Proceedings

of the

5th International Symposium

on

Progress in **A**utomobile **L**ighting

Darmstadt University of Technology

Laboratory of Lighting Technology

Published by

Prof. Dr.-Ing. H.-J. Schmidt-Clausen

in the Series

Darmstädter Lichttechnik

Volume 10

Herbert Utz Verlag Wissenschaft

München

ISBN 3-8316-0257-3

PAL 2003: Volume 10

Bibliografische Information Der Deutschen Bibliothek
Die Deutsche Bibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http://dnb.ddb.de abrufbar.

ISBN 3-8316-0257-3

Herbert Utz Verlag GmbH, München
Tel.: 089-277791-00
Fax: 089-277791-01
utz@utzverlag.de
www.utzverlag.de

Cover: Hundertwasserhaus, Darmstadt, Photographer: Johannes Hahn

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LED Headlamps – Possibilities and Problems

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Abstract

In recent years the efficiency of Light Emitting Diodes (LEDs) has increased rapidly. Using red, amber or white LEDs for signal functions is already state of the art and offers new styling possibilities. Since up to 70 lm / Watt and 120 lm / LED for white LEDs are predicted, they become interesting for headlamp functions like low and high beam. Therefore new styles and technical solutions are feasible. Nevertheless, creating LED headlamps is still challenging.

Main problems, advantages and disadvantages by creating optical components for a LED headlamp will be discussed.

Introduction

Several advantages will result by building a LED headlamp. The first one is the lifetime of the LEDs and consequential the lifetime of the lamp. The lifetime of a car is around 5000 hours. Lifetimes of LEDs exceed this value considerably. Therefor the accessibility of the headlamp is not necessary any more. Another advantage is the external appearance of the headlamp. It is possible to create a couple of small modules which employ one ore more LEDs and combine them to the desired design. The bluish light gives the lamp a technical image. This enables the stylist to create a special design for a car manufacturer. Beyond this points the fuel consumption can be reduced.

Nevertheless, LEDs have several disadvantages, which make their use in headlamps difficult. LEDs have a high flux but very low luminance. Thus it is challenging to create the demanded light patterns with a high maximum and a sharp cut off line. The luminance derives the size of the optical set up, with which the required light pattern can be created. The size of the headlamp defines the number of optical modules fitting into the headlamp. Thus the number of LEDs fitting in a headlamp is limited. The higher the luminance of the LED, the smaller the optical device and the more LEDs are fitting in the headlamp.

LEDs have a completely different light distribution compared to halogen or HID bulbs. These points make new optical designs necessary. Another important point is the dramatic temperature sensitivity.

From both, the design and the optical point of view, the number of LEDs needed in a headlamp is essential. Due to the roadmaps of the LED suppliers and the long development cycles, the luminous flux of the LEDs on the date of homologation or SOP is not known at the beginning of the development of the LED headlamp. The

problem is aggravated by the fact, that LED suppliers only sells their latest products. Thus there is a certain possibility, that LEDs with the flux, the headlamp is created for, are not available over the whole production cycle. Diagram 1 shows the typical flux roadmap for the 1 Watt white Luxeon LED.

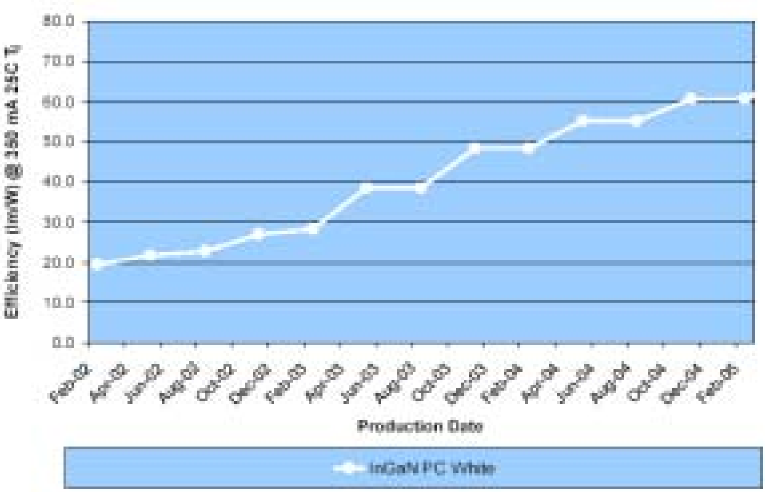

Figure 1: *Luminous flux versus production timing for 1 Watt white LumiLeds LEDs.*

Moreover, the number of LEDs needed for a special headlamp function depends on the assumptions under which this number is derived. Some car makers just want to have a LED headlamp for styling reasons. This headlamp must be just legal. Other car makers want to have the performance of a HID headlamp, because they do not accept less performance for a higher price. The first LED headlamps will be more expensive than HID headlamps. Another point is that different set makers employ a different safety factor in the roadmap of the LED manufacturers. Therefor a enormous variation in the number of LEDs needed for a headlamp are out. Based on the LumiLeds roadmap the number of needed LEDs for a low beam function under several circumstances is calculated:

Efficiency of the system:	40%
Luminous flux on the street:	300 lm (just legal)
	1000 lm (HID)

The table shows, that the range in numbers of LEDs is from 5 LEDs in 2005 for a just legal low beam function to 60 LEDs for a low beam function with HID performance in 2003. The range of the luminous flux of the LEDs themselves is not taken into account.

	Number of LEDs			
	October 2003		October 2005	
P [Watt]	HID	Just legal	HID	Just legal
1	60	17	30	10
2	35	11	18	5

Table 1: Number of LEDs needed for a low beam module calculated under several circumstances.

Discussion of white LEDs Characteristics and Comparison with other light Sources

White LEDs converts blue light from a InGaN chip to higher wavelength by phosphor conversion. The use of this LEDs will became possible for automotive front lighting functions soon. To get a feeling for the feasibility of LED headlamps the characteristics of LEDs are compared with halogen and HID bulbs.

Important for a lighting application is the flux of the light source. Two Watt LEDs will reach the 100 lm value by 2005. The H7 bulb (typical halogen bulb) has 1100 lm, a HID bulb has 3300 lm.

Even more important as the flux is the luminance, and this is the weak point of a LED. In 2005, LEDs will have a luminance of 10 Cd/mm^2, a H7 bulb at nominal light flux 20 Cd/mm^2, HID bulbs (DxS): 62 Cd/mm^2. To get a good ECE low beam, a maximum of at least 20,000 cd is necessary. The position of the maximum must be as closed to the cut off line as possible. This results in a intensity factor of approximately 40 within one degree.

The next point is the efficiency, because the fuel consumption should be reduced by using LED headlamps. In 2005 the efficiency of a 1 Watt LED will approximately 60 lm/Watt that of a 2 Watt LED approximately 50 lm/W. The efficiency of a halogen bulb (H7) is 20 lm/Watt, for a HID (DxS) 90 lm/Watt, respectively. LEDs will exceed the efficiency of a halogen bulb, but it will be very hard to beat a HID bulb.

LEDs are available with several radiation patterns. All of them illuminates the half space (2π). Halogen and HID bulbs for automotive application are pseudo-lambertian emitters, illuminating the whole space (4π), except of some areas like toward the wire bonding and the bulb holder.

Shape and position of the lucent area

The chips are square, but the shape of the luminous element is defined by the way, the phosphor is added to the chip. This results in two different shapes of the luminous area available today. If the phosphor is added directly to the chip, the luminous element is square, too.

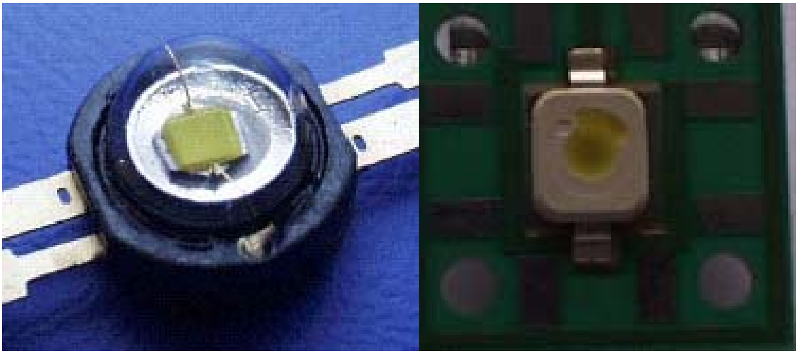

Figure 2: Left: 1,2 and 3 Watt Luxeon package. Size of the Chip: 1 mm x 1mm. The phosphor is added directly to the chip.

Right: 1 Watt Osram Dragon, diameter of the emitting element: 3 mm, Size of the Chip: 1 mm x 1 mm. The phosphor is added into the cavity of the lens.

If the phosphor is added into a cavity of the lens, the shape of the luminous element is disk. Halogen and HID bulbs for automotive application are developed specially for head lamp functions. The shape of this bulbs are well known and enables the set makers to create all function for a headlamp. LEDs for the automotive market are also employed in a lot of non automotive application like signal lamps e.g. Therefor, the shape of the LED is not adapted to headlamp application.

The tolerances of the position of the optical element of the LEDs are high. The tolerances of a helix of a halogen bulb or a arc of a HID bulb are well known.

Optical systems for LED headlamp functions

The characteristics of the LED makes a conventional imaging optics, employing a light source and a reflector for a low beam function difficult to realise. This systems requires a precise knowledge of the light source. The optical principle for a LED optics should be tolerant to different optical characteristics of the luminous element. It should be possible, to insert LEDs from several suppliers into the optics.

One solution is a projection system, using a optical device, which collects the light in a second focal point, like a elliptical reflector or a lens. The cut off is created by projecting the light pattern at the second focal point by a lens. Due to free-form technology, there is no shield necessary to create a cut off.

Optical Principal of a proposed LED Fog Lamp:

Figure 5: Vertical section through a proposed LED fog lamp. This module employs a LED, a lens, which directs the light into a certain area and a cylinder lens, which projects the light on the street.

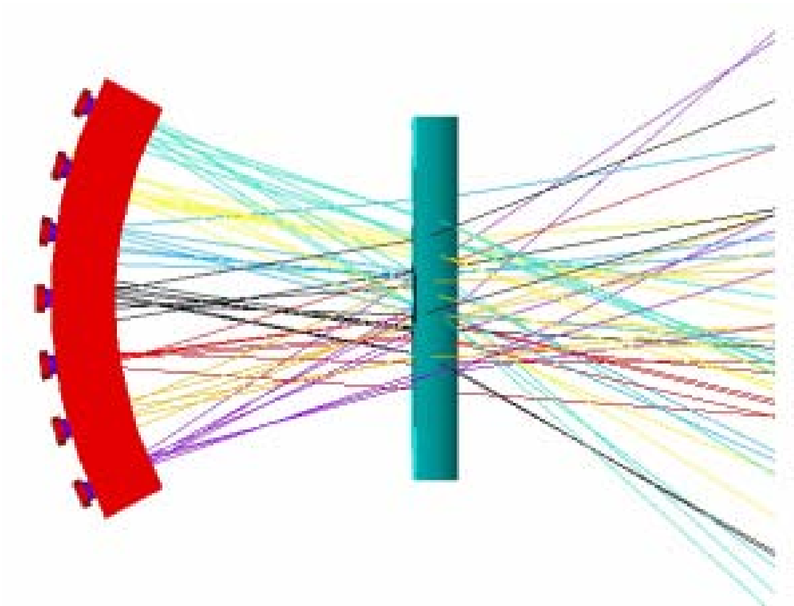

Figure 6: Horizontal view of the proposed LED fog lamp. The broad light distribution is achieved by the position and the angles of the LEDs and the associated optics.

The requirements for a fog lamp is a horizontal broad and vertical narrow light pattern. This LED fog lamp module consists of several LEDs, a freeform lens or reflector associated to each LED, which creates an image of the LED in a distance of some 10 mm in front of the LED. A cylinder lens projects the light pattern on the street. The narrow vertical light distribution is achieved by the cylinder lens, which has only a curvature in vertical direction. The broad horizontal light distribution is achieved by the position and the angle of the LEDs and the associated optics. The big advantage is, that the individual modules do not have to be adjusted to each other to get a straight cut off. The height of the cylinder lens can be as low as 35 mm. The width of the system depends on the number of LEDs in the module, which depend on the luminous flux of the LEDs which depends on the roadmap of the LED manufacturers.

Comparison between simulation and measurement

Input data for the simulation:

- Light source: LumiLeds Luxeon lambertian
- Luminous flux per LED: 90 lm (Flux of a 2 W LumiLeds LED in a headlamp, reduced value due to temperature) reasons ect.)
- Number of rays per LED: 10^6

Simulated light pattern:

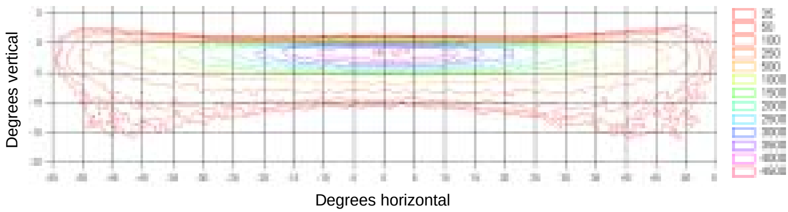

Figure 7: Simulated light pattern (isolines in cd).

The maximum is approximately 4600 cd, the luminous flux on the screen is 390 lm (Input: 630 lm), therefor the efficiency is 62 %. The 625 cd line is located at 45° horizontal.

Data of the measured LED fog lamp:

LumiLeds LEDs, operated at 150 mA, total luminous flux: 70 lm.

Measured light pattern: