

Lithography-Free Fabrication of Extraordinary Transmission Plasmonic Metasurfaces Over Large Areas Employing Ultrafast Lasers

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Plasmonic metasurfaces based on the extraordinary optical transmission effect (EOT) can be deliberately designed to efficiently transmit specific spectral bands from the visible to the long-infrared regimes, but can also provide high electric field confinement in regions much smaller than the operation wavelength [1]. Such nano/microphtonic devices (which, as shown in **Fig. 1(a)**, consist of subwavelength periodically or randomly arranged apertures on ultrathin metallic films) could therefore find applications in important technological fields such as compact multispectral imaging, biosensing, transmissive colour displays, non-linear optics or enhancement of the Raman signal. However, due to their subwavelength nature, fabrication of EOT metasurfaces operating in the visible and infrared spectral regimes is typically conducted through expensive, micro- and nanofabrication techniques carried out in strict cleanroom environments. Therefore, patterning of large areas required for applications currently dominated by conventional optical elements are translated into several fabrication steps and long lithography writing times: procedures that significantly increase the operation cost and energy consumption to a non-acceptable level for most industrial entities.

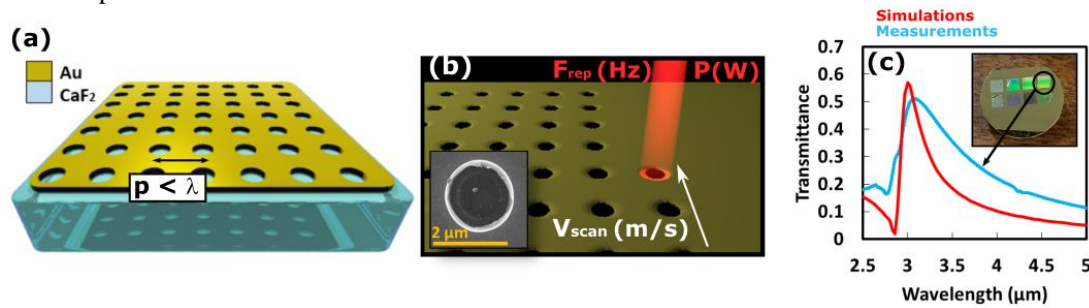


Fig. 1 (a) Generic diagram of a plasmonic EOT metasurface consisting of circular holes on ultrathin gold films deposited on a CaF₂ substrate. (b) Schematic description of the DLW fabrication methodology, where the scanning velocity V_{scan} , laser repetition rate F_{rep} , power P , and spot size, can be individually adjusted to achieve the desired geometry. (c) Example of numerical (red) and experimental (blue) transmittance spectra of EOT metasurfaces fabricated via DLW. Inset shows the macroscopic view of the sample.

In order to be competitive in terms of fabrication cost and throughput with currently-employed conventional optical components, EOT plasmonic metasurfaces would strongly benefit from novel, single step, high throughput and rapid fabrication methods [2]. In this work, we propose and experimentally demonstrate “on-the-fly” fabrication of EOT plasmonic metasurfaces based on pulsed direct laser writing (DLW) techniques, exploiting laser-induced ablation of gold. As generically depicted in **Fig. 1(b)**, via carefully adjusting the experimental parameters (namely laser power, spot size, repetition rate and scanning velocity), we have successfully achieved dimensions (i.e. aperture sizes and spacing) close to nominal design specifications for a wide variety of devices operating in different spectral bands such as the mid and the long-wave infrared. For instance, **Fig. 1(c)** shows the computational (red curve) and experimentally-obtained (blue curve) transmittance spectra of one of our fabricated devices, specifically designed to operate in the 3 to 5 μm wavelength atmospheric window. Our results reveal good agreement between numerically predicted (employing finite element methods) and measured (via FTIR) optical responses. Furthermore, we have also successfully demonstrated that alternative aperture shapes (such as elliptic holes) can be readily achieved via beam shaping. This offers additional degrees of freedom in terms of achievable optical performances, including, for instance, polarisation-dependent extraordinary transmission and/or circular polarisation capabilities.

In summary, our novel approach to nano/microphtonic fabrication of EOT metasurfaces allows for single step processing of large areas with a demonstrated throughput of 0.24 mm²/minute (i.e. several orders of magnitude faster than mask-based lithographic processes), which can be scaled up further, offering high reproducibility and versatility in terms of achievable dimensions and hole shapes. We believe our results open up a new technological direction that puts EOT metasurfaces in a realistic position to fairly compete with classical bulky optical components, while overcoming them in performance.

References

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