SAE TECHNICAL PAPER SERIES

2008-01-0339

LED Headlamp Development for Mass Production

Tetsuaki Inaba
Koito Manufacturing Co., Ltd.

Shinya Watanabe and Yuji Yamada
Toyota Motor Corporation

Reprinted From: Automotive Lighting Technology, 2008 (SP-2149)

ISBN 978-0-7680-1631-4

9 780768 016314

2008 World Congress
Detroit, Michigan
April 14-17, 2008

SAE International™

400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A. Tel: (724) 776-4841 Fax: (724) 776-0790 Web: www.sae.org

By mandate of the Engineering Meetings Board, this paper has been approved for SAE publication upon completion of a peer review process by a minimum of three (3) industry experts under the supervision of the session organizer.

For permission and licensing requests contact:

SAE Permissions
400 Commonwealth Drive
Warrendale, PA 15096-0001-USA
Email: permissions@sae.org
Tel: 724-772-4028
Fax: 724-776-3036

SAE® Global Mobility Database®

All SAE papers, standards, and selected books are abstracted and indexed in the Global Mobility Database.

For multiple print copies contact:

SAE Customer Service
Tel: 877-606-7323 (inside USA and Canada)
Tel: 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org

ISSN 0148-7191

Positions and opinions advanced in this paper are those of the author(s) and not necessarily those of SAE. The author is solely responsible for the content of the paper. A process is available by which discussions will be printed with the paper if it is published in SAE Transactions.

Persons wishing to submit papers to be considered for presentation or publication by SAE should send the manuscript or a 300 word abstract of a proposed manuscript to: Secretary, Engineering Meetings Board, SAE.

Printed in USA

2008-01-0339

LED Headlamp Development for Mass Production

Tetsuaki Inaba
Koito Manufacturing Co., Ltd.

Shinya Watanabe and Yuji Yamada
Toyota Motor Corporation

ABSTRACT

To meet the market requirement for headlamps having lower power consumption, high photometric performance and long life whilst providing new styling opportunities, it has been anticipated that LED light sources would provide the necessary technological basis. Against this backdrop, Koito has succeeded in developing the necessary headlamp technologies and commercializing the world's first headlamp utilizing white LED's. The key point is that the various challenges associated with the development of an LED headlamp such as the commercial application of a synthesized light distribution, control of the light axis structure for the multi-lamp system, development of adequate thermal management for the cooling of the LED's and the achievement of volume production of the lamps have been successfully overcome.

1. INTRODUCTION

In recent years, LED's have been adopted for an ever widening range of applications and numerous examples of the replacement of incandescent and fluorescent light sources due to the dramatic improvements in the efficiency of white LED's can be found.

Automotive lighting devices, as with other lighting equipment, should exhibit low power consumption, long lifetime and provide new design opportunities. LED light sources provide the best potential to realize these requirements and Koito has succeeded in developing the world's first headlamp installed in the LEXUS LS600h and incorporating white LED's.

This report describes three key elements in the development for commercial production; the superimposition of beam patterns through the application of a novel method of light axis alignment for a multiple lighting unit arrangement; the design of a passive thermal management system to cool the LED's; and the approach toward the requirement for snow melting with a headlamp using LED's that due to their characteristics will not generate heat on it's front surface.

2. HEADLAMP SPECIFICATION

The LEXUS headlamp incorporates LED's for the low beam and the clearance and front side-marker lamps. The LED low beam module, which is a core element in the development of this headlamp, is indicated by the area marked in figure 1 below. The optical system of this low beam module consists of three projector units, capable of swiveling left and right as an AFS system, and one parabola unit. Passive heat sinks are located on the die cast supporting bracket.

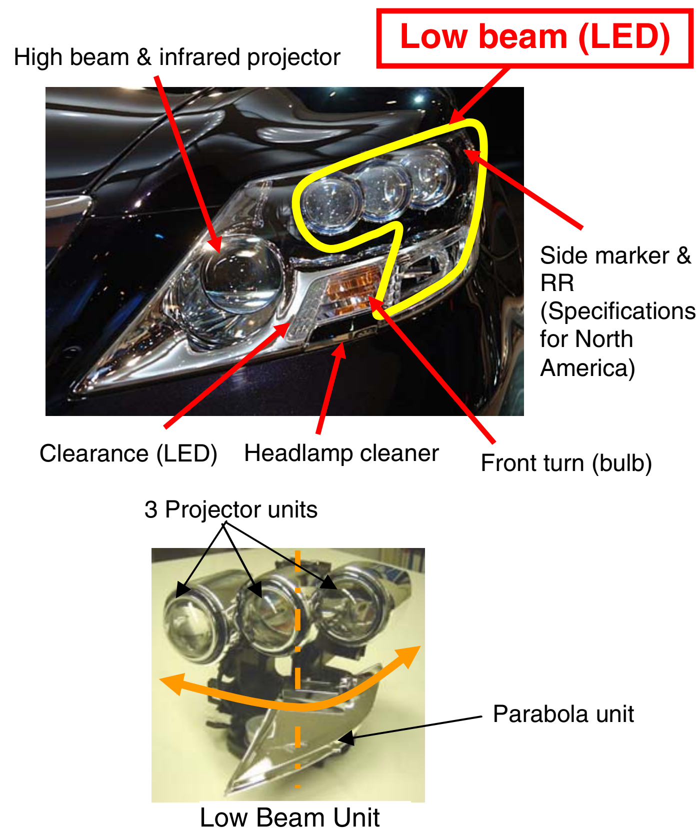


Figure 1. Overview of the LED Headlamp

2.1 PRINCIPAL FEATURES

a) The photometric performance of the LEXUS headlamp is comparable to that of high performing headlamps fitted with High Intensity Discharge light sources as demonstrated in figure 2

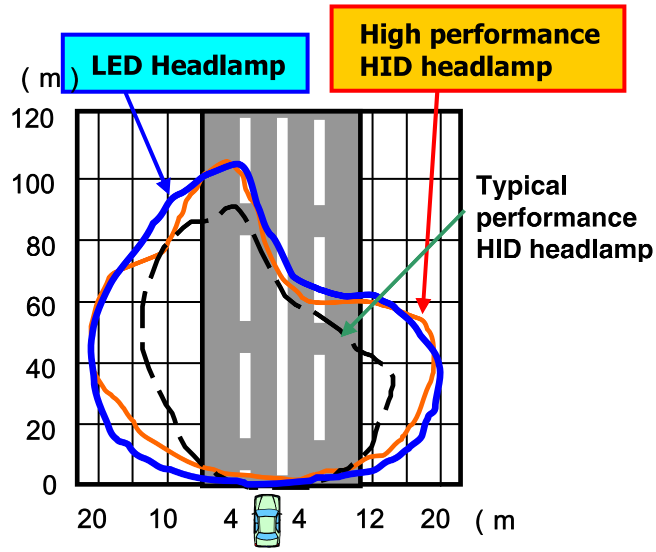


Figure 2. Comparison of low-beam performance on a road

b) A unique approach using multiple LED light sources in a triple projector system as shown in figure 3

Figure 3. Design of the triple projector lamps

Even though three projectors are placed so close that they overlap each other, the cone shaped footprint of the diverging light from each projector is designed not to be interrupted by the next projector.

2.2 ADVANTAGES OF LEDS

a) Longer life
Halogen and HID headlamps usually burn out suddenly, while the LED headlamps gradually lose brightness. (see figure 4)

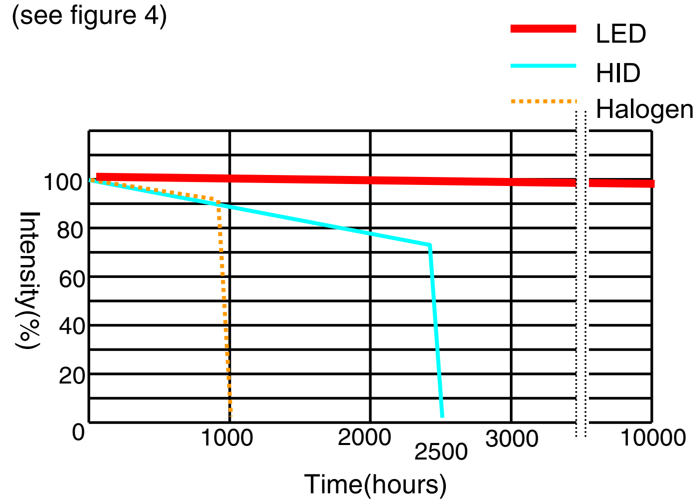


Figure 4. Comparison of light source life

b) Superior startup characteristics
(LED: 0.1 sec, HID: several seconds); see figure 5

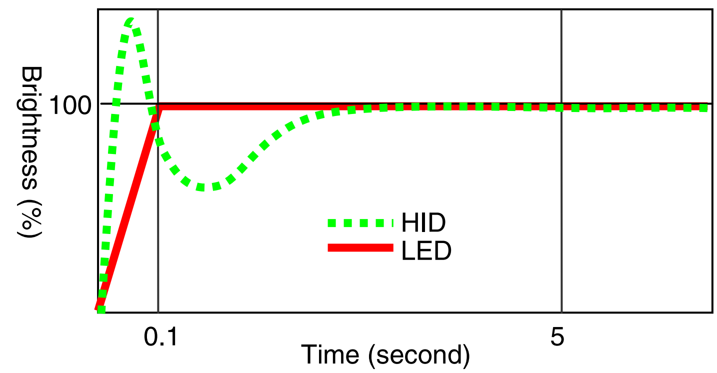


Figure 5. Comparison of Start-Up Characteristics

c) New styling opportunities

3. TECHNICAL CHALLENGES

The employment of LED light sources is a major innovation in the history of headlamps and since they involve new technologies and constructions, there were many technical challenges to be overcome, such as:

- Arrangement of the optical axes to ensure that the beam patterns from the multiple-light unit are accurately aligned and correctly superimposed
- Development of an optimal heat dissipation structure to ensure that the high output of the LEDs is maintained under normal operating conditions
- Development of a snow melting measure to provide a substitute for heating effect of conventional headlamp light sources that is not present in the case of LEDs

4. OPTICAL AXIS DESIGN

4.1 CONCEPT OF THE OPTICAL AXIS

The concept of the multiple lighting unit system, the beam distribution is achieved by the accurate superimposition of the beam patterns produced by the various contributors. In the LEXUS headlamp the optical system consists of four units:

a) A projector unit producing a narrow focused beam providing the central intensity,
b) A projector unit producing a medium width light distribution
c) A projector unit producing a wide light distribution
d) A small parabolic reflector unit providing a very wide light distribution

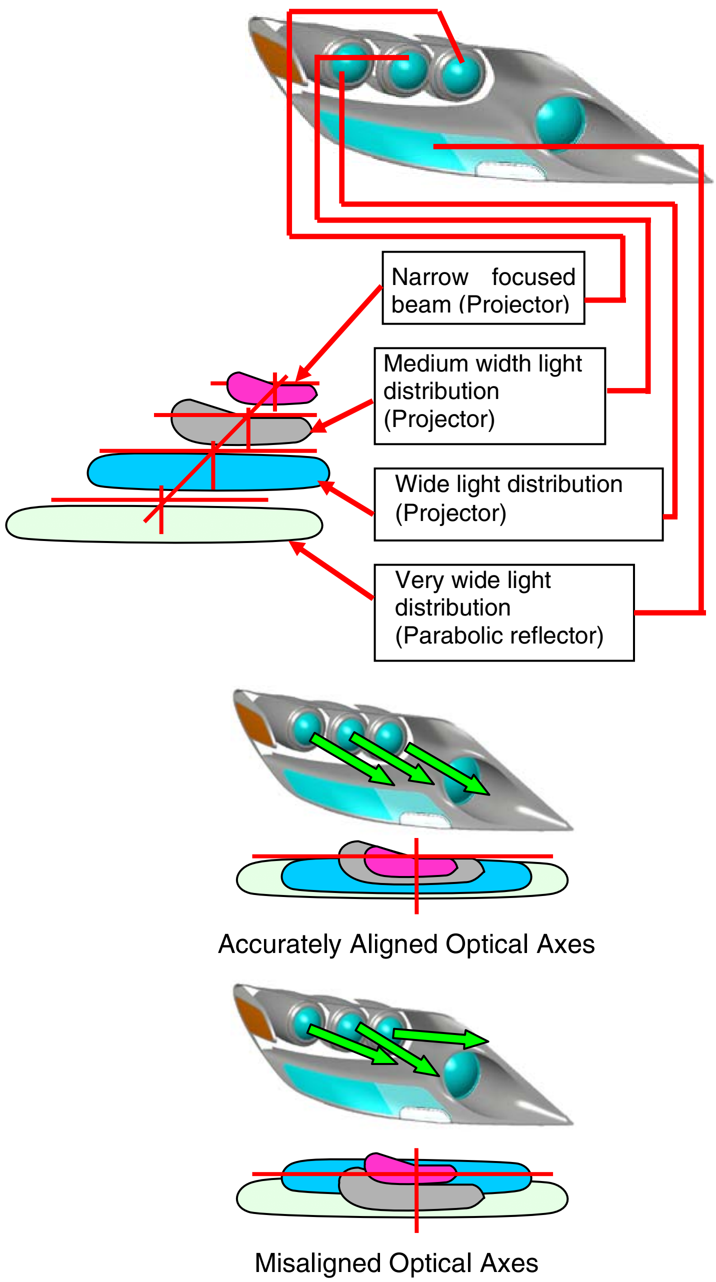


Figure 6. Superimposition of the Beam Patterns from the Various Contributors

In order to create the required beam distribution, the axes of the four units must be accurately aligned. This is particularly important in the case of the lighting units producing the cut-off as discussed below.

4.2 FACTORS CONTRIBUTING TO OPTICAL AXIS MISALIGNMENT

There are two elements that influence accurate alignment of the optical axes as shown in figure 7:

1. Misalignment of the positional relationship between the lens and the internal shield in the projector unit

2. Displacement of the supports of the optical units affecting the positional relationship of the three projector units

Since the dimensions of the optical system of the LED headlamp are smaller than those of conventional headlamps, even very minor dimensional errors affect the accuracy of the optical axis alignment. This means that great attention is required in the design of the components that affect the accuracy of the optical axis alignment and at the manufacturing stage.

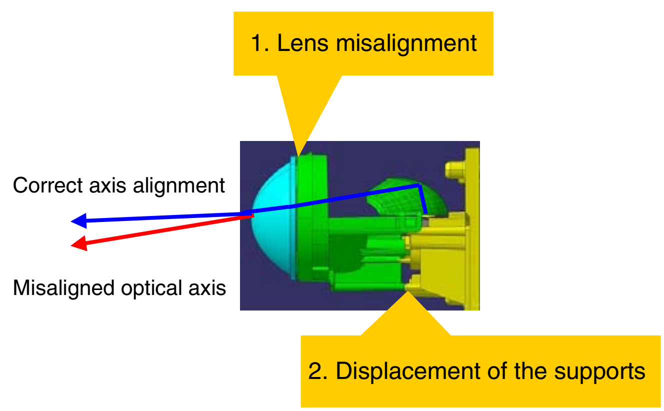


Figure 7. Factors Contributing to Optical Axis Misalignment

4.3 ENSURING THE ACCURACY OF OPTICAL AXIS ALIGNMENT

The following elements have been incorporated into the design to ensure the accuracy of the optical axis alignment

a) Lens Positioning Structure

To increase the accuracy of the positions of the lens and the internal shield of the projector unit, a positioning mechanism with highly accurate pins and holes is provided. The assembly is then completed by laser welding and by the use of only three welding areas, flatness after welding is enhanced (Figure 8).

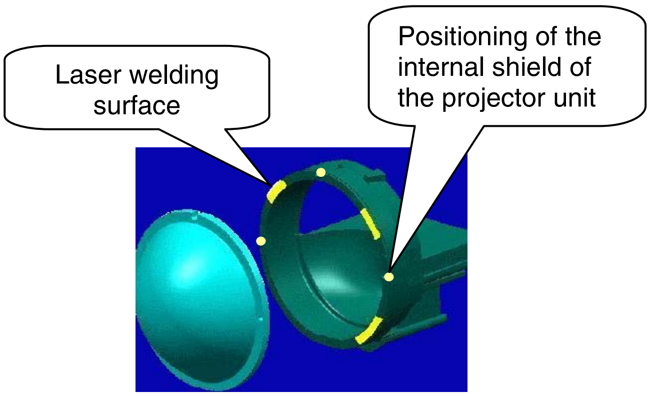


Figure 8. Lens Positioning Structure

b) Optical Unit Support Structure

To increase the accuracy of the optical unit support system, a 3-point arrangement is provided for the assembly of the optical units and brackets to fix the optical axis position (Figure 9).

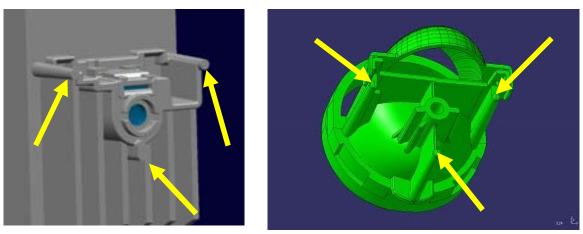


Figure 9. 3-Point Support Structure

5. HEAT DISSIPATION DESIGN

5.1 HEAT DISSIPATION MECHANISM

As more power is input to a LED, the brighter it becomes. However, this also raises the temperature of the LED, and if it exceeds the service temperature limit, the LED will fail or its life will be shortened. Therefore, high heat dissipation is required. The heat dissipation mechanism of the LEXUS headlamp is shown in Figure 10. The temperature rise of the LED is controlled by dispersing heat from the LED to the heat sinks for dissipation.

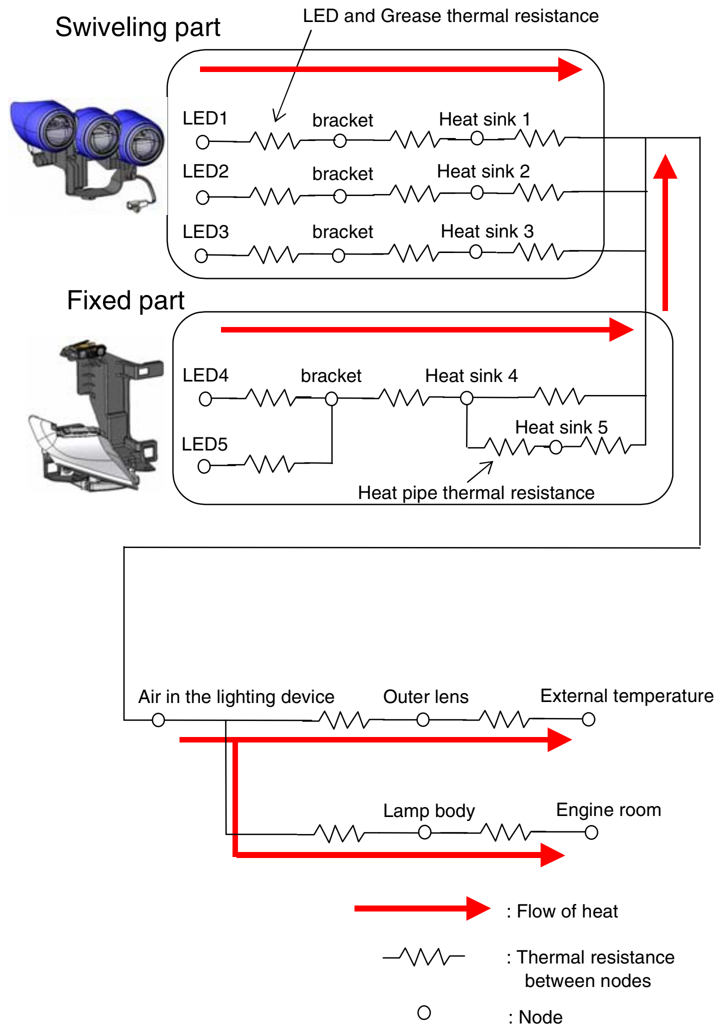


Figure 10. Heat Equivalent Circuit

5.2 NATURAL CONVECTION COOLING DESIGN

To achieve the highest-class beam performance of existing HID headlamps, the LEXUS LED headlamp consumes about the same power as the HID headlamp. One option for heat dissipation is forced cooling using fans, but a complex system with fail-safe mechanisms is required to ensure the reliability of the fans, and this was considered not to be cost effective. It was therefore decided to employ an optimized heat sink configuration to create natural convection without cooling fans to keep the junction temperature of the LEDs below the maximum value (Figure 11). The simulation results show a large air flow at the heat sinks, meaning that natural convection is created (Figure 12).
This simple heat dissipation method ensures long-term reliability at low cost.

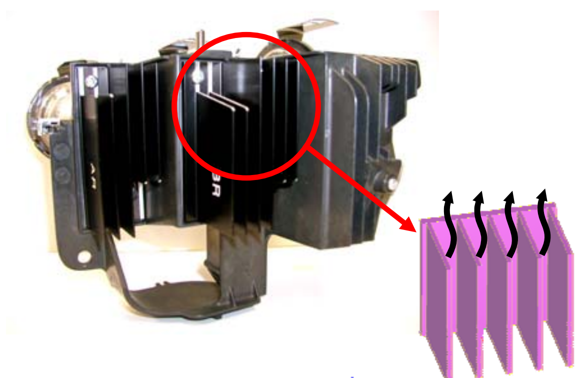


Figure 11. Heat Sink Configuration

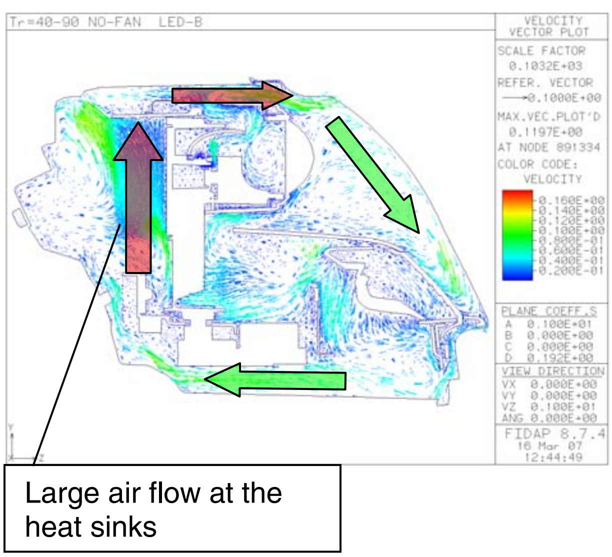


Figure 12. Convection Flow Simulation in the Headlamp

The Lexus LED headlamp has a cylindrical parabolic reflector equipped with two adjacent LEDs, and heat is concentrated in this area. Due to the requirement for a swiveling AFS unit, a sufficiently large heat sink could not be accommodated behind the reflector, so a heat pipe is used to conduct heat to other parts of the assembly in order to cool the LEDs.

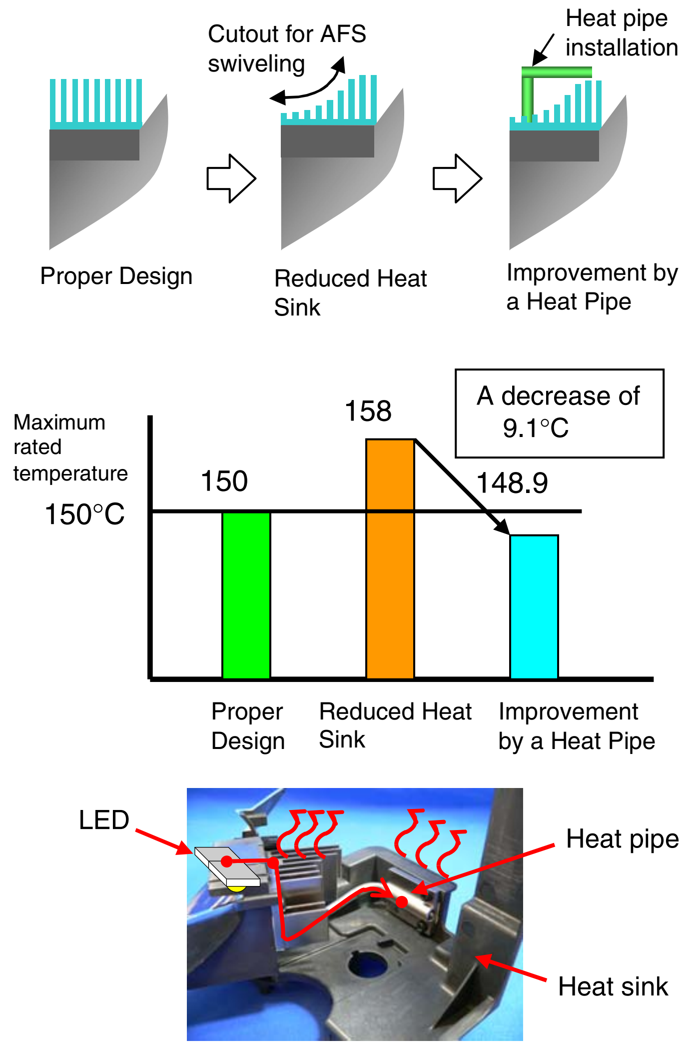


Figure 13. Effects of Heat Pipe

5.3 RESULTS

To achieve high performance LED headlamps a dissipation mechanism to remove heat from LEDs is required. By adopting a system of natural cooling electrical failure of fans is precluded ensuring long-term reliability and a higher quality LED headlamp. The efficient heat dissipation design also minimizes the size of the heat sinks and thus reduces weight. This is an important factor where it is necessary to move the low beam assembly in the case of swiveling AFS and leveling.

6. SNOW-MELTING MEASURES

Since the light emitted from LEDs does not contain heat, the surface temperature of the lens of LED headlamps remains cool compared with halogen and HID headlamps. This presents a major challenge for melting and clearing snow.

Table 1. Surface temperature of the lens

	Halogen	HID	LED
Surface temperature of the lens	40-50°C	17-35°C	10°C

Ambient temperature
−3 - −5°C

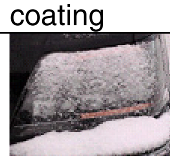
Figure 14. Snow Accumulation

Three approaches were examined as shown in the table below:

a) The use of the headlamp cleaner in conjunction with an anti-freeze washer fluid,
b) Installation of a heater on the inner surface of the lens,
c) The use of a water-shedding coating.

Both the headlamp cleaner and heater were found to be effective, and the cleaner was finally chosen in view of its lower cost.

Table 2. Study of snow melting method

	Cleaner	Heater	Water-shedding coating
Test results	 50% diluted washer fluid sprayed	 A wire heater attached to the inner surface	 Contact angle of 100° in specification
Performance	Effective	Effective	Ineffective

7. CONCLUSION

Koito has succeeded in mass-producing the world's first LED headlamps by solving the problems specific to LEDs where a very different approach to that adopted with conventional bulb headlamps is required. Since the development of LED light sources will continue, it is expected that the luminous efficiency of LED headlamps will exceed that of HID headlamps. In addition, LED light sources have the advantage of longer life (high lumens maintenance even after 10,000 hours of use) and offer a safety improvement for cars entering tunnels in the daylight as they light up in just 0.1 second. Additionally LED light sources are mercury-free and provide greater flexibility of design and headlamp style. White LEDs are clearly the next-generation light source and there are great prospects for the development of LED headlamps producing high performance beam patterns whilst also satisfying the trends in vehicle design and packaging.

REFERENCES

1. Masaru Sasaki, *LED Headlamps*, Proc. Progress in Automobile Lighting, Darmstadt, 2003, p.930-941

2. Kiyoshi Sazuka, *LED Headlamps*, SAE 2004-01-0437

3. Masaru Sasaki, *Applications of white LED for automotive lighting devices*, Japanese Journal of Applied Physics, Vol.74 No.11 p.1463-1466 (2005)

4. Shigeyuki Watanabe, Shinya Watanabe, *Development of LED Headlamp*, Proc. Int. Sympo. Automotive Lighting, Darmstadt, 2007, p.930-941