Amplitude–only spatial light modulation using phase-change meta-films

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Abstract:

Current spatial light modulator (SLM) technology offers off-the-shelf spatial phase control of light, but amplitude control is much more limited. The development of amplitude-only modulators would enable devices to perform full-wavefront control. Here we present an approach to the realization of such modulators, using a phase-change material based approach. Fabricated devices allow for the control of the amplitude, with near zero effect on the phase of the reflected wave, offering a potential route to ultra-fast, solid-state wavefront control.

The ability to fully manipulate the spatio-temporal nature of optical beams opens the route to dynamic wavefront control of light, providing a powerful tool for applications across a wide range of technological fields such as light lithography, optical computing, imaging though scattering media for biomedical diagnostics, or reconfigurable holography. Current SLM technology provides good spatial phase control, but is not generally suitable for directly controlling the spatial amplitude of light. Digital micromirror devices do allow for amplitude control, but usually only in a binary manner. Moreover, conventional SLMs and micromirror devices are relatively slow (millisecond, or at best hundreds of microseconds, range typically), relatively bulky, and of course volatile (switching off the power loses any control). The missing tool required to enable efficient full wavefront control is a device that is capable of fast, reliable, amplitude-only modulation, which could then be coupled to a phase-only modulator to provide full-wavefront control.

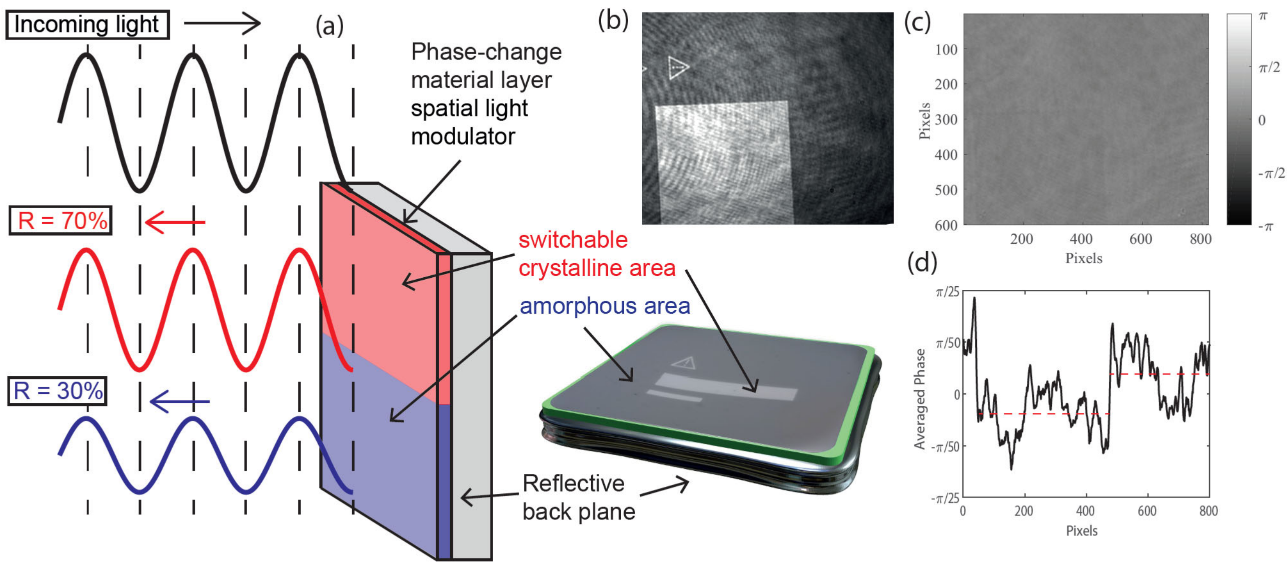

Figure 1. (a) Schematic of device and example of spatial crystalline patterning. (b) Measured reflection intensity and (c) phase distribution across the sample. (d) Averaged phase distribution across crystalline/amorphous boundary, showing less than π/50 phase difference between crystalline and amorphous sections.

In this work we design, fabricate and characterize an active meta-film spatial light modulator using phase-change materials (PCMs) which, when switched from amorphous to crystalline gives a large modulation in the amplitude and a near-zero modulation of the phase of the reflected light (Figure 1(a)). For this purpose, we exploit the high amorphous-to-crystalline electro-optical contrast of GeTe at visible wavelengths upon crystallization [1], allowing for the optical response of the device to be controlled in reflection. The device design is that of a simple 3 layer film: Ti (70 nm), GeTe (30 nm), ITO (5 nm), deposited using magnetron sputtering, with an example spatially varying crystalline pattern being laser-written into the GeTe phase-change layer.

In order to fully characterise the devices the spatial phase variation of the reflected light was measured from amorphous and crystalline sections simultaneously. To do this, an off-axis digital holography interferometer [2] was designed and built. Typical results can be seen in figure 1 (b), (c) and (d), which reveals the amplitude and phase response from the same area of the devices with amorphous and crystalline sections written. The relative amplitude modulation between the amorphous and crystalline sections is high ($\Delta R(\%) = 220\%$) at the operation wavelength of 632.8 nm, whereas the phase modulation remains nearly stationary, with spatial phase variations taking values of less than $\Delta\phi < \pi/50$ radians.

These results offer a novel and viable route to amplitude-only spatial light modulation. In-situ switching of the PCM layer is also potentially possible through the use of electrically activated embedded microheaters (as for example in [3]). In addition, due to the non-volatile and inherently fast structural phase transition of PCMs, as well as the high number of switching cycles until their degradation, our devices are expected to have additional properties such as high modulation speeds (sub microsecond), large endurance, and low power consumption, paving the way for the development of ultra-fast, low power and compact solid-state spatial light modulation.

References

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