Large Scale Fabrication of Extraordinary Transmission Plasmonic Metasurfaces Employing Ultrafast Lasers

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Abstract: We demonstrate a versatile micro-fabrication technique based on ultrafast direct laser writing, towards the reliable, large-scale and low-cost fabrication of high-performance extraordinary transmission metasurfaces. Contrary to well-established lithographic-based fabrication methodologies, our technique enables the single-step realization of the EOT devices of several mm^2 in a few minutes. Our fabrication methodology can be carried out in cleanroom-free environments and without generating chemical residues: conditions which reduce fabrication costs and are therefore affordable for a vast majority of industrial entities.

Plasmonic metasurfaces based on the extraordinary optical transmission effect (EOT) can be deliberately engineered to efficiently transmit specific spectral bands from the visible to the long-infrared regimes, while providing high electric field confinement (hot spots) in regions much smaller than the operation wavelength [1]. Such nano/microphotonic devices (which consist of subwavelength periodically or randomly arranged apertures in ultrathin metallic films) could therefore find many likely applications in key technological fields such as compact multispectral imaging, biosensing, transmissive and reflective color displays, non-linear optics or Raman signal enhancement. Nevertheless, due to their subwavelength nature, fabrication of EOT metasurfaces operating in the visible and infrared spectral regimes requires the use of expensive, micro- and nanofabrication techniques consisting in various steps, generating contaminants, and carried out in strict cleanroom environments [2], as shown in Figure 1(a). Therefore, patterning of large areas required for applications increase both the operation cost and energy consumption to a non-acceptable level for most industrial entities.

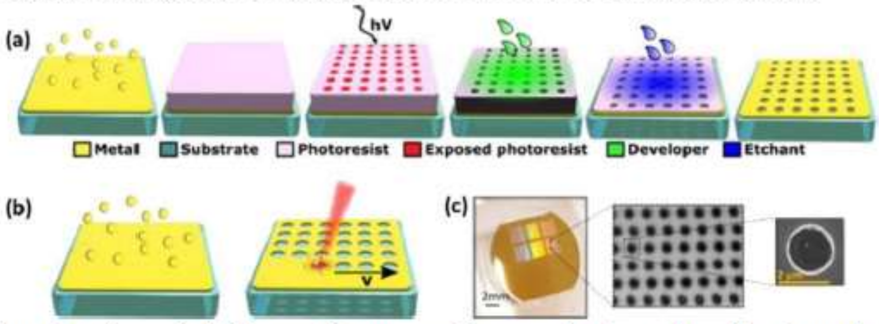

Figure 1 (a) Example of a typical lithographic process (5 steps after layer deposition), employed for the fabrication of EOT metasurfaces. (b) Implemented fabrication methodology based on direct laser writing (single-step after layer deposition). (c) Macro- and microscopic views of some of the fabricated devices. Taken from [3]

As schematically represented in Figure 1(b), in this work we demonstrate a novel, single-step process for large scale fabrication of high-performance mid- and long-wave infrared EOT metasurfaces employing ultrafast direct laser writing. EOT meta-devices were fabricated over areas of 4 mm^2 within units of minutes (Figure 1(c)), employing single pulse ablation per aperture of 40 nm thick Au films on dielectric substrates mounted on a high-precision motorized stage. Since laser-matter interaction is a highly deterministic process, we show how by controlling only three experimental parameters (namely, laser pulse energy, scan velocity, and beam shaping slit), we can obtain full and repeatable control of the processed aperture size and ellipticity, and therefore of the optical characteristics of the extraordinary transmission effect in terms of transmission wavelength, quality factor, and polarization sensitivity of the resonances. As a proof of concept, a range of EOT metasurfaces having different functionalities and operating in different spectral regimes have been designed, fabricated, and tested. As revealed by Figures 2(a-c), comparison between experimental and numerically obtained transmittance spectra demonstrate that fabricated devices behave as expected, proving the high performance, flexibility, and reliability of the proposed fabrication methodology.

We believe that our findings provide the pillars for mass production of EOT metasurfaces with on-demand optical properties, and could inspire new research trends toward single-step laser fabrication of metasurfaces with alternative geometries and/or functionalities.

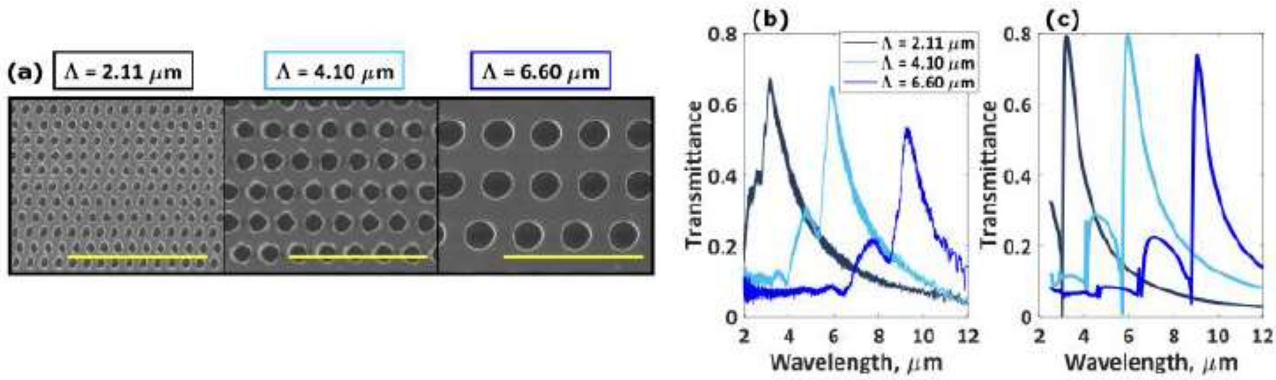

Figure 2 (a) SEM images of 3 of the fabricated structures comprising microhole arrays having different periods Λ (scalebar is 10 um). (b) Experimentally-obtained transmittance spectra for the fabricated devices shown in (a), where the presence of extraordinary transmission peaks at different wavelengths can be clearly observed. (c) Numerically-obtained transmittance spectra, confirming that pre-designed devices behave as-expected.

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References

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