Glass reflectors for LED downlight applications

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ABSTRACT

The increasing market demand for LED illumination requires new design approaches for the replacement of conventional recessed luminaries. In this paper we present a series of glass reflectors covering a broad range of beam angles between 10° and 40°. The key feature of this development is the identical size of all reflectors making a modular set-up possible complying to a Zhaga-standardized LED module. The reflector dimensions are comparable to halogen MR16 lamps and allow an immediate use in existing downlight systems.
Here, we present light technical measurements of these reflectors and compare the performance to already existing MR16 LED retrofit solutions.

Keywords: LED, reflector, MR16, color mixing, Zhaga

1. INTRODUCTION

Today, the segment of recessed downlights is still dominated by conventional light sources as MR16 halogen or metal-halide lamps. Especially for demanding top level products the advantages of halogen lamps are highly appreciated. MR16 lamps are individually replaceable, standardized, and available in numerous beam angles and wattages. The great color rendering index and the correlated color temperature of 3000 K combined with a negligible color over angle deviation establishes a challenging benchmark for all other downlight solutions. Competition between different suppliers guarantees economic prices for MR16 installations and maintenance.
Disadvantageous for the application are the short life time of the bulbs requiring regular replacement and the fact that halogen lamps suffer from low energy efficiency. Conventional MR16 lamps have typical efficacies below 20 lm/W but by exploiting new technologies like infrared reflective coating of the bulbs the light output can be increased by approximately 50 % [1].
Today's trend towards LED illumination is mainly driven by the potential energy and operating cost savings. The easiest way for the above described application is the replacement of MR16 halogen lamps with LED retrofit solutions. Unfortunately the performance of existing retrofit lamps is still not sufficient with respect to the total luminous flux, color rendering index and color deviation over angle. Another open topic is the integration of retrofit lamps into an adequate cooling system which is required to achieve the luminous flux that is realized with typical 50W halogen lamps. So, new approaches for recessed LED downlights are needed.
In this paper we present a solution based on glass reflectors and a Zhaga-compliant[2] LED module. The idea of the development is to combine the energy efficiency of LEDs with the optical performance of MR16 reflector lamps. Main focus is given to a modular setup, which enables an easy exchange of the optics as well as the LED module.

This paper has the following structure: Section 2 defines the requirements and goals used for this project. In section 3 the development process is described. In section 4 the results of the sample production are compared to the performance of existing LED retrofit lamps.

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2. REQUIREMENTS AND GOALS

The dimensions of the light engine including optics are mainly limited by the space available for the recessed downlight. Contrary to existing MR16 halogen lamps, where light source and reflector are combined and require only a small volume, the LED light engine needs separate space for cooling, the LED module and the optics. For the project presented here the following geometrical dimensions of the optics were defined:

- Diameter of 50 mm to enable system compatibility to existing MR16 downlights
- Length of 40 mm, identical to all optics of different beam angles, to ensure real interchangeability.

For the optics two general concepts are common: coated reflectors and solid refracting optics using total internal reflection (TIR). Both approaches have pros and cons. While only refracting optics allow to influence the light emitted in forward direction, the TIR condition may be constraining if the dimensions are fixed as described above. On the other hand, the reflector optics allows higher efficiency as only one optical surface without volume material absorption is involved. Faceting of the optical surface allow precise light guidance with good color mixing, which is a well-established technology with current MR16 reflector production.

For this project the reflector solution was preferred. In general the reflector can be made of different materials: Glass, plastic or metal. A detailed analysis of different features gives a strong indication for glass as the material of choice:

- Glass is extremely durable. Neither high temperatures, UV-light, organic solvents or water can damage the material. It is fire-proof and will not deteriorate during application.
- Glass has advantageous physical properties. It impresses by higher scratch resistance, higher thermal conductivity and lower thermal expansion compared to commonly used plastics like PMMA or PC.
- Glass is the best substrate for high performance coatings. While plastic is typically aluminum coated with a reflectivity of below 88 %, glass can be used with scratch resistant multi-layer dielectric coatings with a typical reflectivity of 96 %. By choosing the appropriate coating, a benefit of 15% compared to metal coatings can easily be realized.
- The hot molding process for glass production allows direct integration of additional features for the reflector mounting. This reduces the number of required production steps and enables cost competitive production.

The selection of the LED module is more challenging as a confusing variety of models from many different suppliers are available. The life cycles of these products are often short, which requires a continuous adaption of the systems by the luminaire manufacturers. For this reason a standardized LED module is of advantage, which is currently developed by the Zhaga consortium[2]. For the LED module following features are preferred:

- Small light emitting surface for better beam control
- Large beam angle for an effective reflector solution
- Only one LED primary optic (dome lens) to avoid imaging of the separated light sources

The choice for this project was a Zhaga-compliant LED module from Philips. The Fortimo LED SLM 1100 17W/830 L9 G2 spotlight module has a beam angle of 115 degree, a total luminous flux of 1100 lm with a correlated color temperature of 3000 K.

For the optical performance the following goal was defined: Development of a reflector family with strong color mixing, high efficiency and beam angles of 10, 15, 25 and 40 degrees. The benchmarks for the development were 50 W halogen lamps with similar beam angles.

3. DEVELOPMENT AND COLOR EVALUATION

For the development non-sequential ray tracing calculations were used. The ray files were created from luminance measurements of the LED using ProSource and no further assumptions were made for the light source. Color information was included as Tristimulus X, Y, Z ray files were available for calculating the color mixing of the reflector.

The performance of the reflector is achieved by a combination of the contour of the optical surface and the facets applied to it. This is a multi-parameter system as both the contour and the facets can be described in many ways. Here, exploiting the rotational symmetry, we choose a NURBS curve description for the optical surface that was optimized with a simplex algorithm. Geometrical and optical constraints as well as the predefined target distribution were combined to merit functions that were minimized during the optimization process. The second part of the development was the facet design, where the number and shape of the facets were individually adjusted to achieve the final distribution with the required color mixing. If necessary both steps were iteratively repeated until the result reached the target.

Special care was taken to the color mixing. A typical feature of white LEDs is their color over angle dependence of the light emission. Figure 1 shows the color emission of the LED. Depicted is the correlated color temperature (CCT) as well as geometrical distance Δu'v' in the CIELUV color space to the color coordinate in forward direction. The effects shown here are recognizable to people that are skilled to evaluate the color effects of illumination systems.

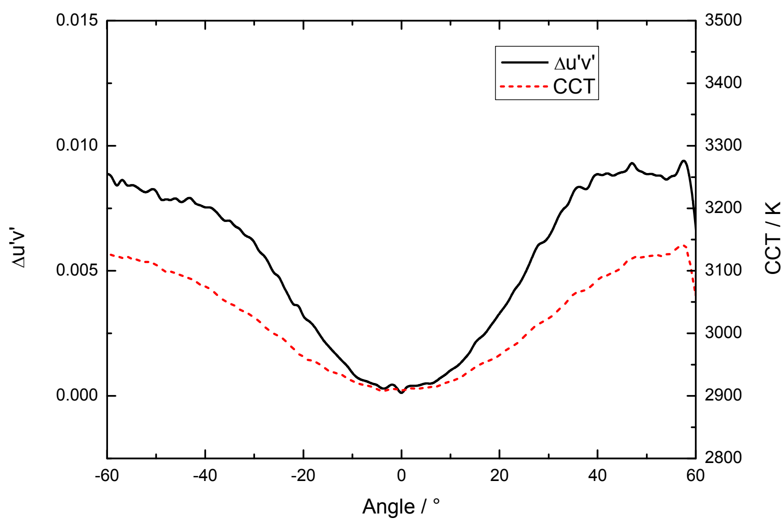
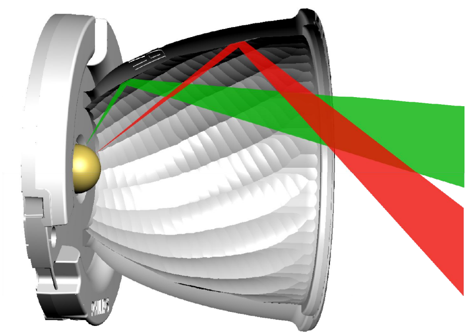


Figure 1: Measured angular dependent emission of the LED.

Particularly with reflectors having larger beam angles the color decomposition becomes more relevant as the light is spread out over a large solid angle. As indicated in Figure 2 the LED emits more greenish light at high angles and more reddish light in the forward direction. With a non-faceted reflector this leads to a direct mapping of the color deviation to the final light distribution. By applying an effective faceting, the light hitting a single facet is directed into a larger angular range and results in a colorless superposition of all facets in the light distribution.
This influence of the faceting is demonstrated in Figure 3. Here two different facet designs are compared that both produce nearly the same light distribution with a beam angle of 40 degree. Besides the total deviation of Δu'v' the human eye is quite sensitive to the slope of the color change. As shown in Figure 3 the Design 2 has a smoother color change, which is definitely preferable.



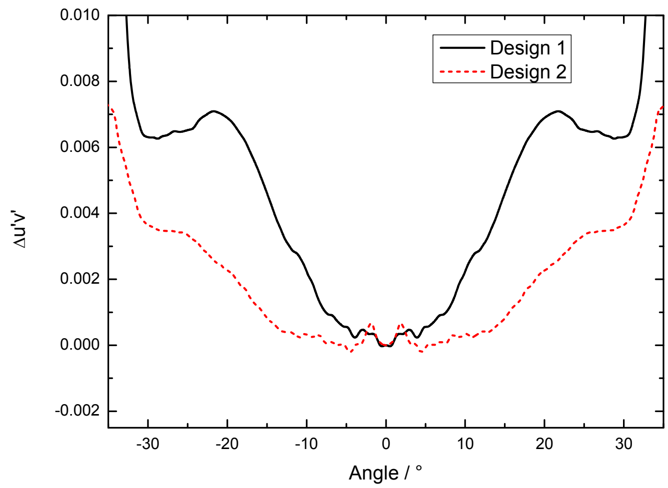


Figure 2: The LED emits greenish light at high angles and reddish light in forward direction. With a sufficient facet design the effect of color decomposition is strongly reduced as every facet is responsible for a large angular range.

Figure 3: Simulated color deviation of different facet designs for 40° reflectors. With the appropriate design the color deviation is considerably reduced.

4. RESULTS

Four reflectors with beam angles of 10, 15, 25 and 40 degrees were developed as described in the previous section. The reflectors were produced in SUPRAX 8488 glass with a hot molding process. As shown in Figure 4 all necessary parts for reflector mounting were immediately pressed in. This step requires high precision as the allowed tolerances for the reflector mounting are in the range of 0.2 mm.
It's worth to point out, that the sample production is done with the same tools that are used for high volume mass production, so the results presented here are absolutely comparable to final products.
After hot forming the SUPRAX substrates were coated with a PICVD process using SiO_2 and TiO_2. The dielectric multilayer coating with about 60 layers was specially designed for each reflector type to achieve highest reflectivity for the given angles of incidence. The typical reflectivity of such PICVD coatings reaches 96% in the final product.

The optical characterization was done with a goniometric set-up in the far field. The goniometer allows 2-axis angular measurements and uses a calibrated Colormeter C3300 from LMT. The measurement distance between the reflector and detector was 3.16 m for all results presented in the following sections.

4.1. Light distribution

The reflector family is designed for a direct replacement of common MR16 halogen lamps. For better evaluation of the sample production a frequently used[3] product series was chosen as a benchmark.
In Figure 5 the results for each reflector-type are shown. Both the measured and simulated luminous intensity distributions are compared to the commonly used 50W halogen lamp with same beam angle.

Figure 4: Reflectors with beam angles of 10, 15, 25 and 40 degree. The outer dimensions are identical for all types. All structures needed for the reflector mounting are already pressed in during the hot-forming process.

The results prove that the simulated light distribution is found for the final product in each case. This demonstrates the high precision that can be realized with the glass hot-forming production process as well as the quality of the simulation results.

Analyzing the light distributions in Figure 5 the results for the LED and halogen lamp are quite similar. The main difference is the background found for angles between ± 30° in the distribution which is caused by direct emission of the LED. The direct emission, which includes approx. 30% of the luminous flux, is hardly to influence with the reflector optic but during application it is only noticeable as a smooth transition to the outer field.

4.2. Color effects

Color effects of luminaires are of the same importance as the luminous intensity distributions. Nowadays LED lamp manufacturers typically provide the light distribution without any comment what color deviation a customer has to expect. This subsection contains the color measurements done with reflectors presented above. The next section gives a good overview how the color mixing is implemented in LED MR16 retrofit lamps available to customers.

For the following results the angular dependent color coordinate was measured in the far field. After transformation to the CIELUV color space for each angle the chromaticity distance Δu'v' to the color coordinate in forward direction was calculated.

The LED reflectors presented here were designed to realize a good color mixing during operation. Tailored faceting is needed to achieve the best result for each reflector type. As described in section 3 the color mixing was included into the simulations. The high prediction precision found for the light distribution is also reached with the color calculations. As shown in Figure 6 only small deviations of the chromaticity distance Δu'v' are found for the final product. Here the important angular range of ± 30° is evaluated, which is also illuminated by the direct emission. Depending of the beam angle, the maximum chromaticity distance of Δu'v' = 0.006 is found for the 40° reflector. During operation this color deviation is barely visible and can be neglected in the investigated illumination scenarios.

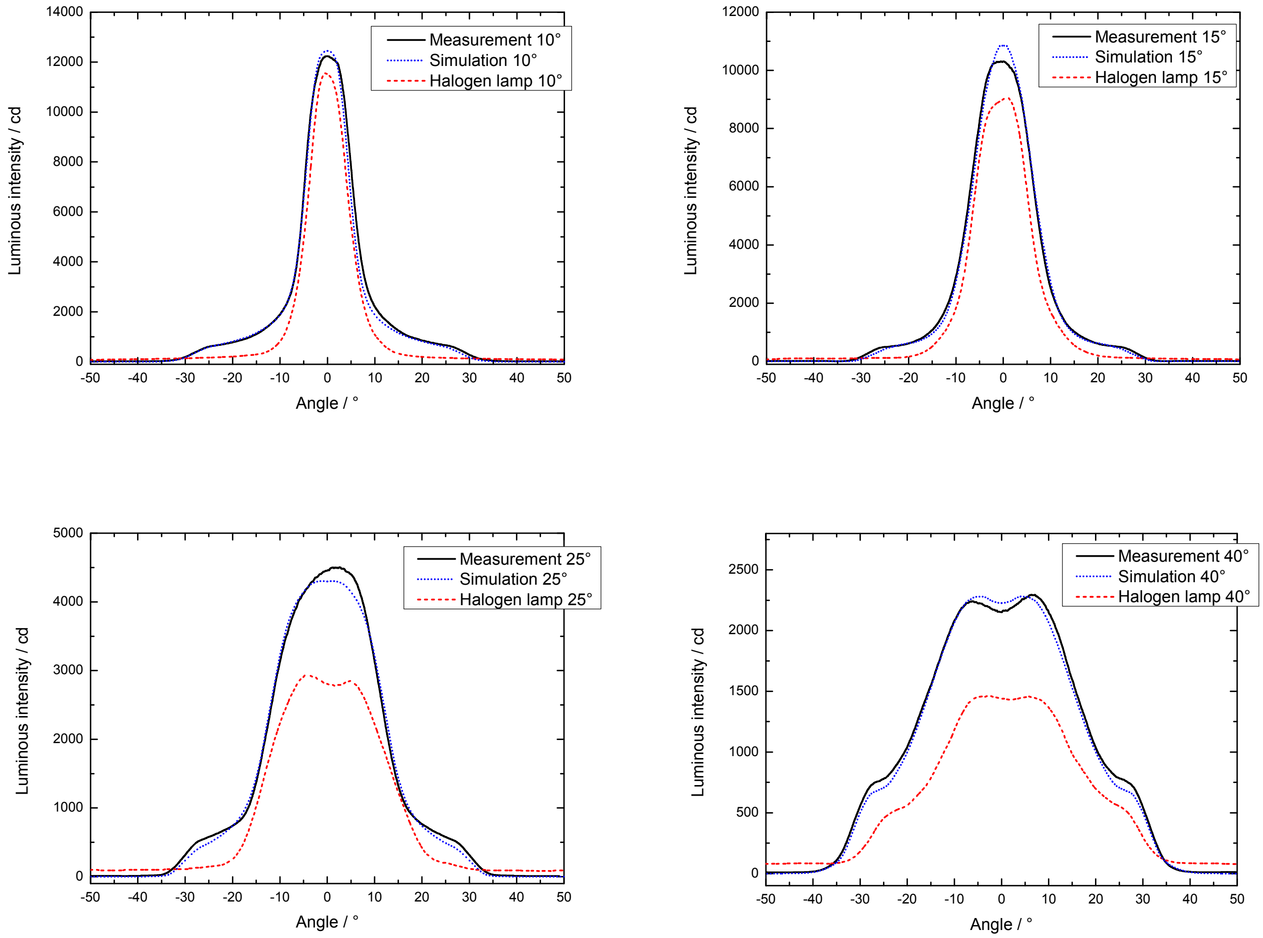


Figure 5: Comparison of LED Reflectors to MR16 halogen lamps with same beam angle.

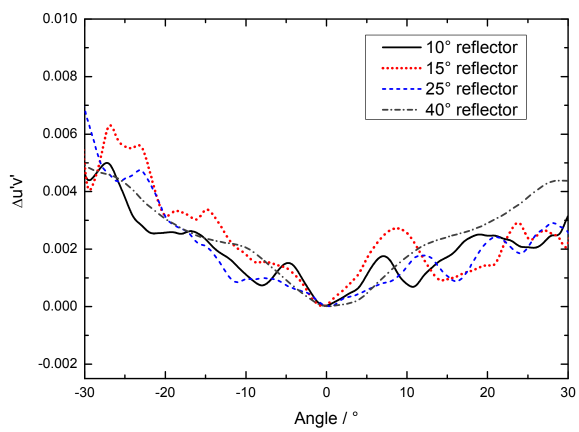


Figure 6: Measured color deviation of the LED reflectors.

4.3. Color effects of LED MR16 retrofit lamps

For rating the color mixing of the above presented reflectors also different MR16 LED retrofit lamps were investigated. The selection shown in Table 1 was done according the following requirements:

- MR16 GU5.3 socket, 12 V AC
- Beam angle close to 24° and 36°
- Power approx. 7 W
- CCT around 3000 K

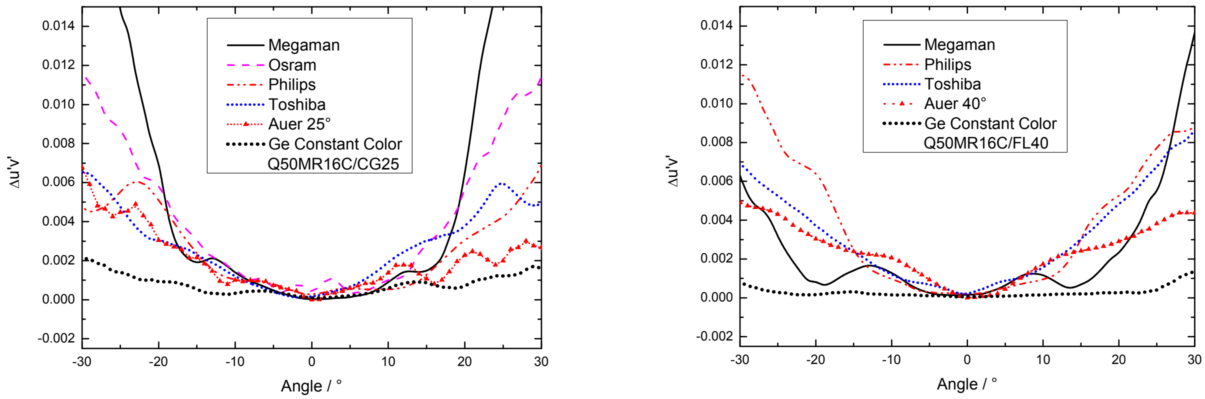
Lamps from Megaman, Osram, Philips, and Toshiba were measured in the set-up described before. Three of the product lines employ 3 or 4 LEDs with a lens and diffusing structures. Only Megaman uses a reflector set-up with two compound reflectors with a vertically oriented flat LED each. During operation the Megaman lamp shows a more colorful illumination on a screen, which indicates an insufficient color mixing by the applied reflectors.

In Figure 7 the angular dependent color deviations for both beam angles are shown. For benchmarking also a conventional MR16 halogen lamp from GE is added to the plots. The color performance of halogen lamp cannot be reached with any of the LED retrofit lamps. But the differences between the retrofit lamps are notable. At beam angles of 24° the best performance is found for the Philips and Toshiba lamps while the color mixing of the Megaman lamp is definitely too low. At beam angles of 36° the reflector solution from Megaman performs best, which proves that no general preference can be given to any of the basic optical concepts. If done properly with both reflectors and lenses good color mixing can be achieved.

Finally, the color mixing performance of the LED reflectors presented in this paper can be evaluated. A comparison of the measurements presented in Figure 7 shows, that the glass reflectors reach the color mixing level of the respectively best LED retrofit reflector.

Table 1: MR16 LED retrofit lamps selected for color evaluation.

Lamp	Rated beam angle / °	Measured beam angle / °	Power / W	Measured max. intensity / cd	Number of LEDs	Type
Megaman LED MR16 MM27212	24	20	6	970	2	Reflector
Megaman LED MR16 MM27202	36	31	6	580	2	Reflector
Osram Parathom Pro MR16 35 24° Advanced	24	25	7	1305	4	Lens with diffuser
Philips MASTER LEDspotLV D 7	24	24	7	1400	4	Lens
Philips MASTER LEDspotLV D 7	36	32	7	1335	4	Lens
Toshiba LDRA0730MU5EUD	25	23	6.7	1275	3	Lens with diffuser
Toshiba LDRA0730WU5EUD	35	35	6.7	650	3	Lens with diffuser



(a) 24° beam angle (b) 36° beam angle

Figure 7: Measured color mixing for different LED reflectors.

5. CONCLUSION

A complete family of glass reflectors with different beam angles for application in downlights was presented. Main focus of this study was the replacement of existing halogen lamps by an LED solution. In our opinion this can best be realized with standardized components. On the LED side this standardization is already done by the Zhaga consortium. The light source, cooling system, and electrical drivers can directly be exchanged by luminaire manufacturers. For the optics an exchangeable solution was needed. We developed a reflector series with identical size that enables real interchangeability for different beam angles. The diameter of the reflectors is identical to the MR16 standard which offers direct application in existing halogen systems.

The reflectors were made of glass that offers many benefits compared to plastic or metal. Besides chemical and physical durability, glass also allows highest contour accuracy which is needed for the beam control and color mixing. Highly reflective coatings can easily be deposited on glass which gives another advantage to metalized plastic components. We proved that with today's glass production technologies all needed features for the reflector mounting can already pressed in during production. In conclusion, glass is the ideal material for LED applications.

REFERENCES

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