Spectral Control in Metal Halide Perovskites Metasurfaces

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Abstract: We demonstrate that nanostructuring and hybridization of perovskites with metasurfaces allow to engineer structural colour and radiative emission properties, providing new opportunities to control emissivity and directivity of light-emitting devices.

Metal halide perovskites have emerged as a new class of solution-processable semiconductor materials for solar cells, light emission diodes and other photonic device applications thanks to a combination of unique properties like large broadband absorption, long charge carrier diffusion length and high mobility and compositional tunability of the refractive index. We have recently shown that perovskite optical response can be engineered using metamaterial design concepts [1]. Here we go beyond direct fabrication of all-perovskite dielectric metasurfaces and explore hybrid perovskite/plasmonic metamaterial concepts with large Purcell enhancement of luminescence, resonant optical response across the entire visible region, and potential for active spectral control via phase change switching.

We hybridized 3D and 2D (layered) perovskite systems with different excitonic properties with resonant plasmonic metamaterials (Fig. 1a, b), spectrally tuned throughout the perovskite emission range (Fig 1c). We report strong photoluminescence (PL) enhancement in both $MAPbI_3$ and (EDBE)PbBr hybrid perovskite/metamaterial platforms, when the emission peak of the perovskite emitter matches the metasurface resonance (Fig 1d). The PL enhancement strongly depends on the wavelength mismatch between the metamaterial optical absorption resonance and the perovskite emission peak, up to more than one order of magnitude increase in $MAPbI_3$. Correspondingly the decay lifetime of the perovskite on the nanostructured film significant reduces in comparison to the unstructured films on glass substrate.

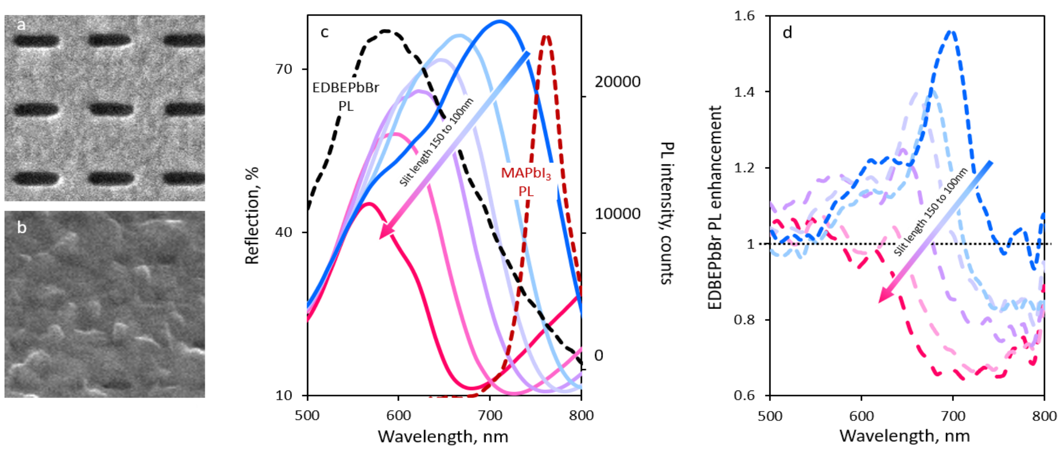

Figure 1: a) Secondary electrons images of slit metamaterials with slit length of 140 nm, carved by Focused Ion Beam (FIB) milling of a 30 nm Au + 5 nm SiO2 film on glass substrate; b) secondary electrons image of a 150 nm slit metamaterial coated with 65 nm thick perovskite film; c) optical reflection resonance spectra for slit metamaterials with length varying from 100 nm to 150 nm, in 10 nm steps, overlaid with photoluminescence (PL) emission spectrum of a 3D MAPbI3 (dashed black curve) and 2D (EDBE)PbBr (dahed red curve) perovskite films; d) enhancement of TM polarized photoluminescence spectrum of (EDBE)PbBr perovskite on metamaterials with various nanoslit length.

2D perovskite are particularly interesting for the large exciton binding energy and strong radiative properties, due to exciton confinement within the inorganic interlayers, which are strongly dependent on temperature induced structural phase change transition [2]. This provides new opportunities for realizing actively tunable, large area perovskite metasurfaces with structural colour and radiative emission properties on-demand.

References

[1] B. Gholipour, G. Adamo, D. Cortecchia, H.N.S. Krishnamoorthy, M.D. Birowosuto, N.I. Zheludev, C. Soci, "Organometallic perovskite metasurfaces", Adv. Mater., 29, 1604268 (2017).
[2] D. Cortecchia, S. Neutzner, J. Yin, T. Salim, A.R.S. Kandada, A. Bruno, Y.M. Lam, J. Martí-Rujas, A. Petrozza, C. Soci, "Structure-controlled optical thermoresponse in Ruddlesden-Popper layered perovskites", APL Materials, accepted (2018).