Optically Switchable Gallium Metasurfaces

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We report on the first experimental demonstration of an optically nonlinear gallium-based photonic metamaterial, in which a reversible light-induced transition between solid and liquid phases occurring in a confined nanoscale surface layer of the metal drives significant changes in reflectivity, offering high contrast all-optical switching in the visible/near-infrared range at low, μW/μm^2, optical excitation intensities.

There are marked differences between the properties of gallium's solid 'semi-metallic' α-phase (the stable bulk form) and those its liquid phase, which is essentially a free-electron metal. As such a significant change in optical properties is associated with the solid-liquid transition occurring at T_m = 29.8°C. But gallium shows strong 'surface melting' behaviour whereby a layer (only a few nanometres thick) of the highly metallic liquid exists at interfaces between the solid α-phase and a dielectric even at temperatures several degrees below T_m. The thickness of this surface layer, and thereby the optical properties of the metal/dielectric interface are highly sensitive to both temperature *and* incident light intensity.

In the context of a photonic metasurface comprising a solid gallium backplane and a gold metamaterial disc array separated by a nanoscale silicon nitride spacer (as illustrated in fig. 1a), which provides strong resonant absorption at a frequency initially set by the design of the gold layer and thickness of the spacer, this sensitivity offers a mechanism for dynamically controlling the resonant response with light. Moreover, one that is based upon induced changes within the plasmonic framework of the metamaterial itself as opposed to an additional hybridized functional medium.

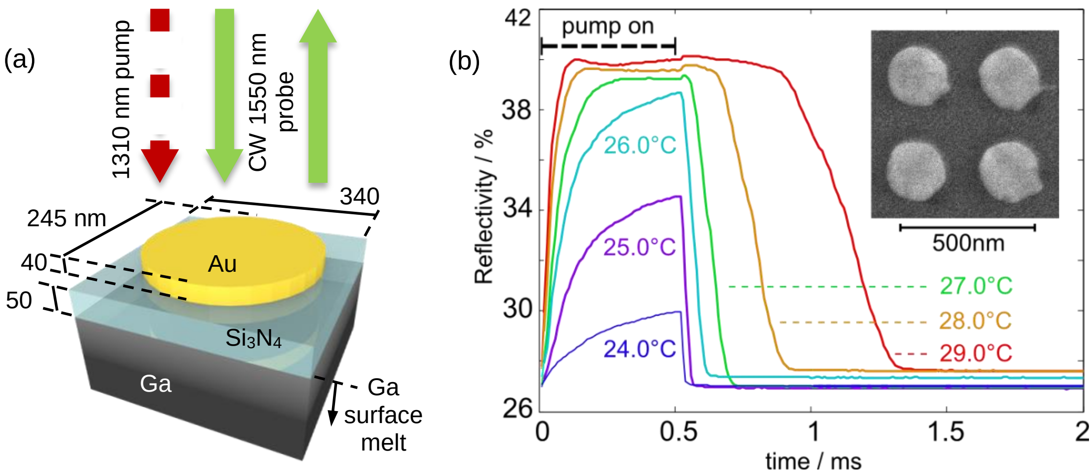

Fig. 1 (a) Artistic impression and unit cell design dimensions for a gallium-backplane metasurface with an absorption resonance at a wavelength of ~1310 nm. (b) Absolute reflectivity of the gallium metasurface probed at 1550 nm as a function of time during and after excitation with a 0.5 ms, 16.8 μW/μm² pump pulse at 1310 nm, for a selection of sample temperatures (as labelled) approaching the metal's bulk melting point.

The nonlinear reflectivity switching characteristics of gallium metasurfaces are interrogated at near-IR telecoms wavelengths: 1310 nm excitation can change the metasurface reflectivity at 1550 nm by as much as 50% (maximized at temperatures just below T_m) with sub-millisecond response and (thermal) relaxation times (fig. 1b) at intensities <20 μW/μm^2 – an order of magnitude lower than those required to induce a comparable response at the same temperature in a planar gallium/silicon nitride interface.

Ultrathin photonic metasurfaces with actively controllable, nonlinear and self-adaptive spectral response functions offer applications potential in fields ranging from radiation emitters and sensors to spatial light modulators. As a functional material platform gallium presents the possibility of continuously tuneable and switchable spectral response controlled by low-intensity light with a nonlinear figure of merit that is resonantly enhanced relative to unstructured gallium/dielectric interfaces.

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