Design of Interfacial Antireflection Nanostructures in Multilayers

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Multilayer film stacks have many applications in photonics/optoelectronics. In these systems, the layers are made from different materials with varying refractive indices. While the choice of materials present electrical, optical, or mechanical advantages, there are drawbacks in terms of optical transmission. Refractive index mismatch at the interface between two different materials causes Fresnel reflection losses [1-3], which reduces transmission. Multiple reflections in multilayer film can also interfere and result in iridescence [4]. These effects, illustrated in Figure 1, are especially problematic at wider viewing angles. These losses may be mitigated considerably if the discontinuity in refractive index can be replaced by an effective medium with continuously changing index. Tapered nanostructures are an effective method to emulate such a medium, and can reduce reflection losses, increase transmission, and suppress iridescence. This can mitigate wavelength/angle-dependence and enhance broadband transmission in multilayers.

In this work we present the rigorous optical design of interfacial nanostructure in multilayer materials to enhance transmission and suppress interference effects. The goal is to determine the optimal structure geometry, namely the height, period, and profile, and minimize interfacial reflection. This model will be based on rigorous coupled-wave analysis (RCWA), where the tapered nanostructures are approximated by discrete two-dimensional gratings with varying duty cycles. Preliminary design results are illustrated in Figure 2(a), where the transmission of a multilayered stack with alternating polymer (n=1.70) and dielectric (n=1.45) layers is plotted vs total height of interfacial nanostructures. The results show that the transmission can approach 1 as the structure height approaches to the incident wavelength of 633 nm. The enhancement can be dramatic for periodic multilayer stacks, and Figure 2(b) depicts the transmission for N stacks with and without interfacial nanostructures (500 nm tall). It can be observed that the presence of interfacial nanostructures result in low transmission degradation regardless of number of layers. The reduction of interfacial reflection can also suppress iridescence due to interference effects. The broadband transmission of a polymer/oxide/polymer stack (each layer 600 nm) with and without interfacial nanostructures is shown in Figure 3(a). Strong intensity oscillations can be observed for the planar interface samples, which is heavily suppressed by the nanostructures. The interference contrasts can be compared and shows significant improvement especially at high incident angles, as shown in Figure 3(b).

Initial fabrication to demonstrate the proposed concept focus on structure with height of 300-400 nm and period of 250 nm. A Lloyd's mirror interference lithography set up is used to create a 2D pillar array in photoresist, which can be transferred to the underlying substrate using CHF_3 reactive ion etching (RIE). The initial SEM of the fabricated glass structure is shown in Figure 1(c). The nanostructures will be patterned on both sides and bonded with UV-curable epoxy to form a multilayer stack with nanostructured interfaces. We will present the design results and fabrication of interfacial nanostructure geometry to improve transmission in multilayers. The optimized design will be demonstrated experimentally, where the transmission will be characterized as functions of incident angles and wavelength.

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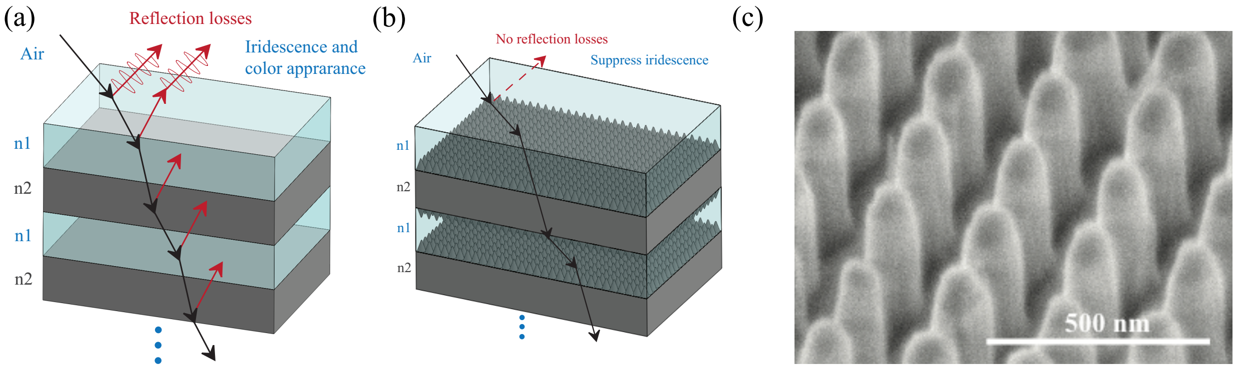

Figure 1. Schematic of (a) reflection and scattering losses in multilayers. (b) Interfacial nanostructures reduce reflection losses and suppress iridescence. (c) The initial SEM of the fabricated glass structure.

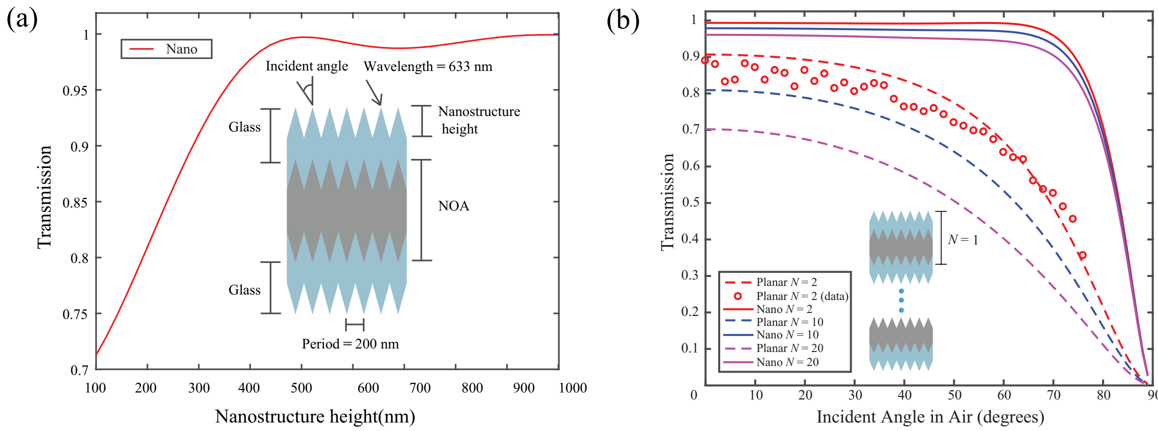

Figure 2. (a) Optimal designed to approach antireflection effect with varying the nano-structures. (b) Simulated transmission versus angle for planar and nano-structured interface.

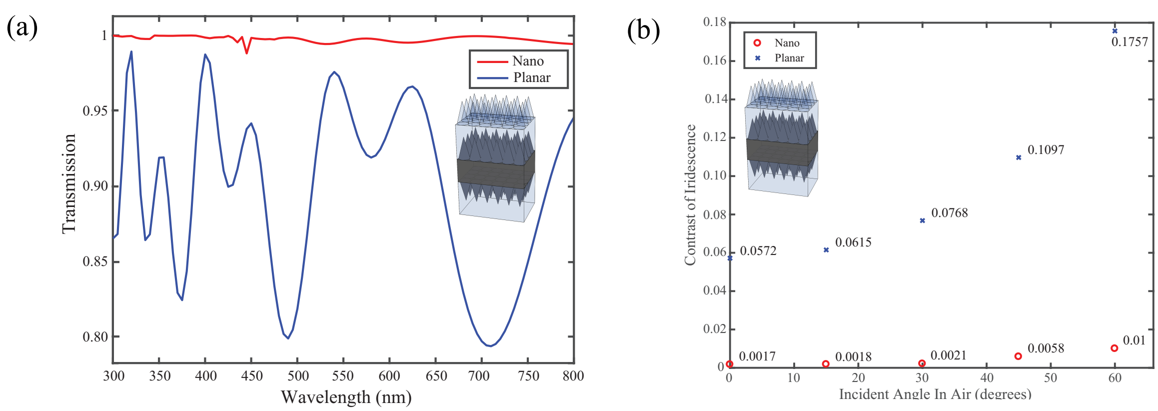

Figure 3. (a) Transmission comparsion between planar and nano-structured interface. (b) The iridescence contrast comparsion between planar and nano-structured interface.

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