Enhanced performance in plasmonic integrated phase-change memories

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ABSTRACT

We here propose feasible strategies to improve the performance of integrated phase-change photonic memories by the use of plasmonic enhancement. Several solutions are investigated, focusing in particular on optimising the optical readout contrast (transmission modulation) that can be achieved between crystalline and amorphous states. Results show that by embedding the plasmonic nanoantenna within the body of the waveguide, or by using multiple coupled nanoantennas in series, significant improvements in optical readout contrast can be achieved, while maintaining relatively small insertion losses.

Key words: $Ge_2Sb_2Te_5$, amplitude modulation, all-photonic memory, plasmonics. In_3SbTe_2

1. INTRODUCTION

Stemming from the work on the integrated phase-change photonic memory [1], we have recently reported an alternative memory architecture [2] with the potential to reduce the device switching energy and increase the switching speed. This alternative approach utilises a plasmonic dimer nanoantenna deposited on top of the waveguide of the memory device, which enhances the light-matter interaction between the phase-change cell and propagating light mode in the waveguide. As a consequence, a phase-change memory cell with much-reduced volume (compared to the conventional approach) can be utilised, and is situated in the antenna's nanogap. However, the maximum Optical Contrast $OC = |\Delta \mathrm{T}|/\mathrm{T}_{min}$ (where T refers to the optical transmission through the waveguide memory) achievable by our prevouisly reported plasmonically enhanced structures is intrinsically limited, whereas the 'conventional' architecture can reach arbitrarily large OC values (i.e. arbitrarily large readout contrast) by extending the length of the phase-change cell (along the along the waveguide). We therefore here explore, via numerical methods, approaches that can dramatically extend the readout contrast of plasmonically-enhanced memory architecture.

2. METHODOLOGY

We devise a dimer-bar Ag nanoantenna, with thickness, width and gap size of 30 nm, 40 nm, and 40 respectively. The device is built on the top surface of a SiN/SiO_2 ridge waveguide, of width 1300 nm and thickness 330 nm (165 nm ridge size), with GST ($Ge_2Sb_2Te_5$) as the phase-change material, see inset in Figure 1(a). The investigation is carried out via COMSOL Multiphysics (see Gemo et al. [2] for further details), with the propagating mode in the waveguide being at 1550 nm. In Figure 1(a) we determine the device OC response (readout contrast) as a function of the bars' length, with the view to provide a suitable comparison standpoint for further development. The optical properties of SiN, Ag and GST are taken from Ref. [2].

3. RESULTS & DISCUSSION

We initially test the exploitation of multiple nanoantenna structures fabricated along the waveguide. Due to the antisymmetric resonant mode of vicinal nanostructures, suppressing the waveguide mode propagation [3], we expect that a finely tuned centre-to-centre distance between nanoantennas could increase the OC by a decrease of the transmission in resonant configuration. Figure 1(b) shows the concept and simulation results for two nanostructures (bar lengths b of 155 nm). We find that the concept is indeed increasing the peak OC by a factor of ~4 with respect to the single structure (for b = 155 nm) while maintaining a relatively small *Insertion Loss* (IL) - see Figure 1 (c). Multiple nanostructures can further improve the OC metric, although further analysis is required.

We then test the concept of embedding the nanostructure within the waveguide core, which would increase the energy exchange between propagating mode and plasmonic mode. The suggested fabrication process would see the deposition of the SiN waveguide interrupted mid-height, to then proceed with the nanoantenna and phase-change cell fabrication, followed by the completion of the waveguide fabrication. For this configuration, we calculate a large increase of the achievable OC (Figure 1(d)) by a factor of ~4.5 (for a peak value of 1.45), at the cost of a ~2.5× increase of the IL.

The embedding approach can also be extended to enable mixed-mode functionality [4], as the exploitation of the quadrupolar resonant mode with a bar length of 650 nm retains a useful OC and low IL also when applying an overlapping electrical contact (see Figure 1(e)).

Whilst GST often remains the phase-change material of choice for many applications, there are of course many alternatives that can be explored. As an example, the In_3SbTe_2 alloy (hereafter IST) displays interesting optical properties [5]. The inclusion of IST in place of GST (for the structure simulated as in Figure 1(a)) further increases the achievable OC by a factor of ~1.3 (see Figure 1(f)), also reducing the IL. These results, in conjunction with IST's higher thermal conductivity and remarkably fast switching dynamics, suggest IST here as a beneficial alternative to GST.

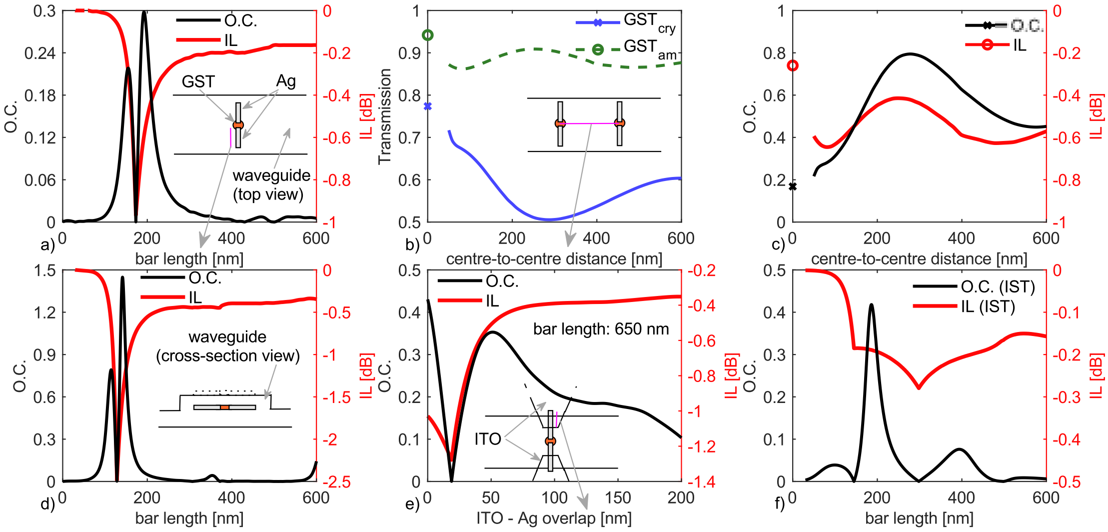

Figure 1. Optical performance of the plasmonically-enhanced phase-change photonic memory in several (dimer bar) configurations: OC and IL data (black and red lines respectively). (a) Top-surface mounted device. (b) Top-surface mounted double-device (transmission data for the amorphous and crystal phases). Markers highlight the single-device performance. (c) Top-surface mounted double-device. (d) Embedded configuration device. (e) Mixed-mode embedded device, as a function of the ITO contact – Ag bar overlap. (f) IST-enabled, top-surface mounted device.

4. CONCLUSIONS

The plasmonically-enhanced integrated phase-change all-photonic memory can not be arbitrarily extended in size to increase the optical contrast, as in the 'conventional' architecture. However, it allows one to capitalise on its near-field shaping capabilities by way of the other degrees of freedom: location of the nanostructure, number of nanostructures and phase-change alloy optical properties. Our findings show that such alternative design approaches, in particular the use of multiple nanoantenna structures and the embedding of the nanoantenna in the waveguide itself, can improve the optical contrast of the previously proposed designs, with marginal increase of the insertion loss.

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