The cross-section of the modeled waveguide is shown in Fig.2a. It is a typical monomode InP wire used in previous works [6]. All simulations are carried out at 1.5 μm wavelength, considering only the fundamental TE mode and neglecting dispersion effects. Furthermore, the (complex) refractive index of the PCM layer is set to that of $Ge_2Sb_2Te_5$ (GST), a prototypical PCM [3]: $n_{covalent} = 4.0 + i\ 0.1$ for the covalent bonding phase or $n_{resonant} = 6.5 + i\ 1.4$ for the resonant bonding phase.

One can already observe that, in the infrared, the real part of the refractive index of GST, for both phases, is higher than the refractive index of the material composing the waveguide ($n_{InP} = 3.17$). This means that in order to minimize the losses due to mode mismatch at the junction between the ring section without PCM and the ring section with PCM, the PCM thickness t_{PCM} has to be kept small with respect to the waveguide thickness.

Another point requiring attention is the strong imaginary part (equivalent to high optical losses) of the refractive index of GST's resonant bonding phase. During measurements on a real device, it is desirable to be able to obtain parameters such as α_{PCM} and n_{effPCM} from the recorded data. In practice, this means that the resonance dip which is characteristic of this type of resonator's transmission spectrum has to be deep enough to be detected and analyzed (fitted) using (1). Since the depth of this resonance dip decreases sharply when the round-trip losses increase (light needs to do many round-trips in the ring in order to exhibit a strong resonating behavior), it is necessary to keep these losses within a reasonable range (e.g. $\tau > 0.8$). Considering that most losses in the ring come from the absorbing nature of the PCM considered, limiting the round-trip losses can be done in two ways: either by reducing the length x of the ring section covered with PCM, or by increasing the buffer distance d_{SiO2} and reducing the PCM layer thickness t_{PCM} in order to limit the overlap of the mode (mostly confined in the InP) with the lossy PCM layer.

After setting the PCM layer thickness to $t_{PCM} = 0.02$ µm, a set of calculated values of n_{effPCM} and α_{PCM} as a function of d_{SiO2} is obtained for each bonding phase (covalent and resonant) of the PCM layer deposited on top of the waveguide. It is found that switching the PCM from the covalent to the resonant bonding phase only increases the effective index (n_{effPCM}) of the fundamental TE mode by less than 3 %, while making its absorption coefficient (α_{PCM}) shoot up by more than 3000 %.

C. *Modelled transmission*

In order to observe the effect that switching the PCM between its two phases has on the transmission of the device of Fig.1, the values of n_{effPCM} and α_{PCM} just obtained are input in (1), (2) and (3), together with the parameters of a fabricated device. A typical set of output curves (obtained for $t_{PCM} = 0.02$ µm, $d_{SiO2} = 0.2$ µm and $x = 2$ µm) is plotted in Fig.2c. The dotted curve is the fitted transmission of a fabricated ring of perimeter $L = 43.5$ µm without any PCM on it. The plain (green) curve shows how this ring's spectrum would be modified if covalent GST were to be deposited on a section of length $x = 2$ µm of the ring. Finally, the bold (red) curve shows the transmission of the same device after switching the GST layer from the covalent to the resonant bonding phase.

As expected from the small relative change in effective index n_{effPCM} upon PCM switching reported in the previous section, the resonance wavelength of the structure with PCM in its resonant bonding phase (bold curve) differs by only 0.28nm from that of the structure with PCM in its covalent bonding phase (plain curve). However, due to the large relative change in the absorption coefficient α_{PCM}, the transmission spectrum exhibits a dramatic change in shape (width and depth of the resonance) when switching the PCM from one phase to the other. In this case, the structure's Q-factor drops from 3000 to 1000, and its extinction ratio from 11.3 dB to 0.7 dB. This behavior could very well be applied to novel phase-change switches. For tuning applications, where one wishes to change the resonance wavelength of the ring without decreasing its Q-factor, an optimized design of the coupling constants $\xi_{a,b}$, or other PCMs exhibiting lower absorption values, should be considered.

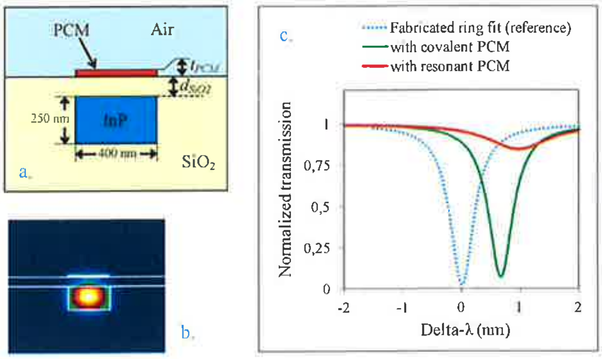

Figure 2. (a.) Schematic and (b.) typical mode profile of an InP wire with PCM on top; (c.) Simulated transmission spectra of the structure of Fig.1 ($L = 43.5$ µm, $t_{a,b} = 0.998$, $t_{PCM} = 0.02$ µm, $d_{SiO2} = 0.2$ µm, $x = 2$ µm)

III. CONCLUSION

The design of a structure which enables switching a microring resonator using the phase transition of PCMs has been considered. Simulations run with the parameters of GST, a prototypical PCM, show that both a shift of the resonant wavelength of the ring and a dramatic modification of its Q-factor and extinction ratio can be obtained when switching the PCM between its covalent and resonant bonding phases. Experiments are currently being conducted to verify this behavior.

REFERENCES

[1] W. Bogaerts, P. De Heyn, T. Van Vaerenbergh, K. De Vos, S. Kumar Selvaraja, et al., "Silicon microring resonators," Laser Photonics Rev., vol. 6, pp. 47–73, 2012

[2] M. Wuttig and Noboru Yamada, "Phase-change materials for rewriteable data storage," Nat. Mater., vol. 6, pp. 824–832, 2007

[3] R. E. Simpson, P. Fons, A. V. Kolobov, T. Fukaya, M. Krbal, T. Yagi, et al., "Interfacial phase-change memory," Nat. Nanotechnol., vol. 6, no. 8, pp. 501–505, 2011.

[4] FIMMWAVE v.5.1, Photon Design, 2008

[5] A. Vörckel, M. Monster, W. Henschel, P.H. Bolivar, H. Kurz, "Asymmetrically coupled silicon-on-insulator microring resonators for compact add-drop multiplexers," IEEE Photonics Tech. L., vol. 15, no. 7, pp. 921–923, 2003

[6] J.J.G.M. van der Tol, R. Zhang, J. Pello, F. Bordas, G. Roelkens, et al., "Photonic integration in indium-phosphide membranes on silicon," IET Optoelectron., vol. 5, no. 5, pp.218–225, 2011.

Thursday, 19 April 2012 / Hall-Auditorium. Poster 2. 15:30h – 17:00h

- *Gallium Nitride-on-Sapphire Tunable Photonic Crystal Directional Coupler (ID 92)*

We have designed and simulated a photonic crystal coupler in the GaN-on-Sapphire material system. In this asymmetric layer structure, the losses resulting from above light line operation can be tolerated with devices having short lengths. A 50-50% directional coupler of 5µm length is designed and tuning of the coupling ratio using electro-optic effect is presented.

E.Engin; J.L. O'Brien; M. J Cryan

- *Accurate dispersion characterization in nanophotonic integrated waveguides (ID 210)*

We report an interferometric technique to measure chromatic dispersion and its slope which is immune to thermal fluctuations and suitable for waveguides with high losses. Experimental results are complemented with theoretical simulations.

S.Mas; J.Matres; J.Martí; C.Oton

- *Experimental demonstration of an ultra compact SOI polarization rotator (ID 36)*

We report the design, fabrication and characterization of a polarization rotator in SOI technology. The device is compact (26µm), and features a measured crosstalk above 10dB, over a 35-nm bandwidth with a polarization conversion efficiency above 90%.

M.Aamer; A.M.Gutierrez; A.Brimont; A.Griol; J.Martí; P.Sanchis; D.Vermeulen; G.Roelkens

- *Design and simulation of DBR lasers with extended modulation bandwidth exploiting photon-photon resonance effects (ID 209)*

In high–speed laser devices the occurrence of a pho-ton–photon resonance increases the modulation bandwidth sub-stantially. In this paper our attention is focused on the design of DBR lasers in which this effect is exploited.

P.Bardella; I.Montrosset

- *Chalcogenides applied to microring switching (ID 173)*

We show that switching a phase-change material between its two bonding states can be used to shift the resonant wavelength of a ring resonator and change its Q-factor and extinction ratio, in a reversible and non-volatile way.

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