Simple Laser Beam Line Shaping Demonstration Using Clear plastic LEDs

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Abstract

In this work, we substituted rod lenses by the cylindrical body of clear plastic Light Emitting Diodes (LEDs), as a cheap laser line shaping optical element, for physics classroom demonstrations and experiments. A laser pointer was used to test three different LEDs, to reveal the correlation between their diameters and the beam fan angle. The results show that the performance of the LED body with smaller diameter was the best in terms of maximum laser line length. This application is useful in pedagogic activities, low cost optical designs, large field automotive shadowgraphy and non-Doppler laser shadow vibrometry of incandescent linear objects.

Keyword: Clear plastic LEDs, Cheap laser line shaping optics, Rod lens, laser pointer, classroom demonstrations, Automotive shadowgraphy, Shadow-vibrometry.

Introduction

Rod lenses are key element in line beam shaping optics for certain laser applications, such as, anamorphic beam shaping [1], laser line generators [2], refractive diffuser [3], laser particle image velocimetry (PIV) systems [4,5], astigmatic collimation [6], laser tile leveling [7], light pipes and endoscopes [8]. Moreover, rod lenses were used recently for generating high efficiency large field automotive shadowgraphs [9,10] and for illuminating incandescent linear tungsten filaments for ultrahigh temperature non-Doppler laser shadow vibrometry [11,12]. A simple rod lens usually has the form of a cylinder of diameter D and of length L (as shown in figure 1a.). The basic idea behind its function is simple: If collimated light of cross section a, passing through the lens diameter D, with a focal length f then it will be focused into line of length l , at distance d and at fan angle θ (as shown in figure 1b.).

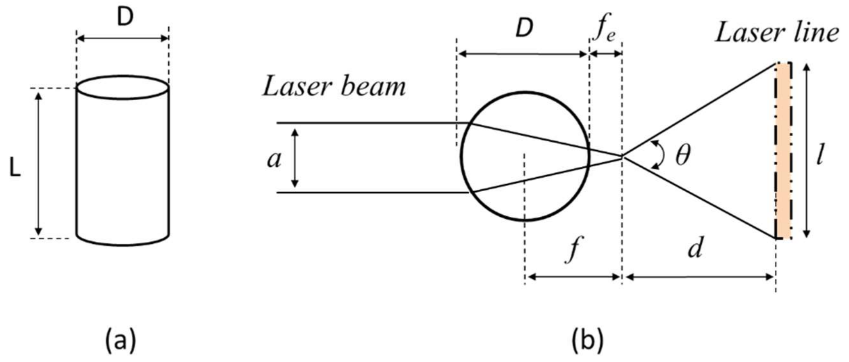


Figure 1. Rod lens basics geometry and optics

The effective focal length of a rod lens f_e measured from the lens surface, depends on the refractive index of its material and is given by the expression [13]:

$$f_e = \frac{nD}{4(n-1)} \quad (1)$$

Equation 1 shows a linear dependence between f_e and D with proportionality constant $\frac{n}{4(n-1)}$, hence f_e tends to $\frac{D}{2}$ if n tends to 2. The refractive index for most glass materials is close to 1.5, therefore equation 1 take the form:

$$f_e = \frac{3D}{4} \quad (2)$$

To describe a the laser line, there are four commonly used parameters [2]: the first is the length, calculated from equation 3:

$$l = 2d \tan\left(\frac{\theta}{2}\right) \quad (3)$$

the second is the fan angle, calculated from equation 4:

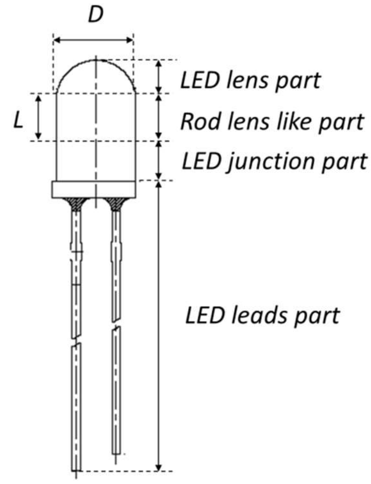
$$\theta = 2\tan^{-1}\left(\frac{l}{2d}\right) \quad (4)$$

the third is the laser line intensity I (which is a function of θ) calculated from equation 5:

$$I = 2\tan^{-1}\left(\frac{a}{2f}\right) \quad (5)$$

and the fourth is the thickness which depends on both beam diameter and divergence. Rod lenses are manufactured from various materials, like BK7, optical glass, fused silica, CaF2, MgF2, Sapphire, ZnSe and ZnS, with different diameters ranging from 1 to 30 mm according to their applications [13]. Unlike spherical lenses, rod lenses are difficult to mount and relatively hard to find with reasonable price for implementation in simple illumination projects, where accuracy is unnecessary. This work will test standard LEDs as a low cost alternative for glass rod lens, because of their geometrical and optical resemblance. In this context the laser line shaping abilities of different diameters clear plastic body LEDs, will be studied.

The idea of using LEDs as a low-cost alternative for fancy rod lenses, arises from the unique structure of a LED, and uses its leads as mounting mean, while using its body middle part (with cylindrical shape), as rod lens. The diameter tolerance of the LED is about $\pm$ 0.01 mm, which is tenfold that of the BK7 and most glass rod lenses, but still very convenient and suitable for illumination purposes. LEDs came into various diameters mostly 3, 5 and 10 mm, while the only limitations here is their small cylinder length as shown in figure 2.



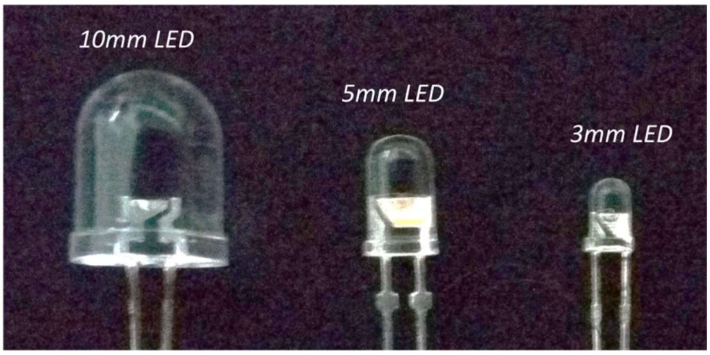


Figure 2. LED body features

LEDs are manufactured using molded clear epoxy resin or liquid plastics. The refractive index n of the LED body is 1.5 which is very similar to that of most glass rod lenses.

Experimental work

The simplest experimental setup was designed using a 1000 mw 532nm military laser pointer, type c303 china, with 1.5 mm beam diameter equipped with variable optical divergence control knob. The laser beam was introduced through the LED body (as shown in figure 3). A laser line was formed 2 meters away on a distant screen.

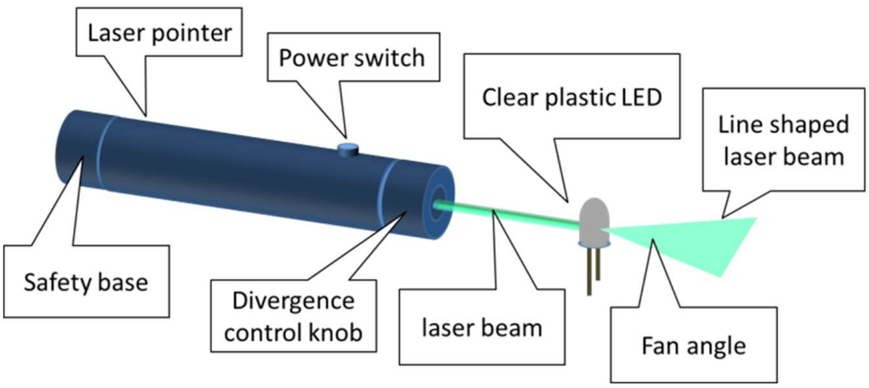


Figure 3. Experimental setup illustration

A set of three commercial LED samples of different diameters was tested to obtain another set of laser line spans and fan angles. Table 1 shows the basic samples geometrical parameters.

Table 1. Geometrical and optical description of experimental sample

LED Sample	D (mm)	L (mm)	f_e (mm)
First	3 (± 0.01)	~ 2	2.25
Second	5 (± 0.01)	~ 3	3.75
Third	10 (± 0.01)	~ 5	7.5

One important experimental remark that worth to be mentioned, is to keep the introduced laser beam at the center of rod lens like part of the LED, preventing it from illuminating any part of the LED internal structure, specially the LED bond wire. If not diffraction patterns will be seen in the vicinity of the formed laser line as shown in figure 4.

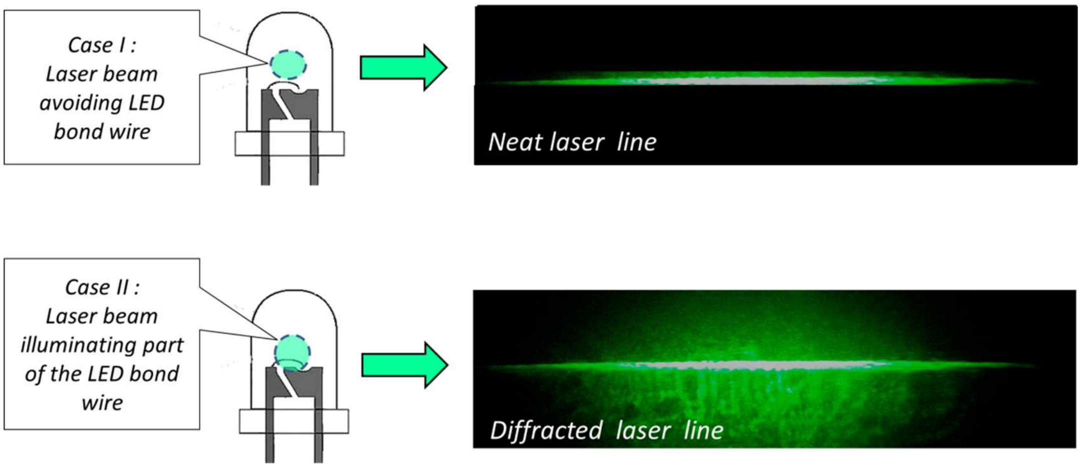
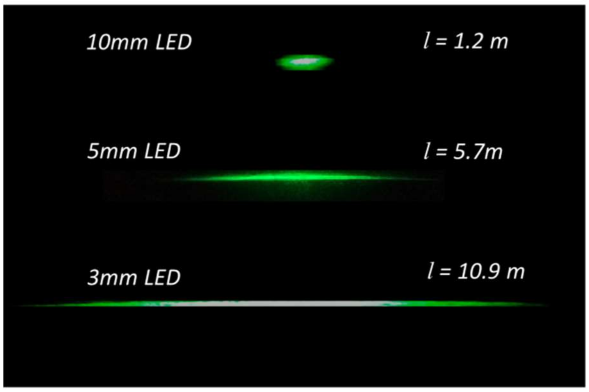


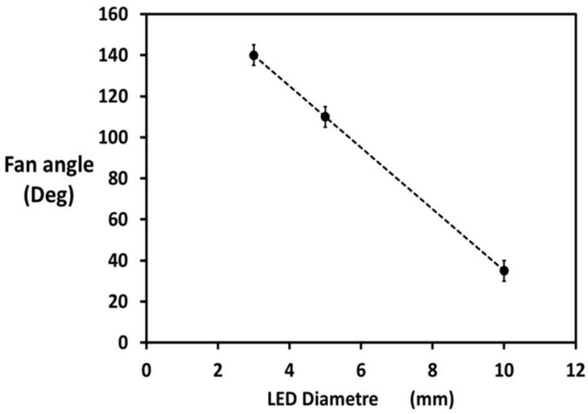
Figure 4. Effect of laser beam- LED body alignment on the quality of the yielded laser line

Results and discussion

The Results showed that the resulting laser lines obtained by LEDs body beam shapers were neat and uniform. As the diameter of the LED decreases, the line length increases in return (as shown in figure 5a). Using equation 4, a plot showing the inverse proportionality between the fan angle and the LED diameter was obtained (as shown in figure 5b).



(a)



(b)

Figure 5. Basic experimental results

The relative laser beam intensity distribution produced by diffractive diffusers and rod lenses, $I(\theta)$, is represented through Lorentz distribution by the equation:

$$I(\theta) = \frac{I_o}{1+\left(\frac{\theta}{\theta_o}\right)^{\alpha}} \tag{6}$$

Where I_o is the initial intensity of the laser beam, $\frac{\theta_o}{2}$ the fan angle at the full width half maximum and α is a constant on which depends the flatness of intensity profile (in this particular case $\alpha = 2$)[9]. By applying equation 6, the relative angular intensity distribution along the longitudinal axis of the obtained laser lines for both 3 LED samples, is represented in figure 6. where the most flattened curve was that of the least LED diameter and vice versa.

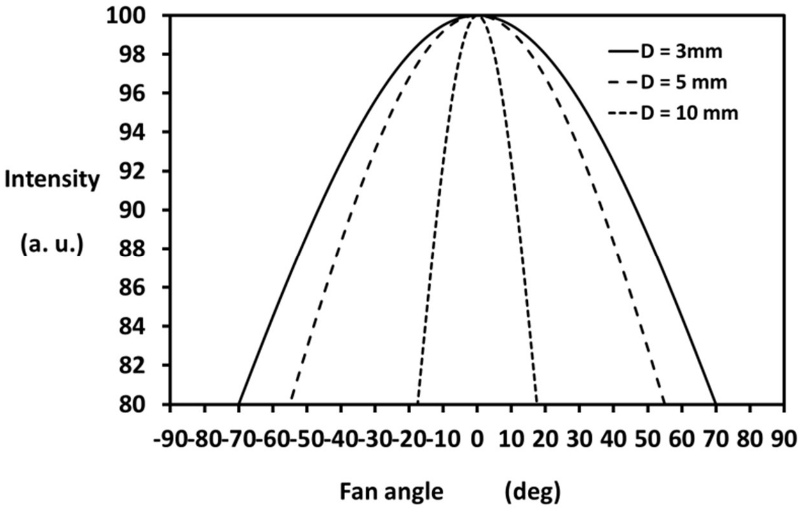


Figure 6. Relative laser line angular intensity distribution.

This idea were applied in several scientific and pedagogic applications, where the three most important are: The first, is the demonstration of rod lens theory and applications in physics classrooms, where the students are taught to experiment by themselves the basic laser line beam shaping using moderated and easy to find tools (i.e. LEDs and laser pointers). Students were able then, to re-obtain the same previous results that has been shown earlier. The second, is the design of high efficiency laser diffuser for automotive shadowography [9,10], where a simple setup made of a laser pointer, diffractive dot matrix beam shaping film and a 10 mm LED as a replacement of rod lens, is used to generate a high divergence homogeneous laser beam as shown in figure 7a . This beam is used to illuminate the automotive interior to generate an external shadowgraph panorama on a cylindrical screen outside the vehicle as shown in figure 7b.

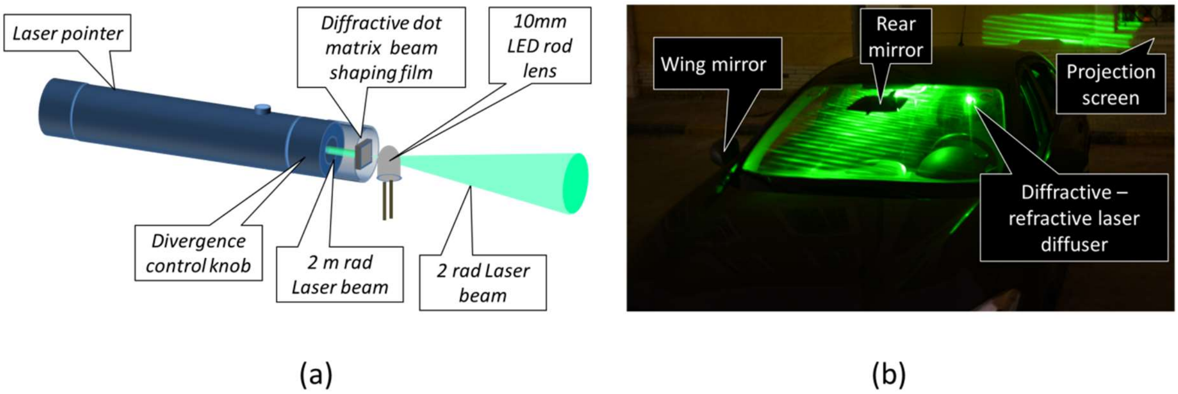


Figure 7. Application of LED rod lens in high efficiency laser diffuser for automotive shadowgraphy.

The third application is the shadow vibrometry of refractory materials linear filaments, this noncontact technique is used to measure the dynamic properties of materials at elevated temperatures. The technique merges between optical lock-in amplifiers, shadowgraphy and pulse excitation technique (figure 8a) [11,12]. The linear symmetry of the refractory filaments requires a rectangular field laser illumination (figure 8b). This field is generated by rod lenses and their LEDs replacement.

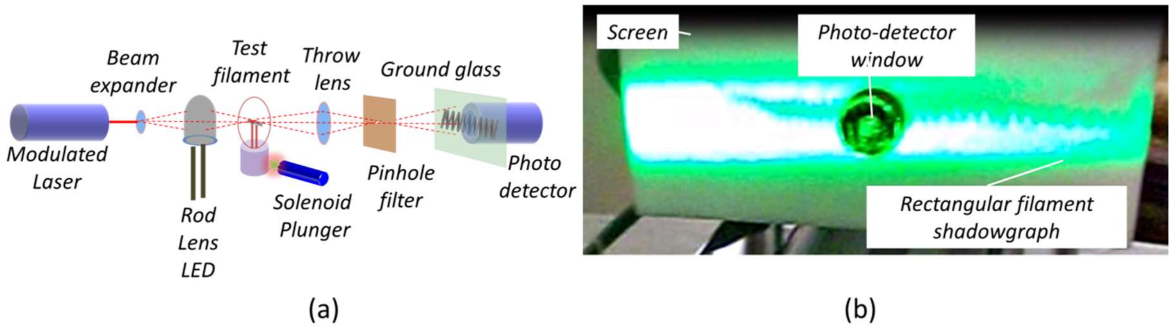


Figure 8. Application of LED rod lens in shadow vibrometry of refractory materials linear filaments

Conclusions

The use of LED body as a simple rod lens for illumination purpose, has proven very successful. This replacement has improved the low cost solutions required in some applications, where the use of fancy optical elements such as rod lenses is not possible. LED body preserve all optical properties of a rod lens, especially at its middle part with cylindrical shape. rod lens LEDs were used recently for demonstrating rod lenses laser line shaping principals as pedagogic activity in physics class rooms, for generating high efficiency large field automotive shadowgraphs and for illuminating incandescent linear tungsten filaments for ultrahigh temperature non-Doppler laser shadow vibrometry.

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