Anti-Reflection Structured Surfaces

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Anti-reflection structured (ARS) surfaces can be regarded as a subset of surface-relief gratings. Unlike typical gratings, ARS surfaces have subwavelength periods that enable only the reflected and transmitted zeroth order to propagate (higher diffraction orders are evanescent). ARS surfaces have been shown both theoretically and experimentally to exhibit extremely low reflectivities over broad spectral bandwidths and wide field-of-views (see, for example, Refs. 1 and 2). Unlike thin-film coatings, ARS surfaces are created by etching a surface-relief pattern directly into a substrate. Consequently, ARS surfaces do not experience cohesion problems or problems with thermal expansion mismatches, as do thin-film coatings. Analysis of ARS surfaces are performed using both vector diffraction theory and effective medium theories (EMTs).

When light interacts with periodic structures much finer than its wavelength, it does not diffract, but instead reflects and transmits as if it is encountering a non-structured medium. Effective medium theories (EMTs) describe the interaction of light with subwavelength structures by representing regions of subwavelength heterogeneity in terms of a homogeneous material possessing a single set of effective optical constants: permittivity \( \varepsilon \), permeability \( \mu \), and conductivity \( \sigma \). The optical properties of these effective mediums are governed by the specific structural intermixing between the incident and substrate material, but, in general, the more substrate material present as compared to incident material in a given region, the closer that region's optical properties are to that of the substrate. For the case of a multi-level surface-relief grating structure, the effective medium is a film stack, where each layer in the film corresponds to a specific level of the profile. For the continuous case (e.g., a blazed triangular profile), the effective medium is a gradient film. The intermixing of substrate and incident medium need not be identical in all directions. Hence, the effective medium, resulting from a weighted spatial averaging of the profile's optical properties, need not be isotropic, i.e., it can be birefringent.

In our research, we have investigated various forms of ARS surface profiles. Binary, multi-level, and continuous profiles have been investigated for both 1-D and 2-D surface patterns. For randomly-polarized radiation, we have found that 2-D profiles, due to their extra degree of symmetry, are advantageous over 1-D profiles for the suppression of Fresnel reflections. One-dimensional ARS profiles, though, can adequately suppress Fresnel reflections for polarized light, as well as simulate polarization devices such as beam splitters and waveplates. Though applications do exist in the visible portion of the spectrum, due to their subwavelength period, ARS surfaces are more easily manufactured for application in the infrared spectral region. Materials used in the infrared, as opposed to the visible region of the spectrum, also tend to be optically dense, thus necessitating some type of reflection suppression.

In Part (a) of the figure, a 2-D binary ARS surface made on a silicon is illustrated. The ARS surface covers an area three inches in diameter and was fabricated using the optical lithography equipment at Cornell's National Nanofabrication Facility (NNF). Part (b) shows the theoretical plot of the power reflected as a function of angle of incidence for a wavelength of 10.6 \( \mu \)m. Experimental testing of the ARS surface performance is currently underway at the Institute of Optics.

REFERENCES


![Silicon 2-D binary ARS surface. Design wavelength is 10.6 \( \mu \)m. The plot in (b) indicates the theoretical performance of such an ARS surface. Note that a half field-of-view of 55° is achieved for 95% transmission. For the sake of comparison, an uncoated, non-structured, silicon surface transmits less than 70% of normally-incident radiation.](image-url)