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Miniature long-range light beam transmitter resorting to a high-power broad area laser diode

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ABSTRACT

A miniature long-range light beam transmitter, which taps into a high-power broad area laser diode (BALD), was realized to exhibit a uniform detectable width. An effective model was proposed to practically emulate the multimode characteristics of the beam generated by the BALD. The model, solely based on the emitting region and far-field divergence angle pertaining to the LD, is established through an incoherent superposition of multiple normalized Hermit–Gaussian modes. The feasibility of the proposed model was successfully verified in terms of the calculated and observed irradiance distributions of the light beams. A long-range light beam transmitter was then designed and constructed taking advantage of the BALD source in conjunction with a beam shaper. The manufactured transmitter was corroborated to provide an infrared beam with a constant detectable width of ~1 m, over a distance ranging up to 400 m, for a predefined threshold level.

1. Introduction

The laser transmitter has attracted enormous attention in a variety of short-, medium- and long-range applications, such as laser-assisted welding and marking, free-space optical communications, and light beam generators [1–4]. For long-range beam transmitters, the emitted beam is preferentially required to maintain a constant beam width along the propagation direction with respect to a threshold level [5]. Previously, a continuous wave laser diode (LD) with a peak power of around 100 mW was utilized as the light source for the transmitter, due to its single-mode beam characteristics [6]. In order to extend the range of the transmitter, however, a pulsed broad area LD (BALD) with a watt level of optical power is particularly preferred in view of its salient features of high power and low cost [7,8]. The BALD is supposed to support a multimode profile along the horizontal direction parallel to the junction, in contrast to a single-mode characteristic along the direction perpendicular to the junction, because the emitting region is usually created to exhibit a high aspect ratio [9]. Hence, the multimode beam characteristics of the BALD should be meticulously scrutinized for its practical applications [10]. To date, the light beam generated by a BALD was either calculated by taking into account the structural parameters of the emitting region and its refractive index, or reconstructed by decomposing observed beams in accordance with the correlation filter technique, the spatial coherence measurement, and the transverse irradiance profile measurement [11–16].

In this paper, we suggest a practical, effective modeling scheme for a multimode BALD, based simply on the emitting region and the far-field divergence angle. The feasibility of the modeling is primarily validated in terms of the irradiance profile of the generable beam along the propagation direction. A compact long-range laser transmitter incorporating a BALD is then designed to give rise to a uniform detectable beam width, by thoroughly taking into account the estimated beam characteristics of the light source. The transmitter is finally constructed and evaluated with respect to the output efficiency, the beam profile, and the detectable beam trajectory along the propagation direction.

2. Proposed modeling scheme applicable to a multimode BALD

As depicted in Fig. 1, the emitting region of the BALD resembles a long thin strip, with dimensions of L_x and L_y along the fast (x) and slow (y) axes, respectively. Multiple transverse modes are presumed to be supported along the y axis, whereas a single mode is guided along the x axis. Our objective is to establish a practical model, which involves simply the dimensions of the emitting area and the far-field divergence angle. According to the Gaussian–Schell model described in Fig. 2, the complicated beam profile associated with the BALD can be established through the incoherent superposition of a group of equivalently normalized Hermit–Gaussian (HG) modes [9,13,17,18].

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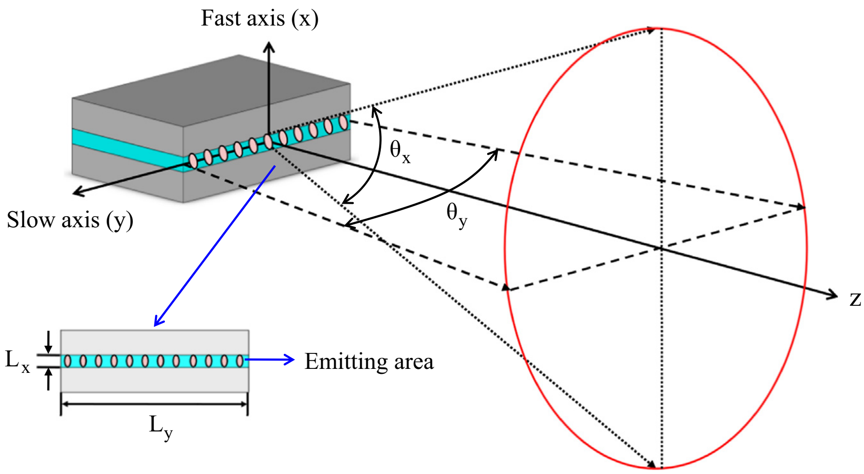

Fig. 1. Schematic configuration of a BALD, with the generated beam profile indicated.

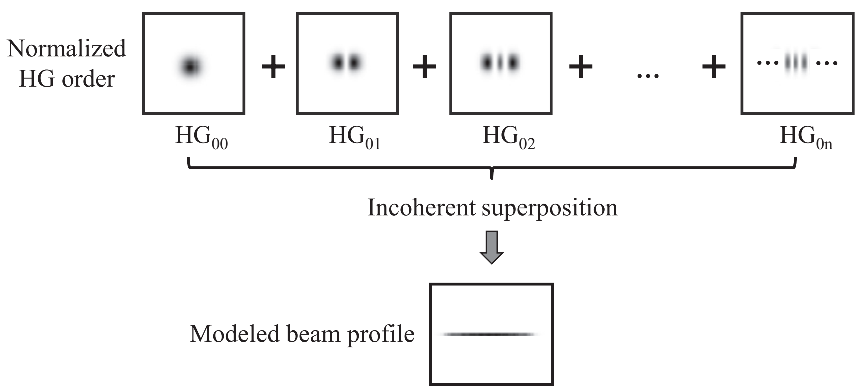

Fig. 2. Proposed modeling scheme for building the multimode beam profile of a BALD.

For the modeling of concern, the infrared (IR) BALD operating at $\lambda = 905$ nm is assumed to exhibit a peak power of 6 W, an emitting region with dimensions of $75 \times 1\ \mu\text{m}^2$, and FWHM (full width at half maximum) beam divergence angles of 12° and 20° along the slow and fast axes, respectively. For an arbitrary Gaussian-like beam, the M^2 factor can be obtained by comparing it to a Gaussian beam in terms of the product of the waist diameter and far-field divergence. The M^2 factor of the BALD is calculated to be ~13.6 along the y axis. Considering that the M^2 factor pertaining to the HG modes is also given by L_y^2/W_{0y}^2, where L_y and W_{0y} are respectively the length of the emitting region and the waist diameter of the HG_{00} mode along the y axis [13], W_{0y} for the BALD turns out to be ~20.3 μm. Because the LD merely excites the fundamental mode along the x axis, for the case of the HG_{00}, the waist W_{0x} is equivalent to the length L_x. The irradiance distribution for each HG mode can be expressed as follows:

$$I_{x0i}(x,\ z) = A_{0i} e^{\left[\frac{-2x^2}{[W_{0x}(z)/2]^2}\right]} \text{ for } \ i = 0,\ 1,\ 2, \ldots \quad (1)$$

$$I_{y0i}(y,\ z) = A_{0i} H_i^2 \left(\frac{2\sqrt{2}y}{W_{0y}(z)}\right) e^{\left(\frac{2\sqrt{2}y}{W_{0y}(z)}\right)^2} \text{ for } i = 0,\ 1,\ 2, \ldots \quad (2)$$

where $A_{0i} = \sqrt{2/\pi}[2^i (W_0(z)/2) i!]^{-1}$ is a positive constant, where $W_0(z)$ refers to $W_{0x}(z)$ in Eq. 1, which is the waist diameter of the HG_{00} mode along the x axis at a distance z. $W_0(z)$ corresponds to $W_{0y}(z)$ along the y axis, as given in Eq. 2. $H_i(y) = (-1)^i e^{y^2} (d^i e^{-y^2}/dy^i)$ is known as the Hermite polynomials of order i [13]. Each of the HG modes is first normalized with respect to its own peak irradiance, and then incoherently superposed so as to form the multimode beam profile belonging to the BALD. The power portion pertaining to constituent HG modes can be estimated from their irradiance distribution. For instance, the HG_{00} mode is calculated to account for 4.0% of the total power of the light source. The obtained multimode profile is expressed as $I(x,z) = \Sigma_{i=0}^{n} I_{x0i} / \max(I_{x0i})$ along the x axis, and $I(y,z) = \Sigma_{i=0}^{n} I_{y0i} / \max(I_{y0i})$ along the y axis, where n is the number of supported HG modes. The waist diameter of the modeled beam along the y axis should obviously be equal to the emitter length L_y, which in this case is 75 μm. As a result, the number of required HG modes was discovered to be $n = 13$.

In order to validate the applicability of the proposed modeling scheme to multimode light sources, we explored the irradiance profile relevant to a pulse BALD. Fig. 3(a) and (b) presents the calculated and measured beam profiles observed at $z = 8$ and 15 mm away from the LD. Both a Gaussian profile and a multimode profile were theoretically and experimentally proven to be supported along the x and y axes, respectively. Since an aspheric lens is usually used to collimate highly diverging beams, the distribution for the beam passing through a lens was investigated, in order to appraise the proposed modeling under the condition of a focused narrow line beam. As presented in Fig. 4(a) and (b), the calculated and measured profiles were in good agreement along both the x and y axes. It should be noted that if only the fundamental HG_{00} mode is simplistically considered, the corresponding beam profile along the slow axis produced by the collimating lens would be much different from the result for the current case, where higher order HG modes should be taken into account simultaneously. That is, a single-peak profile will be obtained along the slow axis instead of a multi-peak profile.