Tailoring diffraction characteristics of resonant, large area metagratings employing mask-free UV laser interference patterning

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Over the past decade, metasurfaces comprising arrays of localised ultrathin resonant subwavelength resonators (“meta-atoms”) have been successfully employed to engineer the wavefront characteristics of optical beams, resulting in several recent demonstrations of ultra-compact devices for focusing, beam mode conversion or beam steering. To date, for the particular case of beam steering metasurfaces (nowadays known as phase-gradient metasurfaces), reflection or transmission of light at pre-designed angles has been realized based on the ray optics approximation (generalized Snells’ law), via forcing linearly varying, discrete transverse phase increments to impinging waves [1]. This is typically carried out via the design and engineering of periodic “supercells” made of various meta-atoms having different shapes, sizes and/or orientation, thus imposing abrupt, local phase jumps for a given excitation frequency, which in turn results in constructive interferences at pre-designed angles [2]. However, phase-gradient metasurfaces exhibit fundamental limits in terms of maximum achievable steering efficiencies, especially at large angles of incidence [3].

Recently, it has been pointed out that metasurfaces based on periodic 1D identical plasmonic dipoles lying on ultrathin insulator/metal substrates exhibit beam steering capabilities at oblique incidence with near unit diffraction efficiency when operating in the (0^{th}, -1^{st}) diffractive regime [4-5]. Therefore, such an approach offers clear benefits with respect to more conventional phase-gradient metasurfaces, both in terms of optical performance and in terms of ease-of-fabrication using current lithographic techniques. Nevertheless, the physical realization of such “metagratings” today still requires e-beam lithography with several steps involving spin coating of appropriate photoresist masks combined with thin film deposition and lift-off or etching techniques.

In this work, we propose and experimentally validate a single-step, mask-free, nanopatterning technique for a virtually instantaneous realization of high performance, large area, near-infrared metagratings consisting of 1D metallic nanostripes. Our method exploits controlled pattern ablation of continuous gold films deposited on a SiO_2/Al/Si substrate. Nanostripe structures were fabricated by making two in-plane pulsed top-hat UV laser beams interfere at a specific angle onto the sample surface (λ = 193 nm, τ_{pulse} = 23 ns), resulting in a large area 1D sinusoidal intensity distribution. A systematic study of the effect of the laser fluence and number of pulses on the final topography has revealed that a wide range of nanobar geometries can be achieved using this approach, ranging from low aspect ratio, wide nanobars, to high aspect ratio, narrow nanobars depending on the processing conditions. Finite element analysis of the m=0 and m=-1 diffraction orders against the angle of incidence have revealed that the high diffraction efficiency characteristics of the fabricated devices in terms of bandwidth and dispersion can significantly vary depending on the resulting nanobar geometry. Finally, diffraction measurements of as-fabricated devices employing spectroscopic scatterometry have been performed, confirming that laser-processed metagratings behave as predicted by our calculations, thus validating the versatility of our fabrication approach. Based on these results, we believe that our work paves the way for the realization of low cost, single-step and large area metagratings, with exotic and on-demand diffraction properties, which may find applications in many exciting fields including holography or free-space optical communications.

References:

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