Phase-change meta-photonics

C D Wright[1*], C Ruiz de Galarreta[1], L Trimby[1], S Garcia-Cuevas Carrillo[1], J Bertolotti[1], D W Hewak[2], M Cryan[3], M Klemm[3], P Hosseini[4] and H Bhaskaran[4]

[1]CEMPS, University of Exeter, Exeter EX4 4QF, UK
[2]ORC, University of Southampton, Southampton SO17 1BJ, UK
[3]Dept. Electrical and Electronic Engineering, University of Bristol, Bristol BS8 1UB, UK
[4]Dept. Materials, University of Oxford, Oxford OX1 3PH, UK
[*]e-mail: david.wright@exeter.ac.uk

ABSTRACT

We combine phase-change materials and metamaterial arrays (metasurfaces) to create new forms of dynamic, tuneable and reconfigurable photonic devices including 'perfect' absorbers, infra-red light modulators, optical beam steerers and enhanced phase-change optoelectronic displays.

Key words: phase-change metadevices, reconfigurable photonic devices, metasurfaces, perfect absorbers, reflectarrays

1. INTRODUCTION

Exploiting the crystalline/amorphous electro-optical contrast of phase-change materials for the provision of non-volatile memories is well established [1]. Similarly, the development of so-called metasurfaces - arrays of miniature light scatterers/resonators – that allow control of the amplitude, phase and polarisation of light using flat, thin-film devices is now quite well-advanced [2]. Metasurface-based devices usually consist of patterned arrays of metal plasmonic resonators combined with a dielectric material, with the optical properties of the device being determined by the specific design used (array pattern structures, film thicknesses etc.). The functionality of conventional metasurface devices is therefore fixed by design. However, by combining metasurfaces with a phase-change material, whose dielectric properties can be changed 'on demand' by switching between amorphous and crystalline states, we can realise a whole new generation of dynamic, tuneable and reconfigurable metadevices. Here we demonstrate just some of the possibilities, by designing phase-change meta-photonic devices that can act as switchable absorbers, optical beam-steerers, infra-red light modulators and enhanced phase-change optoelectronic displays [3]

2. DEVICE DESIGN

Figure 1 shows, by way of example, two typical phase-change meta-photonic devices structures. The device in Fig. 1(a) can operate as a tuneable absorber/modulator and has a patterned top metal layer, an ITO layer, a phase-change layer (here shown as $Ge_2Sb_2Te_5$, or GST) and a continuous (i.e. un-patterned) bottom metal layer. The ITO layer provides environmental protection for the GST layer, while also allowing for both optical and electrical access to the device. The device in Fig. 1(b) is slightly more complex, having both patterned top metal layers and patterned GST regions; this device can provide a dynamic beam-steering capability. The performance of both devices shown in Fig. 1 was simulated using COMSOL Multiphysics®, and the device design (i.e. the sizes of the patterned structures, the thicknesses of the various films in the stack) varied to provide optimum performance (i.e. optimum beam modulation in the case of Fig. 1(a), optimally efficient beam steering in the case of Fig. 1(b)) at the technologically important wavelength of 1550 nm.

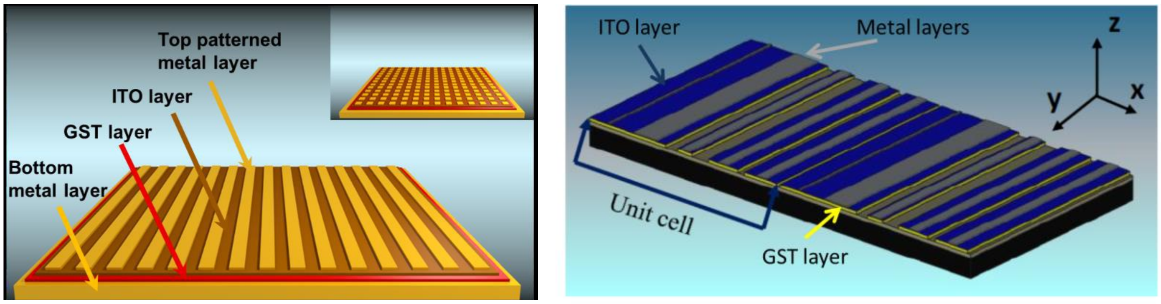

Fig. 1: (a) Typical structure of a phase-change meta-absorber/modulator type device (inset shows a polarisation insensitive design). (b) Typical structure of a phase-change meta beam steering device.

3. RESULTS & DISCUSSION

For the GST-based absorber/modulator device shown in Fig. 1(a), a coupled resonant behaviour between the top and bottom metal layers allows for a near zero reflectance when the GST layer is in the amorphous state. However, when we switch to the crystalline state, the coupling between the metal layers is broken and we obtain a large reflectance, as shown in Fig. 2(a). By switching the GST layer between phase states we can thus realise a thin-film reflectance modulator, with properties as shown in Fig. 2(a). For the beam-steering device of the type shown in Fig. 1(b), proper design of the structure (i.e. of the patterned regions and layer thicknesses) yields a device that reflects light in the usual manner with the phase-change layer in one phase state, but reflects anomalously when the state is changed. We show an example in Fig. 2(b), where an incoming normally incident beam is reflected normally with the phase-change layer in the amorphous phase, but reflected at an angle of ~ 30^0 to the normal for the crystalline state – note that here we actually used a GaLaS (GLS) phase-change material in the place of GST – since GLS has excellent properties in the infra-red [4].

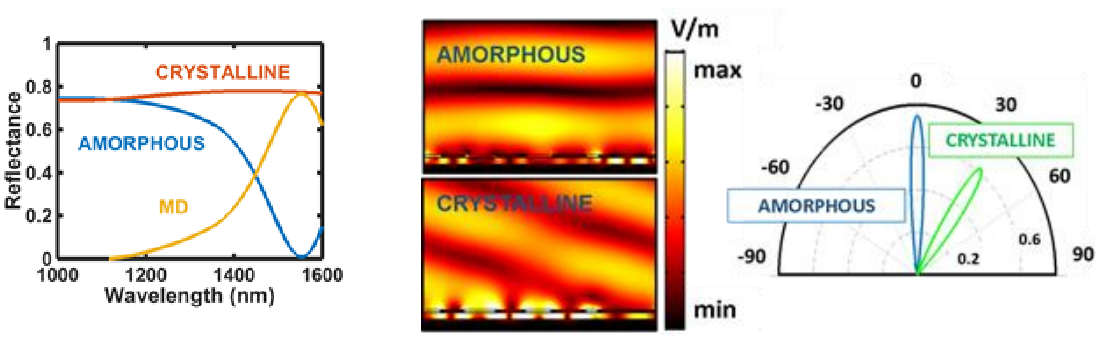

Fig. 2: (a) Reflectance spectrum for a GST-based modulator device of the form shown in Fig. 1(a). (b) Scattered electric field profile and far-field radiation pattern for a GLS-based beam steering device similar to that shown in Fig. 1(b).

4. CONCLUSION

We have shown that the proper combination of phase-change materials and metamaterial arrays (metasurfaces) opens up a route to a world of new photonics functionalities.

REFERENCES

1. M Wuttig and N Yamada, *Nature Materials* 6, 824 (2007)
2. N Yu and F Capasso, *Nature Materials* 13,139 (2014)
3. P Hosseini, C D Wright and H Bhaskaran, *Nature* 511, 206 (2014)
4. P Bastock et al., Properties of gallium lanthanum sulphide glass, CLEO 2015