Non-volatile Dielectric Metamaterials Reconfigurable With Light

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In this work we combine the concepts of low-loss dielectric metamaterials, phase-change media and femtosecond-laser writing to produce a novel technology for manufacturing rewritable metamaterials and optical devices with advanced functionalities. By shining spatially- and temporally-engineered femtosecond laser pulses onto a phase-change nano-film, we can write arbitrary grayscale patterns into the film. These patterns are used to create metamaterials and other complex optical devices.

Metamaterials are promising a new avenue for controlling the optical properties of matter to achieve unprecedented functionality and novel devices. Unfortunately, plasmonic metamaterials unavoidably suffer from serious ohmic losses at optical frequencies and dielectric metamaterials have recently been demonstrated to mitigate these losses. At the same time, reconfigurable metamaterials have also caused great interest because their optical properties can be changed in the field, promising a new class of metadevices. Phase change materials offer the possibility to realize reconfigurable dielectric metamaterial because their phase state can be reversibly switched through thermal cycling, causing large changes in optical and electrical properties. Here, we demonstrate direct writing of dielectric metamaterial patterns onto a phase-change nano-film, which paves the way for building compact reconfigurable optoelectronic device in integrated systems. Unlike existing reconfigurable materials, which retain their basic structure during reconfiguration, these directly-written structures can be re-written at will to introduce completely different optical structures whenever required.

Our work uses as its 'canvas' a sputtered three-layer phase-change stack (buffer layer/chalcogenide layer/capping layer). When illuminated with moderate intensity light, the atom arrangement in the phase change film changes from a disordered (amorphous state) to an ordered lattice structure (crystallized state), causing a substantial change in optical properties. In our experiment, sketched in Fig 1 (a), a 730 nm fs pulse train consisting of 80 low-energy pulses (0.28 nJ) is applied to the sample by focusing with an objective lens. Each pulse locally heats the chalcogenide layer above the glass-transition temperature but below the melting point. As the number of applied pulses increases, the thin film gradually changes from amorphous to crystalline resulting in the formation of an optically white mark with a diameter of several hundred nanometres. The size and contrast of the crystallized mark can be precisely controlled by changing the number of pulses and pulse energy applied to the phase change thin film. We can then use a high energy (0.95nJ) fs pulse to melt and quickly quench the phase change marks one by one, returning them to an amorphous state. As shown in Fig 1 (b), an 8-level spiral plate pattern was written on the phase change thin film, where each partially crystallised level is written using a different number of pulses. Fig 1 (c) demonstrates a dual Fresnel zone-plate pattern with 50 μm focal length producing two focal spots, which is written point by point into the three-layered thin film. The two contrast levels correspond to amorphous (dark gray) and crystalline (light gray) phase change marks. A plane wave incident on the zone-plate focuses to two bright focal points. The pattern is then reconfigured to remove the right hand Fresnel zone-plate without altering the left hand one. The resulting pattern is shown in Fig 1 (d), which focuses to one bright focal spot.

This work demonstrates reconfigurable and completely rewritable optical elements written using carefully controlled laser pulses, providing a unique and unconventional platform for building dielectric metamaterials. Notably, each crystallized/reamorphized mark is sub-micron, making it possible to directly write reconfigurable dielectric metamaterials for the near-infrared region.

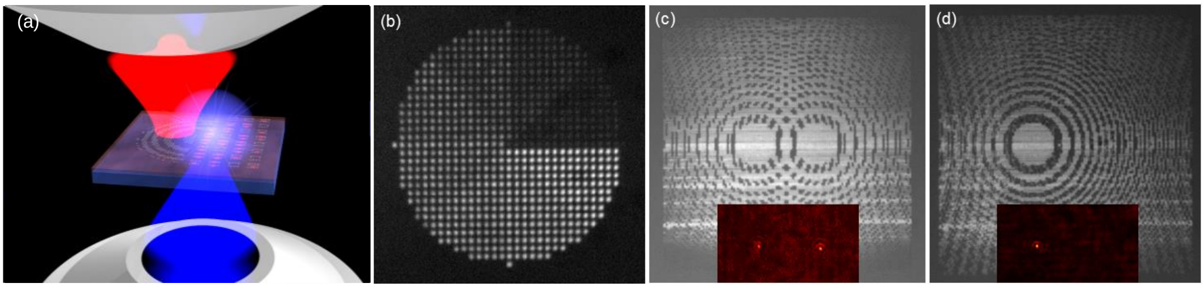

Fig. 1 (a) Artistic impression of the direct-write system, showing a Fresnel zone plate being erased and a metamaterial being written. (b) Spiral mask of 8 levels gray scale pattern written into phase change thin film. (c) Reflection image of dual Fresnel zone-plate with two focal spots under 633nm LED light illumination. The inset is the CCD image of two focal spots at the Fresnel zone-plate focal plane with 730nm plane wave laser illumination. (d) Reflection image of reconfigured single Fresnel zone-plate. The inset shows the single focal spot of reconfigured Fresnel zone-plate.