Inverted Refractive-Index-Contrast Subwavelength Gratings by 3D Micro-Printing

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The field of sub-wavelength optics investigates the interactions between light and objects that are smaller in size than the wavelength of light. A canonical example is a sub-wavelength grating, which is made of dielectric slabs spaced periodically to produce a one-dimensional structure. Typically, a high-refractive index material is used to create the sub-wavelength grating, which is either suspended in air or placed over a layer of low-refractive index cladding. The grating, functioning as a highly effective and compact mirror, presents an appealing alternative to the commonly employed multilayer and bulky Distributed Bragg Reflectors (DBRs) in optics and photonics.

Here, we present a completely new approach to the design and fabrication of subwavelength gratings, breaking two paradigms hitherto in force. First, in our design a subwavelength grating made of a low refractive index material is deposited on a cladding layer made of a high refractive index material. We call the proposed design an "inverted refractive-index-contrast grating". There have been no previous studies on the design and optical performance of subwavelength gratings in which a material with a lower refractive index is deposited on a higher refractive index bulk layer. Second, subwavelength gratings have been produced solely by technologically demanding, subtractive-type methods, such as 'wet' or 'dry' etching combined with electro-lithography so far. A frequent assumption is that 3D micro-printing cannot produce reflecting subwavelength structures due to the low refractive indices (from 1.5 to 1.58) of the polymers it uses. We employ 3D micro-printing (3D laser lithography) and show that an additive-type technique can be successfully utilised to fabricate a subwavelength grating.

Our numerical analysis shows that the inverted refractive-index-contrast grating enables nearly total power reflectance, regardless of the refractive index of the cladding layer, as long as the refractive index of the grating material is larger than $\sim$1.75.[1] Moreover, the grating enables efficient polarisation discrimination and phase tuning of the reflected light, properties that are not obtainable using DBRs. We calculate a map of the reflectance of the structure versus wavelength of the incident light and the grating height normalized to the grating period. We design the grating for the peak of TE-polarised reflection at 1500 nm, thus for the spectral region of the third telecommunication window. In our experimental demonstration, we deposit sub-µm periodically arranged stripes of IP-Dip photoresist on a Si cladding layer utilising the 3D micro-printing. A qualitative and quantitative comparison of the measured and calculated power reflectance spectra reveals very good agreement. We observe, in particular, almost 90% reflection into all diffraction orders and efficient polarization control.

The proposed design and fabrication method open wide perspectives for research and applications in photonics, optics, sensing technology. In particular, (i) The production of highly reflective mirrors becomes greatly facilitated and accelerated, as no high-vacuum techniques such as vapour deposition or epitaxy are required; (ii) 3D micro-printing offers the advantage of scalability, which is beneficial for possible industrial production; (iii) The method relaxes the requirements for the refractive index of the cladding layer that hosts the grating, broadening the range of materials that can be applied. For instance, it becomes possible to use a monolayer of transition metal dichalcogenide as a cladding/active layer. As we showed previously, the optical properties of these fragile materials do not degrade as a result of 3D micro-printing on their surface.[2]

References

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[2] A. Bogucki *et al.*, Light: Science & Applications **9**, 48 (2020).