Tuning MoS_2 Metamaterial with Elastic Strain

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Abstract: We provide a first demonstration that stress in nanostructured MoS_2/Si_3N_4 membranes can lead to substantial reversible changes (more than 150% of relative change) of its optical properties in the visible part of the spectrum.

Metamaterials can be efficiently tuned by the reconfiguration of their structural components via thermal, electric, magnetic and optical forces, while metamaterials on stretchable membranes can control their response upon mutual movements of the plasmonic metamolecules. Here, we demonstrate for the first time that metamaterials can be tuned through changing of the optical properties of its constituting material through elastic strain.

Molybdenum disulfide, MoS_2 is a layered structure composed of molybdenum and sulfur atoms held together by weak Van der Waals forces. Several theoretical reports based on DFT calculations indicate that strong energy bandgap renormalization can occur on MoS_2 upon stress, which is expected to alter its optical response.

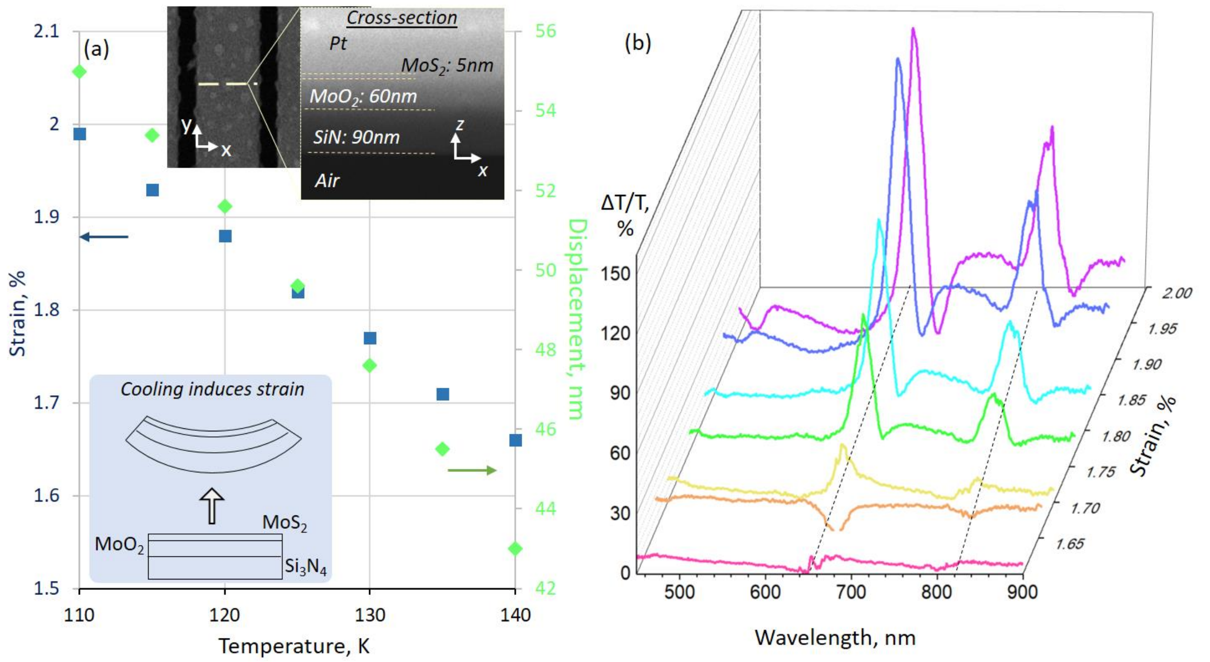

Fig. 1 Strain induced reconfigurable MoS_2 metamaterials (a) Finite element analysis of thermal expansion in a bilayer nanowire. Strain induced (left axis) and displacement excited on the central part of the nanowire (right axis) upon cooling due to thermal mismatch. Inset a 500 nm period grating fabricated by focused ion beam milling, with cross-sectional scanning electron microscopic image. (b) Relative transmission changes (ΔT/T) upon strain, as indicated, on a MoS_2 metamaterial across the visible part of the spectrum.

By nanostructuring nanowire arrays on a tri-layer membrane made of $MoS_2/MoO_2/Si_3N_4$, we engineer high quality transmission, reflection and absorption resonances (Q>30) with a total thickness of 155nm, inset Figure1a. Finite element analysis shows that upon cooling, thermal expansion of a single nanowire results in a maximum mechanical deflection of 54nm from its initial position and as a result strain up to 2% is induced at 110K, Figure 1a. Next, we verify that strain induced upon cooling, due to the large thermal coefficient mismatch between Si_3N_4 and MoO_2 on a periodic array of nanowires (metamaterial), produces substantial changes on its optical properties. More specifically, by gradually cooling the metamaterial, we increase induced stress on MoS_2 and record a maximum transmission relative change of 150% at the resonant wavelength of 660nm, upon 2% strain, Fig. 1b. This effect suggests that a near unity refractive index change of MoS_2 can induced upon strain.

In conclusion, we have reported for the first time a novel method to achieve reconfigurable optical responses based on strain induced effects of MoS_2. The reversible transmission change is based on the change of refractive index upon application of thermal stress. The excellent mechanical and robust properties of MoS_2 can offer a new high index reconfigurable material platform for stress tunable nano-mechanical metamaterials.