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Review

Understanding laser beam brightness: A review and new prospective in material processing

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ABSTRACT

This paper details the importance of brightness in relation to laser beams. The 'brightness' of lasers is a term that is generally not given much attention in laser applications or in any published literature. With this said, it is theoretically and practically an important parameter in laser-material processing. This study is first of a kind which emphasizes in-depth, the concept of brightness of lasers by firstly reviewing the existing literature and the progress with high brightness laser-material processes. Secondly, the techniques used to enhance the laser beam brightness are also reviewed. In addition, we review the brightness fundamentals and rationalize why brightness of lasers is an important concept. Moreover, an update on the analytical technique to determine brightness using the current empirical equations is also provided. A modified equation to determine the laser beam brightness is introduced thereafter. work The modified equation in turn is a new parameter called "Radiance Density". Furthermore, research studies previously conducted to modify laser design to affect laser beam brightness are also discussed. The paper not only involves a review of the techniques used to improve laser beam brightness but also reviews how bright lasers can be employed to enhance/improve laser process capabilities leading to cost reduction of the laser assisted processes in areas such as manufacturing.

Contents

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1. Introduction

1.1. Background of laser beam brightness

Brightness is a visual perception of light. The brightness of objects or a light source varies with change in the distance and the angle at which the object is visualized. Brightness also varies depending on the reflection, absorption and transmission of a light beam in relation to the surface in contact [1]. Thus, it could be defined as the amount of light in form of 'luminosity' observed on an object per unit of area [2,3]. Luminosity defines the measure of brightness, though such a term is rather suitable for only selected areas in science. As such, each discipline defines luminosity with its own term. Brightness is classified in two ways: one is photometric and the other is radiometric. The former quantifies light in terms of the judgement made by the human eye in assessing the brightness of an object, whereas, the latter quantifies brightness in terms of absolute power [1,4]. The photometric light refers to luminance and its luminosity. On the other hand, the radiometric light refers to 'radiance'. Both luminance and radiance, however, are so-called, cousins and have similarity in the sense that they ultimately relate to the brightness of a light source. However, luminance refers to contrast, glair and eye sensitivity to a particular wavelength. Luminance adheres to the principle that brighter the object – the more power it emits, and the higher the temperature of light (in relation to a particular distance). Comparably, radiance refers to a specific measure irrespective of eye sensitivity and wavelength of the light source and is dependent on power emitted per unit area in the solid angle of light divergence.

One of the first reported literature in relation to brightness was on the measurement of brightness and its colour over the sky by Reesincks in 1946 [5]. Reesincks developed a technique to obtain measurements of brightness during the summer period of 1946, in the Netherlands. Later, Zhang et. al. [6] reported on the feasibility of cloud remote sensing by ground based sky thermal infra-red brightness temperature measurement [6]. However, brightness in relation to lasers was a concept developed in the early 1960s [7]. Earlier work referring to a specified light source such as a laser was much focused on enhancing and improving the capability of lasers to produce brighter beams. The first time brightness was reported in relation to a laser beam was by Rampel in 1963, and showed that the obtainable power per unit area that could be produced for a diffraction limited beam is proportional to the brightness of a light source. Rampel further reported that such a laser beam is necessary for applications namely: microcircuit machining, drilling and cutting since controlled material removal in localized area was necessary. In the 1970s and 1980s papers were published by several authors in relation to increasing the laser beam brightness [8-10], and the use of high brightness lasers in the military sector [11]. Thereafter, numerous papers were published with respect to enhancement of laser beam brightness and modification of the transverse mode [12], changing the cavity design within the optical resonator [16,22], and the beam delivery design [23,25]. However, only handful of publications could be found in relation to the effects of brightness, thereof on engineering and variety of general materials [26,35].

Last decade was said to be the decade of short-wavelength lasers by laser physicists [36]. Short wavelength lasers operate at ultra-fast pulse rates and are very much in demand in this decade but more so are the high brightness lasers namely the fibre laser in particular. The brightness of a laser beam is not frequently mentioned in laser processing research and or during general laser processing of materials in factory shop floor or a job–shop environment. Notwithstanding this, various investigators have shown the importance of these parameters and have demonstrated that considering brightness as a parameter could be useful, though, to a limited extent. Having said this, not only experimental investigations are called for to demonstrate the effect of laser beam brightness [26,35], but also an up-to-date literature review focused on various areas relating to brightness of laser beams is desired, as it has received very little attention over the years, since the introduction of a laser as a manufacturing tool.

1.2. Significance of laser beam brightness

High brightness lasers have been around since over a decade. Initially, it was the disc lasers, diode, tapered, semiconductor lasers and short-pulse, short wavelength excimer lasers that were in the industry, classified as high brightness sources but they suffered from lack of beam quality [37-42]. However, fibre lasers have been commercially introduced since 2005 [43]. They offer the missing aspects of the previous lasers. These are the superior beam quality along with many other technical advantages [43]. They offer the missing aspects of the previous lasers. In recent years, a development of a solar pumped laser was also reported [44,46]. High brightness laser, however, offers considerable advantages over the conventional lasers. Those are, namely: superior beam quality; longer field of focus; smaller beam divergence; low cost per wattage; cleaner/sharper beam foot-print and higher power density than a low brightness laser. This allows cheaper laser process to take place, due to the usage of low cost per wattage. The high power density of a bright laser could also enable one to obtain higher processing speeds during laser material processing. High brightness fibre lasers could be moderately flexible, offering three dimensional processing of parts. Moreover, the high brightness also allows a tighter focus but a less expensive optics and beam delivery systems.

The reason why brightness is important in laser processing applications is because the intensity obtained within a focusing area through a lens is proportional to the brightness of the beam. High brightness laser processing allows fine spot size of the beam and creates a longer focusing distance. Hence, flexibility is further achieved with material processing as more distance is covered during laser operations. This is particularly offered by the fibre and the high power diode lasers (HPDL), and also the disc lasers [37,39].

High brightness laser sources such as a fibre laser or a HPDL produces high temperature during material interaction [36,47]. A fibre laser with high brightness in particular offers a longer depth of field (long focal length), small spot sizes, beam quality and a stable laser beam execution. The brightness of a laser is more effective in comparison to the laser power intensity or any other parameters singularly. This is because by achieving high brightness high processing temperatures would be generated [47]. The use of high brightness laser for material processing is also advantageous due to its potential for achieving low cost per wattage output [48].

The first reported work on laser beam brightness was in 1963 by Rampel [7]. Having said that, brightness in relation to lasers became a concept in the 1970s. Earlier work in this field was somewhat focused on enhancing and improving the capability of