Shape Memory Metamaterial

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We report the first shape-memory-alloy-based reconfigurable metamaterial. Upon heating and cooling, the structural elements of this metamaterial exhibit a hysteresis-type shape transformation that leads to non-volatile switching of its optical properties.

Mechanically reconfigurable metamaterials actuated by thermal, electrical, magnetic or optical signals enable modulation of light with up to 50% optical contrast and at up to 150 MHz modulation frequencies. However, so far reconfigurable nanomembrane metamaterials do not offer a rewritable memory functionality, i.e. their optical properties only depend on the applied control signal driving the actuation, but not on its history. Mechanically reconfigurable nanostructures exploit that the optical properties of metamaterials are sensitive to nanoscale displacements of their components. Therefore, shape memory alloys, which recover their original shape upon heating after deformation, provide an opportunity to realize memory metamaterials. Here we report the first reconfigurable metamaterial based on a shape memory alloy, demonstrating a memory metamaterial, which exhibits different transmission levels when heated or cooled to a given temperature.

The shape memory metamaterial was manufactured by sputtering of a 50 nm layer of CuAlNi shape memory alloy on a silicon nitride membrane of 50 nm thickness. In order to realize a plasmonic reconfigurable metamaterial, an additional 50 nm layer of gold was deposited on the shape memory alloy. The metamaterial was created by focused ion beam milling, cutting through the gold, shape memory alloy and silicon nitride layers to fabricate an array of freestanding nanostructured bridge actuators of 29 µm length, unit cell dimensions of 830 nm x 1060 nm and only 150 nm overall thickness. Actuation of the nanostructure is driven by temperature changes due to differential thermal expansion of the constituent materials as well as phase transitions of the shape memory alloy.

The metamaterial’s transmission has a strong temperature dependence with hysteresis. At the telecommunications wavelength of 1300 nm, the shape memory metamaterial is 14% more transparent after cooling from 240 °C to 150 °C compared to having been heated to from 30 °C to 150 °C. Such a non-volatile memory functionality could be used to store optically readable data, for example the higher-transparency state could store a logical “1”, while the lower-transparency state could store a logical “0”.

In summary, we demonstrate the first reconfigurable metamaterial consisting of a shape memory alloy. By introducing a phase change material to mechanically reconfigurable metamaterials, we realize the first mechanically reconfigurable metamaterial with a memory functionality. We expect that shape memory metamaterials will enable advanced photonic functionalities: In principle, they can be programmed by permanent deformation into complex shapes, tuned by reversible actuation driven by thermal, electrical, magnetic or optical control signals, and reset with heat.