Beam steering and beam shaping phase-change metasurfaces working in the near infrared

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Abstract. We show how to create simple, efficient and practicable phase-change plasmonic metasurfaces for tunable beam steering and beam shaping purposes in the near infrared (λ = 1550nm).

Introduction

The use of phase-change materials (PCMs) outside the memory technology area is growing fast. Particularly, the high electro-optical contrast of chalcogenide alloys [1] in combination with plasmonic metasurfaces have paved the way for a new type of ultra-fast compact and reconfigurable photonic devices, such as switchable perfect absorbers or optoelectronic displays [2]. Recently, the combination of $Ge_2Sb_2Te_5$ (GST) with plasmonic metasurfaces has been also proposed as a way to create novel reconfigurable beam steering devices [3,4]. Figure 1 summarizes the working principle of such devices, where incident light is reflected in a mirror-like way when the phase-change layer is in one state (say the crystalline state), but is reflected anomalously at a pre-designed angle when the state of phase-change layer is switched. This gives the ability to steer beams without any moving parts. In this work we consider the design, fabrication and characterisation of such devices.

Device working principle

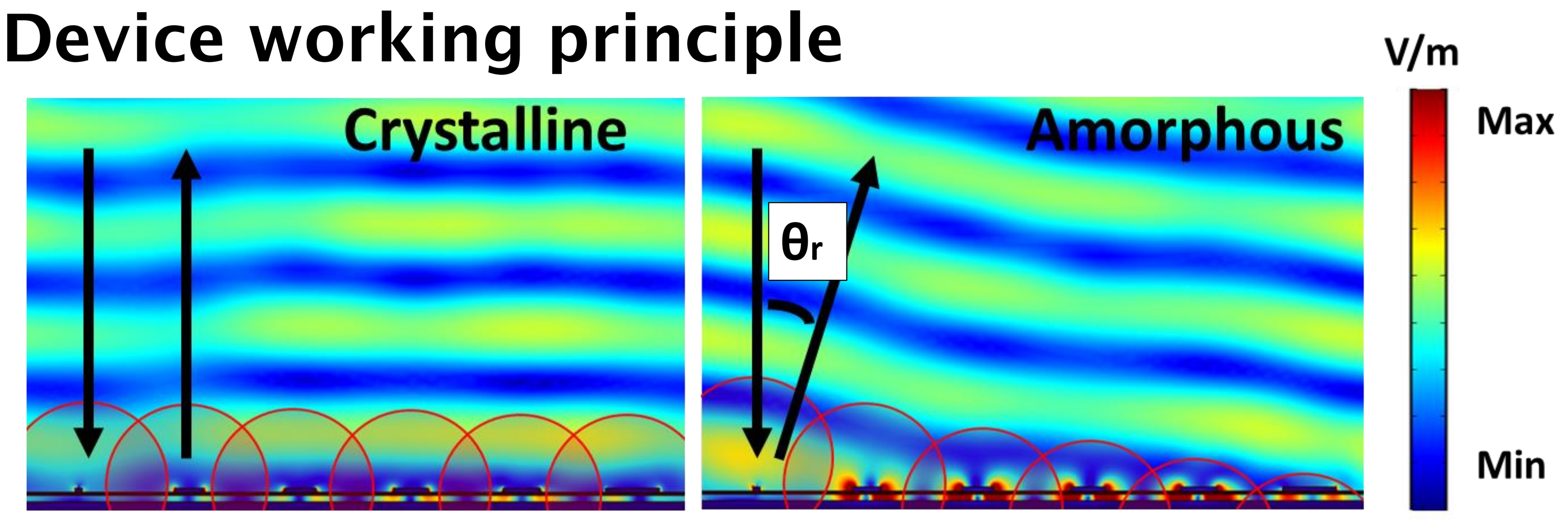

Figure 1: Electric field distribution showing the device working principle for crystalline (left) and amorphous (right) states.

Generalized Snell's law

$$\sin\theta_r = \frac{\lambda_0 \Delta\phi}{2\pi d}$$

θ_r = Angle of reflection
$\Delta\phi$ = Local phase shift
λ_0 = Free-space wavelength
d = spacing between elements

Design & Analysis

The unit cell of our meta-device is depicted in Figure 2(a). It consists in a metal/insulator/metal configuration, where a SiO2/ITO/GST/ITO multilayer stack is sandwiched between a continuous bottom Al plane and a top Al dipole antenna. The GST provides an active dielectric environment to switch the device behaviour, whereas ITO layers were introduced to act as transparent top and bottom electrodes/heaters to electrically switch the device between its amorphous and crystalline states. As shown in Figure 2(b), such type of configuration supports magnetic plasmon resonances which can be exploited to control the optical phase of light re-radiated to the free-space. As shown in Figure 2(c), local phase control can be achieved by varying the width of the top Al antenna when the GST layer is amorphous. However, after crystallisation of the PCM layer the underlying resonant behaviour is cancelled due to an abrupt change in the refractive index, which results in a near invariant phase response.

The final super cell of our device (shown in Figure 2(c) caption) consists of 4 amorphous-GST antennas giving a constant phase increment of Δϕ = 90° along the surface.

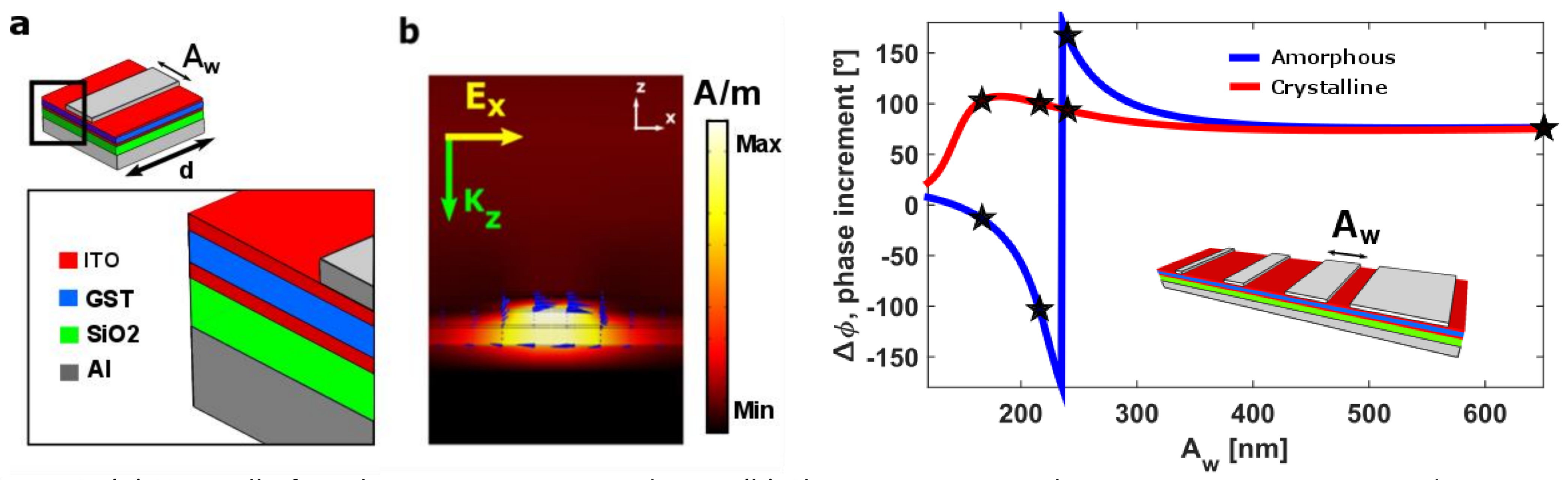

Figure 2: (a) Unit cell of our beam steering meta-device. (b) Characteristic gap plasmon resonance supported my metal-insulator-metal configurations. (c) Optical phase of the reflected wave as function of the aluminium antenna width A_w. A near 2π phase overage can be achieved when the GST is amorphous, and a near invariant phase response for the crystalline phase. Star-like markers correspond to the A_w sizes selected to build the supercell shown in the figure caption.

Fabrication

Our device has been successfully fabricated using common microfabrication techniques (E-beam lithography and magnetron sputtering).

Figure 3 shows an SEM picture of one of the fabricated structures.

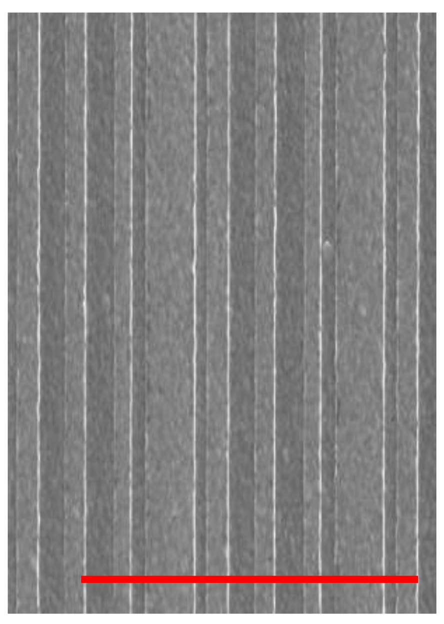

***Figure 3**: SEM image of one device. Scalebar corresponds to 5μm.*

Characterisation

Experimental characterisation of our devices was carried out via Fourier imaging micro-spectroscopy. As shown in Figure 4, the results obtained were in excellent agreement with the calculated theoretical performance.

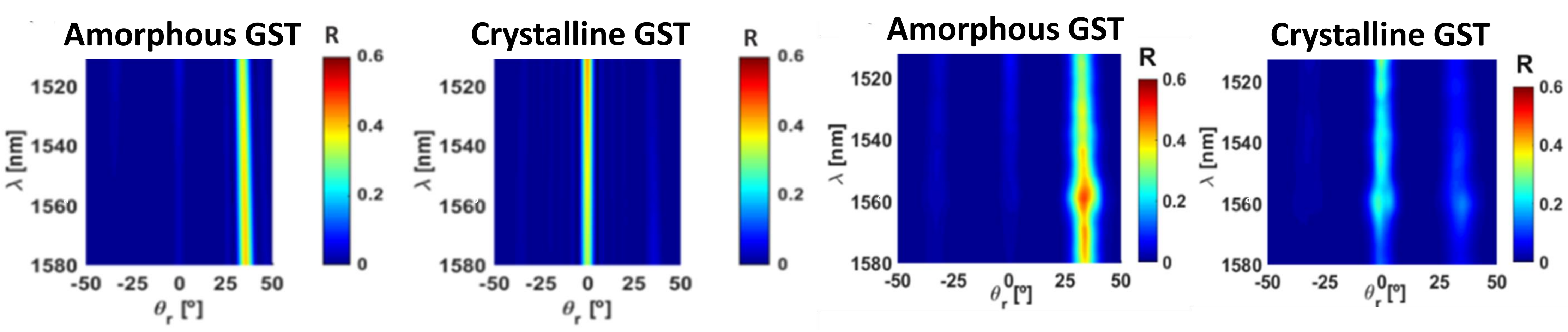

***Figure 3**: Theoretical (a-b) and experimental (c-d) angular reflectance for amorphous and crystalline states.*

Conclusions

We have shown how to create simple, efficient and practicable phase-change plasmonic metasurfaces for tunable beam steering and beam shaping purposes in the near infrared (telecommunications C-band). The relative simplicity of our design has allowed to successfully fabricate various devices of this form. In addition, experimental results have shown an excellent agreement with the numerically-predicted performance. Our approach is also suitable for other infrared wavelengths, and/or other beam steering configurations.

References

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