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Research note

Small Gaussian laser beam diameter measurement using a quadrant photodiode

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Abstract

A method that uses the quadrant photodiode has been shown to be relatively inexpensive and robust in measuring Gaussian laser beam diameters in two axes. This approach requires neither component rotation nor precision alignment, and it facilitates integration of Gaussian laser beam diameter measurement with laser beam tracking in instruments. The physical gap between sensors in the quadrant photodiode, however, limits laser beam diameter measurements to those in the millimeter range. Here, we describe a modified approach to measure Gaussian laser beam diameters that are significantly smaller.

Keywords: Gaussian beam measurement; Quadrant photodiode

1. Introduction

Accurate knowledge of the Gaussian laser beam diameter is useful in many areas of application. Some of the practical methods used to measure the Gaussian laser diameter include the usage of burn spots [1], knife-edges [2–3], and gratings [4–6]. The burn spot method is generally inaccurate and suited for interrogating the output from high power lasers. While the knife-edge and grating methods both possess high accuracies, precise alignment between the knife-edge/grating with the photodiode, often placed after it from the laser light source, is important as a less than careful set up will result in erroneous measurements. Furthermore, it may be necessary to measure the beam diameter in two orthogonal axes in certain applications or simply to ascertain that the laser illumination is normal to the detector plane (a non-normal illumination will result in an elliptic as opposed to a circular Gaussian beam profile). With the knife-edge or grating methods, it would be necessary to rotate these entities orthogonally in-between each measurement. This requires the addition of a precise optomechanical stage to the setup.

The quadrant photodiode is a proven sensor used for laser beam position tracking. It is relatively low-cost and robust in nature. Its use had been reported in diverse areas such as atomic force microscopy [7], particle tracking [8], and photothermal diffusivity measurements [9]. Recently, the quadrant photodiode was demonstrated as an inexpensive device to measure Gaussian laser beam diameters [10] in the millimeter range. When smaller diameter beams need to be interrogated, the technique is beset with a practical limitation as all quadrant photodiodes have a typical physical gap of about 50 μm between the sensors. A modified measurement approach is thus needed in order to measure small Gaussian laser beam diameters using the quadrant photodiode.

In the approach previously reported [10], the Gaussian laser beam illuminates the quadrant photodiode directly (see Fig. 1(a)). As light impinges over all the quadrants, voltages proportional to the amount of light power incident are generated. The interrogation of these voltages as the quadrant photodiode is moved in the x- and y-axis permits the laser diameter to be measured.

In the case where the laser diameter is small, no voltages will be generated corresponding to beam illumination on the physical gap between the sensors on the quadrant

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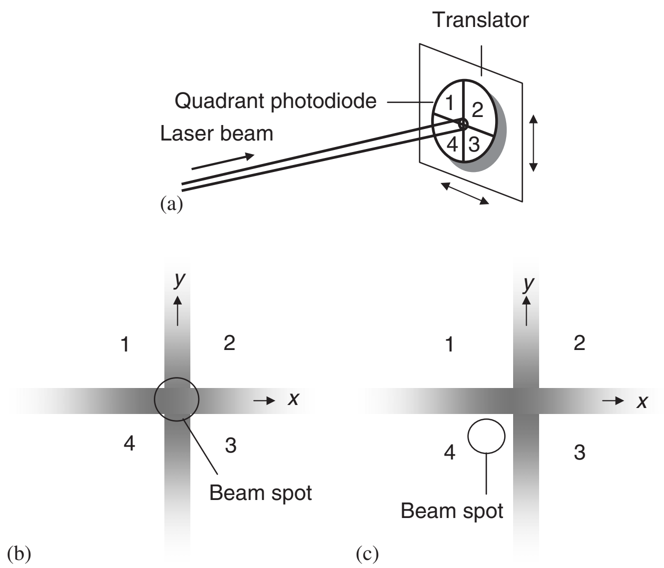

Fig. 1. Schematic description of the Gaussian laser beam diameter measurement method using a quadrant photodiode (a). The physical gap between sensors in the photodiode does not permit accurate measurement of the beam diameter using the previous reported method [10] (b). In the modified approach, the original position of measurement is exclusively within one sensor (c).

photodiode (see Fig. 1(b)). Hence, applying the previous scheme to determine beam diameter will result in error. In the alternative scheme reported here, the small laser beam is first made to impinge exclusively on any of the four quadrants. Since the beam diameter is much smaller, any overlap with neighboring sensors can be avoided.

2. Technique description

Suppose that the beam is exclusively located in quadrant 4 (see Fig. 1(c)). By interrogating the voltage from this quadrant alone, it is possible to find the beam diameter along the x-axis and the y-axis. Suppose that the total power of the laser beam is P_0. As the quadrant photodiode is moved in the x-axis, the power corresponding to quadrant 4 at any position X can be determined using

$$P(X) = \left(\frac{2}{\pi}\right)^{1/2} \frac{P_0}{w} \int_X^{\infty} \exp(-2x^2/w^2)\,\mathrm{d}x, \tag{1}$$

where w is the beam radius at the $\exp(-2)$ points in intensity. By creating the following variable:

$$\beta = \frac{\sqrt{2}}{w} x, \tag{2}$$

the expression in (2) reduces to

$$\frac{P(X)}{P_0} = \frac{1}{2}\mathrm{erfc}(\beta). \tag{3}$$

Values of $P(X)P_0$ between 0.1 and 0.9 correspond to β having values of 0.9062 and -0.9062, respectively. Therefore the beam radius is given by

$$w = 0.7803(X_2 - X_1), \tag{4}$$

where $(X_2 - X_1)$ is the translation between the 0.9 and 0.1 points. A similar approach of moving the quadrant photodiode in the y-axis, and interrogating the voltage in quadrant 4 will give the beam radius in that axis.

3. Experiment and results

A commercially available quadrant photodiode (Pacific Silicon QP50-6SD) was used for verification. The laser used was an elliptical Gaussian beam diode laser with 10 mW power and 632.8 nm wavelength. The quadrant photodiode was mounted on an x–y optical translation stage with 0.5 μm resolution along each axis of travel.

In the experiment to determine the laser beam diameter along the x-axis, the quadrant photodiode was first positioned such that the laser beam was fully illuminated within quadrant 4. Voltage readings from this quadrant were made as the photodiode was translated in the x-axis (see Fig. 1(c)). A similar procedure in the y-axis was applied to determine the diameter along this axis.

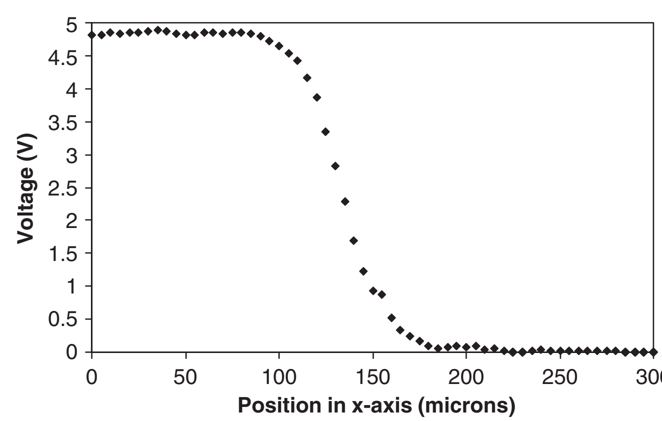

Fig. 2. Plot of the sensor voltage against translation of the quadrant photodiode in the x-direction.

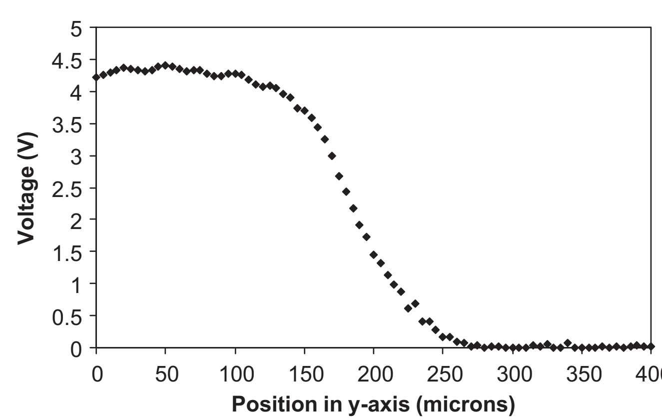

Fig. 3. Plot of the sensor voltage against translation of the quadrant photodiode in the y-direction.

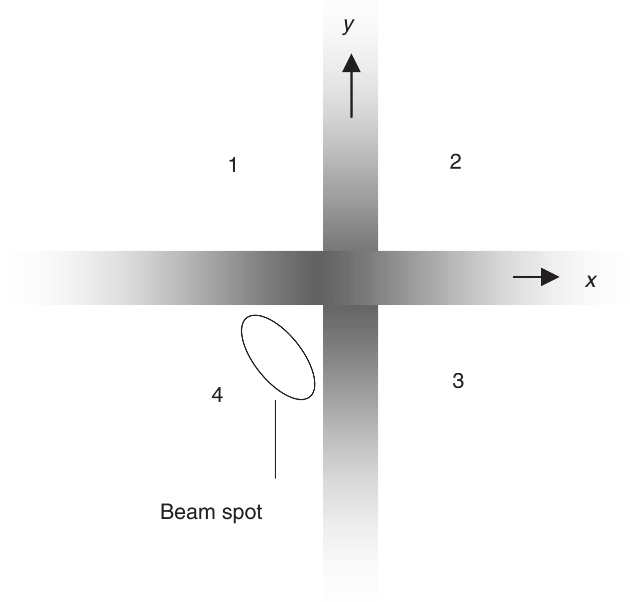

Fig. 4. A Gaussian elliptical laser beam that has the principal axis not coincident with the x-or y-axis of the quadrant photodiode. The alignment method also requires monitoring the voltage of one sensor as the beam traverses over one edge.

Figs. 2 and 3 give plots of the voltage readings against translation of the quadrant photodiode in the x- and y-directions. By identifying $P(X)P_0$ equal to 0.1 and 0.9 in each plot, the beam diameters were calculated using Eq. (4) and found to be 85.8 and 154.5 μm from the respective x- and y-axis plots. This indicates the elliptical Gaussian nature of the laser beam used.

The quadrant photodiode clearly provides an easy way of determining the Gaussian laser beam diameter. The accuracy of this technique is limited only by the resolution of the translator used to move the quadrant photodiode. By removing the need for any intervening elements (such as knife-edge and grating) a more robust measuring system is afforded. Imperfections on the knife-edge and grating have been known to affect measurement accuracy.

As mentioned in a previous work [10], the real important advantage with this approach lies in the ease of integrating a laser beam diameter measurement feature into instruments that already use the quadrant photodiode to track beam deflection. The approach here permits designs that are compact and that use fewer components.

It should be noted that, while the technique described here allows measurement of diameters of elliptical Gaussian laser beams, there is a need to align the principal elliptical axes of the beam to coincide with either the x- or y-axis of the quadrant photodiode. To accomplish this, the small Gaussian beam is first made to completely illuminate one quadrant (see Fig. 4). Suppose the intention is to have the major axis of the beam to be parallel to the y-axis. The beam is then moved towards the right edge. By interrogating the voltage output, the point of first contact between beam and edge can be ascertained. Rotating the beam and monitoring the voltage as the beam is scanned from left to right along the edge then allows orientation of the beam such that its major axis is made parallel to the y-axis.

One last pertinent issue to note pertains to which measurement method (the one in Ref. [10] or the one described here) to adopt in relation to the laser beam size. A simple rule of thumb would be to use the method here for beam sizes smaller than the area of one quadrant and the approach in Ref. [10] when otherwise.

4. Conclusions

In summary, we report the ability to measure very small Gaussian laser beam diameters using the quadrant photodiode. This method is relatively inexpensive, robust, circumvents the alignment requirement needed with knife-edges and gratings and allows two axes laser beam diameter measurement without the rotation of any component. The approach is demonstrated to provide accurate measurements in a verification experiment. This technique facilitates incorporation in instrument designs that integrates small Gaussian laser beam diameter measurement with laser beam tracking in a compact manner using fewer components.

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