Microstructured Optical Components for Waveguide-based Luminaires

Fresnel Optics
A Reflexite Company

The Management of Light™

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1.0 Abstract

Precision microstructured optical components made from polymers are the enabling technology in a new generation of office lighting designed to reduce eyestrain for computer users. New products which utilize waveguide technology and precision microprisms are now available which manage light from luminaires powered by high output T5 lamps. The optical system design can be optimized to control glare in office lighting, while maintaining exceptional photometrics and aesthetics. Design considerations such as efficiency, proportion of uplight versus downlight, and cutoff angles will be discussed and quantified. Manufacturing challenges such as tight tolerances and component and system cost will be detailed. Photometric output (analytical models from TracePro and empirical data from a goniophotometer) will be presented. Reduction to practice and examples drawn from the successful market introduction of the technology will be discussed. Next generation designs, which feature similar performance at a lower price point, will also be revealed. This revolutionary optical technology is changing the way lighting designers approach luminaire design in applications which demand glare control and specified photometrics.

2.0 Introduction

A waveguide and precision microprism technology (see Figure 1) are combined to create a new generation of office lighting designed to reduce eyestrain for computer users. This patented [1] system utilizes waveguide technology and prism designs originally developed for high output/highly collimating backlights for flat panel displays. The product was never commercialized in LCD backlights due to difficulty in manufacturing the optical components. In a partnership with two European lighting companies, Fresnel Optics has now reduced the concept to practice and successfully commercialized the technology.

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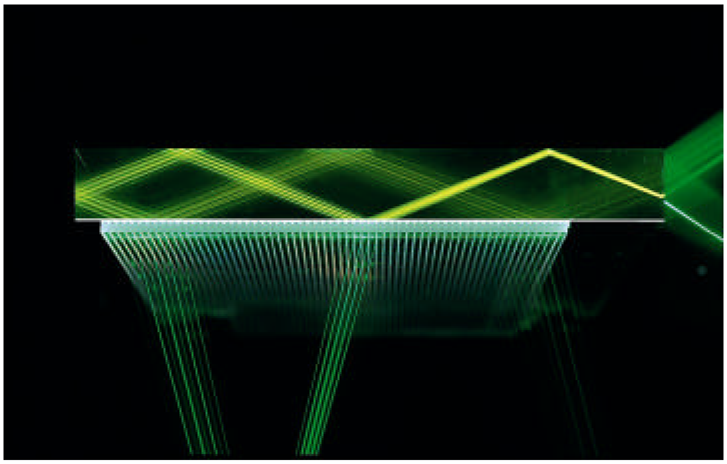

Figure 1: Photograph of waveguide and microprisms, demonstrating principle of operation

3.0 Market Requirement for Innovation

The driving forces behind the introduction of this new technology are twofold. They relate to the requirement for glare free lighting in offices using flat panel displays, as well as the desire to proliferate the new T5 lamp technology.

In office environments which use CRT and LCD monitors, engineered photometrics are desirable to minimize glare on the computer screen. New lighting standards have emerged in North America (Illumination Engineering Society RP-1) and Europe (DIN ISO 5035/7), which recommend photometric distributions specifically engineered to minimize glare on a computer screen. In fact, in worker health-conscious Europe, the EU has proposed a new regulation (CEN TC 169), which would legally mandate that employers install lighting that is compliant with the DIN standard. These requirements are designed to protect workers from the negative effects of glare (eyestrain and fatigue known as "Computer Vision Syndrome"). A side benefit to employers is also documented: measurable increases in productivity are found in offices that utilize compliant lighting. Examples of the light quality and aesthetic appearance produced by the luminaire are included in Figure 2.

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Figure 2:
Waveguide-based luminaires produce glare free light for offices utilizing CRT and flat panel displays

The second driver is the availability of new T5 lamp technology. The T5 lamp, while still representing a cost premium in comparison to T8 and other technologies, offers great advantages to luminaire designers. Some T5 designs offer high brightness – up to 70% brighter than an F32T8. Other T5 designs have better energy efficiency - up to 10% percent more efficient than F32T8 lamp. In addition, the package size for the T5 is smaller which enables new freedom in fixture design. At the same time, in addition to higher lamp cost, another disadvantage of the T5 is that it is so bright it can be very uncomfortable to view the lamp directly. This has driven luminaire designers to innovate. The waveguide based luminaires described in this paper are edge lit. Edge lighting makes it impossible to see the lamp or any coherent lamp image directly.

4.0 Principle of Operation and Technical Features

The schematic in Figure 3 demonstrates the principle of operation for the first generation design. Light exits the lamp (a Lambertian source) and is reflected within the waveguide through Total Internal Reflection (TIR). At some point, the light enters into the microprism array, which is coupled to the waveguide by means of an index matched optical adhesive. Inside the microprism, the light bounces again due to TIR, off the prism face and out of the waveguide. The direction of exit is a function of the design of the microprism angles, and can be engineered to achieve a variety of photometric outputs. In the first generation design, the microprisms run in the direction parallel and perpendicular to the lamp (see Figure 4). Prism pitch is optimized to achieve a pleasing, precise aesthetic – in practice a pitch of 0.5 to 1.5mm is large enough that the microprism is resolvable but still precise in appearance. A coarser prism yields a non-precise appearance, like a prismatic lens.

In the first generation product, prism angles were engineered to deliver a photometric output that complies with the ISO/RP-1 65° cutoff requirement (see Figure 5 for empirically measured photometrics). Note these measurements were for a direct/indirect pendant luminaire, where the uplight component is generated using parabolic reflectors, and the downlight component comes from the light that is coupled into the waveguide. Note also, European units and axis convention were used.

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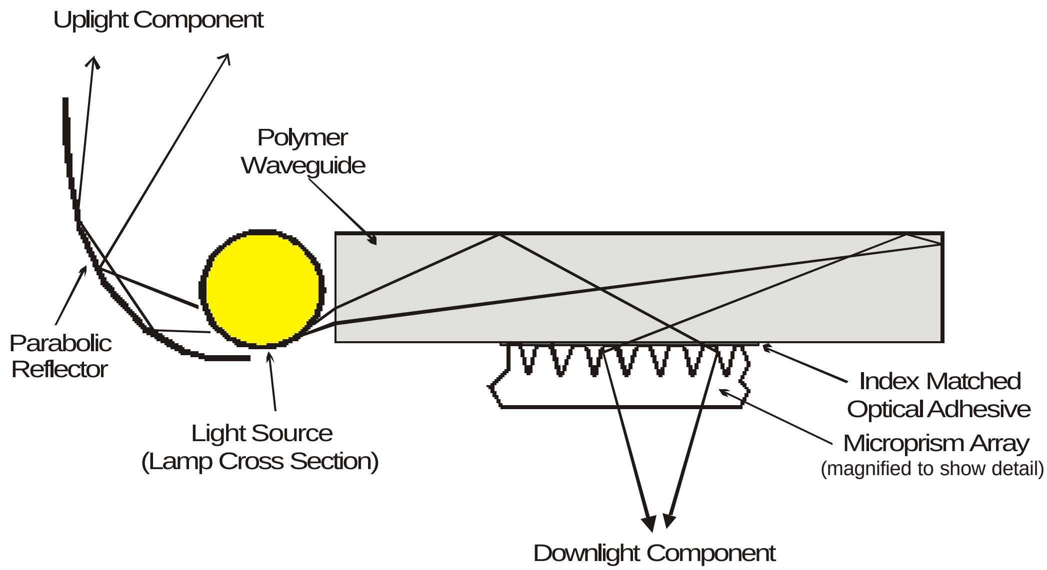

Figure 3: Cross-sectional schematic of waveguide and microprism array

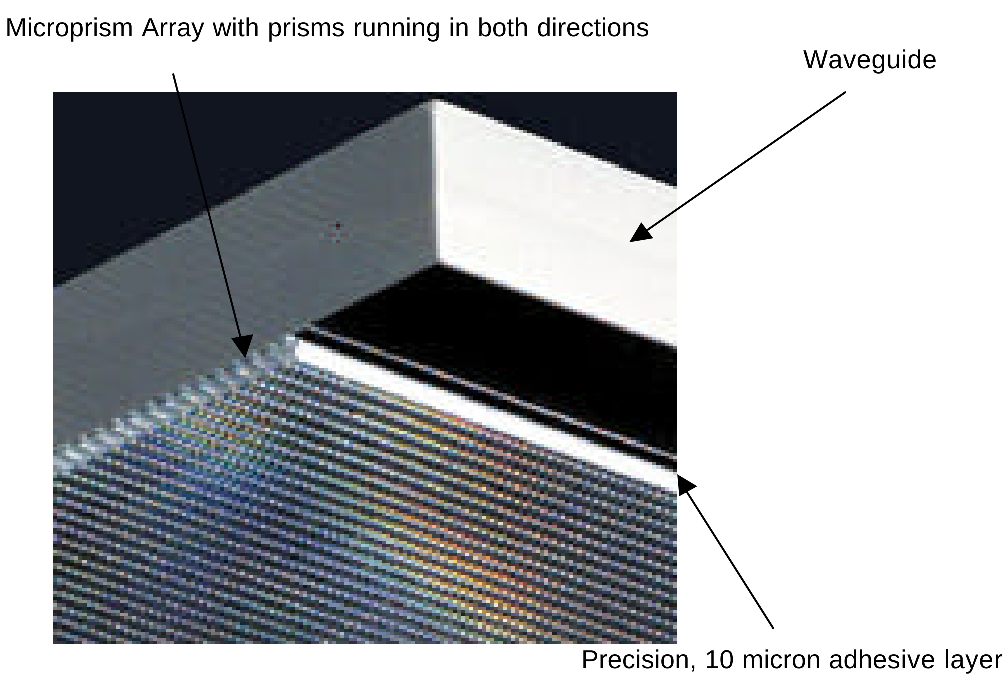

Figure 4: Close-up photograph of first generation product

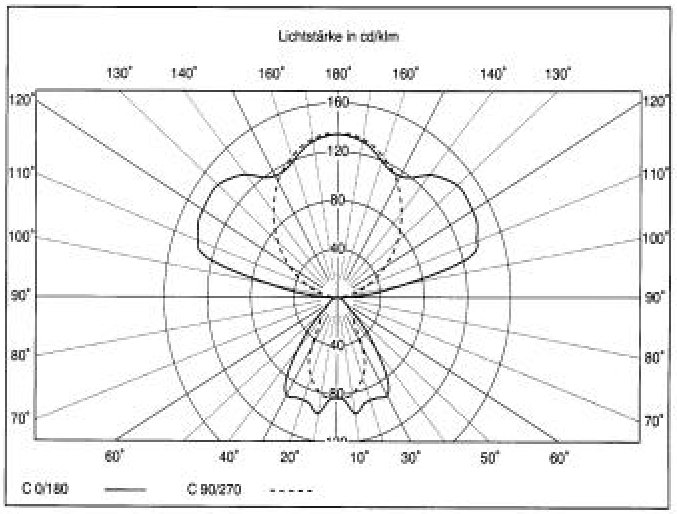

Figure 5: Actual photometric output: first generation product (direct/indirect pendant luminaire)

5.0 Challenge in Manufacturing the Product

The manufacturing challenges include molding a high aspect ratio (in some cases over 3:1 ratio between prism depth and width), fine pitched (as fine as 0.5mm) pyramidal microstructure obtained from crossing prisms in two directions. Prism angles need to be close to dead sharp (minimal radii at any edge breaks) in order to avoid scattering light outside the specified range. The top of the pyramidal prism is a plano (flat) surface, with a surface are of only 0.75 mm^2, which is bonded to the waveguide. Over a 4-foot length, the adhesive layer bonding the prism tops to the waveguide is held to a nominal thickness of 10 microns with a maximum variation of 5 microns. Any meniscus in the adhesive scatters light in an uncontrolled way. The waveguide itself is a custom extrusion of optical grade acrylic material, which is held to exacting flatness despite its 5/8” caliper. For maximum efficiency, waveguide edges are flycut to a near polish finish. While each of these challenges has been overcome, the product is currently commercially viable only in certain niches.

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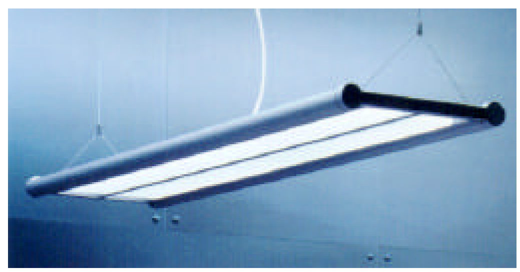
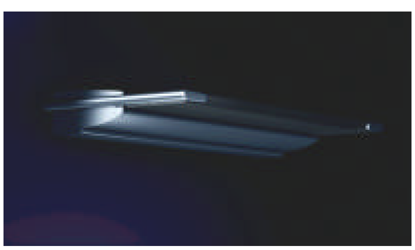
6.0 Commercialization

Fresnel Optics, Inc. in Rochester, N.Y. produces the complete plastic optical assemblies, which are incorporated into fixtures designed and produced by lighting manufacturers such as Siteco Lighting Systems (formerly Siemens Lighting) and Zumtobel Staff in Europe. Families of products are now available which employ the technology (see Figure 6). The reception and unit volumes in European specification and custom project markets have been very auspicious, due to the aesthetics, photometrics, and the state-of-the-art of the technology embodied in the product. The product is now being offered in North America exclusively by Zumtobel Staff lighting.

Floor Lamp (SITECO)



Pendant Luminaire (Zumtobel Staff)



Wall Washer (SITECO)

Task Lamp (SITECO)

Figure 6: Photographs of commercially available lighting fixtures incorporating waveguide/microprism technology

7.0 Next Generation Products

The overwhelming initial commercial response has prompted follow-on efforts to improve the product's performance and manufacturing cost position. Cost reduction efforts, which have focused on designs which are inherently more manufacturable, have led to substantial decreases in the cost of the optical components. At the same time, we have preserved the unique aesthetics (glare free light, no coherent bulb images, and a crisp, high tech appearance). More importantly, while cost is decreasing, photometric results continue to improve. The most recent designs have enhanced the "batwing" effect (see Figure 7) which enables an improved spacing-to-mounting height ratio, while preserving the 1000 cd/m^2 maximum at angles greater than 65º in all downward directions.

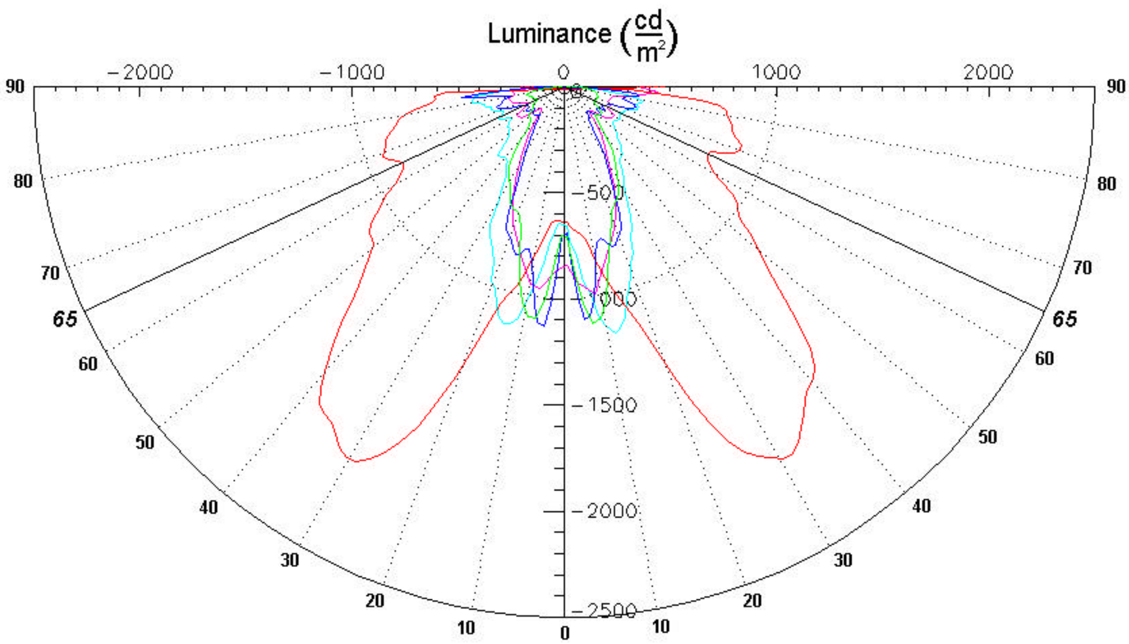


Figure 7: Downlight component of next generation design

8.0` References

1) US Patents 5,396,350 and 5,428,468. Other U.S. and international patents granted or filed.