# Nanorods Form Thin Films with Ultralow Refractive Index

*Structures improve performance of multilayer coatings, photonic crystals.*

Devices based on interference from alternating layers of high- and low-index materials are ubiquitous in today's photonics technology. Laser mirrors, antireflection coatings, fiber Bragg gratings and photonic bandgap fibers all employ the same basic principles of interference. The quality of such

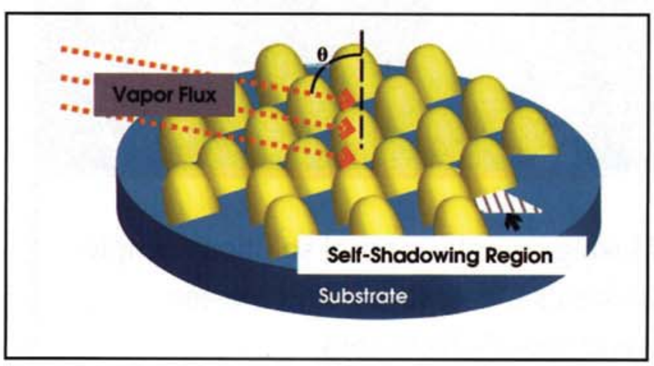


***Figure 1**. In oblique-angle deposition, random growth fluctuations in the substrate produce shadows that result in preferential deposition and the formation of nanorods. Images ©OSA.*

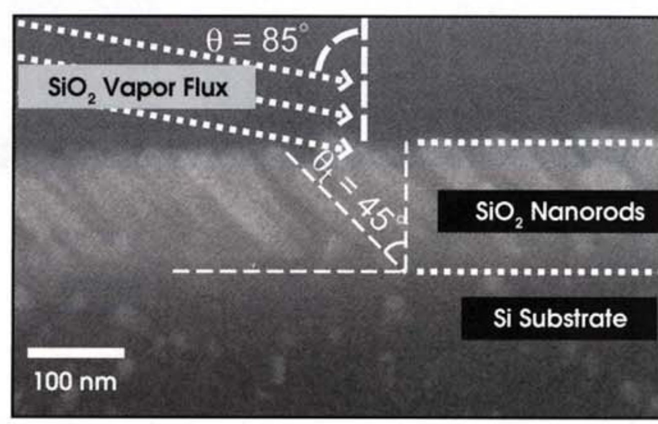


***Figure 2.** The ~150-nm-thick film of $SiO_2$ nanorods is roughly 80 percent air, resulting in a very low refractive index.*

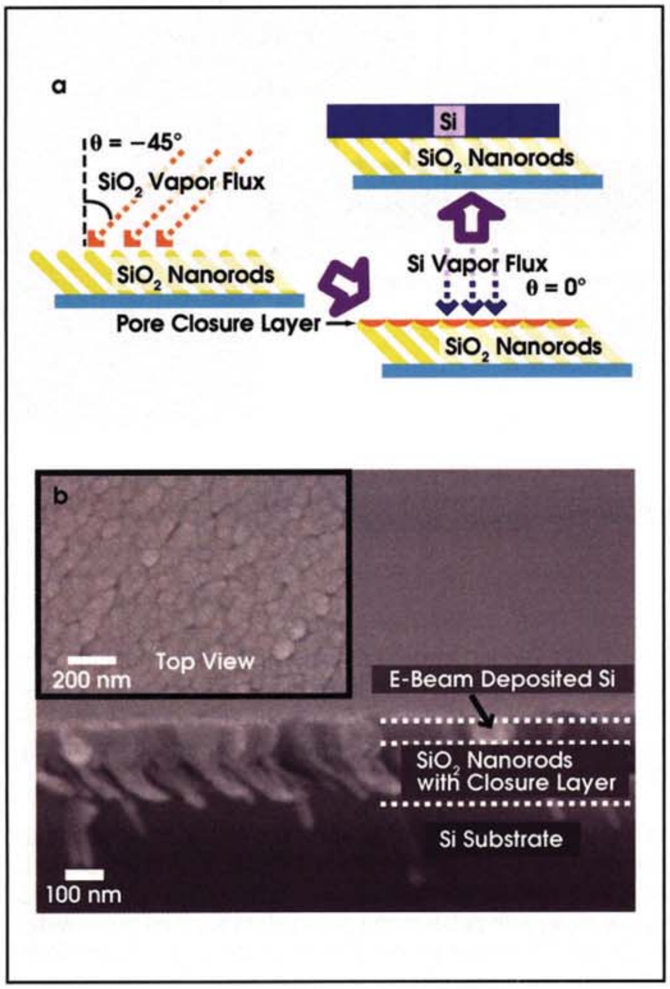


***Figure 3.*** *The investigators sealed the top of the nanorod film with a thin layer of $SiO_2$ and deposited a high-index layer of silicon (a). A scanning electron microscope image of the device shows the sharp boundary between the high- and low-index layers (b).*

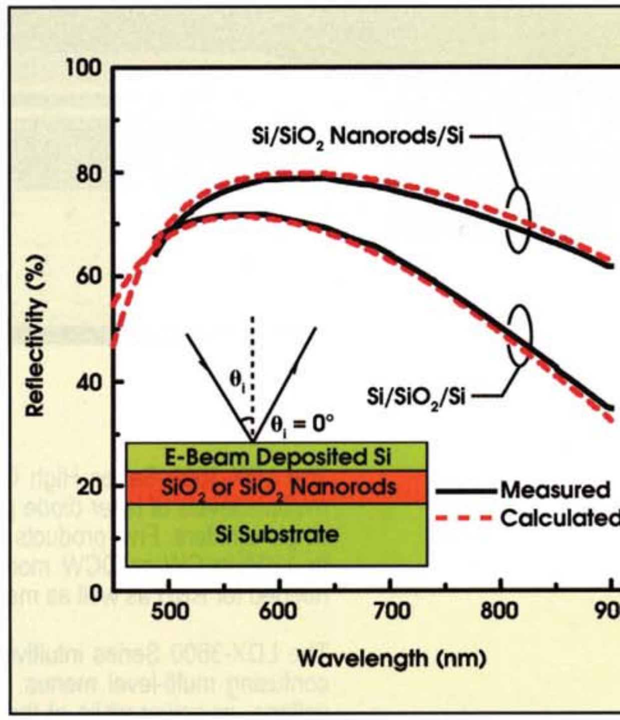


***Figure 4.*** *A comparison between a normal reflector and a nanorod-based reflector showed superior performance from the latter.*

devices depends on the contrast ratio between the high- and low-index materials, so a reliable low-index material, with refractive index close to the unity index of air, would be very advantageous.

Recently, scientists at Rensselaer Polytechnic Institute in Troy, N.Y., demonstrated thin films constructed from $SiO_2$ nanorods, and they believe that the films' refractive index of 1.08 is the lowest reported for a thin film.

They aren't the first to seek airlike materials for multilayer interference devices. Indeed, air itself has been used in some devices, but it lacks the mechanical properties necessary in most applications. Sol-gel materials have a low refractive index and good mechanical properties, but it is difficult to precisely control the thickness of a sol-gel layer, and interferometric devices require subwavelength thickness precision.

The scientists used oblique-angle deposition to grow their thin nanorod films. They passed an $SiO_2$ vapor flux across a substrate at an oblique angle so that random growth fluctuations in the substrate produced shadow regions where no deposition occurred (Figure 1). Deposition instead occurred on the adjacent edges, so that the incident flux created an array of nanorods. The nanorods occupied only ~20 percent of the volume of the ~150-nm-thick film, and the rest of the space was air (Figure 2). Ellipsometry measurements indicated that the film's refractive index was 1.084 at 700 nm.

The air gaps in the film were less than 30 nm — much less than optical wavelengths — so scattering from the material would be minimal. Because the films are grown by evaporation, their thickness can be very precisely controlled.

To demonstrate the effectiveness of the nanorod thin films, the researchers fabricated a simple, dual-layer reflector with the material (Figure 3). Before depositing a silicon layer atop the nanorod film, they employed oblique-angle deposition to seal the surface with a 20-nm-thick layer of oppositely directed nanorods, thereby preventing the silicon from filling the airspaces between the nanorods. They then deposited a 40-nm layer of silicon on the nanotubes.

For comparison, they fabricated a conventional dual-layer reflector of silicon on top of normal (solid) $SiO_2$. The optical distance across the solid $SiO_2$ was the same as that across the $SiO_2$ nanorods, so the difference in optical performance of the two devices resulted only from the difference in refractive index. The nanorod-based reflector showed markedly superior performance (Figure 4). □

*BH*

*Optics Letters*, March 1, 2006, pp. 601-603.