Chalcogenides applied to microring switching

J. Pello, J. J. G. M. van der Tol, M. K. Smit
COBRA Research Institute,
Eindhoven University of Technology (TU/e)
Eindhoven, The Netherlands
j.pello@tue.nl

S. Keyvaninia, G. Roelkens
Photonic Research group, INTEC, Ghent University-IMEC,
Ghent, Belgium

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/µm². 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:

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

(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 $\phi$ and $\tau$ 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), $\phi$ and $\tau$ can be expressed as follows:

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

(2)

$$\tau = e^{-a (L - x) + a_{\text{PCM}} x} / 2,$$

(3)

where $k_0 = 2\pi/\lambda_0$ is the propagation constant of the field in vacuum, and $n_{\text{eff}}$ and $a$ ($n_{\text{eff,PCM}}$ and $a_{\text{PCM}}$) 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, $\tau_a, \tau_b, n_{\text{eff}}, a, n_{\text{eff,PCM}}$ and $a_{\text{PCM}}$ 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 Ge2Sb2Te5 (GST), a prototypical PCM [3]: $n_{\text{covalent}} = 4.0 + i 0.1$ 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 part (equivalent to high optical losses) of the refractive index thickness without PCM and the ring section with PCM, the PCM due to mode mismatch at the junction between the ring section covalent to the resonant bonding phase.

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