LEDs MAGAZINE

Micro-optics promote use of LEDs in consumer goods

Module size and power limitations impose major challenges for the design of optics for portable consumer products. According to **Markus Rossi** and **Michael Gale** of Heptagon, diffractive micro-optics can play an important role in meeting these requirements.

Improvements in the intensity and color output of LEDs has led to an explosion in their use for lighting applications in consumer products such as mobile phone cameras, LCD TVs and LED-based projectors. The requirement is for a compact, efficient light source that emits a well defined light distribution. This is achieved by using extra micro-optical elements for beam shaping and for enhancing the emission efficiency.

Since LEDs are basically broad-area wide-angle emitters, designing and realizing such micro-optics in a compact form is a challenge. The introduction of customized diffractive optical elements (DOEs), made possible by recent advances in design and fabrication technology, has resulted in a major advance in producing compact, functional and cost-effective LED lighting modules. The main issues for such lighting modules are:

- luminous efficiency – optimizing light collection, leading to brighter illumination and longer battery lifetime;
- optical function – optimally converting the LED output into the required light distribution (beam shaping), and minimizing unwanted color effects from white LEDs;
- packaging – reducing the size, in particular the thickness, of the lighting module;
- cost – reducing the component and assembly costs, and realizing surface-mountable micro-optics.

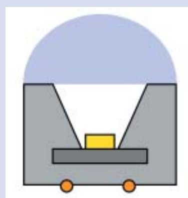

Fig. 1. The evolution of optics for LED lighting in portable consumer products. The final step, monolithic micro-optics, can significantly reduce volume production costs.

Optical approaches

The evolution in optics for LED lighting in portable consumer products is illustrated in figure 1. The classical approach has been to use conventional optics (figure 1a) such as dome lenslets and mini-reflectors to collect and form the light.

The use of micro-optical elements (figure 1b) enables the manufacture of thinner modules – this is an important advantage in applications such as the light source for cameras in mobile phones. Such elements can be produced by UV replication technology on thin glass substrates in polymer films, which withstand the infrared (IR) reflow process for the module assembly (1, 2). This lowers the cost of assembly and production.

Refractive Fresnel lenslets are a first step in this evolution. They replace conventional dome lenslets with a much thinner microstructure that is highly suited to fabrication by replication technology. The next step is to move to DOEs, which can offer much higher functionality for homogenizing and beam shaping the LED light output. The earlier limitations of diffractive elements, when used with broad spectral bands such as white light LEDs, have been overcome by using advanced design techniques and fabrication technology.

The ultimate step in the evolution is to fabricate the optical microstructure directly on the LED at wafer level. This monolithic solution (figure 1c) essentially eliminates, or at least greatly simplifies, the subsequent assembly and thus leads to a significant decrease in volume production costs. UV replication is highly suited to this approach (3).

Design methods for micro-optical elements

Designing beam-shaping DOEs for LED modules is a challenge that requires highly sophisticated design methods, in particular for white LEDs. A typical structure is shown schematically in figure 2. The LED die typically sits in a reflector, which may also contain a wavelength-converting resin. The optical element should be positioned as closely as possible to the LED, an extended white light source, and has to perform a highly efficient and flexible beam-shaping function. →

Parameters such as the die geometry (shape, size and position), the reflector form, properties of the light-converting resin, and the spectral distribution of the emitted light must all be considered in the design and optimization process.

New software has been developed to design DOEs that take these and other parameters into account and that find the best solution for optimizing efficiency and the output beam shape. The resulting designs represent a significant advance in customizing the micro-optical element for a given LED module. The DOEs typically contain finer and deeper microstructures than in earlier designs, and these can be fabricated and replicated by recently developed advanced technologies. Typical solutions are fabrication-tolerant designs that realize features such as:

- conversion of a Lambertian emission into a Gaussian flat top;
- customized far-field light distribution, including rectangular and round forms;
- opening angles typically between 20° and 60° at FWHM (full width at half maximum);
- optimization for LED die shape or arrangement for multichip LEDs;
- correction and compensation of color effects in white LEDs, in particular with wavelength-conversion luminous resins.

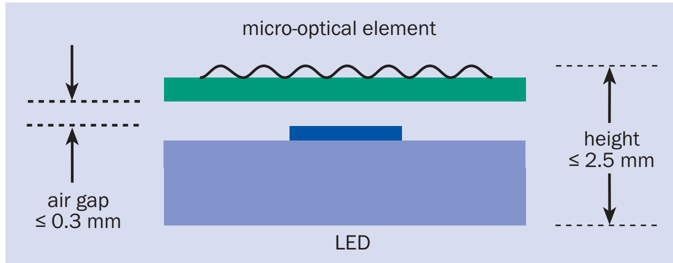

Fig. 2. Schematic drawing of an LED module that incorporates a micro-optical beam-shaping element.

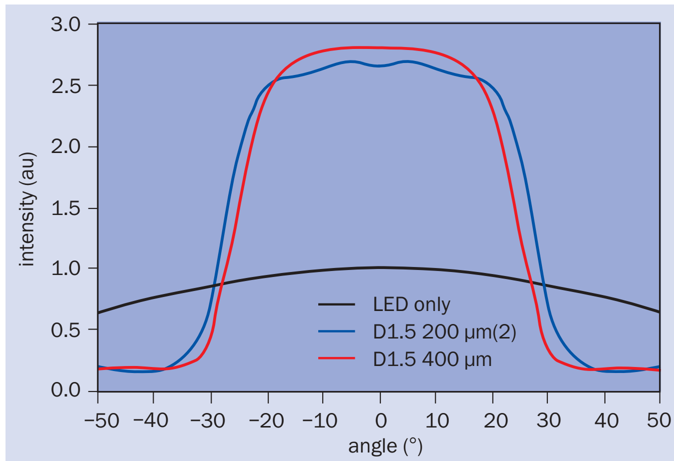

Fig. 3. The effect of a fabricated LED beam-shaping element. Black line: angular illuminance distribution of white LED without micro-optical element. Red and blue lines: output with a beam-shaping element positioned at different distances from the LED.

Mastering and prototyping

The mastering technology of choice for a given DOE depends primarily upon the microstructure properties, such as feature size and depth. Direct laser beam writing in photoresist (3) is a fast, high precision technology that is highly suited to such mastering. A first assessment of the optical properties of the DOE and the LED module can usually be made at this stage. A more thorough evaluation requires a replica fabricated from a mould.

Figure 3 shows an example of a beam-shaping element that converts the Lambertian illuminance characteristics of a white light LED (one chip with an active area measuring 1 × 1 mm) into a Gaussian distribution with a FWHM of about ±30°. The active area of this particular DOE is 4 × 4 mm and it is positioned at a distance of 0.2 mm from the LED surface. The on-axis brightness increases by a factor of approximately 2.7. Depending on the opening angle and the shape of the output distributions, this value can be between 1.5 and more than 4 for typical LED modules.

Volume production technologies

An overview of replication technology for DOEs can be found in (4). UV replication technology is highly suited to the production of DOE beam-shaping elements for LEDs. Following mastering and the fabrication of the mould, the elements are replicated into UV-curable liquid polymer in a batch wafer-scale process, which produces glass-like elements at highly competitive prices (1). Materials are available that can withstand an IR reflow process (temperatures up to 280 °C), long-term storage and humidity tests, and temperature shocks (in conformance with Telcordia/JEDEC regulations).

In addition to producing the optical microstructure, mechanical mounting features can also be integrated into the replicated element. Figure 4 shows an LED module with a replicated DOE positioned using replicated macroscopic mounting pins at the corners of the element.

Associated coating, packaging and dicing steps are compatible with other wafer-scale processes, thus guaranteeing the same advantages in terms of precision, efficiency and pricing. The process can also be adapted for implementing the monolithic solution with replication directly onto the LED wafer. The UV replication approach, which does not require additional heat and pressure, has particular advantages here.

Applications and outlook

The use of customized micro-optics for LEDs results in major improvements in brightness, beam shape and battery lifetime. Portable consumer products in particular benefit from these features. The LED flashlight for cameras in mobile phones is just one example. The LED pocket lamp is another in which efficient beam shaping is a major requirement. LEDs are also used for display illumination in PDAs, mobile phones and a host of electronic consumer products. New, optimized micro-optics is resulting in a continuous improvement in the quality and power consumption of these displays.

Other areas of application are to be found in lighting for products such as machine vision systems, medical devices, and flat displays

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Fig. 4. Beam-shaping elements with a replicated DOE, assembled using replicated mounting pins. Inset shows latest version.

in general. The emerging markets of LED lighting for automobiles and interior building lighting are not so critically dependent upon the size benefits, but power consumption and beam shaping are always a major factor, and micro-optics will play an increasingly important role in such products.

Diffractive micro-optics technology offers more degrees of freedom for the complex optimization of LED module optics, and can achieve better results than simple Fresnel microlenses. Improvements in design methods and fabrication technology are enabling the full potential of diffractive optics to be realized and implemented in advanced LED lighting modules.

About the authors

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Further reading

1 *Wafer scale micro-optics replication technology*: www.heptagon.fi/downloads/WaferScale%20Replication%20Technology%202003.pdf
2 *Micro-optical modules fabricated by high-precision replication processes*: www.heptagon.fi/downloads/MO%20Module%20Fabrication%202003.pdf
3 *One stop shop – prototyping*: www.heptagon.fi/oneStopShop/prototyping.html
4 M T Gale 1997 Replication technology for holograms and diffractive optical elements *J. Image Sci. and Techn.* **41** 211

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Heptagon: www.heptagon.fi