Journal of Theoretical and Applied Physics, 3-3, 27-30 (2009)

Source light effects in optical fiber output beam imaging

H. Golnabi[1,*], M. Kiani Majd[2]

[1]*Institute of Water and Energy, Sharif University of Technology, Tehran, Iran*
[2]*Physics Department, Central Tehran Branch, Islamic Azad University, Tehran, Iran*

Received: 18 June 2009/Accepted: 10 September 2009 / Published: 20 December 2009

Abstract

In this paper the output beam images and intensity profiles of an optical fiber are investigated by imaging technique. Different experiments are performed for the given fiber and captured images for the white LED and red LED sources are compared. The real-time images are investigated for two types of light sources and major differences are discussed. The effect of the light source frequency bandwidth on image formation is also investigated and obtained image patterns are discussed in detail. The resulting field intensity distributions and their relative changes with respect to the illumination source are examined and the role of fiber parameters in image cross sections is discussed. Two major differences are observed in terms of base width and FWHM bandwidth of the intensity curves for white and red LED lights. The white light LED source intensity curve shows a wider bandwidth in comparison with the red light LED intensity profile for the same fiber transmissions.

***PACs*:** 42.25.Dd; 42.15.Eq; 42.15.Dp; 42.30.Lr; 41.85.Ew
Keywords: *Light source, Fiber, Image, Intensity*

1. Introduction

Optical fibers are now efficient wave-guides and are used as transmitting media for the power and fast information deliveries. Large volume of the digital data in different forms of audio and videos can be transported quickly in a short or even a very long link. Image transmission investigation is an effective method for probing light information transmitted through an optical fiber, which is discussed in literature [1-6]. Power transmission is mainly used in industrial applications such as machines for cutting, welding, drilling, and smoothing. In these applications usually a low loss, large core, silica fiber is used to carry the high power laser beam to the target under operation. Another optical power transmission is in laser surgeries and clinical laser treatments [7]. In practice, optical units used in medical applications are the most challenging areas for the light beam shape investigation because the dept and area of the tiny cuts in the body cells are crucial and must be accounted for in an optimum laser treatment.

In telecommunication systems information mostly transmitted via temporal modulation of light and the bandwidth of transmission is limited by the material and the inter-modal dispersion effects. Transmitted information greatly depends on spatial optical distribution of the carrier light source. Following our research on the optical fiber imaging techniques [8] in this study we have used different kinds of light sources, specifically white and red LEDs as incoherent light sources with different bandwidths to illuminate a multimode step-index fiber for image analysis.

2. Experimental Arrangement

The experimental arrangement used in this investigation is shown in Fig. 1. As shown a light source illuminates the transmitting fiber and the output light is projected on a CCD camera. The xyz-translation stages are used for the precise adjustment of the optical elements and fiber holders. All the mechanical holders and optical elements are fixed on firm positions in order to eliminate the ambient effects. The output signal of the CCD camera is transmitted to a PC via an interface module.

We have used the dome structure white or red light emitting diode (LED) as alternate light source, which operated with a fixed voltage supply of 5 V. For a better comparison care was taken to keep the light source supply voltage constant during the experiments. The spectrum of an LED is a band of incoherent spectral curve, which is distributed around the mean center wavelength. The typical spectral output characteristic for LED results a Full Width at Half Maximum (FWHM) of 75-125 nm for the center wavelength of 1300 nm.

The spectral bandwidth depends on the diode geometrical structure type such as surface emitting (SLED) or edge emitting (ELED), material types and emitting center wavelength of the spectral output. Usually for the edge emitter LED the spectral bandwidth is smaller (75 nm) than that of surface emitter one (125 nm for the mentioned one). New GaAlAs LEDs with emitting wavelength range of 800-850 nm show a bandwidth of 30-60 nm. For the GaInAsP in

*Corresponding author: Hossein Golnabi;
E-mail: golnabi@sharif.edu
Tel: (+98) 21 66164652
Fax: (+98) 21 66005118

the range of 1300 nm the spectral bandwidth is reported higher to be about 50-150 nm range. The FWHM is generally 3 to 6% of the mean wavelength range within the 850 nm range and 6 to 12% at longer wavelength. For multi-mode laser diode spectrum the FWHM is in 3.5-30 nm range. For single-mode diode laser with good care the spectral bandwidth can be reduced to about 0.02 nm.

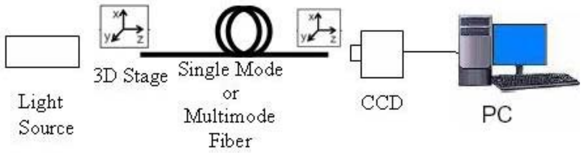

Fig. 1. Experimental arrangement used in this study consists of light source, transmitting fiber, CCD camera and PC.

If we consider a 3-6% of mean wavelength of 650 nm as a merit for the FWHM determination then for the red LED the spectral width (SW) is in the range of 1950-3900 nm. If we consider the white light bandwidth as a convolution of three spectral curves namely red, green, and blue then we expect a band with a FWHM, which is given by

$$(SW)_w = \left[(SW)_r^2 + (SW)_g^2 + (SW)_b^2\right]^{1/2}, \qquad (1)$$

where the subscript *w* shows the bandwidth for the white, r for the red, g for the green, and b for the blue sources, respectively. For the case of equal bandwidth for the combining spectrum elements the bandwidth (BW) for the white LED source is greater than red LED bandwidth by a factor of square root of 3. Thus the estimated FWHM for the white LED is in the range of 3377.5 -5755 nm.

The fiber tested in this experiment is a step-index multi-mode glass core fiber with plastic protective jacket. The overall diameter of the used fiber is 1.2 mm, cladding plus core diameter of 850 mm and core diameter of about 500 μm. The specification of the CCD camera are: A miniature camera (34 × 34 mm size, model TBC-312C, TEVICOM). It is a camera with alternate lens configuration such as flat pin-hole, Con type pin-hole lens and 1/4 inch color interline transfer CCD, built in microphone, extremely low power consumption, and high quality image. Other specifications of this camera are scanning system (2-1 interlace 625 Lines/50 Fields, 25 Frames), effective pixels 510(H) × 491(V), resolution of 380 TV Lines, illumination minimum of 0.8 LUX, S/N ratio >48 dB, video output 1 V p-p 75 ohm, VBS, with auto white balance, background compensation and internal synchronization. Power source requirement is 12 VDC and 200 mA with a power consumption of 4.5 W. The used lens option is Con-pin-hole lens (F2.0:f3.6) type that its selection depends on the application requirements.

The output of the CCD camera is a PGM file type, which is often hard to be processed by the regular programs. In this experiment arrangement is made to convert the portable graphical (PGM) files to MATLAB files, which can be easily manipulated by the MATLAB or EXCEL program. A typical matrix dimension of 480 (240) rows by 640 (320) columns is provided in which the pixel data of the camera are stored. The real-time framed images are grabbed by the proper interfacing program controller (Capture card and Pixel View controller) and transmitted to the PC for further correction and possible processing. Using a CCD camera is a useful method and image evaluation for synchronized laser scanning systems and precise CCD image analysis for planar laser induced fluorescence experiments using CCD cameras are given in literature [9, 10].

3. Experimental Results

In the first experiment a multi-mode large core fiber is tested with the white LED as the illumination source. The captured real-time image is displayed in Fig. 2. The pixel arrays shown in Fig. 2 in which the vertical axis in graph shows the Y-pixels (240 pixels) and the horizontal axis shows the X-pixel arrays (320 pixels). As can be seen from image in Fig. 2, the images are shown in RGB color format and concentric circular images around a central disk are obtained in this case. A careful observation of the image circles shows that the color of the rings around the brown center disk is changing from red to yellow, green, and light blue, respectively. The dark blue around the real circle images show the background image of stray light with the minimum intensity in the color map image.

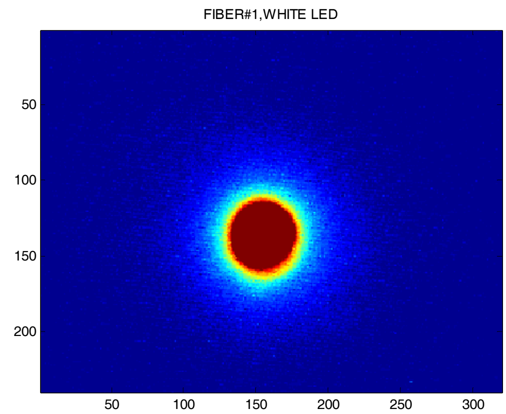

Fig. 2. Real-time image of the fiber output using white LED for illumination.

Considering the order of the colors in the color map it is clear that much of the imaged light is as a result of illumination from the fiber core part as indicated by brown color in Fig. 2. The next circle in image of Fig. 2 shown with red color shows a lower light intensity, which shows a drop of light intensity and a similar reduction in light intensity is observed as we move to outer circles in image of Fig.2. From color map of circular images it is suggested that the output intensity distribution is decreasing by radial increase.

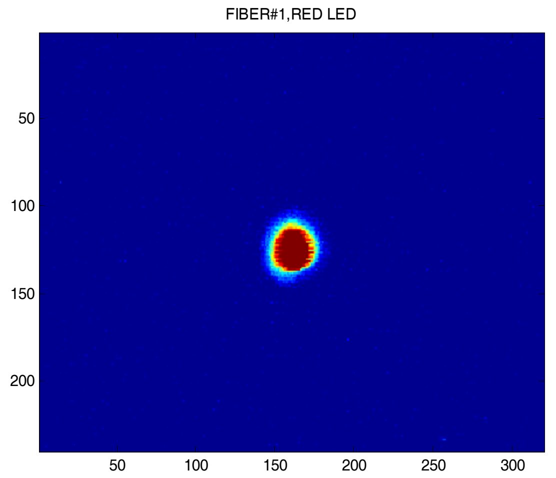

Fig. 3. Real-time image of the fiber output using red LED for illumination.

In the next experiment the similar multi-mode large core fiber is tested while the red LED is used in the experimental set up instead of the white LED. The captured real-time image with the same display format is shown in Fig. 3. As can be seen from image of Fig.3, the images are again shown in RGB color format and concentric circular images around a central disk are obtained in this case. A careful observation of the image circles shows that the color of the rings around the brown center disk is changing from red to yellow, green, and light blue, respectively. As mentioned the dark blue around the real circle images shows the background image of stray light with the minimum intensity in the color map image. Concerning the source light change, there is notable difference between the white LED and red LED images as can be seen in Fig. 2 and Fig. 3. The center portion as mentioned is attributed to the light transmission by the core of fiber is much larger for the white LED in comparison with that of the red LED on the same scale. In general the image patterns are very similar as can be noticed by comparing Fig. 2 and Fig. 3 images

Even though the real-time images provide a good body of information, however more information is required to investigate the field intensity. In order to study the intensity distribution, MATLAB functions are used to store the real image data into a M-file matrix, which is executable in MATLAB protocol. In order to show image intensity profile the image data are stored in a buffer matrix, full dimension of 640 rows and 480 columns in the MATLAB program and such data are used for intensity profile representation.

The intensity profile for the white LED illumination at a given distance is shown in Fig. 4, which is a plot of image intensity image versus scanning distance in X-direction. As shown in Fig. 4, the image intensity starts to grow from s distance of about 600 μm and reaches its peak value at a distance at about 800 μm. The intensity remains about constant of about 0.69 on the given arbitrary scale up to about 1000 μm and then decreases quickly. From 1100 μm to 1200 μm range the intensity shows a gradual decrease and from that distances drops to almost to near zero at about 1400 μm as can be seen in Fig. 4. We note that in Fig. 4 the intensity profile is very close to the flat-top distribution with a base width of about 600 μm for this case.

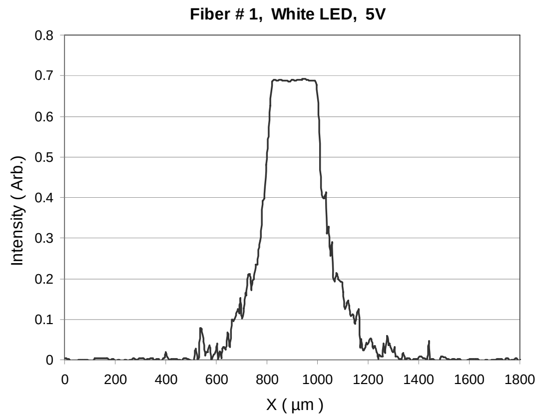

Fig. 4. Intensity profile of the fiber output beam using white LED for illumination.

In a similar study the intensity profile for the red LED illumination at the same profiling distance is obtained and shown in Fig. 5, which again is a plot of the middle row image intensity versus scanning distance, X. As shown in Fig. 5, the image intensity here starts from 820 μm and reaches its peak value at a distance of about 900 μm. The intensity in this case remains about constant about 0.69 on the given arbitrary scale up to about 1000 μm and then decreases quickly. From 1000 μm to 1100 μm range the intensity decreases and reaches to almost zero at about 1100 μm. It can be seen in Fig. 5 that the intensity profile is very close to the flat-top distribution with a base width of about 300 μm for this case.

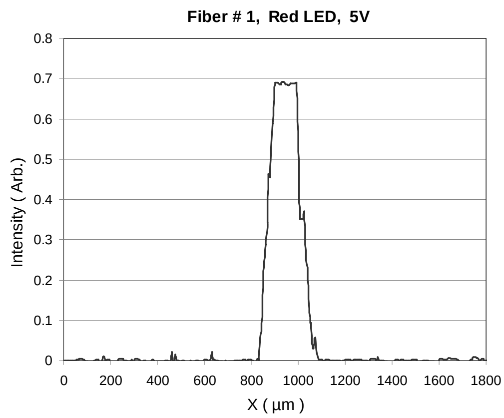

Fig. 5. Intensity profile of the fiber output beam using red LED for illumination.

Clear difference in two intensity profiles of Fig. 4, and Fig. 5 requires more attention. Thus in the last study in order to investigate the effect of source light characteristics on the image formation, the intensity profiles of the multi-mode fiber for two light sources together are shown in Fig. 6. As can be seen in Fig. 6, two major differences can be recognized between two cases. The base width of the intensity curve for the white light LED source is wider than that of the red light LED. Compare 800 μm for the white light source with the base width of about 300 μm for the red LED source, which is greater by a factor of ~3.0. This indicates that for the red light propagation in comparison to white light in the same fiber most of the red light is confined in core region near optical axis of the fiber while for white light a larger portion of the light is propagated in the further radial distance close to core-cladding interface.

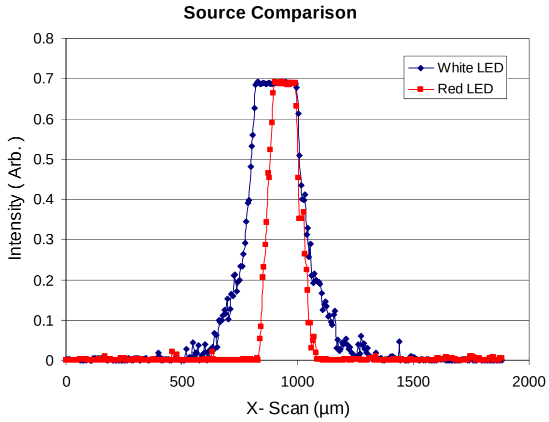

Fig. 6. Comparison of two intensity profiles for two LEDs.

Second difference can be explained in terms of the curve FWHM. To compare the bandwidths, the (FWHM) merit is used for such a comparison. The FWHM for the white LED image intensity is about 300 μm while for the red LED is about 175 μm for the case of reported scanning distance. Concerning the source light change, there is notable difference between the white LED and red LED image profiles as can be seen in Fig. 6, which verifies the role of the source light on the image formation as well as the role of the transmitting fiber. This agrees with the real-time images for the two sources, which indicated the same conclusion. Considering the recorded output images it is noted that the FWHM image determined experimentally for the white LED is larger by a factor of 1.71, which agrees with the given theoretical estimation from Eq. (1) that is about 1.73.

4. Conclusions

Generation of the incoherent light beams is simple in design and usually inexpensive, which makes them suitable for many applications. However, for more precise measurements and high power deliveries coherent laser light sources are preferred [11-13]. As stated in our recent report [14] incoherent light sources can be considered as very good illumination means for fibers in order to investigate the output beam cross sectional imaging and intensity profiles. Using an incoherent light for fiber illumination, the differences between single mode and multimode fibers output beams can be recognized in terms of the spot widths and delivered intensity. As described in [14] for a single mode fiber beam transmission the output spot is much smaller and sharper than that of a multimode fiber.

As shown here beam shape study is a simple and effective method for investigating optical characteristics of the source and transmission line. Clear difference in two intensity profiles for different light sources requires more attention and we show experimentally such a difference for a multi-mode fiber. Two major differences in terms of base width and FWHM of the intensity curves can be recognized for two cases. For the white light LED source both factors are wider than that of the red light LED (compare 800 μm width for the white light with 300 μm for the red LED source). The FWHM for the white LED image intensity is about 300 μm while for the red LED is about 180 μm. This agrees with the real-time images for the two sources, which indicated the same conclusion. Considering the recorded output images it is noted that the FWHM image obtained experimentally for the white LED is larger by a factor of 1.71, which agrees with the given theoretical estimation of about 1.73.

Acknowledgement

This work was supported in part by the Sharif University of Technology Research program. The authors gratefully acknowledge the grant money devoted to this research.

References

[1] J. D. Gilmore , R. C. Lind. Opt. Lett. **7**, 558 (1982).
[2] A. Gover , C. P. Lee, A. Yariv. J. Opt. Soc. Am. **66**, 306 (1976).
[3] W. D. Heacox. J. Opt. Soc. Am. A **4**, 488 (1987).
[4] P. Naulleau, M. Brown, C. Chen, E. Leith. Opt. Lett. **21**, 36 (1996).
[5] A. M. Tai . Appl. Opt. **22**, 3826 (1983).
[6] A. Yariv. J. Opt. Soc. Am. **66**, 301 (1976).
[7] H. Fujii, T. Asakura, T. Matsumoto, T. Ohura. J. Lightwave Technol. **2**, 1057 (1984).
[8] A. Asadpour, H. Golnabi. J. of Applied Sci. **8**, 4210 (2008).
[9] H. Golnabi. Opt. Laser Technol. **38**, 152 (2006).
[10] H. Golnabi. Opt. Laser Technol. **31**, 225 (1999).
[11] S. Fang-Wen , J. Chen. Opt. Express **16**, 22113 (2008).
[12] C. Rick , J. Hsu, A. Shah, B. Jalali. IEICE Electron. Express **1**, 392(2004).
[13] C. P.Tsekrekos , R. W. Smink, B. P. de Hon, A. G. Tijhuis, A. M. Koonen. Opt. Express **15**, 3656 (2007).
[14] A. Asadpour A. and H. Golnabi. J. of Applied Sci. **10**, 312 (2010).