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Opportunities in laser cutting with direct diode laser configurations

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ABSTRACT

This paper explores the opportunities associated with the use of well-designed direct diode laser configurations for cutting of metal sheets. Continuously improving diode stacking, and consequently greater brightness, allow the requirements for laser cutting to be met without the use of further brightness converters (diode-pumped solid state lasers). This contributes to a reduction in the number of optical components and increased energy efficiency. Furthermore, laser architecture related degrees of freedom for tailoring the wavelength, beam polarization and beam shape are instrumental to increase the cutting performance. Different stacking configurations, optical structures and related cutting strategies are discussed, with performance validation through experimental verification.

1. Introduction

Laser technology for material processing has been improving at a fast pace. Less than a decade ago industrial cutting of metal sheets was fully dominated by CO_2 gas lasers, mainly characterized by a long wavelength (10 μm) and poor efficiencies (5–10%) [1]. Today, solid state fiber lasers with a shorter wavelength (1 μm) and significantly better efficiencies (>30%), are becoming dominant for metal cutting applications [2]. Diode lasers are important building blocks for the majority of these laser systems, as they are used for pumping the active medium. Fig. 1 provides a schematic overview of the laser technology involved in building up a multi-kW solid state laser. Single diode laser emitters produce an asymmetric beam shape and deliver just a few Watt of output power. Nevertheless, they are typically cheap components that can be used in combination to obtain much higher laser powers. The first natural step to increase power, at the cost of beam quality, is a side-by-side combination of multiple emitters. This is typically done in diode bars that share cooling and controlling channels (**step 1**) and that are stacked (**step 2**) into high power diode modules, which are mostly used for pumping solid state fiber lasers.

Direct Diode Laser (DDL) technology, that involves the direct use of a diode beam for material processing, is a recent achievement in cutting applications and emerges from developments in diode pump components such as higher single emitter power, improved coupling optics coatings and, more effective cooling strategies. The use of less optical components brings advantages in efficiency, compactness, reliability and price. Nowadays the technology is mainly limited to the availability of the above mentioned diode pump modules. As can be seen in Fig. 1, smart arrangement of emitters of strategically chosen wavelength and polarization direction, allows power scaling at no cost to beam quality (**step 3**). While polarization multiplexing is limited to doubling the power, variants using different wavelengths are theoretically unlimited in achievable power range. In practice a limited number of available wavelengths (800–1100 nm) and their broad bandwidth (around 30 nm) narrow the possibilities [3]. Such beams are commonly coupled into guiding fibers (**step 4**), which deliver the laser from the resonator closer to the workpiece, and were, until recently, used only for less brightness demanding applications. Even though substantial research efforts still focus on further improving the brightness of DDLs [4–6], the associated costs are typically too high when evaluated against established brightness converting techniques, such as the fiber laser principle. Witte et al. [6] provide a more detailed description of the state of the art for brightness increasing techniques, while documenting a novel approach for increasing the number of possible wavelength multiplexing steps by wavelength stabilization of commercially available pump modules. Most recently, it has been demonstrated that state-of-the art DDLs already meet the requirements, in terms of achievable cutting speed and edge quality, for cutting certain material and thickness combinations [7].

This paper aims to discuss opportunities associated with innovative DDL based systems that are smartly designed for cutting applications. In the free beam concept, where the laser source is built into the cutting head, not only can further elimination of optical components (e.g. guiding fiber and related coupling optics) be achieved, but this also allows to tailor polarization and beam shape to the cutting process. Regarding the latter, Fig. 2 illustrates the potential of a beam tailored for cutting purposes: laser absorption in the cutting kerf is highly influenced by the incidence angle and laser polarization. The red dot represents the typical absorption in the material for randomly polarized solid state lasers. The beam shape is responsible for kerf formation and can be used to positively influence the incidence angle, (strategy represented by the yellow dot in Fig. 2). Laser polarization can also imply a significant gain in absorption when

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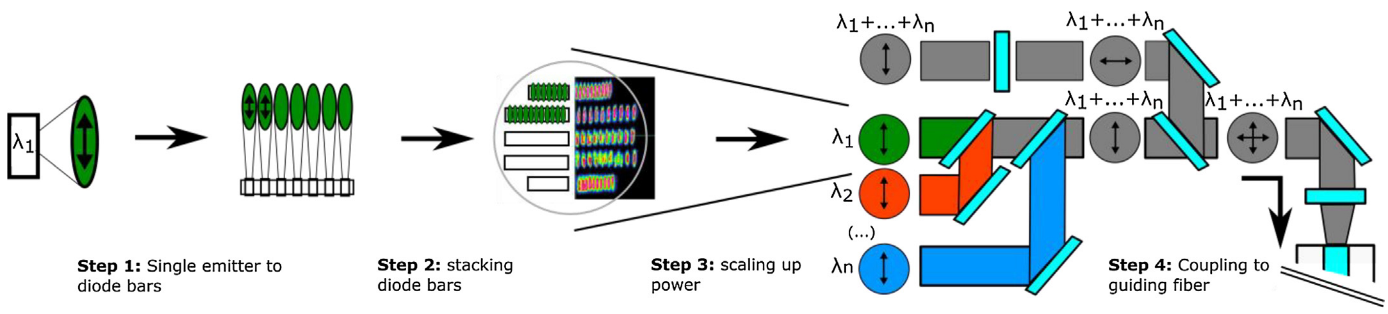

Fig. 1. Different system stages from single diode laser emitter to laser beam delivery system.

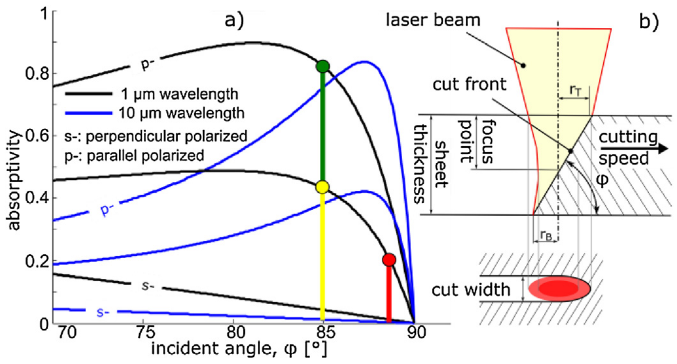

Fig. 2. Laser material interaction: (a) Fresnel laser absorption curves for steel and (b) laser to kerf interaction scheme. Note that s- and p- are defined for an electrical field which is perpendicular and parallel, respectively, to the plane of incidence.

smartly controlled [8], as depicted by the green dot on the p-polarization absorption curves.

2. Cutting performance comparison: DDL vs CO_2 vs fiber

Currently CO_2 and fiber laser sources dominate the industrial application landscape. A comprehensive study has been published by the authors in Ref. [7] that assesses a 2 kW *Fiber Guided* (FG-) DDL as compared to industrial cutting machines, as summarized in Fig. 3.

This optimized performance comparison, that takes into account acceptable cutting edge quality requirements according to ISO 9013, leads to the following observations:

- Flame cutting: similar achievable cutting speeds for the different types of tested lasers, with exception of 1 mm sheets where DDL offers an advantage.

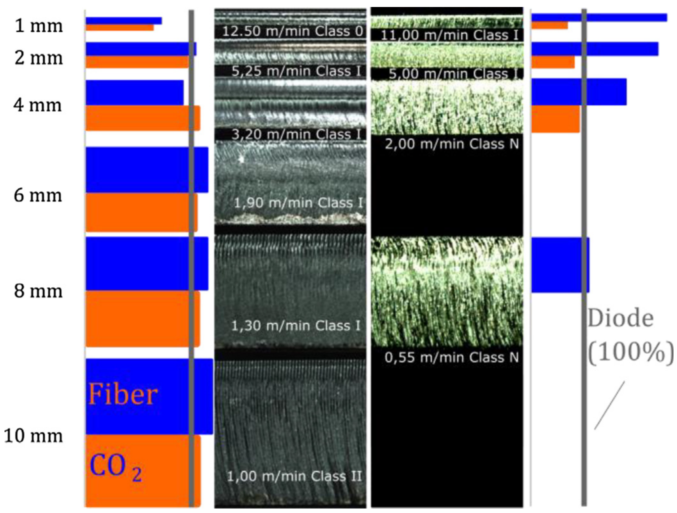

Fig. 3. Comparison of cutting performance for flame (O_2) cutting of steel (left) and fusion (N_2) cutting of stainless steel (right): the cut edges shown, feed rates and quality class provided were obtained for the diode laser setup. The bar graphs represent the relative cutting speed obtained with industrial fiber and CO_2 machines for the same output power level.

- Fusion cutting: achievable cutting speeds for DDL are always faster than for the equal power CO_2 source. The fiber laser has a significant productivity advantage for thicknesses up to 4 mm. The edge quality criterion (ISO 9013) is not met for thicknesses greater than 4 mm. This is also the case for typical fiber laser cuts at these power levels.

This performance overview creates a reference for comparative assessment of the opportunities proposed in the next sections and forms the basis for the discussion section.

3. Free beam opportunity

3.1. Description

In cutting machines the way the laser beam is guided from the resonator to the cutting optics is significantly different for different laser sources. CO_2 resonators require a considerable amount of floor space and the laser beam is typically guided through a complex system of reflective optics requiring precise alignment and beam divergence compensation. With solid state fiber lasers and FG-DDLs the beam is typically guided through an optical fiber that simplifies the beam delivery process. The *Free Beam* (FB-) DDL concept consists of integrating the resonator directly in the laser head, thus avoiding the use of a guiding fiber. This is a unique opportunity for DDL sources due to their inherent compactness. Since less optical components are used, this architecture supports a higher energetic system efficiency and thus reduces both investment and operational costs compared to a conventional beam delivery system.

3.2. Experimental verification

A FB-DDL system emitting 1,7 kW nominal output power at wavelengths of 920 and 960 nm was integrated, within the laser head, in a gantry platform, as shown in the left part of Fig. 4. In contrast with the FG-DDL setup and due to the need of less optical components, this configuration is able to deliver 350 W extra power per wavelength used, reaching wall plug efficiencies of 40% (15% more than the FG-DDL, including internal cooling [1]). The laser module was mounted on a Precitec LightCutter laser head with 100 mm focusing lens. With a weight of less than 20 kg, this configuration is able to withstand accelerations in the order of 5 m/s^2. A protective shutdown system, detecting excessive back

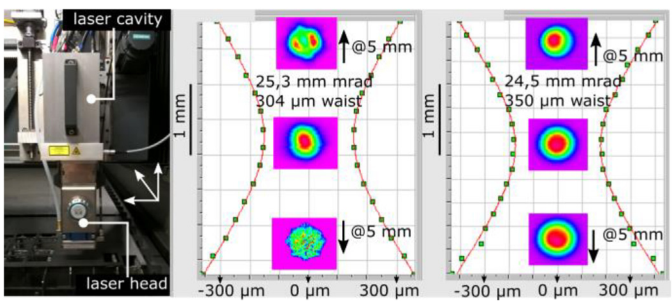

Fig. 4. FB-DDL setup (left) and beam measurement (Primes FocusMonitor) of FB-DDL (middle) and FG-DDL (right).