Ultra-thin LED optics with novel angular filters

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Dielectric multilayers can shape the emission profile of LEDs for compact collimators and thin, large-area illumination systems.

High-brightness LEDs are energy-efficient, compact light sources that are widely used in various lighting applications. They are frequently used where the illuminance (luminous flux per unit area) on a distant target surface is increased by using collimating lenses (that make light beams parallel) and reflectors. However, commercial collimator optics, although efficient, are often too large to combine many light sources in a small volume. In addition, they struggle to adequately create thin, large-area light sources such as office ceiling luminaires or LCD backlight systems (e.g., flat-screen TVs).

In large-area light source systems, the luminous flux of individual LEDs must be spread out, in a spatially uniform manner, in a very thin system. The optics convert the point-source LED into a thin-area source, with a surface area $10^3$–$10^5$ times larger. This results in a surface brightness that is accordingly lower but spatially uniform. The thinnest systems are achieved by using a light guide, where the light of the LEDs is injected from the edges and spread out by total internal reflection (TIR). However, a fundamental problem arises when the system is scaled to larger areas—the area scales quadratically with the edge length (and thus the number of LEDs that can be installed)—reducing the luminance.

We have developed a new approach that could lead to more compact, but equally efficient collimation optics. It also enables LEDs to be distributed over the entire surface area of the light guide, rather than just at the edges. In our novel method, single-color LEDs are coupled to a light guide using a dielectric multilayer as an angular interference filter (see Figure 1). The filter is designed to only transmit light emitted from the LED at angles larger than the critical angle, $\theta_c$, at the light guide-air interface. The light emitted at smaller angles is reflected back toward the rough LED surface where it is subsequently recycled by reflection and redistribution. Figure 2 illustrates how this principle is used to create a compact collimator.

A filter made from 54 layers of niobium pentoxide and silicon dioxide on a 1×1mm$^2$ 150μm thick glass substrate is mounted on an LED with silicone adhesive. A PMMA—poly(methyl methacrylate)—circular disk light guide is mounted onto the filter glass. The PMMA piece is cone shaped: 1mm thick in the center region, tapering down to zero at 6.5mm diameter, with a facet at a 26° angle. Luminous intensity profiles of prototypes show 26° full width at half maximum (FWHM), which agrees with...
the predicted value. The measured efficiency of the prototypes is about 50%. It is hampered by the limited reflectivity of the LED surface and by the polarization dependence of the interference filter. An optical design study revealed that using different materials for the interference filter can minimize the polarization dependence and increase the predicted efficiency from 58% to 70%.\(^5\)

The use of interference filters in combination with LEDs offers new options for large-area, thin luminaires. The principle of a novel large-area collimator using a different kind of filter is illustrated in Figure 3. Instead of reflecting the light with small incidence angles, as in the case described above, this filter is designed to transmit light at small angles and reflect the larger incidence angles. Blue LED sources are immersed at the bottom of a silicone rubber layer. Only light with small incidence angles is transmitted by this filter and so the Lambertian distribution (that is, equal luminance in all directions) of the bare LED is changed into a collimated beam output. Light at larger angles is reflected back, either by the filter or by TIR, and recycled by the highly reflective white surface of the silicone.

![Figure 3. Schematic illustrating the operating principle of a large-area flat collimator.](image)

Pictures of a prototype, measuring 50×50mm\(^2\), show a number of randomly positioned LEDs (see Figure 4). The beam pattern, as projected onto a screen, is also shown. We measured its FWHM as 36°. The area of this device can easily be scaled, and no alignment of the LEDs and the optics is required.

In summary, using dielectric multilayers as angular filters in thin, large-area LED illumination systems, combined with the relatively narrow spectral bandwidth of colored LEDs, offers possibilities beyond what can be achieved with conventional refractive and reflective optics. We are now working to develop thin, cost-effective, large-area LED illumination system products, that can be unobtrusively integrated into walls, ceilings, and other surfaces, and offer a high level of design freedom.

*Part of this work was done in collaboration with the Optics Research Group of Delft University of Technology in the Netherlands.*

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Hugo Cornelissen is a principal scientist in the Philips R&D division. Since joining the company in 1980, he has worked on a variety of topics, most recently on optics for LCD backlights and thin LED luminaires.

**References**

2. See, for instance, products available from carclo optics [link](http://www.carclo-optics.co.uk) and Fraen Corporation [link](http://www.fraensrl.com/images/Fraen FLP Rebel datasheet.pdf).