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Integrated phase-change photonics for all-optical processing

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ABSTRACT

Embedding phase-change materials (PCMs) in on-chip photonic circuitry enables nonvolatile all-optical operation of integrated optical devices. This hybrid system has been used so far in terms of memory applications. However, it also provides the capability to all-optically process light signals. Here, we use picosecond pulses to demonstrate both all-optical routing and all-optical arithmetic operations within the on-chip photonic circuitry.

Key words: Phase-change nanophotonics, integrated photonics, all-optical routing

1. INTRODUCTION

Besides information storage, phase-change materials can also be used for all-optical processing of light signals, such as routing[1] and computing[2]. This is of particular interest in the context of integrated photonics due the possibility to build densely packed complex optical networks on a single chip for future all-optical telecommunication links.

2. EXPERIMENTS

The phase-change nanophotonic element in our experiments consists of a nanoscale $Ge_2Sb_2Te_5$ (GST)-cell which is evanescently coupled to an on-chip photonic device by embedding it directly on top of a waveguide section[3,4]. The resulting interaction between the GST and the guided light, which sensitively depends on the phase-state of the GST, changes both the amplitude and the phase of the optical wave transmitted along the cell[4,5] and can thus be used to control the functionality of a photonic device. Here, we operate such GST-cells with 1ps optical pulses. This way we achieve all-optical operation at ultra-fast speeds, no longer limited by the length of the optical pulses. In addition, we exploit the accumulation property of PCMs for all-optical arithmetic operations[2].

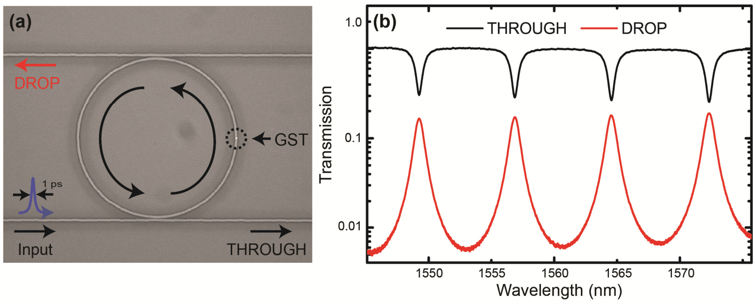

Fig. 1. **(a)** Optical micrograph of the on-chip ring resonator with embedded GST element. **(b)** Measured transmission spectra of both the THROUGH and the DROP port.

We demonstrate all-optical routing in an on-chip channel drop ring resonator, as shown in Fig. 1(a). The guided input light is only coupled into the cavity and from there into the DROP port if the resonance condition is fulfilled. This can be seen in Fig. 1(b) where measured transmission spectra of both the THROUGH and the DROP port are plotted. Since the location, width and depth of the resonance peaks depend on both the roundtrip phase shift and attenuation within cavity, the light flow (on a wavelength close to resonance) can be redirected between the DROP and the THROUGH port by switching the phase state of the embedded GST-element.

3. RESULTS & DISCUSSION

Measured transmission spectra for both phase states of a device with a GST-cell (600x500 nm^2 footprint) are plotted in Fig. 2(a). Upon crystallization, both a shift of the resonance towards higher wavelengths and a depth decrease of the corresponding dip are observed. Thus, a light signal sent into the device at on-resonance wavelength is directed upon crystallization from the DROP to the THROUGH port with a modulation depth, cf. Fig. 2b, exceeding 6 dB in both ports. In Fig. 2c, the optical power coupled into the DROP port of a similar device is plotted during one full switching cycle. As marked, amorphization is induced with a single picosecond pulse, while crystallization is carried out stepwise with pulse sequences (containing 100 pulses each) of decreasing energy since the heat generated by a single pulse is not enough to induce a full crystallization.

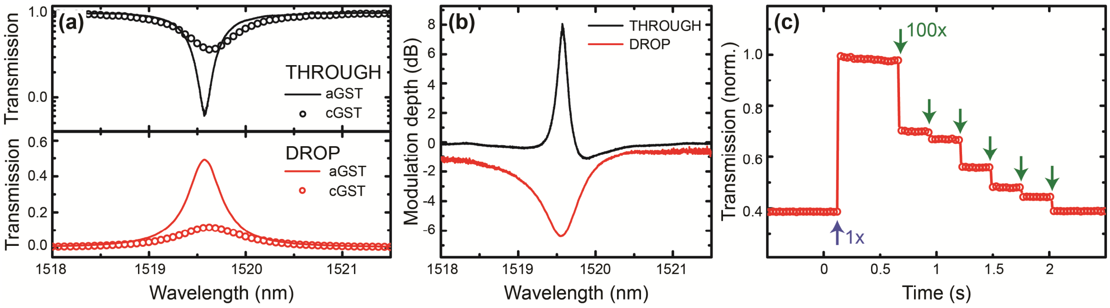

Fig. 2. **(a)** Measured change of the cavity resonance upon switching of the GST. **(b)** Modulation depth upon crystallization, derived from the data in panel (a). **(c)** Power coupled to the DROP port of a similar device during one full switching cycle, consisting of one amorphization (blue arrow) and several crystallization (green arrow) steps.

The number of pulses required to induce crystallization can significantly be reduced by slowing down the heat flow out of the GST. Here, however, we use the accumulation property of PCMs to demonstrate all-optical arithmetic operations within an on-chip photonic device. For this, we induce the crystallization not by pulses with decreasing energy but with identical pulses. This way, arithmetic operations can be carried out by sending a certain number of pulses into the cell while the respective result is simultaneously stored within GST[2]. With this technique, we demonstrate all basic arithmetic operations.

4. CONCLUSION

Our results illustrate that integrated phase-change photonics is not only a non-volatile memory platform but also offers the intruiging possibility to process guided light signals directly in the optical domain. The presented all-optical switch enables routing of the light flow without the need for additional electronic component, a prerequisite for all-optical telecommunication links. Going a step further, our all-optical arithmetic scheme allows us to perform mathematical operations where additionaly the information is directly stored in the GST.

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