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EPSRC Centre for Doctoral Training in Metamaterials XM²

Phase-change meta-devices for near-infrared absorbers and modulators

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In this work we combine phase-change materials with metal-insulator-metal metamaterial electromagnetic absorber structures to create active devices capable of modulating the amplitude of light in reflection. The designed devices pave the way for interesting possibilities in IR light absorption and modulation.

1. Introduction

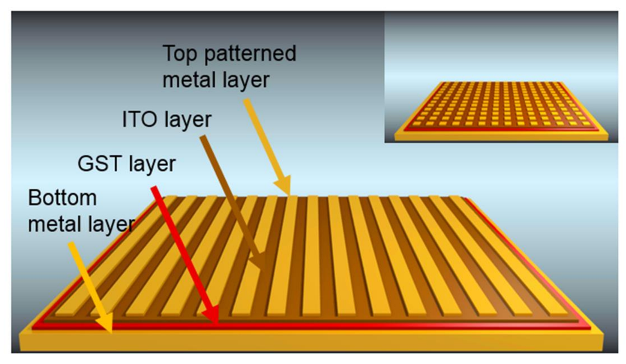
Phase-change materials, like the well-known alloy germanium antimony telluride (GST) used here, are materials that experience an abrupt change in their optical (refractive index) and electrical (conductivity) properties when they change from their amorphous to their crystalline phase. This change is fast (on the order of nanoseconds), non-volatile and temperature driven [1].

Metamaterials, on the other hand, are engineered structures composed of subwavelength resonators. The collective response of the resonators to the incident light can produce exotic effects like beam steering [2] or perfect absorption of light [3], potentially useful in technological applications .

Here we use phase-change materials to modify the response of a metal-insulator-metal electromagnetic absorber structure, Fig 1(a). The structure changes from an absorptive state to a reflective state when the phase (and hence the refractive index) of the phase-change material embedded in it is changed, Fig 1(b).

The structures have been designed to operate optically and electrically, that is, control the amplitude of light in reflection using either optical or electrical signals.

a)



b)

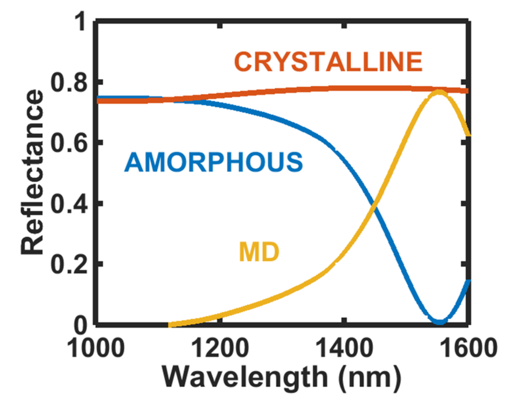


Fig 1. **(a)** Structure and materials of the device. **(b)** Optimal response of the device in terms of modulation depth (MD), defined as the difference in reflectance between the amorphous and crystalline state at 1550 nm wavelength[3].

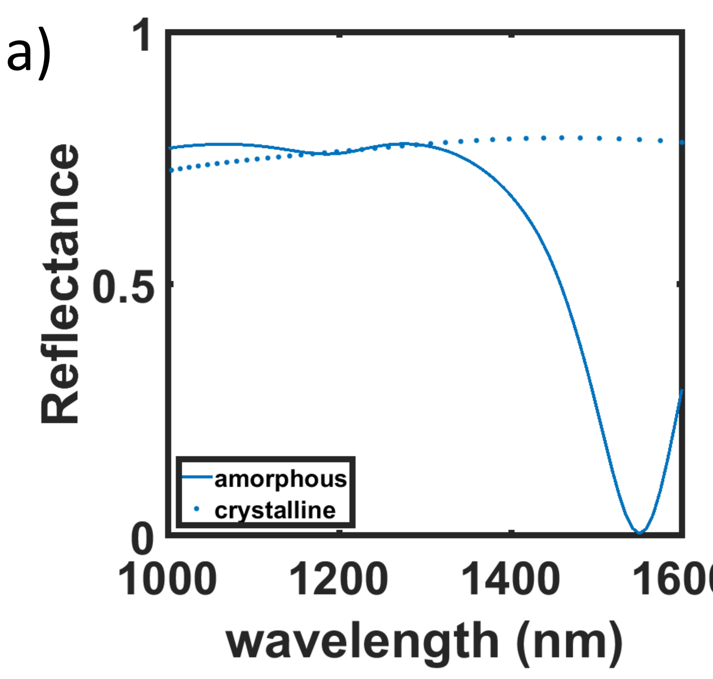
2. Ex-situ optically induced switching

The devices are formed by a stack of layers composed of an aluminium bottom metal plane, a GST layer and a top ITO layer to environmentally protect the phase-change material. On top of the stack an aluminium layer is patterned as strips. The optimal response is calculated using COMSOL Multiphysics in combination with Matlab, Fig 2(a).

The fabricated structures were scanned using a blue diode laser (405 nm wavelength) to raise the temperature in the GST layer and change its phase.

Main expected features are present in the experimental results, Fig 2(b), however the reamorphisation process is not perfect. This can be caused by not good enough cooling rates or partial recrystallization during reamorphisation. Optical microscope images of the devices after fabrication Fig 2(c) and during switching Fig 2(d) are provided.

a)



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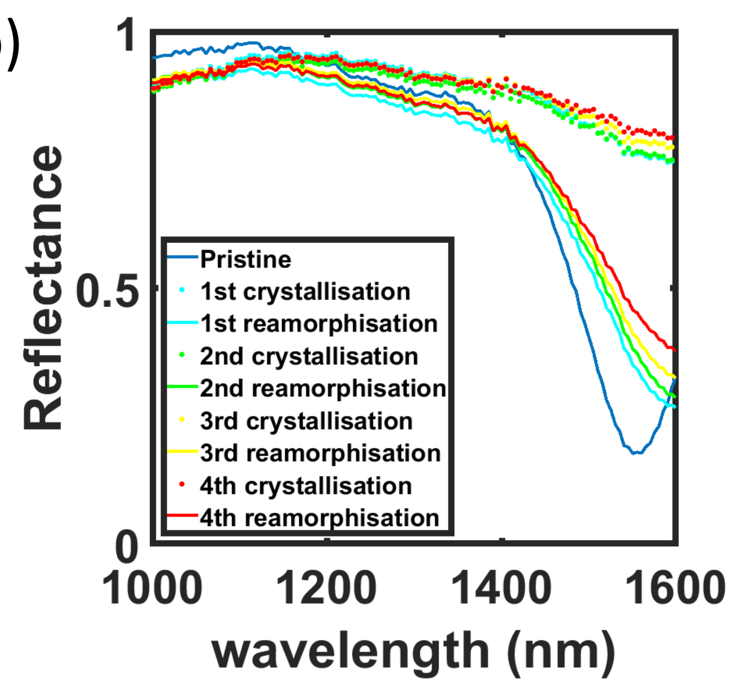
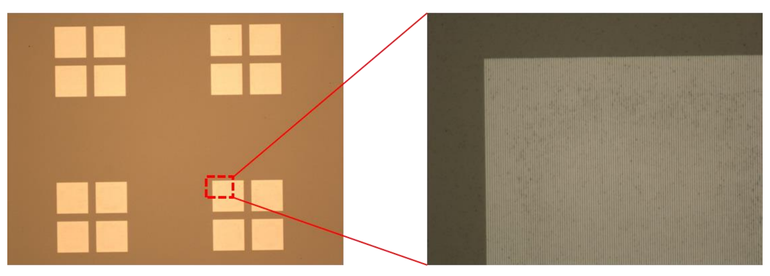


c)



d)

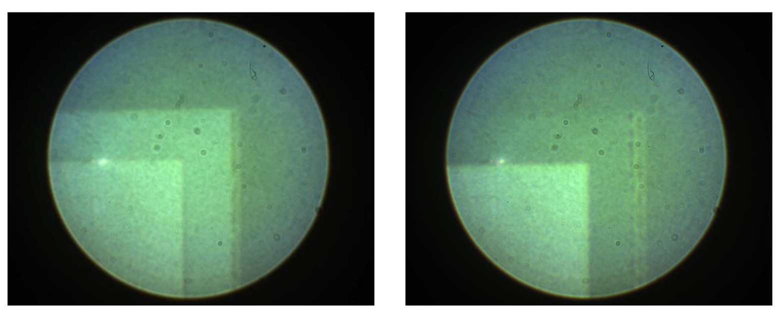
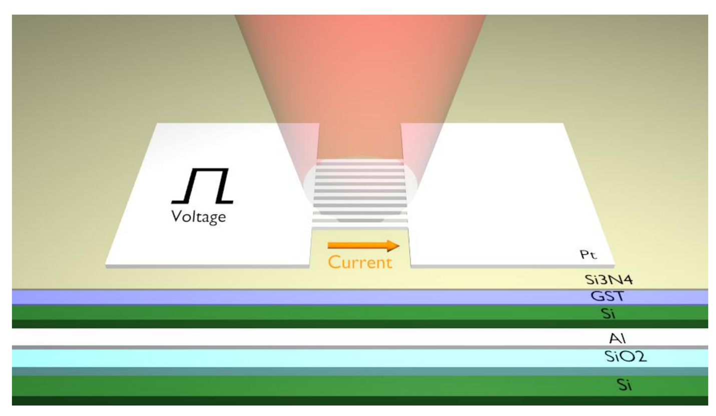


Fig 2. **(a)** Optimal response of the device in terms of MD. **(b)** Measured reflectance of the device after several cycles. Optical microscope images of the fabricated devices **(c)** and **(d)**.

3. In-situ electrically induced switching

Devices with in-situ switching of the GST layer are likely to have much greater technological usefulness cf. externally switched designs. Here we achieve in-situ switching by using the metasurface itself as an electrical micro-heater. The design is shown in Fig 3(a) and 3(b) and is by an aluminium bottom plane, a silicon layer, a GST layer, a silicon nitride layer and a platinum metasufrace/heater. The device has an area of 53 μm^2 and preliminary in-situ switching measurements are shown in Fig 3(c).

a)



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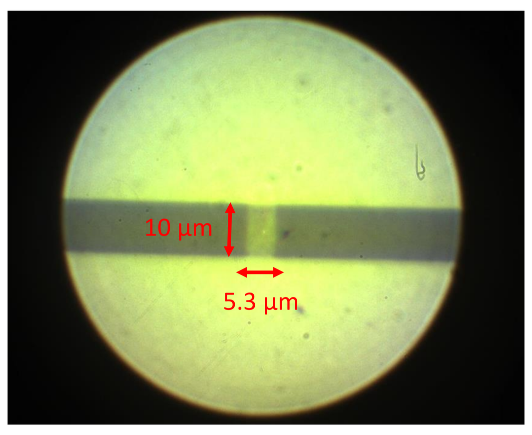

c)

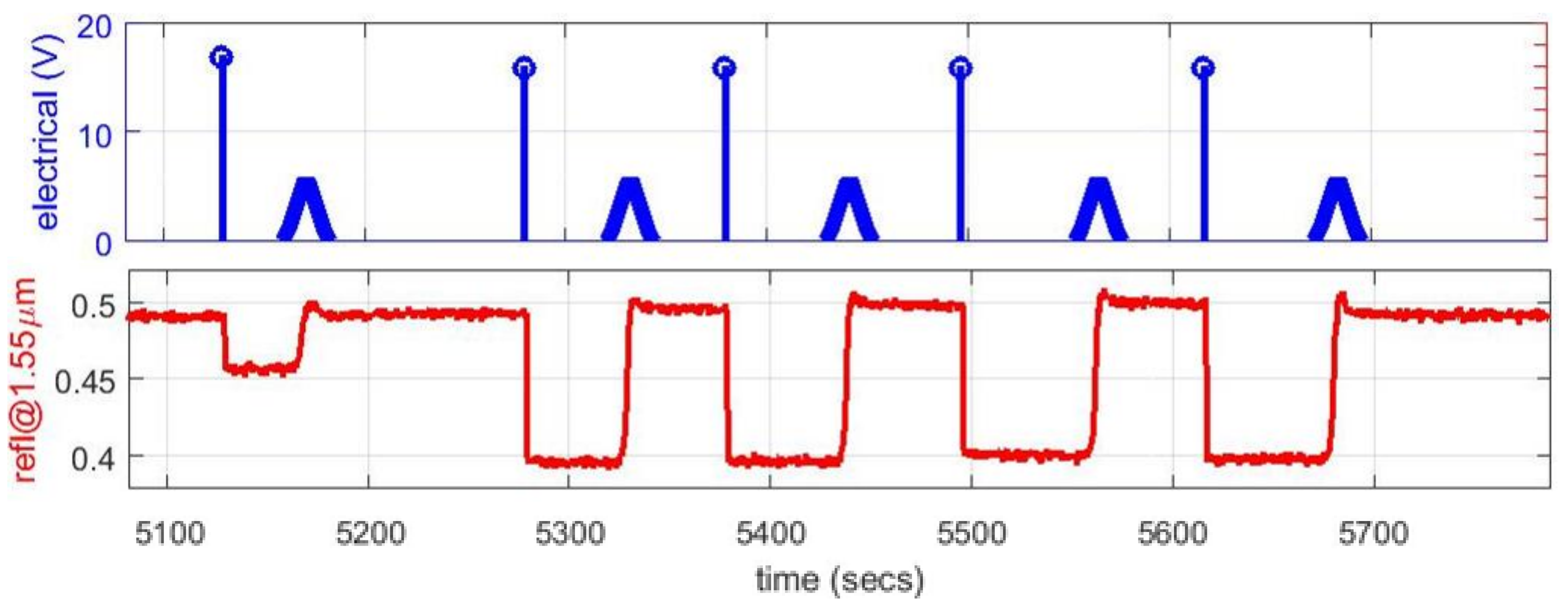

Fig 3. **(a)** Structure and materials for the electrically switchable device. **(b)** Optical microscope image of the device. **c)** Applied electrical pulses (up) and effect in the reflectance of the device (bottom) as a function of time.

5. Conclusion

We have demonstrated that it is possible to use phase-change materials in combination with metasurfaces to control the absorption and reflection of light, using ex-situ optical or in-situ electrical switching. The presented devices have the potential of become an alternative to digital micromiror devices or liquid crystals for near-infrared spatial light modulation.

References

[1] S. Raoux et al., "*Phase change materials and phase change memory*", MRS Bulletin 39 **(8)**, pp. 703-711, 2014.

[2] N. Yu et al. "*Flat optics with designer metasurfaces*". Nature Materials 12 **(2)**, pp.139-150, (2014).

[3] S. García-Cuevas Carrillo et al. "*Design of practicable metadevices for near-infrared absorber and modulator applications*". Optics Express 24 **(12)**, pp. 13563-13573, (2016).

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