Laser Light Sources for Next Generation Automotive Lighting Applications

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ABSTRACT

Progress in development of blue laser diodes and their integration with phosphors enabled a new category of solid state light sources for automotive lighting. In this paper, a dynamic laser light module consisting of blue laser diode, a MEMS scanner and remote phosphor for adaptive driving beam and future intelligent lighting will be introduced.

1 INTRODUCTION

Most recently Automotive OEMs have spent great efforts to develop next generation high resolution adaptive driving beam to improve driving safety and to enable novel functionalities related to autonomous driving and Car-to-X communications, however, conventional techniques including LCD, DLP, MicroLED encounter technical challenges associated with harsh automotive environment and stringent system reliability and efficacy requirements. The objective of our study is to investigate the feasibility of utilizing a MEMS based laser scanner consisting of a high power 450nm LD, a remote phosphor and a biaxial MEMS mirror for adaptive automotive lighting applications.

1.1 Laser Light source Technology

By fabricating a blue laser diode on semi-polar Gallium Nitride (GaN), blue laser light is produced at high levels of optical output power of 3 watts and more due to the high gain in the device [1]. As importantly, these laser diodes show minimal droop characteristics, meaning that, high power lasers with very small scale are being implemented in automotive lighting applications which require high brightness light source with a peak luminance value exceeding 1000cd/mm^2. As illustrated in Fig.1, unlike a blue LED that emits a few watts of diffuse optical energy per square millimeter, several watts of light produced from the laser diode emanate from a light emitting area only tens of microns in width, and can therefore illuminate a tiny spot at phosphor surface that is hundreds of microns in diameter [2].

To complete the spectrum for white light illumination, the blue radiation is partially converted to longer wavelengths by a phosphor element. Innovations in high temperature phosphors and special binding materials have enabled phosphors to convert light efficiently at the elevated power densities and temperatures that result from the laser light radiation. It's worth mentioning that most of previously developed phosphor converted laser light sources utilize a transmissive architecture, namely, blue laser is focused at the rear surface of a laser phosphor layer and white light is emitted from the other side of laser phosphor. Although it involves relatively less efforts to develop a transmissive laser light source, proper heat management of laser phosphor material is challenging since heat is more difficult to be dissipated from transmissive laser phosphor comparing with reflective phosphor which is directly mounted on a thermally conductive substrate. As a result, the minimum laser spot size on transmissive phosphor would be larger than that of reflective phosphor to avoid excessive heat generated by focused laser beam, which leads to lower peak luminance of laser light source with transmissive phosphor.

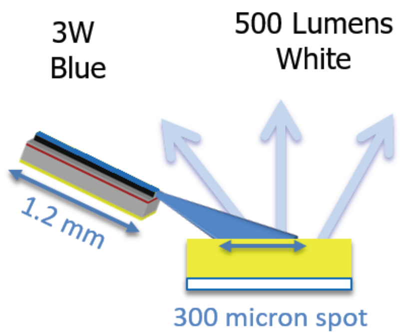

Fig. 1 Schematic drawing of a high luminance laser white source consisting of a high power GaN blue laser diode and reflective phosphor

Except of advantages of high peak luminance, reflective laser light architecture also enables higher level of laser safety. Assuming failure of laser phosphor material either due to shock or degradation, leakage of coherent blue laser from failed transmissive phosphor can induce severe eye injuries. In contrast to transmissive laser light, specular reflection of blue laser in reflective laser light can be readily blocked with a beam dump, direct radiation from blue laser diode has virtually no chance to damage human eye, therefore a laser light source with reflective phosphor can be classified as a class I laser.

1.2 Automotive Fiber Laser Light Source

As shown in Fig.2, a fiber coupled laser light module with reflective phosphor has been developed especially for automotive lighting applications. This fiber coupled laser light is compose of a high power blue laser diode, a multi-mode glass fiber of 30 cm up to 10,000 cm of length to transport blue light to a distal end and a reflective phosphor element enclosed in a metal head.

Fig. 2 A fiber coupled laser light module for Automotive front lighting applications, which is composed of a high power 450nm wavelength blue laser module, a transporting multi-mode optical fiber and a remote reflective laser phosphor packaged in a metal head.

Typical optical fiber carrying 450nm laser radiation operates at a transport efficiency of approximately 99.8 per cent per meter thus losses are neglectable even for significant fiber lengths. As described in previous session, a remote phosphor platelet located at distal end of the optical fiber is operated as a reflecting element. This placement offers the advantage of straightforward heat sinking of the phosphor element which is important due to the high levels of power density. Blue laser module which is most sensitive to heat can be placed in a low ambient temperature environment, for example, at the back side of a laser headlamp or at a mounting position far away from engine components. As a passive component which is much more thermally robust than laser diode, the phosphor metal head will be placed inside headlamp. Since the thermal power of phosphor metal head is 1.7W only, a highly compact system design can be realized by eliminating of active cooling components such as cooling fans.

The laser spot size on phosphor of fiber coupled laser light module is 270um in diameter, which generates luminous flux of 450lm at 50^0C operating temperature and peak luminance exceeding 1400cd/mm^2, which is one order of magnitude higher than the peak luminance of most automotive high power LEDs and two times brighter than the first generation automotive laser white sources. Reflected blue laser radiation is blocked by beam dump which ensures that coherent laser light is never released. Additional safety and performance monitoring features are included in the blue laser module, where the optical power of blue laser and phosphor converted yellow light and case temperature of high power blue laser diode are actively monitored with integrated detectors located in the blue laser module. With this arrangement, the white light emitting element may be sealed in a location remote from the laser and its electronics which may be placed in another location that has more favorable physical and thermal characteristics.

2 LASER SCANNER FOR ADB

2.1 Automotive Adaptive Driving beam

Automotive Adaptive Driving Beam (ADB) is an intelligent automotive front lighting solution which can maximize beam range to targeted illumination area and minimize undesired glare to oncoming and preceding traffic. In pace with continuous performance improvement of ADAS sensors and image processing algorithm, there is clear tendency towards pixelized ADB or matrix beam with higher angular resolution, illuminance and contrast. Recently there were several techniques under development for next generation ADB ranging from LCD, DLP, MicroLED to Laser scanner, besides normal photometric requirements related to resolution, illuminance and contrast, overall system efficacy is an import metric to assess those next generation ADB technologies. It is known that a halogen bulb consumes approx. 60W electric power to fulfill low and high beam requirements, the power consumption was reduced to less than 15W in the past decade through wide adoption of LED but it was again raised to 50W – 60W as demonstrated by some most recent high resolution ADB prototypes[3]. How to further improve system optical efficacy turned out to be a major focus for development of next generation ADB [3].

2.2 Laser Dynamic Scanner for ADB

Among various techniques of high resolution ADB, a laser scanning approach appears promising by offering high illuminance, design flexibility, compact system size and low power consumption. As shown in Fig.3, a laser scanning ADB unit consists of a fiber coupled high power blue laser, a MEMS scanner as beam steering component and a reflective phosphor as light conversion part. High power blue laser beam is coupled into a glass fiber, after passing though collimating and folding optics, it is reflected by a millimeter size biaxial MEMS scanning mirror driven by electrostatic force. The MEMS mirror steers the laser beam angle with kHz scanning rate before the laser beam reaches a reflective laser phosphor plate. A dynamic scanning pattern on phosphor generated by flying laser spots will be projected onto road with aspherical projection lens and relay optics.

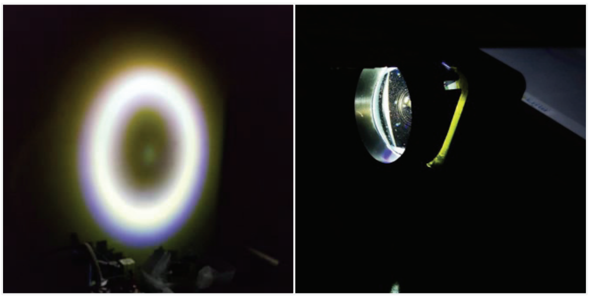

Fig. 3 A dynamic laser scanning unit for automotive adaptive beam. Blue laser is coupled into an optical fiber, reflected by a bi-axial MEMS mirror and focus at a reflective phosphor. A dynamic light distribution pattern is projected on the road through a 2inch projection lens.

System architecture of laser scanning ADB is quite similar to static laser fiber module which has been introduced in previous session, heat management of blue laser diode is decoupled from laser scanner unit and reflective phosphor, no active cooling or sophisticate heat management such as heat pipe is required for the laser scanning ADB. Total electric power consumption of the complete laser scanning module as demonstrated in Fig.3 is 12W only, average illuminance value on road at 25m distance exceeds 200lx. A typical laser scanning range covers +/- 20 degrees in both horizontal and vertical directions with an angular resolution less than 1 degree. The minimum pixel number of laser scanning ADB exceeds 400 and can be further increased by reducing laser spot size on phosphor. The whole scanning system is quite compact with a footprint of less than 2 x 2 inch.

3 DISCUSSIONS

Comparing with previous laser light sources with transmissive phosphor, fiber coupled laser light module with reflective phosphor nearly doubles those key photometric metrics in terms of luminous flux and peak luminance, it is an ideal laser light source for static automotive front lighting application such as high beam assistant based on its unique advantages of passive cooling, high luminance and class 1 laser safety. Integration of a biaxial MEMS scanner into fiber coupled reflective phosphor architecture allows further extension of laser light applications from static high beam to dynamic scanning ADB. A compact size laser scanning ADB prototype has demonstrated long beam range, reasonable angular resolution with a total electric power consumption of 12W only.

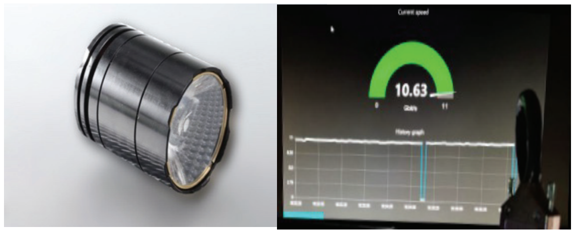

Fig. 4 A laser light LiFi prototype demonstrates a real time date transfer rate of 10.63 Gbit per second. Laser light from a GaN laser diode is modulated to encode data transfer after collimation with a 35mm diameter lens.

In addition to conventional automotive lighting functionalities such as high beam, low beam and ADB, the unique characteristics of GaN laser light allow new types of applications which go far beyond illumination. To put a number in perspective, the laser pulse rise time of GaN laser diode is approximately 0.5ns only, high speed modulation of laser output power can be implemented to integrate either laser ranging or light communication functions into a laser light automotive illumination unit. Some of the recent studies conducted in our group in 2019 have demonstrated a real time data transfer rate of 10.63 Gbit per second with a laser LiFi (Light Fidelity) prototype designed for wireless data transmission, the laser light source and real time data rate are shown in Fig.4. Another investigation related to LiDAR (Light Detection and Ranging) based on both simulation and experimental measurements has proven that a laser light headlamp is capable to measure range information by detecting of back reflected laser pulses emitted from an automotive illumination laser light source, in other words, both illumination and sensing can be realized with a single laser source.

4 CONCLUSIONS

Laser lighting technology has grown more mainstream in automotive applications which were the first to harness its high luminance characteristics in forward lighting like high beam. With new progress in MEMS laser scanner, fiber coupled laser scanning approach is attracting significant interest in developing high system efficacy ADB, which enables the transition of laser light applications from static to dynamic lighting functionalities. Besides conventional automotive front lighting applications, development is ongoing to integrate directional white-light laser sources into next-generation lighting applications such as LiFi for light-based wireless data transmission, LIDAR for range detection and Car2X communications.

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