Luminescence of All-Dielectric Solution-processed Perovskite Metamaterial

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Abstract: We demonstrate that periodic subwavelength nanostructuring of solution-processed organolead halide perovskite films creates optical resonances, position of which can be controlled by design. Such metamaterial nanostructuring strongly enhances photo- and cathodo-luminescence of the films.

Metal halide perovskites are attracting more and more interest as solution-processable materials with outstanding optoelectronic properties for applications beyond photovoltaic energy conversion, such as light-emitting diodes and lasers, owing to their cost-effectiveness and ease of processing. The field of metamaterials has progressively shifted interest from plasmonic platforms to all-dielectric ones, which are showing similar or better performance without suffering from losses which are inherent to their metallic counterparts.

Here we report all-dielectric metamaterials obtained by nanopatterning methylammonium lead iodide perovskite ($CH_3NH_3PbI_3$) thin films (Fig. 1a), enabling structural colour tuning and luminescence enhancement. We observe a three-fold increase of the photoluminescence (Fig. 1b) and a comparable reduction in the decay time for the nanostructured perovskite in comparison with unstructured films and almost one order of magnitude enhancement in cathodoluminescence.

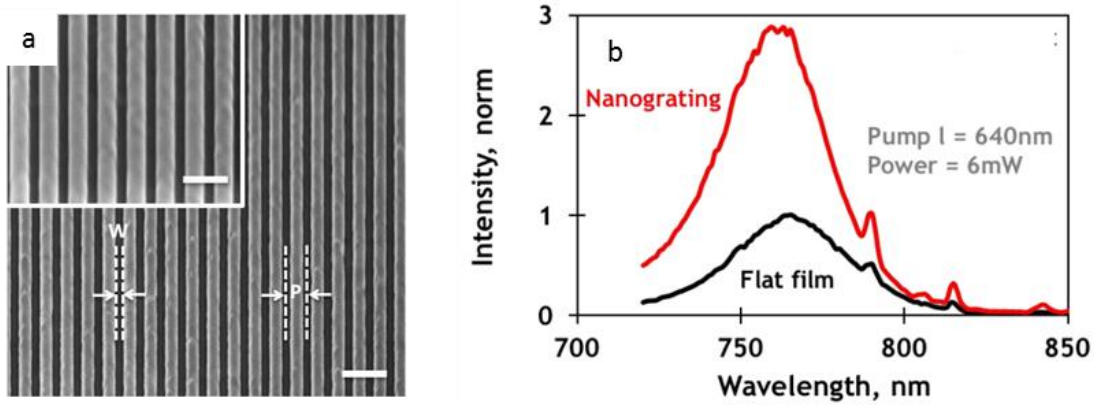

Fig. 1 a) Scanning electron microscope images of $CH_3NH_3PbI_3$ perovskite all-dielectric nanogratings; b) Photoluminescence perovskite nanograting of 350 nm period, showing three-fold enhancement when compared to an unstructured film, using 640 nm excitation polarised parallel to the grating and unpolarised detection.

Perovskite films of 150 nm thickness were spin-coated on quartz substrates and their optical constants estimated experimentally from ellipsometry measurements. Metamaterials composed of nanogratings (Fig. 1a) and nanoslit metamolecules were carved into the perovskite film by focused ion beam (FIB) milling. The spectral response of the perovskite films showed clear colour tuning across the entire visible range, dependent on the metamaterial parameters.

The emission of the perovskite metamaterials was characterised by both photoluminescence, with optical pump at 640 nm, and cathodoluminescence, excited by a 10 kV beam of electrons. Patterned films showed a significant luminescence enhancement with respect to the unpatterned film, a clear manifestation of the Purcell effect, which can be controlled by the metamaterial's design.

This first demonstration of all-dielectric, solution processed perovskite metamaterials, with tunable structural colour and radiative emission properties engineered on-demand, paves a new way to increase the efficiency, control the electroluminescence spectrum, and possibly improve light extraction and directivity of hybrid perovskite light-emitting devices.