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A review on light-emitting diode based automotive headlamps

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ABSTRACT

Benefited from the fruitful results of general light-emitting diode (LED) lighting, the LED is utilized in the automotive forward lighting recently, the LED headlamp, due to its ability of improving the efficiency, durability and comfort of the automobile. Both the rough operating environments and rigorous safety standards make the design and verification of the LED headlamp face more challenges than that of the general LED lighting. Although there are some concerns about the status of the LED headlamp, these efforts mostly focused on a single issue, and little knowledge has been established from a system-level aspect. To obtain an up-to-date and systematical summary of the progress of the LED headlamp, in this review, after a description of the fundamentals of the LED headlamp, its design methods are scanned firstly following the categorized components: the LED array module, the heat management, optics control as well as the driver electronics; then, the verifications of the LED headlamp are explored according to the plug-in efficiency, cost, lifetime and reliability; next, the trends of the LED headlamp with the additional function of data transmission and integration of human factors are illustrated; and a conclusion is given finally. The results show that the LED headlamp is a complex electrical–optical–thermal–mechanical system, involved human factors; currently it reaches the state-of-the-art on the efficiency, while the cost is about 350% more than that of the halogen headlamps; additionally, the lifetime and reliability issues, which are closely related with the junction temperature and the moisture diffusion, least understands in human response to LED light as well as immature regulations do challenge the development of LED headlamp. However, the system-level, functional and human factors based solutions cast a light on the future LED headlamp.

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1. Introduction

The headlamp is a lamp attached to the front of an automobile to provide the driver the visual range while overcome the light glare of oncoming vehicle when driving at night or in obscured light conditions. The headlamp is typically considered as one of the most important safety devices on automobiles. It is reported that about 40% of fatal accidents is happened during night, and declared that the diminished visual performance is the major contributor [1,2]. Regularly, for a headlamp a thousand of lumen light output is required, which is converted from the electric energy of the battery charged by the automobile engine. Although the headlamp working time is only 25% of a day [3], the additional energy consumption or the operating cost of the headlamp cannot be omitted. For example, about 55 billion liters of gasoline and diesel or 66 billion USD costs are spent annually in operating the headlamp [4]. As reported by the U.S. Department of Energy [5], the electrical-to-optical power efficiency of LED luminaires is up to 30%, and it will surpass the 50%, meanwhile, the efficiency of the traditional ones is only 5% for halogen or 20% for xenon respectively. If the LED headlamps can replace all the traditional ones, the automobile will minimize the fuel consumption for the automotive lighting to 10%, and lead to a reduction of CO_2 emission by about 1–3 g/km [6].

Since the high power white GaN-based light-emitting diode (LED) has been invented in the 1990s [7], its application in the concept headlamp dates back to 2002 by Lighting Research center, USA [8]. There have been numerous attempts due to its longer lifetime, lower power demand, faster response time, more visual flexibility and closer to daylight color than the conventional light resources such as halogen and xenon lamps [9–13]. The first LED headlamp prototype is demonstrated by Hella cooperation, France in the 2005 [14], and recently, the commercial LED headlamp can be seen in such as LS600h [15]. Adaptive light beams can be realized by the simple electrical control in the LED headlamp rather than the mechanical control with motors in traditional headlamps. Besides, the LED headlamp also has a function of the visual light communication (VLC) [16], where the data can be transferred by modulating the LED output light. Therefore the LED headlamp is a hot topic in the current automotive industry.

However, the LED headlamp is still not in volume production. The reasons lie in the existing challenges in design and verification of the LED headlamp [17–19]. On one hand, the LED headlamp has a higher power density than signaling lamp [20], on the other hand, the operating environments and the regulated requirements of the LED headlamp are tougher than the general LED lighting such as street lighting [21]. Fortunately, the achievements of the general LED lighting [4,5] provide a clue to deal with these challenges.

In recent years, the electrical–optical–thermal physical issues of LED headlamps have been highlighted, and the unique features of the LED headlamp have been continuously addressed by many proposed design methods involving the thermal dissipation, the optical process, the electrical driver and the material structure, as well as the efficiency, cost, lifetime and reliability. Some of them, especially the thermal issue [22], investigated in certain literatures, reach a better design performance, but most of these attempts focus on a single physical field or unit of the LED headlamp. To the authors' knowledge, systematical and up-to-date review of the LED headlamp's progress is not found at present. To address the above point, this review tries to generalize the studies of the LED headlamp and summarize its technical achievements systematically; some important fundamentals of the LED headlamp are described firstly, then the status of the LED headlamp's design and verification are explored respectively, next, the development trends are illustrated, and a conclusion is drawn finally.

2. Fundamentals of the LED headlamp

Fig. 1 illustrates a boarding interface of the LED headlamp in a vehicle. The LED headlamp is fixed mechanically by screws into the vehicle's front body, powered from the electrical power distributor in junction box and controlled by light or body control module (BCM) through the CAN or LIN communication bus [15]. There are ambient factors (such as the temperature, humidity and dust) and usage conditions (e.g. frequency, maintenance and pollution) influencing the performance of the LED headlamp.

As a type of headlamp with functions of exterior decoration and lighting, the design of the LED headlamp still involves three topics including the geometrical structure design, the power control and management, the environment and usage durability. This review, however, mainly focuses on the last two topics because the geometrical structure design is a relatively dependent topic and out of our scopes.

The power control and management of the LED headlamp is realized by the four main components [15,23]: electrical drivers, LED array modules, thermal solutions, and lens or reflectors, as illustrated by the available products from Koito, Visteon, ZKW,

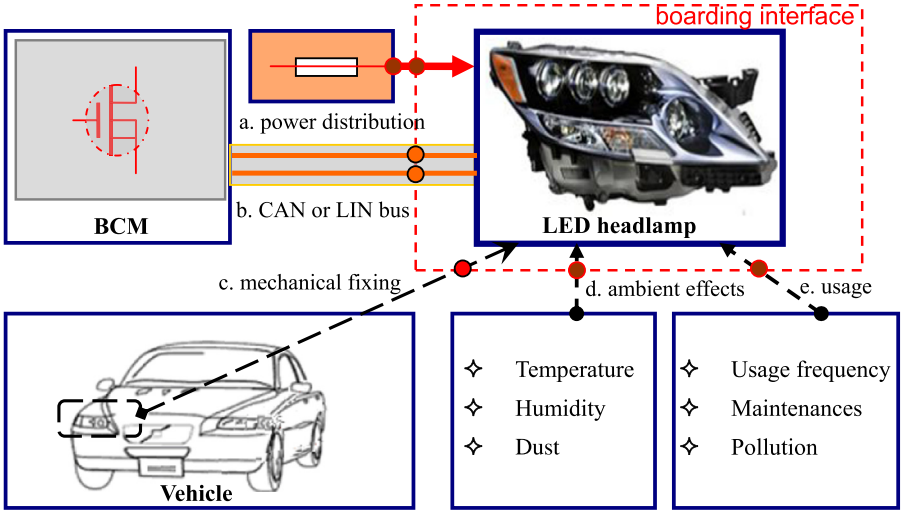

Fig. 1. Illustration of the boarding interface of the LED headlamp in a vehicle.