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Non-volatile Optoelectronic Phase-Change Meta-Displays

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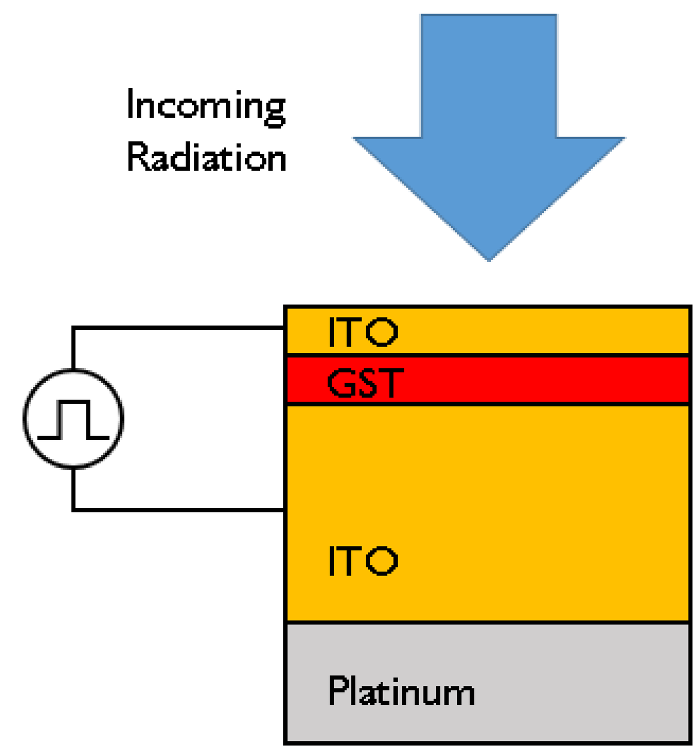
Abstract: Phase-change materials have a pronounced contrast between their electrical and optical properties when in the amorphous and crystalline phases, and can be switched between these phases quickly and repeatedly by electrical or optical means. These characteristics have very recently been exploited to produce a novel form of non-volatile optoelectronic display technology. In this work, we combine such phase-change display devices with metamaterial arrays, so as to gain additional control over their spectral properties.

Introduction

Chalcogenide phase-change materials, such as the ternary alloy germanium antimony telluride ($Ge_2Sb_2Te_5$, GST) used here, are well known for exhibiting a fast reversible change in their structure, from amorphous to crystalline, over a great number of cycles and resulting in a very considerable change in their optical (refractive index) and electrical (resistivity) properties. This has made phase-change materials very attractive for use in non-volatile optical and electrical memory applications [1]. However, in very recent times there has been much interest in the development of new functionalities for these remarkable materials, such as the exploitation of ultra-thin phase-change layers to deliver an entirely new form of non-volatile optoelectronic display [2], along with the combination of phase-change materials with metamaterial structures to provide tuneable/adaptable meta-devices, such as perfect absorbers and reflectarrays [3].

a)



b)

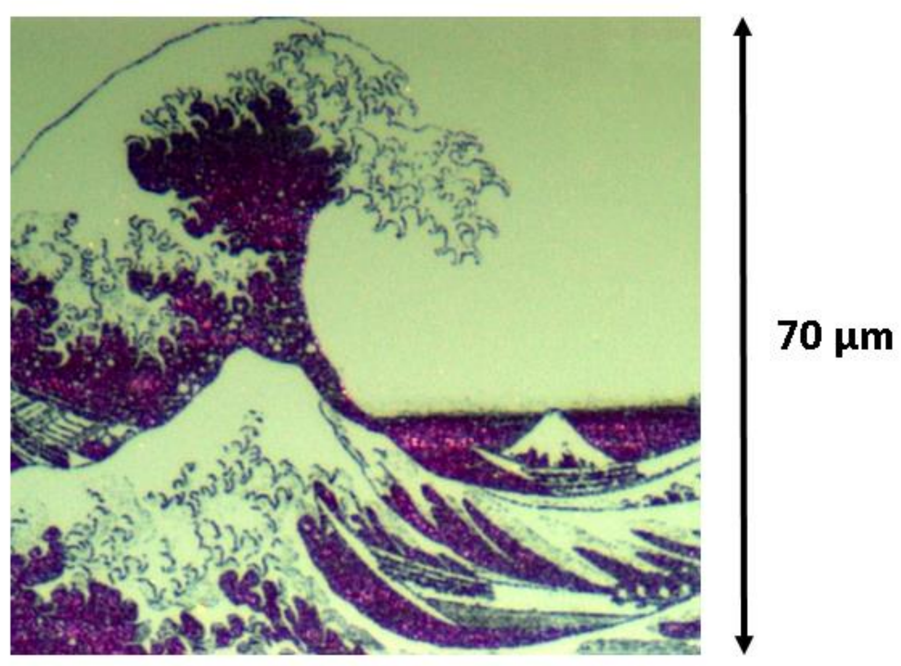


Figure 1. a) Phase-change display device structure proposed in [2], formed by a platinum bottom mirror and a GST layer sandwiched between two ITO layers. **b)** A high resolution (70x70 μm) image produced in such a structure produced changing the phase of the phase-change layer via Joule heating. The electrical pulse is sent employing an atomic force microscope in contact mode (CAFM).

In this work we combine ideas from metamaterial array design with those from phase-change based optoelectronic displays, with a view to providing more control over the purity of the colour spectrum produced by phase-change pixels. Reflectance spectra were here simulated using COMSOL Multiphysics, and photometric and colorimetric calculations and optimisations of various phase-change meta-display configurations were carried out using Matlab and Livelink for Matlab [4].

Reflective Display Colour Enhancement

The reflectance spectrum of the phase-change photonic cavity structure typically used in phase-change displays (Figure 1a) is rather broad, complicating the production of the primary colours that, when appropriately mixed, make it possible to create most of the colours we can perceive. Thus, the strategy followed here is the suppression of parts of parts of the reflectance spectrum we are not interested in by mechanisms of absorption. These mechanisms are the interaction of the photonic cavity with a plasmonic resonator embedded in it and the creation of a perfect electromagnetic absorber structure by periodically patterning a metal layer on top of the photonic cavity.

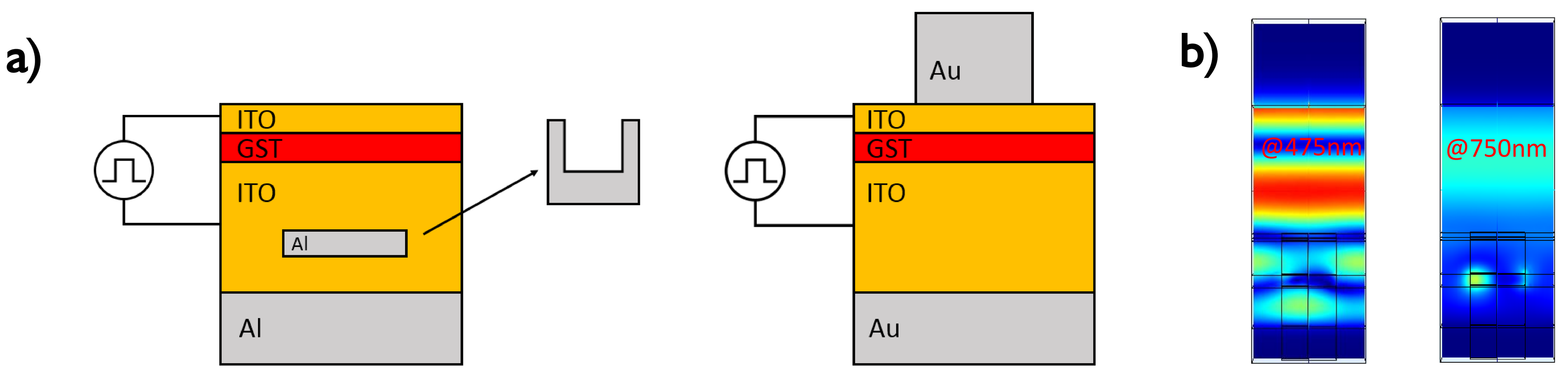


Figure 2. a) (left) Introduction of an embedded split ring resonator (SRR) array into the display structure and (right) alternative metamaterial array structure consisting of patterned metal strips on top of the upper ITO layer. Metal used in the structure on the left is aluminium whereas on the right is gold. **b)** Electric field plot at the excitation wavelengths for maximum (750nm) and minimum (475nm) interaction of the resonance of the cavity with the SRR.

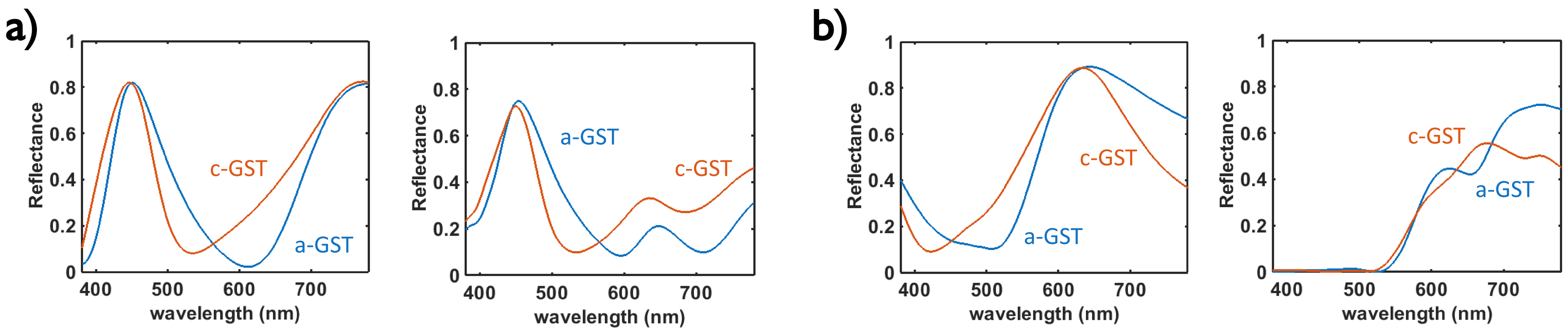


Figure 3. a) Reflectance spectra with the GST layer in amorphous and crystalline phases for the photonic cavity without (left) and with (right) the SRR. A reinforcement in blue wavelengths in the reflectance spectra caused by the interaction of the plasmonic resonator with the standing wave can be observed. **b)** Reflectance spectra of the photonic cavity without (left) and with (right) the array of strips; this structure attenuates blue wavelengths and preserve red wavelengths.

Photometric and colorimetric calculations

Colorimetric calculations on the obtained spectra reveal how the colour coordinates from the structure that includes plasmonic resonators are closer to the spectral locus and hence their colourfulness is greater than that produced by the photonic cavity.

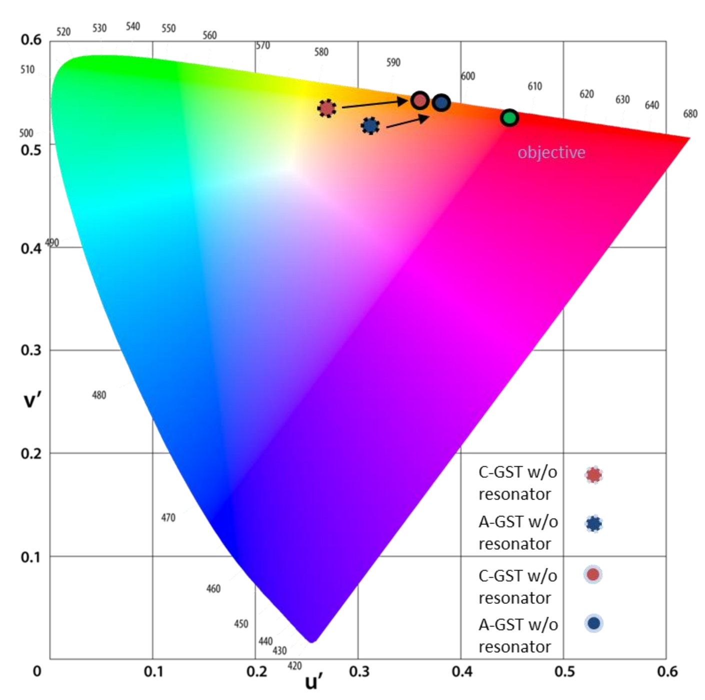


Figure 4. Mapped coordinates of the spectrum produced by the photonic cavity with strips (Figure 2a (right) and Figure 3b). Dashed circles corresponds to photonic cavity and solid line circles correspond to the metamaterial structure.

References

[1] Raoux et al. *Phase-change materials and phase-change memory.* MRS Bulletin, 39 **(8)**. 2014.
[2] Hosseini et al. *An optoelectronic framework enabled by low-dimensional phase-change films.* Nature, 511 **(7508)**. 2014.
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[4] Aldrich, M. *Pspectro: Photometric and Colorimetric Calculations.* Matlab File Exchange, 2010.

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