Plastic Optics Enable LED Lighting Revolution
When Highest Precision Meets Low Prices

Only some years ago LEDs were predominantly used as tiny marker lamps in electronic devices. The recent rapid development in semiconductor and packaging technologies has quickly turned LEDs into powerful lighting components, capable of replacing existing light sources, such as bulbs, halogen lamps or even highly efficient fluorescent tubes.

So far, the adoption of LED technology has been strongest in architectural lighting, signage, automotive lamps, mobile phones and displays. In everyday life, more and more public places such as building facades or bridges are being illuminated by color-changing LED systems. The next major area for penetration of the LED technology will be in general lighting. An essential enabler for LED lighting revolution over the coming years is a clever use of optics to collect and shape the light from the LED package. In the following article we go into the details of how to do it by means of advanced plastic optics.

Illumination Engineering
Applications of optical engineering related specifically to illumination systems are often called illumination engineering. As illumination engineers, who wish to design a good LED lighting system, we need to pay attention to many of the following important issues:

- Which LED and which color is most suitable for this application?
- What is the optimal type of light distribution for this application?
- What is the CRI value needed – is brightness more important than a good CRI (Color Rendering Index, describes color appearance)?
- How uniform shall the illumination be, both in terms of brightness and color, over the object to be illuminated? Do you allow any shadows or other inconsistency in the projected beam of light?
- How consistent shall the quality of the light (intensity, color) be over time?
- Do we need to choose any special materials or components due to the environment where the system is assembled?

FIGURE 1: LEDIL CAT lens for Street lighting.

FIGURE 2: LEDs as light sources vary much from each other. The same optics cannot be used for several LEDs without jeopardizing the performance.

FIGURE 3: LEDIL FLARE lens for Luxeon K2 and LEDIL FLARE-C lens for Cree XR-E show how different light sources lead to different lens design, with the same illumination specification.

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Do we need any modularity of the system components? What kind of flexibility is needed from the system setup, to enable assembly of it next time in another place?

The list above can be endless, which shows the complexity of requirements for good illumination engineering. It also means that a LED lighting system and its components always are results of various compromises. There seldom is a way to fulfill all the requirements at the same time. If it was done, it would often mean a system that is too complex to use, too difficult to manufacture or too expensive. Therefore, let us take a look at the various aspects of a best possible compromise, each in turn, and try to figure out, how we can create a best possible optical system for LEDs.

Challenges with LED as a Light Source

Even as LED packages have developed much during recent years, there does not seem to exist any common idea among LED manufacturers, what an optically good LED package should look like. All of them are different from each other and only a few of them have been designed for easy adoption of secondary optics. Many of them have been designed to get a brightest possible beam out of the LED itself, without thinking how the beam can be used in the following step: secondary optics.

In all LED packages the chip has a square or rectangular shape. If a conventional, highly efficient lens is used and this lens has been designed with an idea to make a most accurate image of the object in its focal point, the illumination result is the same square or rectangular shape of the LED, with all chip details projected on the object to be illuminated. Nobody likes it, as the first rule for an illumination engineer is to make a beam that is smooth and pleasant. Therefore, the challenge is how to maintain the high efficiency of a conventional lens, but at the same time get rid of the square and make a round shape instead.

Another challenge is, how to achieve an even white color on the object, even if the LED used does not emit uniformly white light? The problem here may be a result of variations in the blue LED underneath the phosphor layer, unevenness of the phosphor layer or some die manufacturing details. In many cases, a secondary optics has to heal problems that actually are LED related, but become apparent when the LED is exposed to a secondary optical system.

A third main challenge for optics is multiple-die LEDs, which have a great number of chips, populated densely, close to each other and covered with a common phosphor layer or dome. It is very difficult to develop optically efficient and visually pleasing optics for such LEDs. The reason is that most illumination optics development is based on an idea of a point light source. Having e.g. 4 x 4 dies makes it impossible to use this principle in design, as dies are too near to each other to be seen as separate, but too far away from each other, to be seen as a point light source. The final result is that such light LEDs cannot be used in applications where a good collimation and narrow light distributions are needed.

Main benefits for LEDs, when compared to other light sources, are the directional light they give and the relatively small size of the light source. In that sense LEDs easily outperform all other light sources, such as bulbs and fluorescent tubes.

Optimization with Regard to Light Source Characteristics

Some companies have gone so far in the standardization of their lenses that they have decided to treat all LEDs as similar light sources and offer the same lens for many LEDs. In my opinion, this is not possible, nor rational to do, as every LED is very different from each other. As a clear evidence of this difference I show 3 different simulation pictures, which show the illumination result, when a lens, optimized for LED “A” is put at its correct focal length, but used in combination with lenses “B” and “C”. You can see how the well controlled beam in “A” changes to a scattered plot in “B” and “C”.

FIGURE 4A & 4B: Picture show the light distribution of a lens, with the light source it has been optimized for. The 2nd picture shows the same lens, positioned at a correct focal point, but using a LED, which the lens has not been designed for.
We at LEDIL design and optimize every optical system with regard to the LED it is going to be used with. It guarantees that a full efficiency both in terms of power and visual appearance is achieved.

**Basic Optic Types**

LED optics can be categorized in e.g. lenses, reflectors, combinations of them and systems of multiple lenses or reflectors. It cannot be claimed that some of them would be better than another. It fully depends on the application and its requirements.

Generally speaking, however, lenses are more efficient in shaping the beam than reflectors. The main reason is that light in a lens travels through at least 2 surfaces (often more), before getting out of the system in the desired angle, while for simple reflectors a part of the light gets out without ever hitting any optical surface. On the other hand, every time light enters or exits a surface it looses its efficiency, which speaks against complex lens systems and favors reflectors.

Most companies offering LED optics base their optical idea on collimating the light from the LED with a standard collimator lens design, spreading the light on the top surface of the lens in the angle needed. The quality of the resulting beam depends on how accurately the LED is studied, and the degree and method of inter-connecting the optical surfaces to each other.

**Free Form Lenses**

A more advanced idea is to freely modify all the optical surfaces, when having an accurate model of the LED and knowing what the resulting beam shall look like. This kind of optical system is called free form system. All LEDIL lenses are free form lenses. Free form does not mean that a computer calculates the optical geometry with given input and output conditions. For good free form optics there is also a structured, well-connected underlying optical concept, which the illumination engineer in charge has created. Clear benefits with free form optics are e.g. good modeling of LED resulting in great accuracy, high optical efficiency, controlled beam quality and a smaller physical size.

**Reflectors**

Reflectors have been used as optical element for a longer time in history than lenses. Reflectors are easy to manufacture, therefore cheap. A common denominator for all reflectors is a relatively large opening angle, i.e. a large part of the emitted light from the LED gets out of the system, never hitting the reflector surface. The phenomenon results in a relatively large area of scattered light around the so-called hot spot area. Obviously, the angle can be minimized by increasing the height of the reflector, but it seldom is possible achieve a great extent of control. Reflectors often show a light distribution, which has a higher peak and less smooth curve than what is the case for a lens of the same size.

**Combinations**

Combining reflectors and lenses in one optical system is a challenge, as the optical functioning of them is very different and a combination easily results in a less efficient system than planned.

Combining lenses in a system or doing the same with multiple reflectors may be used with success. As an example of a flexible and cheap optical system using lenses I can mention LEDIL’s series of lenses, where one and the same base lens can be modified with add-on sub lenses, to change the illumination pattern.

**LEDIL Oy**

**SALO, Finland**

LEDIL designs, moulds and markets optical, plastic components for a vast variety of application fields. LEDIL has been the innovation leader of LED optical technology since its foundation in 2002, with proven expertise in optical design and manufacture. LEDIL has an own, highly skilled optical design department where optical, mechanical, materials and production knowledge and know-how are combined to cost-efficient optical solutions for mass production. LEDIL is a globally working company with roots in Finland, but current operations taking place in all continents. LEDIL offers a wide variety of standard solutions for the most popular LED types. LEDIL is very interested in making custom designs, once the standard selection is not enough to fill the requirements.
System Thinking, Integration, Platforms

An important feature, when designing an illumination system, is to develop a modular system that can be easily adapted for different applications. When it comes to optical components, we have chosen a few mechanical optics platforms, which we modify to their optical geometry, but not to their mechanical dimensions. The end user can feel confident that he always finds a standard component of a certain size, with different optical characteristics and the same size and optical choices for several, different LED types.

Another important feature is the shape of the components and the easiness of integrating them in the surrounding mechanical systems of an illuminator. As an example of a standard platform and shape is the LEDIL square lens series, with 50 different optical units with the same size and shape. Furthermore, this component can also be supplied as separate parts, which enables the customer to replace a part of e.g. the lens holder construction by the structure of his illuminator.

In general terms, all kinds of mechanical features can easily be integrated in a plastic optic – let it be a lens or reflector or a group of them. As examples of features used in several lenses are: adhesive tapes, threads, snap hooks, pins, screw holes and welding features.

Optical Materials

Without going deep into the materials science, it is essential to give a quick note on materials to be used in advanced optical systems. There is a difference in materials, which often cannot be seen with bare eyes. Most of the LED lenses of today are manufactured of PMMA (acrylics) or PC (polycarbonate). There are special applications requiring COP or PA12 materials, but they are rare. A special attention should be paid to the variation within materials supposed to be “PMMA” or “PC” only. There are hundreds of different materials in these material groups and only a low percentage of them fulfill the criteria of being excellent for advanced plastic optics. Care must be taken of to insure good dimensional accuracy and stability, heat resistance, UV resistance, molding parameters (parts without stress), chemical resistance etc.

The future is bright

Finally, we want an answer to the ultimate question: why is it beneficial to use plastic optics and why is a good optical solution the key to LED lighting revolution? The answers are many, but they all are simple and understandable:

- Price. No other material has such a high price/performance ratio as optical plastic. Glass outperforms plastics in a few features, but overall, the list for plastic is overwhelmingly long.
- Versatility. Plastics are the only optical materials, which can have numerous mechanical features integrated in the optical system. Different plastic materials can be used in different environments. Different plastics can be used to achieve different optical effects.
- Performance. Only plastic optical systems have made LED flashlights possible in big volumes. The same can be said for most of the automotive LED applications – both interior and exterior. Without plastics and optics it would have been impossible to fulfill the requirements of these lighting systems.
- Starting in a big scale in a few years, we will all see a LED lighting revolution take place in our homes, offices and public places. Take a close look at all of the solutions. I can guarantee that you will see a great number of plastic optics there, too, plastic optics – the enabler of LED Light Revolution.