High-resolution headlamps: An innovative concept for the next-generation

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Abstract— Headlamp systems have been undergoing rapid developments in recent years to enhance traffic safety and comfort, with the trend of having a higher resolution. This higher resolution brings forth functionalities such as precisely glare avoidance and on-road lighting projection. Among them, the on-road projection is a function besides of illumination, which provides the opportunity for drivers to acquire the information directly from the road, and more importantly, to communicate with other road participants. This lighting-based communication is especially significant in the coming era of higher autonomous driving levels since it can display the intentions of a vehicle immediately to other road users. In order to make full use of the advantage of the on-road projection, the chromatic lighting projection is put forward because it enables this lighting information not only visible in the night, but also during the daytime. Current projection technologies have either an undesirable output luminous flux regarding the capability of the light source or a complex structure to generate white light and chromatic projections at the same time. In this paper, an innovative concept using laser diodes as light sources with LCoS devices for a high-resolution vehicle headlamp system is presented. Specific design schemes, according to this concept, are also discussed.

Keywords: High-resolution headlamps; on-road projection; lighting-based communication; chromatic projection

I. INTRODUCTION

Modern advanced vehicle headlamp systems provide drivers with increased visibility of the environment compared to conventional headlamps that just have a low beam and a high beam. Besides, they have been evolving to take care of the traffic comfort for both drivers and other road participants. This function is realized by dividing the entire illumination area into many segments to adapt the illumination pattern to the traffic situation in real-time.

The next generation of headlamps is to improve the number of segments (pixels), ranging from dozens to millions. Such headlamp systems are therefore known as high-resolution headlamps. The high-resolution headlamp system opens new possibilities for more illumination and communication functionalities. Except for improving road safety and comfort, these lighting functionalities are potentially useful in the coming era of higher levels of autonomous driving.

This paper firstly reviews the state of the art, functionalities, and modulation technologies of high-resolution headlamps, followed by a discussion of the encountered problem for further developments. After that, an innovative concept with further design schemes is presented for the discussed problem. At last, an exemplary design of a headlamp prototype based on the proposed concept is introduced.

II. STATE OF THE ART

In the automotive industry, headlamp systems have been undergone tremendous development in the last decade. Compared to conventional headlamps, many active lighting functionalities are considered to be integrated into the system to provide sufficient illumination for different driving situations. Adaptive Front-lighting System (AFS) is the first supplementation to be regulated into force by United Nations Economic Commission for Europe (UNECE) in regulation 123 [1]. The UNECE regulations are widely applied in many other countries and areas. After the introduction of AFS, Adaptive Driving Beam (ADB) has been defined in ECE regulation 48 for wider application scenarios [2]. Therefore, this chapter firstly introduces the main ideas of both AFS and ADB illumination functionalities. In addition to these defined lighting systems, other potential lighting functionalities and the corresponding technologies are reviewed in this chapter.

A. AFS

AFS provides an optimized vision to the driver in poor-sight conditions on the road in different driving situations. It realizes this optimized illumination basically through adapting the low beam modes for the UNECE defined situations. These lighting modes contain a bending light and four other passing beam patterns.

The idea of bending light is to provide the side illumination by an additional beam when a vehicle is turning at intersections and curves with small radiuses. With this bending light, a driver can have a preview in the forward direction. In addition to the bending light, the other four passing beam patterns are categorized into classes as follows [1]:

- Classic passing beam (Class C), the basic low beam pattern that has been incorporated in vehicles
- Motorway passing beam (Class E), the enhanced beam pattern in the forward direction for better visibilities when driving in high speeds or in motorways

- Town passing beam (Class V), the beam pattern in built-up areas without causing glare to other road participants
- Adverse weather passing beam (Class W), the beam pattern that avoids glaring the driver self and oncoming traffic when driving in adverse atmospheric conditions.

B. ADB

The definition of ADB in [2] is “A main-beam of the AFS that adapts its beam pattern to the presence of oncoming and preceding vehicles in order to improve the long-range visibility for the driver without causing discomfort, distraction or glare to other road users." This system is the supplement of AFS in high beam functions. An ADB system normally generates many segments (pixels) to form the entire illumination area, each of which can be independently dimmed, switched on/off. By adapting the illumination segments to the driving situations, the ADB system achieves this de-glare functionality, which allows a long-term use of the high beam in some circumstances where optimized visibilities are needed.

C. Potential functionalities

Besides of the introduced AFS patterns and the ADB functionality, the Correlated Color Temperature (CCT) steerable white light function and on-road projection are introduced in [3].

A CCT that close to the color temperature of sunlight provides a better illumination performance for the human in normal situations. However, in adverse weather conditions, e.g., foggy and rainy weather, a lower CCT offers better visibility for both the driver and other road participants [4][5]. Thus, a CCT steerable white light is helpful for improving road safety.

On-road projection, which enables the display of lighting information directly on the road, is considered to be integrated into a headlamp system in recent years as well. Except that drivers can acquire information without changing the focuses of their eyes, the lighting-based communication between the driver and other road participants is also possible. This lighting-based communication is especially useful in the coming era of intelligent transportation and autonomous driving, due to that other road users are able to understand the intentions of the vehicle quickly. In order to realize the detectable on-road projection not only during the night, but also in the daytime, or some special conditions, e.g., snow-covered or well-illuminated road surface, a chromatic on-road projection is potentially helpful.

III. MODULATION TECHNOLOGIES AND PROBLEM DISCUSSION

Most lighting functionalities introduced in chapter 2 can be achieved by covering the entire Field of View (FoV) of a headlamp with high-resolution light distribution. Different high-resolution modulation technologies with their working principles are introduced in [3] and [6]. These modulation technologies are illustrated in figure 1. Among them, the scanning micro-mirror directly deflects the incident beams; in contrast, the Digital Micro-mirror Device (DMD), Liquid Crystal Display (LCD), and Liquid Crystal on Silicon (LCoS) are area-based lighting modulators. Furthermore, the LCD and LCoS require linearly polarized incident light for the high-resolution beam modulation.

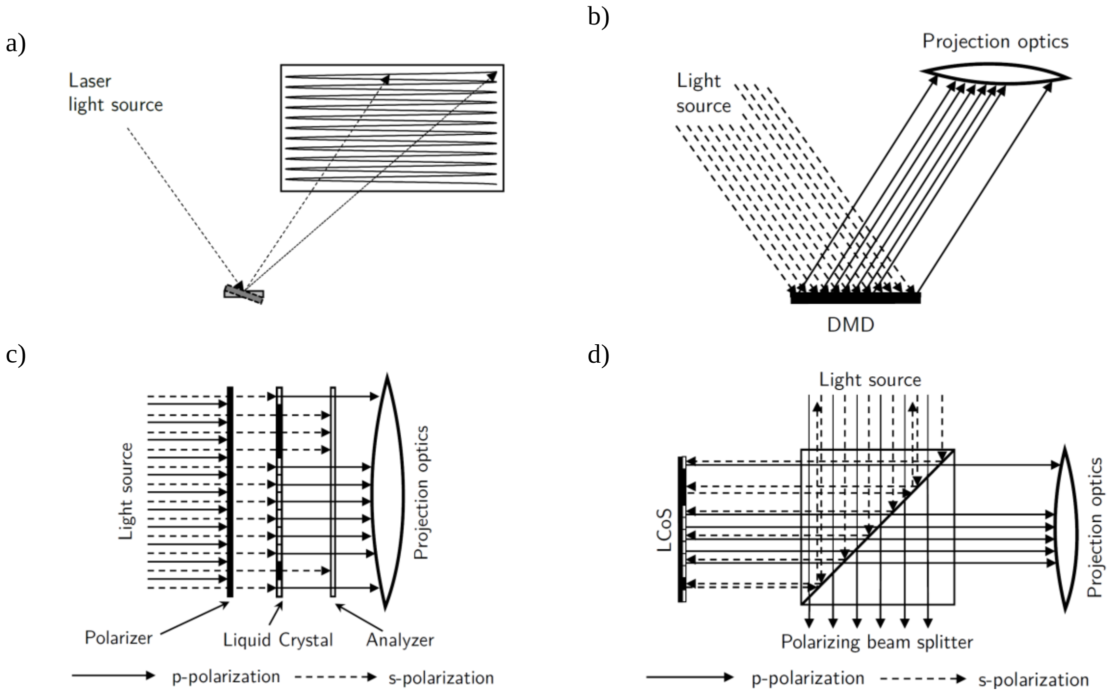

Figure 1. High-resolution modulation technologies with their working principles. a) Scanning Micro-Mirror. b) Digital Micro-Mirror Array (DMD). c) Liquid Crystal Display (LCD). d) Liquid Crystal on Silicon Display (LCoS) [3] [6].

It is possible to use a conjunct light source with light emitters that emit different wavelengths to achieve the CCT steerable white light and the chromatic on-road projection with the technologies in figure 1. For this, a light source composed of Red, Green, and Blue (RGB) colors are normally used.

To approximately calculate the CCT of the emitted light from an RGB-based light source, the following formula can be applied [7]:

$$CCT = 449n^3 + 3525n^2 + 68253.3n + 5520.33 \tag{1}$$

where

$$n = (x - 0.3320) / (0.1858 - y) \tag{2}$$

The x and y in (2) are the chromaticity coordinates of the illumination light according to CIE 1931 chromaticity diagram. Through adjusting the output power of the RGB emitters, it is possible to steer the x and y values.

Apart from the CCT control, there are two methods to realize chromatic projection utilizing the RGB light source with the modulation technologies. They are the spatial method and the color sequential method.

The spatial method means that the RGB light sources are switched on all the time during the operation, and they are superposed by optical components and modulators. A functional schematic diagram of this method is illustrated in figure 2.

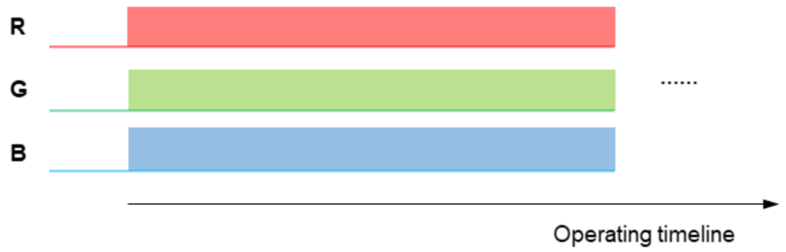

Figure 2. Schematic diagram of the spatial method for the realization of white and chromatic effects.

Area-based modulators realize the spatial superposition by using three of the same modulators, each of them modulates for a single color. After the modulation process, appropriate optical components combine these separately modulated patterns for the final illumination and projection. In contrast, the scanning micro-mirror deflects multiple incident beams with one modulator, the output power of each R/G/B source is individually adjusted connecting to the single deflection direction (single pixel) for a specific pattern.

The color sequential method means that the modulation device separates RGB colors in time rather than in space. A modulator separates each frame into R/G/B sub-frames. In each sub-frame, the modulator generates a monochromatic pattern. A monochromatic emitter of the light source illuminates only during the corresponding sub-frame, then both the emitter and the sub-frame are switched off, shifting to the sub-frame of the next color. By doing so, the three colors are superposed by this fast switching of sub-frames to realize white and chromatic effects in human visual systems. The schematic diagram of the color sequential method is illustrated in figure 3.

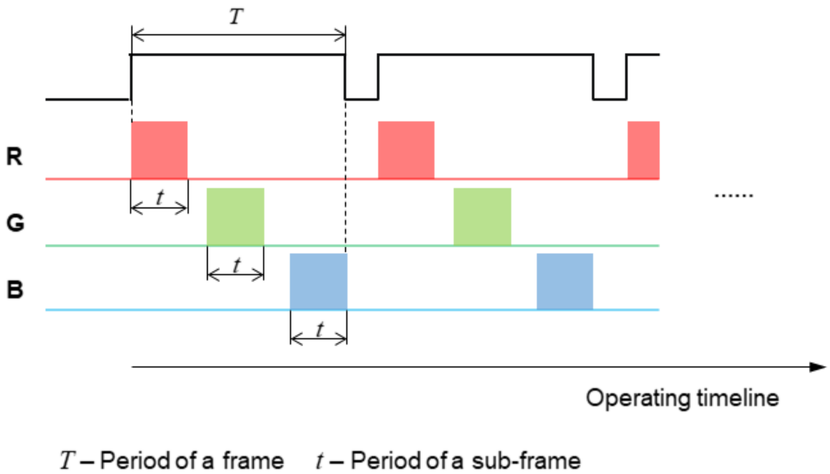

Figure 3. Schematic diagram of the color sequential method for the realization of white and chromatic effects.

The color sequential method is customarily used by area-based modulation technologies, allowing a single modulator to generate chromatic projection. Accordingly, it needs a corresponding control strategy.

Both introduced methods with different modulators have their advantages and disadvantages. When using the spatial method with area-based modulators, it guarantees a high output power regarding the capability of the light source. This is because the modulation mechanism allows that all emitters of the light source can be permanently switched on during operation. However, the use of three modulators with additional optics has a negative impact on the cost, system complexity, and installation space. In comparison, the scanning micro-mirror can realize the spatial modulation method with only one modulator. Nevertheless, the sinusoidal signal, which is normally used to drive the mirror, results in the condition that the luminance at edges of an illumination area is higher than that in the middle. This distribution pattern does not fit the illumination application [8]. Although this can be modified by specifically designed projection optics, this modulator requires a quite fast switching speed of the laser diodes to achieve a high-resolution [8].

Using the color sequential method requires just one area-based modulator, which has a lower demand on cost and system installation in comparison to the spatial method. However, it shows a low luminous flux level regarding the source capability due to the sequential switching on/off of R/G/B light sources. This is unquestionably a disadvantage of a headlamp system that requires high brightness for illumination.

The intention of this paper is to propose a high-resolution headlamp design that is not only capable of realizing all aforementioned functionalities but also has a sizable output luminous flux. Moreover, the headlamp system should not have a very high system complexity so that a compact headlamp is possible.

IV. CONCEPT OF A LASER LCOS HEADLAMP

In order to develop the proposed high-resolution headlamp, a concept is firstly needed. This chapter introduces the concept development of such a headlamp, including the components selection and the correlated implementation mechanism.

In Chapter 3, different modulation technologies are introduced. Among them, LCD and LCoS devices achieve high-resolution light distribution based on the polarization modulation. As introduced, due to the reflective working mechanism, An LCoS works together with a Polarizing Beam Splitter (PBS) in many cases. This working structure allows the integration of another LCoS into the system without increasing system complexity. By using two LCoS devices, the pursued concept can be realized. An illustration of the idea is shown in Figure 4.

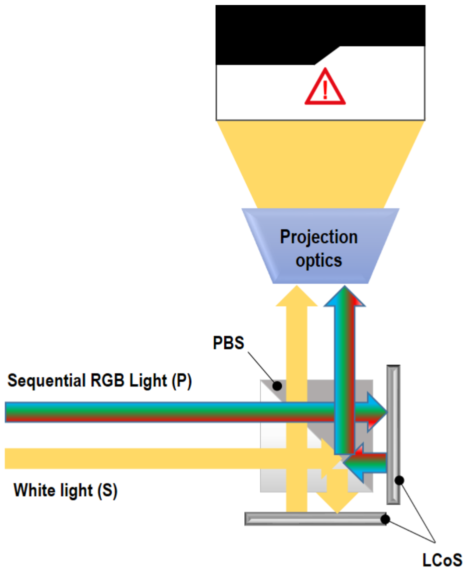

Figure 4. Concept of a 2-LCoS optical system.

As presented in figure 4, the incident light beams that are mutually independent in polarization (S-Polarized and P-Polarized) enter a PBS from the same direction in the first place and then come out from two different sides. Two LCoS devices are located on both two sides of the PBS, where the incident beams come out. Each LCoS in the system modulates the incident light in one linear polarization then reflects it. With the help of the PBS, the two modulated light beams merge into one direction again and go further into the projection optics to participate in the illumination and projection.

Taking the illustration in figure 4 as an example, a typical working scenario of this concept is explained as follows: the incident S-Polarized light is permanent white. In contrast, the P-Polarized light is in the sequential order of RGB. The LCoS, which modulates the white light, can realize different patterns and functionalities for the headlamp illumination. In the meantime, another LCoS that modulates the sequential RGB light is able to create chromatic on-road projection patterns and overlap them onto the white light. Due to the reason that the incident beams in different polarizations are independent of each other, the chromatic lighting projection can be realized without sacrificing the output luminous flux that the light source should have for white light illumination, as introduced in chapter 3. In addition to the lighting output aspect, the system complexity does not increase significantly compared to a 1-LCoS system.

A prerequisite of this concept is the independent linearly polarized incident beams in S and P polarizations. The emission of a laser diode fits this concept well. A laser diode radiates linearly polarized laser light with the polarization ratio from 30:1 to 100:1, and the polarization direction is known [3][9]. Thus, a laser diode can be mounted in a certain position to emit the light in the desired polarization. For the light source of this concept, both white light and sequential RGB light can be the direct emission of laser diodes. The white light can be a synthetic emission of RGB laser diodes that emit light in the same polarization direction, and the sequential RGB light is emitted by rest diodes in the opposite polarization. In other words, both the white light and the sequential chromatic light in this concept are from RGB laser diodes but driven in two different strategies.

Apart from the application exemplified in figure 4, there are other application scenarios of this 2-LCoS concept. Since both the white light and the chromatic light are emitted by RGB laser diodes through different control strategies, each of them can be switched to another at any time through changing the driving strategy. For instance, when an enhanced brightness is needed in some environments, both beams in S and P polarizations can be white for the illumination. When driving in some circumstances, e.g., a well-illuminated or snow-covered road surface, that enhanced chromatic lighting symbols are needed, both beams can be chromatic light to enhance the color contrast.

To summarize, this 2-LCoS concept has the following characteristics:

- Projecting chromatic lighting symbols without reducing the illumination luminous flux
- Dynamically switching between enhanced illumination and enhanced chromatic projection
- Low system complexity

The further development of this concept for high-resolution headlamps is discussed in the following text.

V. Headlamp Concept development

In chapter 4, the initial idea of the 2-LCoS concept is introduced, together with the explanation of using RGB laser diodes as its light source. In this chapter, the realization and branch design schemes of this concept are discussed. Section A firstly introduces the specific implementation of a headlamp system with this concept, then section B discusses illumination strategies and correspondent realization methods of headlamp systems. Finally, section C introduces two potential design schemes for different headlamp applications.

A. System concept

The proposed headlamp system uses two LCoS devices to create the high-resolution light distribution and RGB laser diodes as the light source. In order to achieve a well-operating optical system, also to fulfill the requirements for headlamp systems, other electrical and optical components are needed. These components and their functions are classified and listed below:

- **Power supplies,** to provide electric energy for the light source, lighting modulators and control units in the system
- **Control units,** to realize the control strategies for the RGB laser diodes; in the meantime, these control units provide information to the modulators to adapt the light distribution and synchronize the trigger signals for laser diodes and frames for LCoS devices
- **Primary optics,** to combine beams from RGB laser diodes to achieve the white light, and to pre-shape the light to illuminate the LCoS surfaces
- **Secondary optics,** to project the modulated light for the illumination and projection with the required distribution and FoV of the headlamp

A system concept that includes these components is shown in figure 5. The concept diagram illustrates the component connections and the order of optical components in a headlamp system.

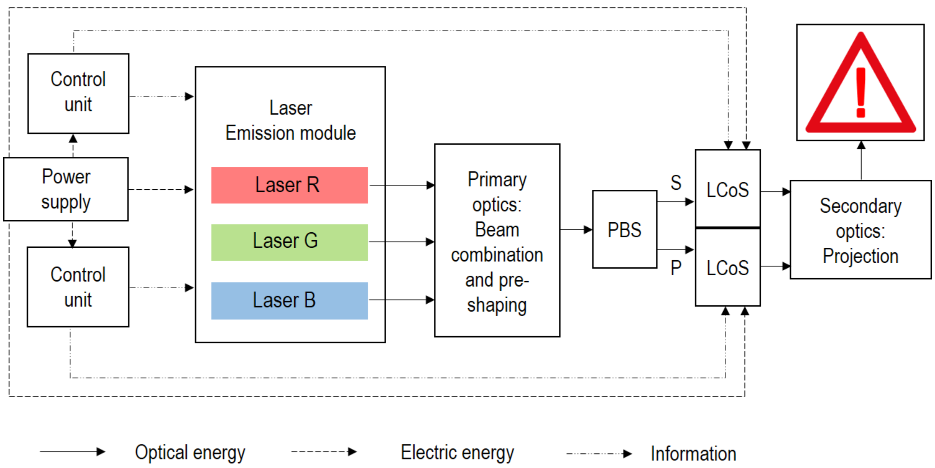

Figure 5. System oncept of a 2-LCoS headlamp system.

B. Illumination strategy

For different application purposes (e.g., full headlamp function or auxiliary lighting functions), the output distribution of the high-resolution lighting module can be homogeneous or with a central hot spot [10][11][12][13]. For this, illumination strategies are proposed in this section for the desired distribution.

Homogeneous distribution

In this illumination strategy, the primary optics combine and homogenize the beams from laser diodes on the modulator surfaces in the first place. After that, the secondary optics project the light from the modulators homogeneously with the desired FoV according to the design requirements. Due to the fact that the aspect ratio of a headlamp FoV is normally broader in the horizontal direction than those of lighting modulators, the secondary optics usually contain anamorphic optical elements. A demonstration of this strategy is shown in figure 6.

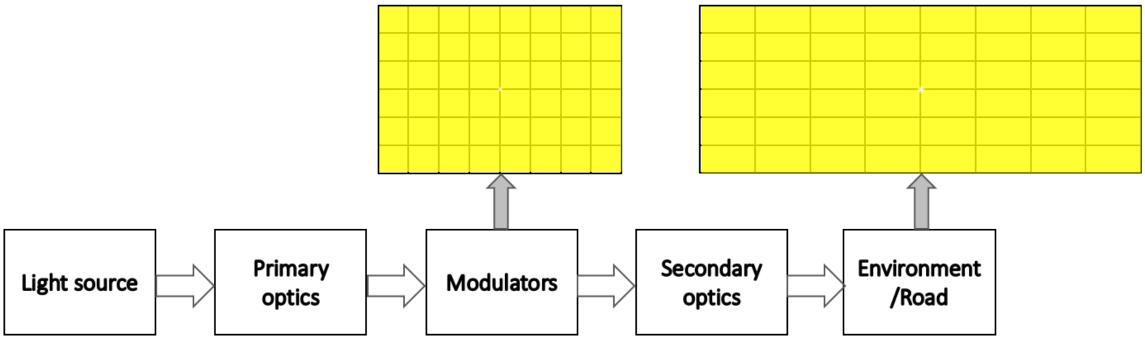

Figure 6. Homogeneous illumination strategy of high-resolution headlamp systems.

Central hotspot generation (primary optics pre-shaping)

With the help of the primary optics, the generation of the central hot spot takes place before the lighting modulators in this illumination strategy [13]. The secondary optics merely change the output FoV for the headlamp illumination and projection, the same as that in the homogeneous strategy. An illustration of this strategy is shown in figure 7.

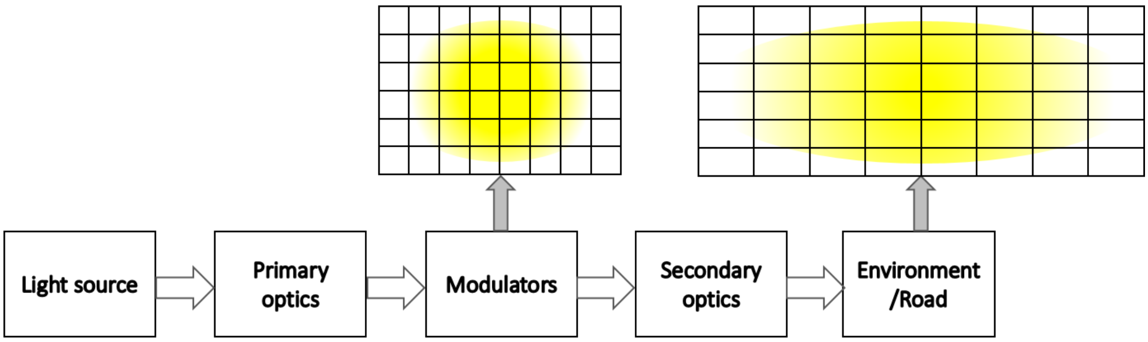

Figure 7. Beam pre-shaping illumination strategy for the hot spot generation of high-resolution headlamp systems.

Because of the beam pre-shaping working principle of the primary optics, a large amount of optical energy concentrates in the center of light modulators. This energy accumulation results in a heavy thermal load for the modulators. Therefore, proper thermal dissipation measures must be taken when using this strategy.

Central hotspot generation (secondary optics pincushion distortion)

In this illumination strategy, the laser beams from the light source are firstly combined and approximately homogeneously shaped on the modulator surfaces. Afterward, a pincushion distortion secondary optics converge the majority of the output light energy into the central area of the headlamp FoV, where a high luminous flux is needed. An illustration of this distortion strategy is shown in figure 8 [12][14].

In comparison with the beam pre-shaping method, to generate the hot spot with secondary optics causes much less thermal management issues on modulator surfaces. However, due to the great distortion of the light distribution, the on-road projection content suffers a pincushion deformation as well. In order to correct the distorted lighting information, appropriate algorithms for image processing, according to the distortion degree, are needed.

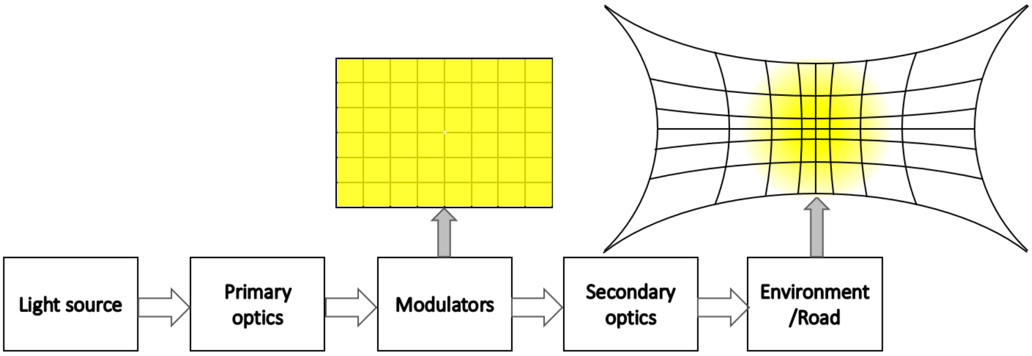

Figure 8. Pincushion distortion strategy for the hot spot generation of high-resolution headlamp systems [12][14].

C. Concept development

In order to apply the 2-LCoS concept with the appropriate illumination strategy to a headlamp system, it is necessary to discuss the realistic design for the concept implementation. This section discusses two design schemes of the headlamp from the perspective of LCoS selection. Correspondingly, the basic concept introduced in chapter 4 is further developed in this section.

Complete superposition

In this design scheme, two same LCoS devices are used for the beam modulation. Due to the fact that the two beams in different polarizations have the same optical length, common optical elements, and a same size of the two LCoS modulators, these two projected beams have the same FoV, i.e., theoretically, they are completely superposed.

The main characteristic of this design is, the pixel of the two LCoS devices are one-to-one correspondent within the FoV of the headlamp. This allows a simple image processing for many functionalities, e.g., different AFS patterns, glare-free illumination, and enhanced chromatic projection that both two beams are in color. Due to the reason that for these functionalities, the generations of the output light distributions in the control units are the same.

Apart from that, the three illumination strategies introduced in section 5-B can be applied to this complete superposition design for both homogeneous distribution and hot spot generation. In order to guarantee the same distribution, the primary optics for both beams are the same.

An example of this design scheme using the homogeneous illumination strategy with its expected effect in the view range of a driver is shown in figure 9.

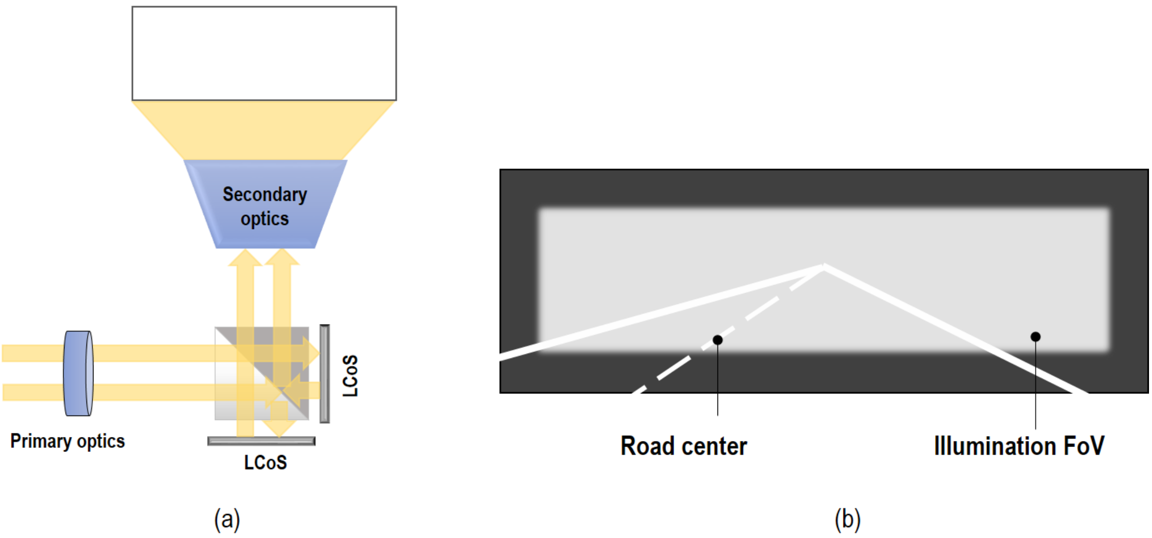

Figure 9. Complete superposition design scheme of a headlamp. (a). System structure; (b). View range of a driver.

Partial superposition

Another design scheme based on this concept uses a large LCoS and a small LCoS to modulate the beams in different polarizations. Different primary optics are applied to pre-shape the two beams to illuminate the two LCoS devices, respectively. The common secondary optics project the modulated beams to the function area of the headlamp. This design results in a partial superposition in the FoV of the headlamp. The light from the big LCoS illuminates the whole FoV; in the meantime, the light from the small LCoS concentrates in the more central area, forming the illumination hot spot of the headlamp when the light is white. Inasmuch as both the big and the small illumination areas are of high resolutions, the functionalities that require many pixels can be realized. Besides of the illumination, the on-road projection of a headlamp is mainly within the projection range of the small LCoS in many situations. Therefore, this small LCoS is in charge of the chromatic projection as well in most cases in this design.

Because of the introduced working principle, the homogeneous distribution is the more suitable illumination strategy for this design scheme to have a good projection effect compared to the other strategies. An illustration of this design scheme and the expected effect in the driving situation is shown in figure 10.

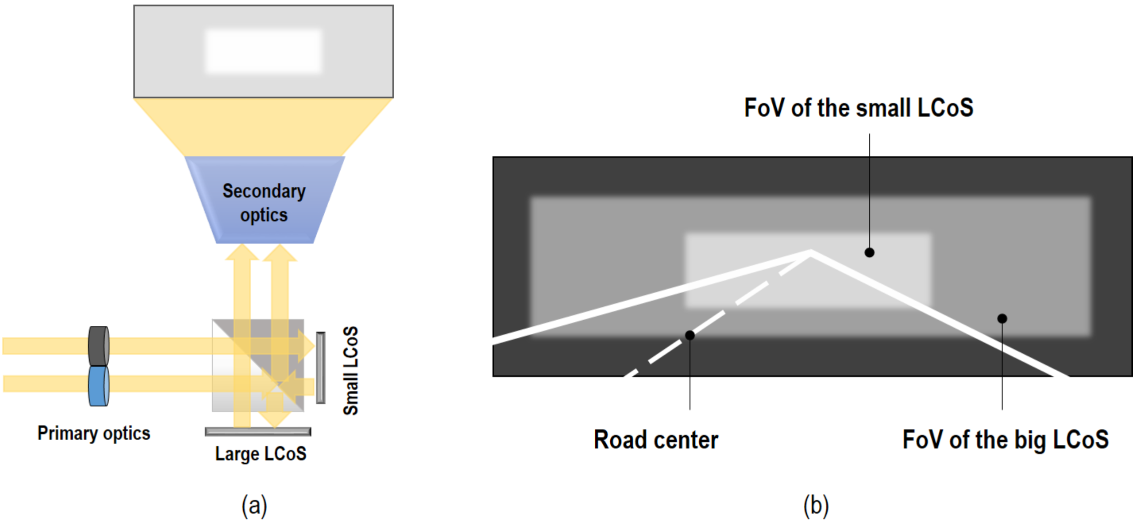

Figure 10. Partial superposition design scheme of a headlamp. (a). System structure; (b). View range of a driver.

VI. HEADLAMP REALIZATION

In this chapter, the realization of the headlamp based on the introduced concept is discussed. The discussion refers to the design of the optical system and the integration of the headlamp system. Section A includes the optical elements that are suitable in the system, followed by a simulation result of an example. Section B introduces the realization of the exemplary system.

A. Optical system

The optical system in this headlamp, as introduced in section 5–A, includes the primary optics and the secondary optics. The secondary optics are, in general, anamorphic or pincushion distortion lens sets to achieve the output FoV and distribution. In contrast, the purpose of the primary optics is combining laser beams from different laser diodes and shaping the distribution according to the specific illumination strategy and the dimensions of used components. In order to apply the suitable types of primary optics for a headlamp, the following further requirements have to be taken into account:

- To maintain the polarization states of the beams
- To realize the beam combination and pre-shaping with as few elements as possible, so that the headlamp system can be compact
- It is favorable if the primary optics of the same category can realize both homogeneous and centralized distributions so that different illumination strategies can be applied

According to these requirements, optical fibers, integration rods, dichroic mirrors, and dichroic prisms, which are the common optical components to combine laser beams in many applications, are not compatible in the system. This is because they are not able to shape the beam distribution. Instead, diffractive optical elements (DOEs), engineered diffusers, and lenslet arrays (LAs) that are used to re-distribute the output beam profile to a homogeneous distribution or with a hot spot are capable of combining the beams as well.

DOEs use interference and phase control to modify the wavefronts of the incident beam by segmenting and redirecting the segments. Because of the diffraction mechanism of a DOE, it is very sensitive to the wavelength of the input beam, which means the applicable occasion of a DOE is normally monochromatic with the coherent light source. In this headlamp system, the laser diodes that emit one wavelength work with one type of DOEs, other DOEs must be applied for the rest laser diodes that emit different wavelengths. By tailoring the output beam profiles and adjusting the installation angles of laser diodes and DOEs, the laser beams from all RGB laser diodes can be overlapped and shaped on the modulator surface according to the design requirements. Nevertheless, the use of DOEs presents the problem of zero-order, which is a bright spot collinear with the incident beam. This problem must be considered before using it. [15][16]

Engineered diffusers consist of differing, individually manipulated microlens units that each of them is specified with respect to its sag profile and its location in the diffuser. With the help of these microlens units, an engineered diffuser segments and redistributes these segments to form the desired beam intensity profile. The beam combination, the same as DOEs, can be realized through adjusting the installation angles of the laser diodes and corresponding engineered diffusers. Different from DOEs, engineered diffusers use the refraction principle for the beam shaping. Therefore, the same engineered diffuser can be applied for different wavelengths to get almost identical performances. Furthermore, it does not present the problem of zero-order. [17]

Lenslet arrays are universally used as homogenizers in projection systems in front of light modulators to realize uniform lighting distributions. A conventional lenslet array is composed of a number of identical lenslets to divide the incident beam into multiple sub-beams. After that, a relay lens is used to collect and superpose all the sub-beams onto the target surface. One lenslet array can be used with multiple incident beams with various wavelengths, with the help of the relay lens, the beam combination can be realized without considering the installation angles of the components. Besides the beam homogenization, it is possible to achieve the tailored centralized lighting distribution using lenslet arrays [13].

B. Optical system design

This paper presents a design example prototype of the headlamp system using the proposed concept. It uses 3 RGB laser diodes to form the P-Polarized beam, while other 3 RGB same laser diodes to achieve the S-Polarized beam in the system. By doing this, both beams are able to be white or chromatic. The parameters of the used laser diodes are listed in table 1. The three laser diodes are P-Polarized, they can be rotated 90 degrees to get S-Polarized laser.

TABLE I. LASER DIODES PARAMETERS

	Wavelength (nm)	*Maximum Power (W)*	*Polarization*
R	638	0.7	P
G	520	0.08	P
B	450	1.6	P

The modulators used in this headlamp prototype are two identical 0.37-inch LCoS display devices with the parameters listed in table 2. The applied illumination strategy is the homogeneous distribution. A lenslet array with a relay lens is used as the primary optics for the beam combination and pre-shaping. After that, anamorphic lenses are used as the secondary optics to change the aspect ratio from 16:9 to 3:1 to realize a FoV of ±15º × ±5º (horizontal × vertical). All optical elements are made of uncoated Polymethyl Methacrylate (PMMA). A simplified simulation model is shown in figure 11.

TABLE II. LCOS PARAMETERS

Parameter	*Active area (mm^2)*	*Resolution*	*Aspect ratio*	*Reflectance*	*Waveband (nm)*
Value	8.20 × 4.61	1366 × 768	16:9	59%	430 - 650

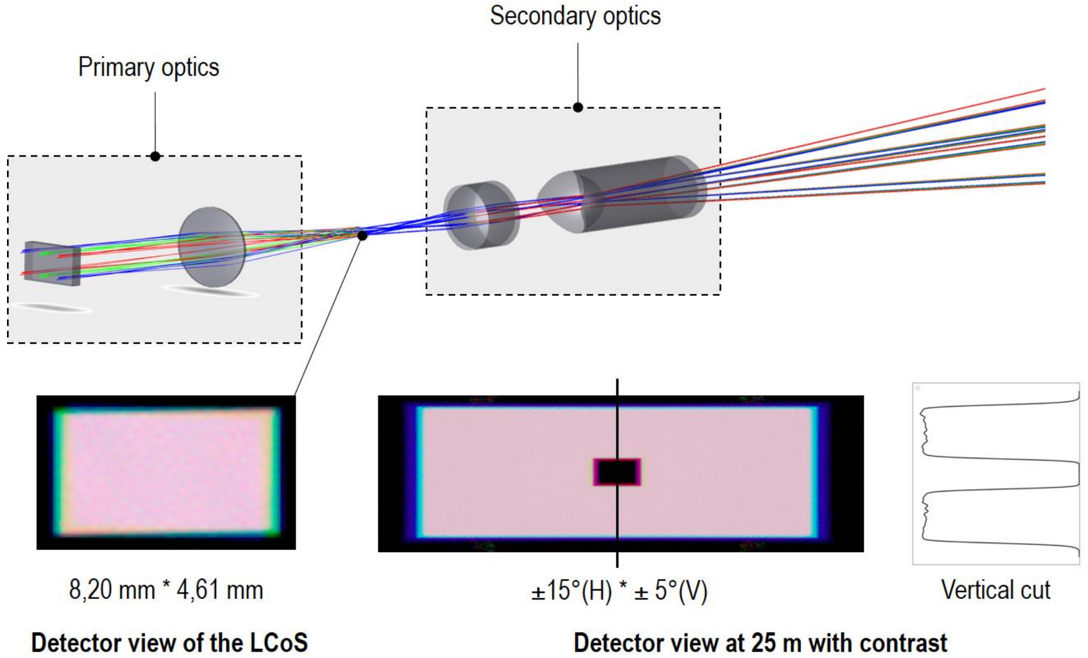

Figure 11. Simulation model and the detector views on the LCoS devices and at the distance of 25 meters.

It can be seen from figure 11 that six collimated laser beams are combined and homogeneously shaped by the primary optics. As a result, uniform white light is achieved at the position of the LCoS surface. The secondary optics composed of two lenses realize the target FoV. Besides, a 1 × 1 mm² square area in the center of the LCoS position is shut down to simulate the pixels that are switched off, the stretch effect with the contrast transfer performance is displayed on the detector at the distance of 25 meters. The output power ratio of R/G/B laser diodes is 5:3:2. This ratio results in a CCT of approximately 5800 K. According to the simulation, the optical efficiency of the system is 65.16% with laser collimation optics but no LCoS and PBS. A further discussion about the optical efficiency is in Chapter 7.

C. Headlamp prototype realization

According to the simulation model, a headlamp prototype is designed and shown in figure 12. The laser emission module contains a heat sink, a Printed Circuit Board (PCB) for the power supply of the laser diodes, and a diode housing that to mount the RGB laser diodes with laser collimators. The prototype additionally integrates a mirror between the primary optics and the LCoS devices. This is for reducing the axial length of the entire optical system so that this high-resolution module can be more compact.

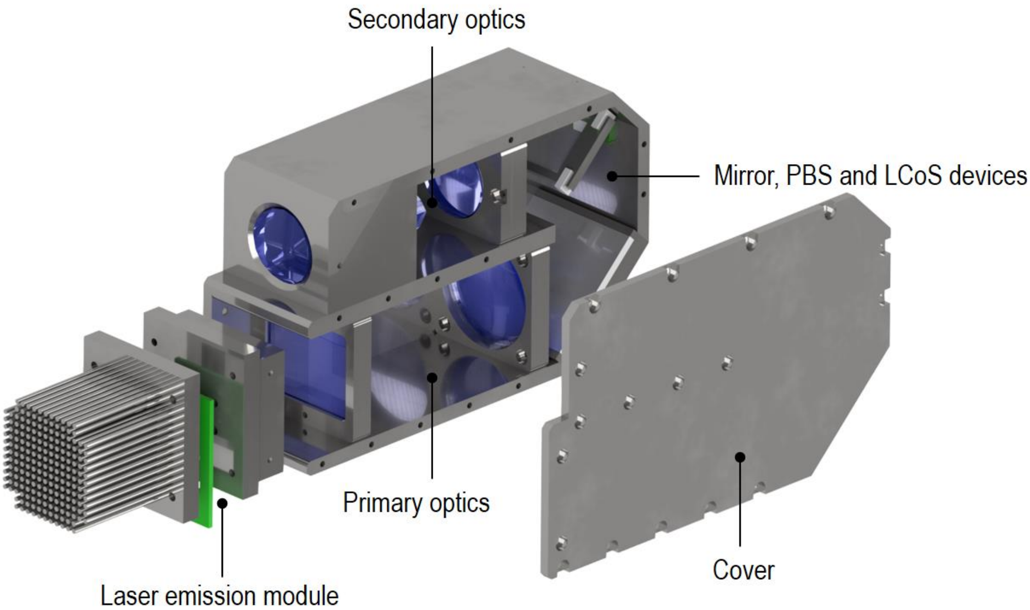

Figure 12. Design of the headlamp prototype.

VII. SUMMARY AND OUTLOOK

Summary

This paper introduces the development motivation of headlamp systems in the first place. After that, it reviews the current measures and efforts on headlamp systems to improve traffic safety and comfort. In addition, more potential functionalities of headlamps, especially for the era of intelligent transportation and autonomous driving, are presented. Due to that, most of the mentioned functionalities can be realized by a high-resolution light distribution. The high-resolution modulation technologies are reviewed as well.

Based on these functionalities and modulation technologies, an innovative concept using two LCoS display devices with RGB laser diodes as the light source is proposed. This concept can theoretically guarantee a high output illumination brightness when achieving the presented functionalities. A discussion on the further developments of this concept is right after the introduction of the proposed concept regarding the design intentions. Finally, methods in terms of the realization of the headlamp are introduced, followed by a design of the headlamp prototype as an example.

Outlook

In the next step, the presented headlamp prototype will be validated. Most optical and mechanical components are manufactured by Institute of Product Development (IPeG), Leibniz University Hannover itself. A proof of concept will be carried out, and further investigations on this prototype and lighting functionalities are going to be implemented.

Due to the reflectance of the LCoS, a big part of optical energy loss occurs on the LCoS. Therefore, the proposed optical system has a maximum optical efficiency of 38.45%. An output luminous flux of 1000 lm from this headlamp needs at least 3.19 W, 1.91 W, and 1.28 W output power from RGB laser diodes, respectively. For a higher brightness under this efficiency, the light source needs more than 6 laser diodes due to the technical limitations on the current production of laser diodes, especially the red and green ones. However, the use of LA as primary optics allows an easy integration of more laser diodes in the system. Besides, the optical efficiency can be improved by using better LCoS devices.

Furthermore, using laser light directly from laser diodes has the potential problem of laser speckle and laser safety due to its monochromatic emission wavelength and high output power intensity. Laser speckle is evident in projection applications. However, the effect of the speckle phenomenon on illumination has to be further investigated. Appropriate means will be considered to mitigate laser speckle when necessary. Finally, to integrate the measures for laser safety have to be taken into account in the next step.

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