Hyperbolic Metasurfaces by Self-Assembled Diblock Copolymers

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Nanostructured materials have attracted significant interest in the photonic field because they allow to engineer the optical environment with unconventional properties [1]. Hyperbolic metamaterials theoretically show high wavevector propagating modes and an unbonded density of optical states (DOS) which results in broadband spontaneous emission enhancement [2]. Typically, metamaterials at visible wavelengths are fabricated by stacking thin metallic and dielectric films, which makes it difficult to access the guided modes within the metamaterial, while surface patterning at 10 nm scale can be done either by Electron Beam Lithography, which is extremely time consuming especially when pattern is required over large areas, or by electrodeposition in porous structures, where the control over the morphology is poor.

Here we propose to exploit self-assembly of di-block copolymers to fabricate hyperbolic metasurfaces over large areas with controlled geometry. In detail, we employ PS-PMMA di-block copolymers. By varying the monomers ratio, we obtain different morphologies, from cylinders to lamellae to gyroids ordered in lattices with grain sizes of the order of few microns [3].

In order to obtain monocrystalline polymeric domains we exploited the dewetting of the polymeric film due to thermal treatment. Single droplets of micrometric size with monocrystalline polymeric nanopatterns are obtained (fig. 1a) and can be exploited as localized regions exhibiting large DOS. Preliminary super-structuration of the substrate can serve as guiding template for controlling size and localization of the droplets (fig. 1b). The polymeric mask can be further processed by means of Sequential Infiltration Synthesis (SIS) and electrodeposition to selectively substitute the two polymeric phases with metallic (Au) or dielectric (Al_2O_3) species selectively (fig. 1c) [3]. Hyperbolic dispersion relation at the surface should provide high wavevector propagating modes at the surface and large decay rates for the spontaneous emitters thereon located.[2]

c)

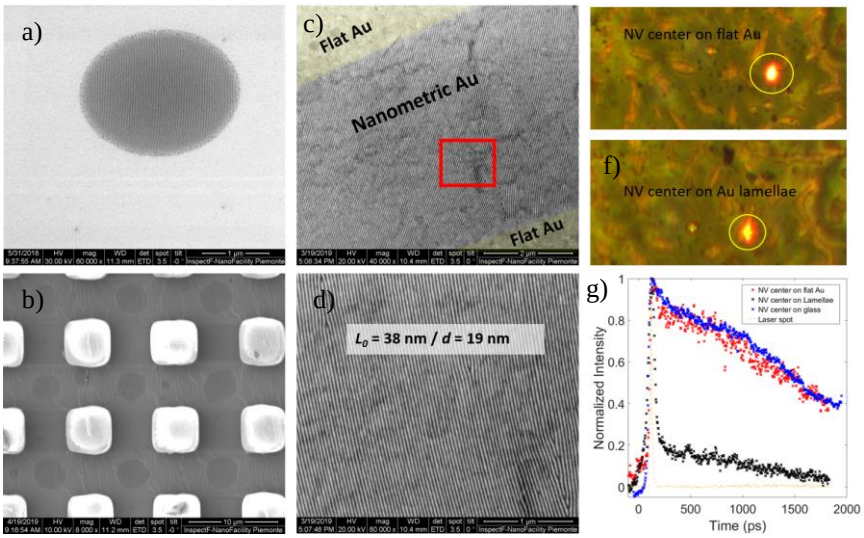

Fig. 1 a) SEM image of a single droplet of di-block copolymer obtained after dewetting of the polymeric film. b) Super-structuration of the sample surface for guiding the dewetting to obtained ordered and size-controlled droplets. c) Detail of a single droplets showing the monocrystalline domain. The red square is further zoomed (d) to show the nanometric gold pattern. e-f) White light image superposed to fluorescence image NV centers in nano-diamonds on (e) flat Au and (f) gold lamellae. g) Time-resolved fluorescence measurements with NV centers in different positions of the sample.

As a proof of principle, we provide experimental evidence of a strong enhancement of the decay rate of color centers (namely NV^- centers in nano-diamonds) when they are located above the nanopatterned metal-dielectric surface (fig. 1e-g).

References

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