A brief analysis of the development process and future trend of automobile headlights

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Abstract. As an important component of automobile lighting, headlights have gone through the development process from acetylene headlights in the early days of birth to a wide variety of new headlights today. The article focuses on the development status, prospects, and trends of LED lamps in the lamp market, and analyses and prospects for the future of new lighting technologies such as OLED lamps, LCD lamps, and laser headlights.

1 Forward

In 1886, Carl Benz invented the world's the first three-wheeled car, and Daimler launched the first four-wheeled car in the same year. The lighting system of automobiles consists of a variety of light types, which can generally be divided into headlights, taillights, steering signal lights, driving lights, interior (ambient) lights, etc. Automotive headlights are an important part of the automotive lighting system, which is related to night driving safety, road condition information interaction, and other functions. At first, cars used candle lights as headlights to realize lighting when driving at night. This lighting device mainly passes through the lens in front of the candle and the mirror behind the candle. The faint light generated by the candle can be converged, thus realizing the effect of enhancing the lighting effect. At the beginning of the 20th century, acetylene lamps became an ideal automotive lighting device due to their advantages of higher brightness and more prominent lighting effects. However, kerosine lamps and acetylene lamps were gradually replaced by halogen lamps with higher luminous intensity, lower energy consumption, and longer lifespan in the mid-20th century due to environmental constraints and poor lighting performance. In 1992, Bosch and Haila respectively released their first xenon headlight product, which has better performance than halogen lamps and was used in BMW 7 Series E32 models in the same year. Decades later, before xenon headlights were fully popularized, LED lights began to emerge and gradually penetrated car lamps. Compared with halogen lamps and xenon lamps, LED headlights convert electrical energy into light energy through light-emitting diodes, so LEDs have many advantages such as bright and rich colors, high brightness, long service life, high efficiency, low energy consumption, small system and light quality [1]. In recent years, the penetration rate of LED headlights in the market has increased rapidly, which has promoted the innovation of automobile lamps in performance and appearance. At the same time, it has attracted the participation of enterprises and successfully owned many potential consumers. The history of car lights is almost as long as that of automobiles. Automotive headlights are also the focus of major car companies and have experienced a complex development process.

2 The development process of car headlights

2.1 Traditional car headlights

(1) Acetylene headlight (before 1925). As the first generation of practical headlights, acetylene is a colorless and odorless gas produced by chemical reactions of calcium carbide and water. It can be used for fuel combustion and luminescence, which was first used in mine lighting [1]. Because its lighting time is much longer than that of electric lamps and has a strong contour light type, it has become the earliest car headlight instead of electric lights, but its service life is low.

(2) The headlight of the electric light source (1925-1970). The electric source headlamp uses tungsten wire as the light-emitting medium. The tungsten wire lamp is filled with inert gas or extracted into a vacuum state. After the tungsten wire conducts the filament to heat it to the target temperature, the filament shines up independently. The disadvantage is that when working normally, the tungsten atom in the tungsten wire will sublimate and condense on the light bulb or body, polluting the lampshade, and thus reducing the brightness.

(3) Double-light wick headlight (1924). Dual-light wick headlight, also known as a symmetric near-light system, an inflatable tungsten bulb with high contour brightness will dazzle the driver because of its strong light when meeting, so it creates two requirements to ensure that the opposite driver is not dazzling while getting good

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lighting. This is still an important indicator to evaluate the safety and practicability of headlights.

(4) Asymmetric near-light headlight. The asymmetric near-light headlight can make up for the hidden danger caused by the shortening of the inter-view distance between the symmetric near-light system when switching high and near-light. The asymmetric near-light headlights are asymmetrically treated with the left and right light sources. The beam near the intersection of the two cars will be lowered to avoid dazzling the driver; the beam away from the intersection will be raised to obtain a wider visual distance. Ensure a safe visual range without dazzling circumstances.

The above four types of headlights have been eliminated by Volkswagen models. Under the premise of good performance, the car lamp market also pursues to promote driving safety and comfort, mainly halogen lamps, xenon lamps, LED lamps, and other types.

2.2 Modern car headlights

The penetration rate of the domestic passenger car headlight market from 2017 to 2022 is shown in Figure 1.

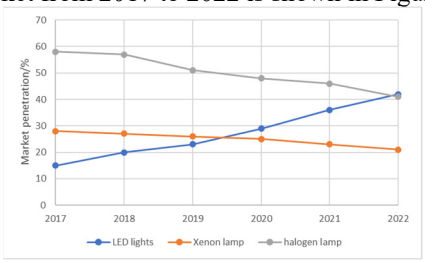

Fig. 1. Market penetration rate of domestic passenger car headlamps from 2017 to 2022

As can be seen from Figure 1, the market penetration rate of LED lamps has increased year by year, and the market share has increased rapidly in recent years. It shows that the development trends of LEDs have been booming in the past few years. It can be predicted that the price trend will tend to be affordable after the technology matures in the next few years. When the effect is stable and innovative, it is expected to replace the dominance of xenon lamps in the market.

(1) Halogen lamp.In the early stage, halogen lamps were mainly used in most middle and low-end models due to their low price. After that, with the advantages of simple structure, easy installation, stable performance, uniform light, and strong penetration, it occupies the largest market of headlights. Its disadvantage is that brightness cannot be guaranteed, vibration powder, and poor night vision cannot be avoided, leading to its gradual elimination from the market [2].

(2) Xenon lamp. Xenon lamp is a plasma discharge luminescence formed by xenon gas after being excited by a high-voltage electric field [3]. It was first used for aerial lighting. Compared with halogen lamps, xenon lamps have lower energy consumption (only 0.6 times that of halogen lamps),longer service life (about 6 times that of halogen lamps), higher absolute brightness (about 3 times that of halogen lamps), and the quality of the light source is close to that of sunlight, which greatly increases the safety and comfort of driving. It is generally configured in high-end models and high-end models. However, the disadvantages of xenon lamps are obvious. They have poor concentration, poor penetration ability, slow response speed (2-4 s), complex structure (which need to be used with lenses and stabilizers), high installation costs, and will dazzle opposite lane drivers and affect road driving safety (which can be improved after installing lenses).

(3) LED lights.The LED light source is a light-emitting diode that uses a solid semiconductor chip to generate excess energy through carriers in semiconductors, causing photons to emit light of different colors [4]. Compared with xenon lamps, LED headlights not only have stable performance, and fast response speed, but also technical strength and appearance. They have the advantages of high light quality (80% to 90%), small dead angle of irradiation, long service life (60,000~100,000 h), high-speed switch and environmental protection, good seismic performance, lightweight, small volume, small load, weak interference, rich color, etc. LED can frequently switch the opening and closing state according to the actual lighting needs, and will not significantly affect the service life and failure rate of the light source. It can be used with the vehicle induction lighting control system [5]. However, due to its high cost than that of halogen lamps and xenon lamps, poor heat dissipation, and technical barriers such as uneven spatial light color distribution and difficult matrix combination, it is mainly used in high-end models in the early stage of the birth of LED headlights. Besides, with the vigorous support of the state in the field of automobile lighting, the light source and lighting system of automobiles in the new era will also continue to improve. It is foreseeable that the design cost of LED light sources will gradually decrease and continue to penetrate the public field [6].

The proportion of headlamp types of some automobile brands in recent years in Figure 2.

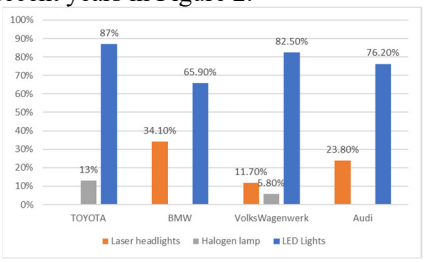

Fig. 2. Proportion of headlamp types in different car factories in recent years

Take Toyota, BMW, Audi and Volkswagen as examples. At present, the most widely used lamp types in the market are halogen lamps, laser headlights and LED lamps. Most of Toyota use LED lamps, and a few cars still use halogen lamps, while laser headlights are not used for production; BMW and Audi are still in the dominant position with the gradual use of laser headlights; Nowadays, the halogen lamps, LED lamps and laser headlights of Volkswagen are in use and production. It can be seen from this that LED lamps account for the largest proportion in the current market and are the most widely used headlamp type in existing car manufacturers. At present,

halogen lamps have been eliminated by most large car drivers and have a very low market share.

Secondly, at this stage, laser headlights are almost all used in high-end models, and mainly used in high beam lamps. However, LED lamps are widely used in various vehicles due to their advantages of excellent performance, good heat dissipation and low cost.

It can be predicted that in the future, due to the continuous innovation and development of technology, laser headlights will gradually penetrate into low-end and medium-end vehicles by reducing production costs while maintaining long service life and high optical efficiency.

3 The overall development trend of car headlights: Take "Digital Light SSL|HD" as an example

In addition to the mass-produced SSL 100 lighting system, Haila has brought forward-looking LED headlight upgrade technology - SSL|HD to the Chinese market. At the Frankfurt Exhibition in 2019, Haila Lighting Factory launched the high-resolution lighting system - Digital Light SSL|HD for the first time, and then at the 7th Shanghai International Automotive Lighting Exhibition (ALE) in 2021, a new generation of chip-based headlight matrix system SSL|H D was pushed into the market. The system has deepened technical treatment to improve road traffic safety and comfort and provides unlimited prospects for creating personalized vehicle driving and promoting the intelligent development of vehicles. For the first time, the lighting system adopts more than 30,000 pixels of intelligent independent control, bringing more accurate safety functions, such as lane light identification, and also bringing more personalized choices to car manufacturers and end users, such as welcome and farewell animation effects and communication functions. In addition, it also improves the existing lighting functions such as adaptive lighting and non-glare high beams. For example, when building roadblocks through roads, the relevant functions can provide the best lane instructions, thus providing additional support for drivers to achieve safe and stable vehicle guidance. Some specific lighting settings can also be independently adjusted through the mobile terminal to move toward the Internet of Vehicles. More critically, Digital Light SSL | HD also opens a perspective for the new business model [8]. Haila provides flexible programming lighting functions for the mainframe factory and a new business model that pays according to use, providing a new direction for future automobile development.

It can be seen that the innovation of "Digital Light SSL|HD" in technology integration, interconnection interaction, and development of programming lighting represents that the development of LED headlights tends to be personalized, intelligent, and flexible in the future. It provides compact size, high-performance, and intelligent software-controlled lighting functions, which is extremely competitive in the Chinese market. SSL|HD will be put into production in China in 2024.

4 Frontier technology of automobile headlights and their applications

4.1 LCD lamps

LCD has the characteristics of low power consumption, low driving voltage, small structural space, large effective display area, thin body, and light material. It is widely used in various electronic products [7]. LCD headlights are liquid crystal display headlights. LCD headlights are composed of optical lenses, LCD cells, LED light-emitting unit modules, a radiator, and other components. LCD itself does not emit light but is a way of presenting a light source. LCD technology can theoretically realize the shielding and lighting of arbitrary shapes in effective pixels and make the control of light simpler. Therefore, it will provide richer, more efficient, and more intelligent lighting conditions when applied to car headlights. At present, LCD headlight technology is still in the R&D stage, but the LCD dashboard has been widely used. With the maturity of technology, LCD headlights will occupy a place in the field of automobile headlights in the future, relying on the advantages of low cost, relatively small size, wide stretchable angle of light, and high contrast between light and dark.

4.2 Laser headlights

The large-scale commercialization of laser diodes is slightly later than that of LED, but it has a wider range of applications, involving measurement, electronics, communication, medicine, processing, and other fields. Laser headlights have many advantages over LED lamps, such as long service life, energy saving and low consumption, low brightness attenuation, high light efficiency, etc. Besides, Laser headlights also have advantages in volume. Individual laser diode elements can already be up to 10 μm in length, which is only 1/100 of the size of conventional LED elements. This means that the size of traditional car headlights can be drastically reduced, which will revolutionize the design proportions of each element on the front of the car [10]. Laser headlights are a new laser lens module superimposed on LED lens modules. They are often combined with adaptive technology. The light range is more controllable, and the automatic adjustment of the light irradiation range can significantly improve driving safety, especially when dealing with complex road conditions without lighting at night, including provincial highways and high speeds. Drivers can rely on the penetration and cohesion of laser headlights to predict road conditions in advance to ensure driving safety. Laser headlights have developed rapidly, and the market demand has gradually increased. Audi and other manufacturers apply laser headlights not only to headlights but also to fog lights and other equipment. Using the controllable characteristics of laser light sources, they can adjust the visual range and improve driving safety [9]. In the future, laser headlights will eventually become the mainstream trend of car headlights.

4.3 OLED lamps

With the continuous development and innovation of science and technology, OLED lamps attracted a lot of attention at the beginning of their launch. It has extremely high visibility and brightness and has the advantages of thin thickness, lightweight, strong personalization, high appearance, and fast response speed. Compared with LED point light sources, OLED has the characteristics of a surface light source and diffuse reflection. The light quality is uniform, which can achieve step-less dimming without projecting any shadows. The lighting effect of OLED can be uniform, with light and dark effects, and even dynamic effects [10]. Using plastic film instead of plexiglass in the OLED structure, you can get a 3D lighting effect. Audi first released concept taillights using OLED technology at the 2013 CE exhibition. In 2016, the M4 GTS produced by BMW was equipped with Osram's OLED taillights, with 14 OLED lights on each side. It was the first brand to mass-produce OLED taillights. In the same year, Audi's TT RS was equipped with four penetrating OLED taillights, which completely won the market for OLED lights. Later, the subsequent Audi A8 and Q5 also chose OLED as the taillights. The emergence of OLED provides a new design idea and scheme for the design of the automotive lighting system. Because OLED has very uniform lighting and does not have serious glare and shadow problems, it is more suitable for the lighting of automobile signal lights and taillights [13]. Although due to its short service life, only 80 °C service temperature, and high price, OLED is currently only used on taillights and interior lamps. But at present， OLED is accelerating its penetration into the high-end market. Mainstream manufacturers have accelerated their imports into the automotive industry, and also regard on-board vehicles as potential target markets. OLED will be the general trend in the future [11].

5 Conclusions

Since the Eighth Five-Year Plan, China's automobile industry has been the pillar industry at the national strategic level. With the implementation of the Fourteenth Five-Year Plan, the automobile industry is booming towards a new energy and intelligent industry. The front light of the car is responsible for the safe driving of the whole vehicle, traffic signal communication, road lighting, and other responsibilities, which need to be constantly innovated and upgraded. At present, the headlight is developing in many directions such as lightweight, intelligence, diversification, and personalization, and the selection of light sources will become more and more exquisite, which can meet people's diverse needs.

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