Multi-kW Thin Disc Lasers And Their Applications

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High power laser systems in the multi-KW range dominate the revenues created in material processing laser applications for decades. The very close contact between laser source manufacturer and end customer has been a key factor in the success of the different types of high power laser systems. The latest addition to the spectrum of commercially available industrial multi-kW laser systems is the thin disc laser. It is the almost symbiotic development of component design, application, laser source and beam delivery that has been driving the high power laser into ever new markets.

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1. Thin Disc Laser Technology

Multi kW Yb:YAG thin disc lasers as shown in Fig. 1 have been developed to maturity during the last decade. [1,2,3] The laser system is advantageous over conventional diode pumped laser systems because of its unique power scaling capability.

A thin disc shaped solid-state laser crystal, typically less then 200 µm thick, is pumped face on by one or more stacks of fast axis collimated high power diode laser arrays. In order to absorb most of the pump radiation it is passed through the thin disc multiple times. In modern kW systems (see Fig. 2) the pump radiation passes the thin disc 16 times.

Fig. 1 Modern 4 kW thin disc laser System with 4 discs.

The beam path of the pump radiation is folded using a set of prisms and is focused at each path onto the disc using a parabolic mirror. At the back of the disc, a broadband reflector ensures reflection of the pump radiation as well as of the generated SSL laser beam. This disc is mounted onto a heat sink with the reflector side facing the heat sink.

In the thin disc solid-state crystal laser action occurs and a classical stable resonator is utilized to extract the beam. With a resonator length of several meters and the serial coupling 4 discs a modern thin disc lasers is capable of generating more than 6kW of output power (Fig. 3). This enables the manufacturers to guarantee 4 kW of cw output power at the work piece in an industrial environment with a beam parameter product of 7 mm mrad.

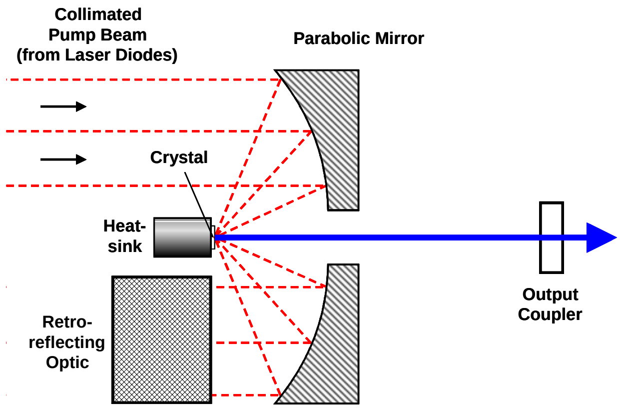

Fig. 2 Schematic representation of the pump scheme for one disc (crystal).

Multi-kW thin disc lasers are commercially available and are successfully integrated into manufacturing environments. They require a pump source brightness of slightly less then one kW/mm²sr. Standard fast axis collimated high power diode laser stacks (FAC-Stacks) easily achieve this brightness. The pump sources are reliable and cost-effective. Such systems are well proven and commercially available at 10$/W. Beginning this year, several diode laser suppliers introduced 120 Watt arrays. This will reduce the cost of the collimated diode laser stack below 5$/W. A value that will be difficult to reach with fiber coupled single emitters.

The cross-section and the numerical aperture of the active fiber determine the pump source brightness requirement of a fiber laser. While commercially available side-pumped fiber lasers provide output brightness that is below or at most equal to that of thin disc lasers, it is evident that the brightness requirement on the pump sources still is orders of magnitude higher than for thin disc or slab geometries. This requirement has its cost. Side-pumped fiber lasers are typically pumped with fiber-coupled single-emitters, which cannot be competitive in price and also bring the additional issue of splicing and handling many individual devices.

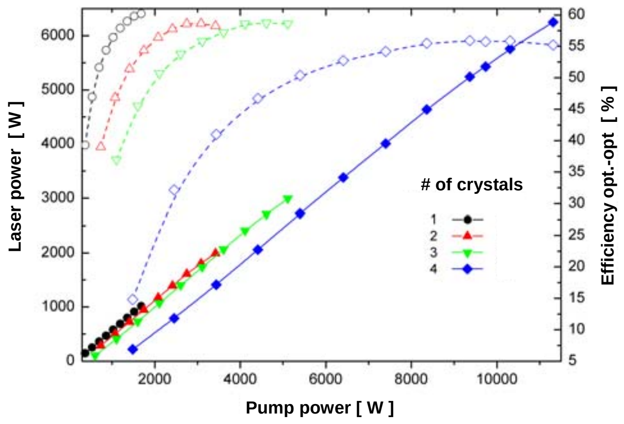

Fig. 3 Pump power vs. laser power and optical – optical efficiency for a system with 1, 2, 3 and 4 discs.

2. Applications

Today hundreds of millions of dollars are spent worldwide on multi-kW CO_2 and multi-kW solid-state lasers (SSL). Currently the market size for both laser types is approaching equality. While modern CO_2 lasers typically require about 2-3 times lower investment than SSL (regardless whether lamp or diode pumped) of comparable power, the multi-KW solid-state lasers are chosen whenever flexible and cost effective beam delivery is a priority, as all modern multi-KW solid-state laser beams are fiber delivered.

This is the major advantage of solid-state lasers over CO_2 Lasers, being required especially in “Body in White” - welding applications in automotive manufacturing. Fiber delivery allows utilization of the existing infrastructure – welding robots. The huge demand for laser welding in the automotive industry is driven by the throughput advantage of laser welding over conventional spot welding. The same amount of car bodies can be processed using laser welding compared to spot welding, while utilizing only about 1/3 the number of welding stations. This reduces the size of the body shop - the major cost driver of a car manufacturing line - and therefore decreases the manufacturing costs in assembly dramatically.

Many exciting new applications were created by the improved beam quality of the thin disc laser [4,5]. While most rod-type lasers and even most of the commercially available fiber lasers in the 4 kW range have beam parameter products of 20 mm mrad or more, the thin disc laser’s beam parameter product of 7 mm mrad allows for very large focal distances. This has lead to the development of programmable focus optics (PFO).

Fig. 4 Robot with a programmable focus optic (PFO) connected to the thin disc laser via fiber.

Such a PFO will utilize two scanner mirrors to deflect the beam very quickly in an elliptical scan area. The coarse movement of the beam is achieved using conventional robots. Such a system is depicted in Fig. 4. The advantage of the PFO is the increase in speed and accuracy over a system that uses a static focusing lens at the end of the robot arm.

In Fig. 5 remote welding of a part is schematically illustrated. The precise weld geometries are generated using the high speed scanning system, while the robot only needs to follow a path that allows the scanner to reach the intended positions. In this case, the improved beam quality of the thin disc lasers allows the user to utilize the rather crude motion control of the robot and still achieve high precision beam steering. In addition to the improved accuracy the scanner allows reducing the downtime of the laser between weldments and therefore can decrease the manufacturing time of complex parts substantially.

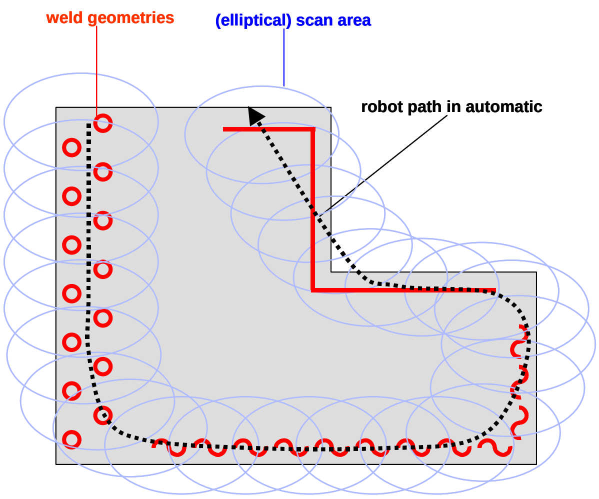

Fig. 5 Weld geometries being generated by the PFO, while the robot moves the PFO only approximating the exact welding geometry.

3. Scalability

The thin disc solid-state crystal provides a nearly axial symmetry for all thermal, mechanical as well as optical properties of the laser. Therefore scaling is best achieved by increasing the diameter of the thin disc solid-state crystal.

The major advantage of the disc laser over the fiber laser is the brightness quotient between pump laser and solid-state laser: The pump power density, the solid-state laser intensity and even the requirements on the brightness of the pump diode laser system are several orders of magnitude lower than for fiber laser systems, while being equally scalable in power. Therefore the thin disc laser technology is the right platform to address the customer's needs for many years ahead.

Already the first commercially available generation of thin disc lasers sets the standards for high power laser systems in material processing. This success will be difficult to match for other, less mature laser systems. It is anticipated that the thin disc laser will break into the classic CO_2 laser market of 2D laser cutting due to the drastic reduction in the cost of pump power. This is a development from which the thin disc laser with its very low requirements on the pump source brightness can fully benefit, while other modern solid-state lasers will remain dependent on the more expensive fiber coupled single emitters.

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