NOVEL FIBER OPTIC COLOR SYNTHESIZER FOR PICO-PROJECTION DISPLAY WITH AN ULTRA WIDE COLOR GAMUT

Kyunghwan Oh*[1]*, Seijin Lee*[1]*, Woosung Ha, Minkyu Park, and Junki Kim
[1]Dept. of Physics, Yonsei University, Seoul 120-749, Korea
TEL:82-2-2123-5608, e-mail: koh@yonsei.ac.kr.

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Abstract

A novel fiber optic solution is provided to efficiently mix visible colors. Full color synthesis was achieved utilizing a novel 3×1 hard polymer clad fiber (HPCF) coupler along with red, green and blue (RGB) light emitting diode (LED) primaries. Varying the intensities of RGB LEDs that are coupled to three input ports, the device rendered a full color with an ultra wide CIE color gamut. Potential applications in pico-projection displays and LED backlights will be discussed.

1. Introduction

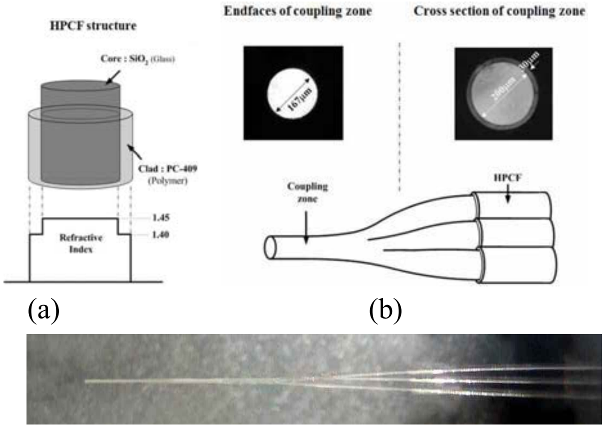
Despite explosive usage of hand-held display devices in recent years, there are fundamental optics limits such that small size displays cannot produce highly discernible images due to the resolution limit [1-2] and yet large size displays with a high enough resolution require a suitable distance from proper view position. In order to cope with these rather contradicting difficulties, light beam scanning display technologies are being intensively developed both experimentally[3-4] and theoretically[5]. Among those attempts Virtual Retinal DisplayTM (VRDTM) combined with the Scanning Photonic System (SPS) have drawn a significant attention. Recently a compact design based on optical fiber has been reported for monochromatic applications[6], where a fiber scanner using dual bimorph piezoelectric actuators was implemented.

In this paper we review a novel fiber-optic color synthesizer (F□CS) that could be applied both in micro scanning display and backlight systems based on LED color sources, which is being studied by the authors laboratory. Using commercial surface mount device (SMD) red, green and blue (RGB) LEDs, we have achieved a full color synthesis by introducing a novel fused taper 3 x 1 hard polymer clad fiber (HPCF) coupler, along which an efficient color mixing occurs over the fused waveguides.

2. Experimental

HPCFs have been playing a major role in short reach optical network due to its large core diameter, large numerical aperture and subsequently easy inter-connection in the optical links. Fig. 1-(a) shows a typical HPCF structure, where the core is composed of 200 m pure silica along with 15m thick low index polymer cladding. Typical numerical aperture ranges from 0.37 to 0.48. In a home-made fiber fusion and tapering system, three bare strands of HPCFs were fused together and the equal power splitting in the entire visible range was achieved using an optimized fabrication condition. The 3 x 3 HPCF coupler showed an average insertion loss of 5.56dB for each port and a low excess loss of 0.78dB measured at 635nm. With optimal heating temperature and tapering conditions, the coupling zone adiabatically turned to a perfect circular cross-section with the diameter of 135 m, where the most uniform mode coupling is achieved.

After fabrication of the 3 x 3 coupler, we cleaved the coupling zone at the mid-point of the waist to make a 3 x 1 coupler for the RGB LED inputs, as shown in Fig. 1-(b), where the photographs of the cross sections at the coupling zone and the end-face of HPCF are shown in the inset. Note that the cleaved end-face at the coupling zone serves, in fact, as the emitting pixel of the synthesized color. The area of circular output pixel can be flexibly controlled in the tapering process and output beam pattern could be also tailored. The outward form of 3 x 1 coupler is described with taper-zone length of 5mm and coupling-zone length of 5mm. A compatible peripheral design utilizing the compact color mixing and light delivery part can further make a progress of the system miniaturization, such as head-mount display..



(a) (b)

(c)

Fig. 1. HPCF fused taper coupler

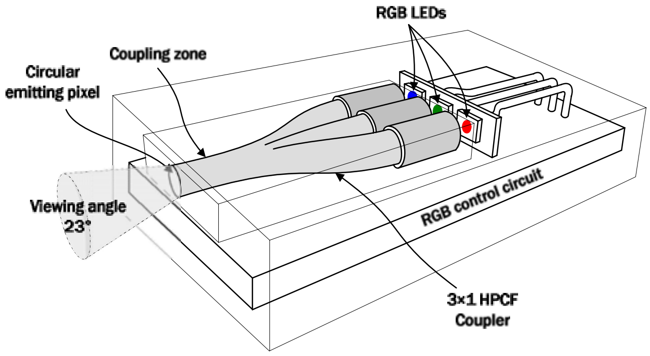


Fig. 2. Schematic Diagram of FOCS

3. Results and discussion

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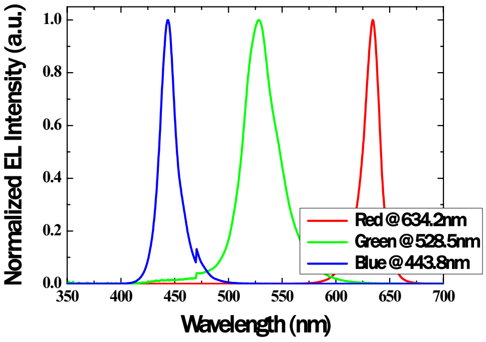
In Fig. 2, a schematic diagram of proposed fiber-optic color synthesizer (F□CS) system is illustrated. The F□CS consists of RGB LEDs and their driving electronics along with fiber optics. The electronics controls LEDs with 8-bits of resolution obtained by a digital-to-analog converter (DAC). The lights out of RGB LED primaries were directly butt-coupled to input ports of the 3 x 1 HPCF coupler using a silicon V-block. The bare SMD LEDs have the viewing angle of 130° for x-axis and 140° for y-axis without lens. Due to the limitation of HPCF numerical aperture, the butt-coupling efficiency from the bare SMD LED to fiber was 35%, which can be further improved with proper optics such as domed lens LED with a smaller radiation angle and higher numerical aperture HPCF. At the circular output pixel, the F□CS emits the color beam with a viewing angle of 23° along with a uniform flat-top intensity distribution, which could provide a high potential in micro-SPS.

Before we investigate the color synthesis, we characterized the RGB LEDs and their transmission characteristics along HPCF. The output spectra of the LED primaries are overlaid in Fig. 3. The peak intensities were located near 634.2, 528.5 and 443.8nm, respectively for RGBs.

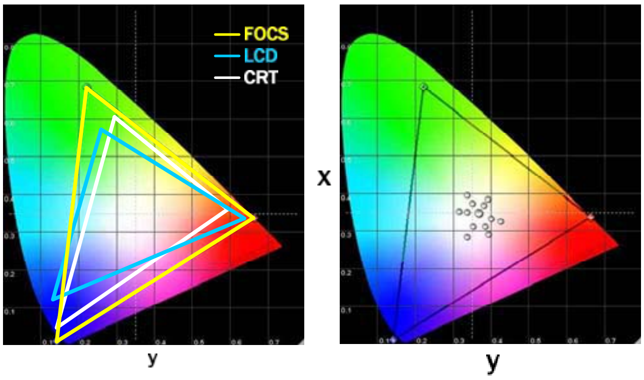


Chip LEDs (λ_{center})	Width (μm)	Length (μm)	Brightness (mcd)	Coupling efficiency from LEDs to 3 x 1 HPCF coupler output (%)
Red (634.2nm)	270	270	279	20.39
Green (528.5nm)	305	305	338	15.03
Blue (443.8nm)	300	400	100	10.76

Fig. 3. RGB LEDs used in FOCS

As the axial gap between input-end of HPCF and LED increased while maintaining the center to center launching, the beam size decreased. □n the while off-centered launchings resulted in ring shaped outputs. For guiding highly multi-modes the ray tracing concept is well matched to understand these phenomena with the diverse radiation of LEDs. In the off-centered case, the ray launched within the limited angle traces the helix path, as the result the ring pattern appears. The launching condition, therefore, is an important factor both for the beam profile and the coupling mechanism for F□CS. In this study, we chose the center-to-center launching along with the butt-coupling to maximize the coupling efficiency and color rendering capability.

HPCF is a highly multi-mode waveguide especially in the visible range, which allows an efficient mixing of colors in the coupling zone. Fig. 4-(a) shows the measured locus of synthesized colors from the proposed device over the CIE 1931 Chromaticity diagram. By controlling of RGB LED power levels, the proposed color synthesizer provided flexible color control over a wide gamut shown as the solid line. It is noted that the proposed FOCS covers much wider color gamut than conventional cathode-ray tube (CRT) display and liquid crystal display (LCD) [10], which experimentally confirmed the strong potential of FOCS for micro projection display optical engines. Scanning MEMS mirror systems and sequentially coded color imaging techniques optimized for the FOCS could provide a new type of 2-dimensional micro projection color displays, which is being investigated by the authors.



(a) **(b)**

Fig. 1. CIE diagram for output of FOCS

Having confirmed wide color gamut, we have focused on the issue of pure white generation out of FOCS and the results are shown in Fig. 4-(b). With proper adjustment of RGB driving currents, we could cover the entire white zone in the CIE diagram. For the synthesized pure white color, the photometric brightness out of the circular end-face of FOCS output port was 20,526Cd/m2, which was produced from red, green and blue LEDs with their brightness of 20,339, 31,442 and 12,000Cd/m2, respectively. That is, the coupling efficiency from three inputs to circular emitting pixel was 32.18%. High brightness is attributed to small diameter of 135μm and well defined emitting area with optical quality surface in the proposed. It is also of noteworthy that FOCS can flexibly locate the input and output by means of light delivery scheme through the HPCFs, inherently separating the white light source from the heat sources, RGB LEDs. The proposed FOCS, therefore, can provide significant advantages in backlighting systems in terms of spectral purity, flexible control of circular emitting surface area, and separation of heat source.

4. Summary

A compact fiber-optic full-color synthesizer has been experimentally demonstrated using a novel 3 x 1 HPCF fused taper coupler. With high temperature fusion technology, a circular emitting surface with the diameter of 135μm was achieved along with 35% LED to fiber coupling efficiency. With RGB primaries at the three input ports of the device, the proposed FOCS provided the flexible color control within full red, green and blue color gamut, whose area exceeded that of LCD and CRT. The device also provided pure white color index with the brightness of 20,526Cd/m2 that could be directly applied to LED based backlight system.

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5. References

(1 line spacing)

1. J. S. Kollin and M. Tidwell, "Optical engineering challenges of the Virtual Retinal Display," Proc. SPIE, vol. 2537, pp. 48-60, 1995.
2. T. M. Lippert, V. Andron, and T. E. Sanko, "Overview of light beam scanning technology for automotive projection displays," 8th Annual Symp. on Vehicle Display, Detroit, Michigan, Session 1.1, pp. 15-16, 2001.
3. G. C. de Wit, "Resolution matching in a retinal scanning display," Appl. Opt. vol. 38, no. 22, pp. 5587-5593, 1997.
4. E. J. Seibel, S. S. Frank, M. Fauver, J. Crossman-Bosworth, J. R. Senour, and R. Burstein, "Optical fiber scanning as a microdisplay source for a wearable low vision aid," Proc. Soc. for Information Display, P-37, pp. 338-341, 2002.
5. G. Harbers and C. Hoelen, "High performance LCD backlighting using high intensity red, green and blue light emitting diodes," Proc. Soc. for Information Display, LP-2, pp. 702-705, 2001.
6. J. S. Kollin and M. Tidwell, "Optical engineering challenges of the Virtual Retinal Display," Proc.

SPIE, vol. 2537, pp. 48-60, 1995.

7. T. M. Lippert, V. Andron, and T. E. Sanko, "Overview of light beam scanning technology for automotive projection displays," 8th Annual Symp. on Vehicle Display, Detroit, Michigan, Session 1.1, pp. 15-16, 2001.
8. G. C. de Wit, "Resolution matching in a retinal scanning display," Appl. Opt. vol. 38, no. 22, pp. 5587-5593, 1997.
9. E. J. Seibel, S. S. Frank, M. Fauver, J. Crossman-Bosworth, J. R. Senour, and R. Burstein, "Optical fiber scanning as a microdisplay source for a wearable low vision aid," Proc. Soc. for Information Display, P-37, pp. 338-341, 2002.