Multifunctional Nanostructured Materials: Blurring the Lines between Optical Interfaces

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Material designs based on biological organisms have received significant interest across many research disciplines. By studying bio-inspired principles, researchers have engineered micro and nanostructures with unique properties that are not found in materials with macroscopic length scale. One such example that has been well-studied over the last decade is the “moth-eye” structures, which offers broadband, omnidirectional antireflection (AR) effects [1,2]. However, the design of bio-inspired materials should not be limited to biology. Enabled by the recently advances in nanofabrication, nanostructured materials can be designed and engineered to have better performance, more functionality, and increased complexity as compared to their biological counterparts.

One approach to improve on nature’s design is to simply combine multiple bio-inspired principles. For example, there are similarities between the moth-eye AR structures and the superhydrophobic surface found on lotus leaf, in that they both consist of microscopic surface textures. By studying the underlying physical principles, it is possible to design a single geometry with co-optimized optical and wetting effects. Our recent work indicated that the structure profile is critical, and higher aspect ratio structures (as shown in Figure 1) result in superior performances in both physical domains. These structures can be implemented on glass for windows with anti-glare, self-cleaning, and/or anti-fogging properties [3].

In addition to removing surface reflections, the moth-eye structures can also implemented in other manners. Light reflection at the interface between two solid materials is a well-known effect in optic, and leads to thin-film interference effects. This results in colored appearance of many naturally occurring phenomenon commonly observed, such as oil on water. While visually appealing, such interference effects can lead to undesirable wavelength-selective behavior in thin-film devices. Using the same bio-inspired principles, we examine the use of such subwavelength structure between two solid materials, as shown in Figure 2 [4]. I will discuss the effect of the interfacial nanostructures on the suppression of color in thin films.

Going beyond planar interfaces, these bio-inspired nanostructured materials can also be integrated on microdevices. One such example is diffractive optical elements, which also suffer from reflection losses due to index mismatch. These elements, such as gratings, Fresnel zone plates, and holograms, often have undesirable reflected orders, which lead to a reduction in the transmitted orders. By integrating tapered nanostructures on the surface (Figure 3), we have demonstrated AR structures for diffraction gratings that can significantly suppress such reflections and shift all energy into the transmitted orders [5]. These structures can lead to more efficient diffractive devices for thin-film integrated photovoltaics, waveguide couplers, and holographic optical elements.

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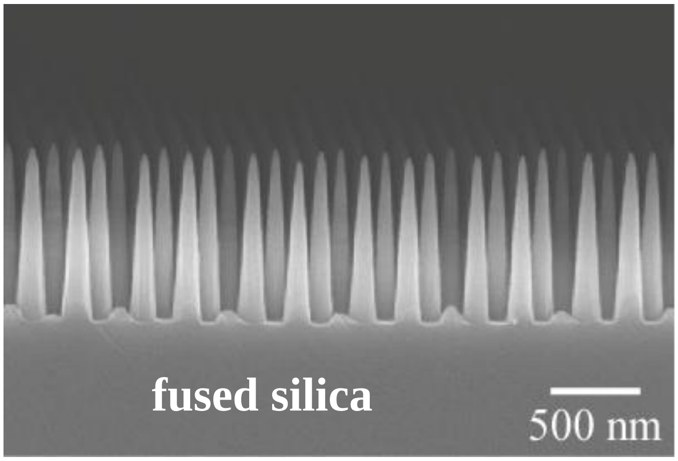

Figure 1. Tapered nanocone structure with anti-glare, self-cleaning, and/or anti-fogging properties.

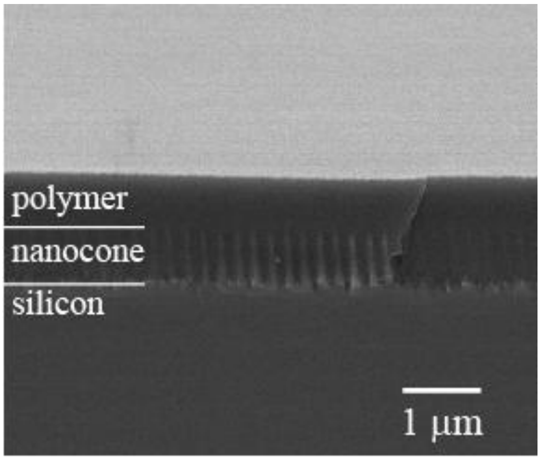

Figure 2. Polymer thin film on silicon substrate with nanostructured interface.

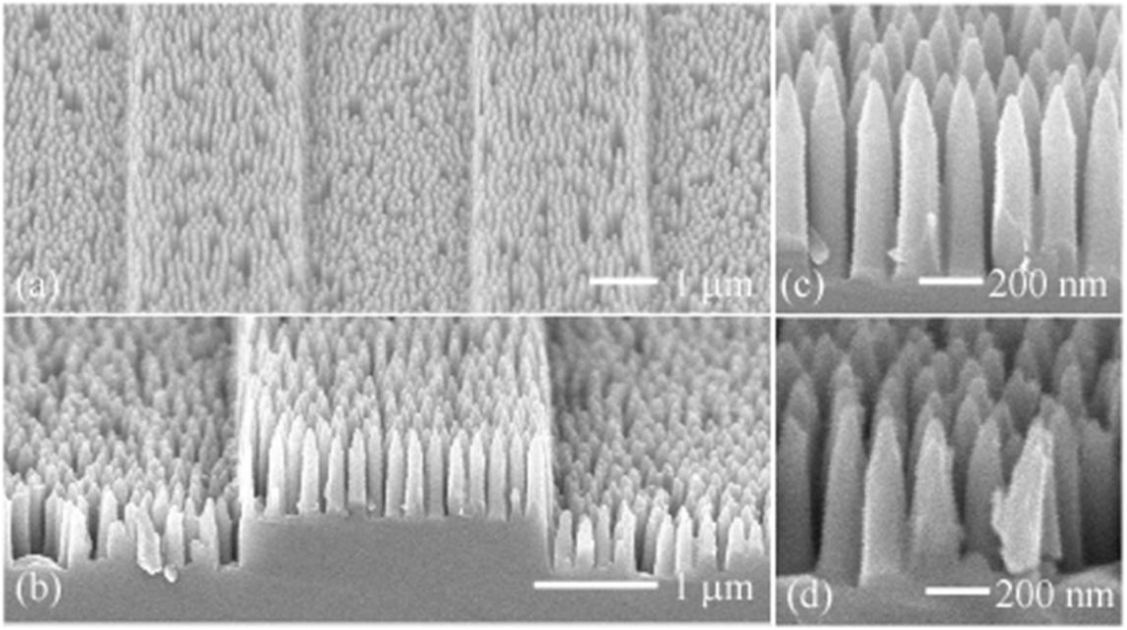

Figure 3. Periodic microstructure with integrated nanostructures in silicon. Such hierarchical approach enables reduced losses in diffractive optics.

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