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Latest trends in high power disk laser technology

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Abstract

Diode pumped solid state lasers have become an important tool for many industrial materials processing applications. They combine ease of operation with efficiency, robustness and low cost. This paper will give insight in latest progress in disk laser technology ranging from kW-class CW-Lasers over fundamental mode beam quality to frequency converted lasers, as well as advances in new applications realized with disk lasers.

As of today, the disk principle has not reached any fundamental limits regarding output power per disk or beam quality, and offers numerous advantages over other high power resonator concepts, especially over monolithic architectures. Recently a TruDisk 6001 with 6 kW from a single disk completed the TRUMPF portfolio. The disk laser enables high beam quality at high average power and at high peak power at the same time. The power from a single disk was scaled from 1 kW around the year 2000 up to more than 10 kW today. Coupling of two disks in a common resonator results in even higher power of 20 kW. Consisting of two 16 kW units laser beam can be applied scalable up to 32 kW through one single twin-fiber.

Recently was demonstrated more than 4 kW of average power from a single disk close to fundamental mode beam quality ($M^2 = 1.38$). The extremely low saturated gain makes the disk laser ideal for internal frequency conversion. We show >1 kW average power and >6 kW peak power in multi ms pulsed regime from an internally frequency doubled disk laser emitting at 515 nm (green). Also external frequency conversion can be done efficiently with ns pulses. More than 500 W of average UV power was demonstrated.

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Besides improvements in efficiency, latest state-of-the-art disk lasers come up with intelligent energy saving modes, wake up and sleep timer functions that allow energy savings also within idle times.

The conclusion will show a quick overview of what type of applications can be performed by these lasers including cutting, welding, remote welding, LMD, hardening and hybrid welding.

Keywords: Macro Processing; System technology; Disk laser; High Power, Brillance, Energy saving mode, frequency conversion

1. Introduction

For years disk lasers have been an ideal choice for the vast majority of high power material processing applications in the CW as well as short and ultra short pulse regime since they combine high output power with high beam quality at low investment and running cost. Ease of operation combined with highest efficiency, precision and robustness have established the disk laser as a standard tool throughout industrial applications. Tailoring laser based manufacturing chains has opened up a magnitude of different areas such as high speed cutting, remote welding, brazing, cladding and hybrid welding.

Over the years many laser processes became standard, highly productive and reliable production techniques. Therefore it is not surprising that the laser became a commodity in industry, with several thousands of installed disk lasers and still increasing demands. Besides the focus on new applications e.g. in lightweight designs (welding of aluminum, copper and dissimilar materials) there has been a clear focus on cost.

Fig. 1: Commercial available TruDisk 6001 with 6 kW laser power per disk at the workpiece and a beam parameter product of 2 mm·mrad.

Disk lasers offer a superior pump cost structure as compared to fiber lasers due to their low demand on pump diode brightness. This is one important fact related to the laser disks unique aspect ratio. In this article we present some of the latest record parameters obtained from disk lasers. In CW operation, the fifth generation of industrial disk lasers is now in mass production with 6 kW / disk at the workpiece. Recently a TruDisk 6001 with 6 kW from a single disk completed the TRUMPF portfolio, see Fig. 1.

2. Disk Laser Principles

The basic idea behind the disk laser geometry introduced more than twenty years ago by Adolf Giesen and coworkers is to use a face cooled medium with a high surface to volume ratio. This provides efficient cooling of the device and thus enables high average power. Furthermore an axial heat flow is generated effectively eliminating internal thermal lensing effects. Typically only low constraints on pump brightness exist. A beam parameter product of 500 mm·mrad is sufficient to pump a high power thin disk laser, whereas fiber lasers in contrast require an order of magnitude higher brilliance. In the 6 kW/disk cw disk laser generation, a further optimized pump cavity boosts the optical efficiency to greater than 72 %, a 10 % increase compared to the previous generation. In summary the disk laser design benefits from five properties leading to an optimized laser for industrial 24/7 use:

1) Low thermal lensing due to axial heat flux enables high brightness of the disk laser.
2) Low brightness constraints of the pump diodes enable cost effective lasers with high electrical to optical conversion efficiency — especially in the high average power regime.
3) Area scaling of the beam size enables power scaling while keeping constant internal intensities.
4) Deep gain saturation eliminates harmful back reflection problems which are commonly encountered in fiber laser systems
5) The beam diameters are generally large compared with the longitudinal extension of the gain medium. Therefore high peak power sources are possible without facing problems due to nonlinearities.

3. Power Scaling and Cost Reduction of High Power Disk Lasers at a Glance

Fig. 2 (left) depicts commercial disk lasers in the high power regime. Today 6 kW laser power per disk at the workpiece is available. Disk lasers ranging from one to six kilowatts can therefore be built with one disk (grey data points), power scaling to higher power is typically done by polarization or serial coupling (blue data points).

Today’s technology focus is on both, cost and brightness for mainly two reasons: The development of the laser diode is still ongoing increasing its output power and such reducing the number of required laser diodes, driving down system cost significantly Fig. 2 (right). Besides this, remarkable performance improvements can be achieved when beam quality is increased in certain application areas such as cutting or remote welding. A typically used disk laser setup is shown in Fig. 3 (left). It consists of a pump source, the pump cavity, and the resonator itself. The resonator is built up of a HR mirror, the laser disk, and an output coupling mirror. Additionally, curved mirrors are used to accommodate for beam quality and optical resonator design. This resonator setup is typical and has been used throughout the following results depicted in Fig. 3, and Fig. 4, respectively. In Fig. 3 (right) beam quality was tailored for the use of a 75 µm fiber delivery system at numerical aperture of 0.1. As can be seen some 8 kW at 62 % optical-optical efficiency can be achieved.

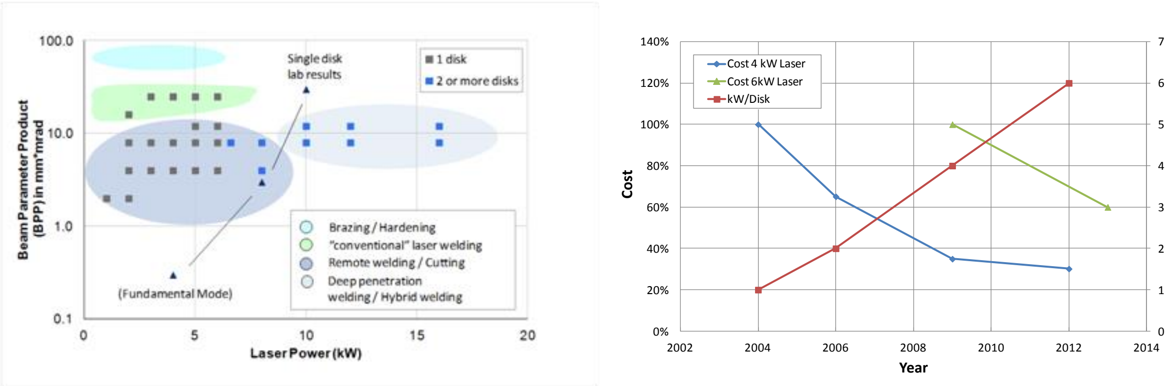

Fig. 2: Survey of commercial available disk lasers for high power applications including lab results for a single disk (left). Development of cost/disk laser 2C: 2 kW/disk, 4C: 4 kW/disk, 6C: 6 kW/disk, referred to a 4 kW laser system (blue line), and 6 kW laser system (green line), respectively, and available power per disk (red line),(right).

Fig. 4 (left) shows the possibility to scale disk power further by increasing the pump spot diameter. This can be done without reducing efficiency. In principle it is possible to combine both, high power with high beam quality without significant efficiency loss. This changes however when beam quality is close to fundamental mode. Until mid of 2013, the highest reported power has been some 1 kW shown by Peng et al., 2013.

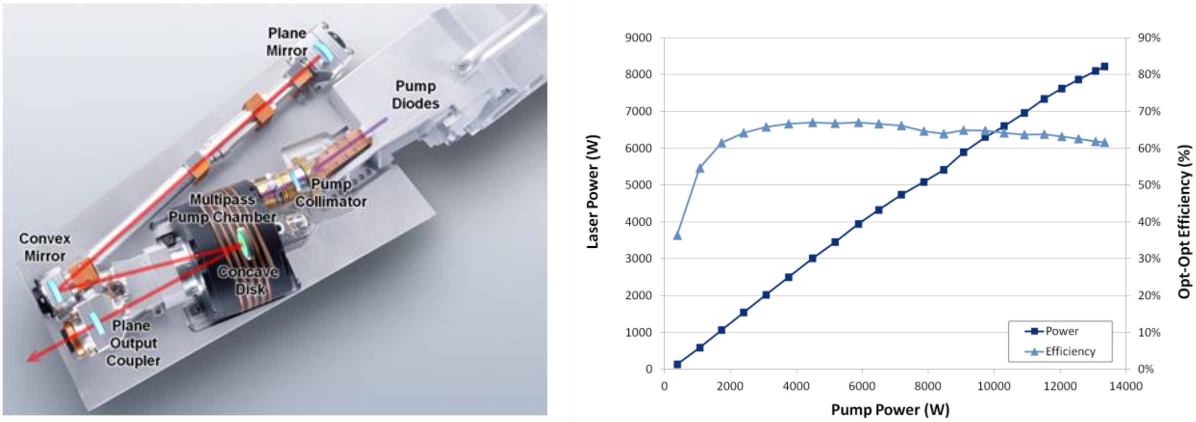

Fig. 3: typical quasi-monolithical disk laser setup (left).8 kW, M² = 8, suited for NA = 0.1, 75 µm diam. fiber delivery, 940 nm pump, pump power limited (right).

Besides improvements in efficiency, latest state-of-the-art disk lasers come up with intelligent energy saving modes, wake up and sleep timer functions that allow energy savings also within idle times. Today's disk technology offers significant advantages in regards to thermal management and aberration losses enabling much higher power. In Fig. 4 (right) recent fundamental operation results are depicted. As shown, the power can be increased to about a factor of four yielding some 4 kW at M^2 = 1.38 All of these results where pump power limited – clear evidence that even more power is achievable. Until now experimental investigations have not reached any fundamental limitations of maximum output power per disk.

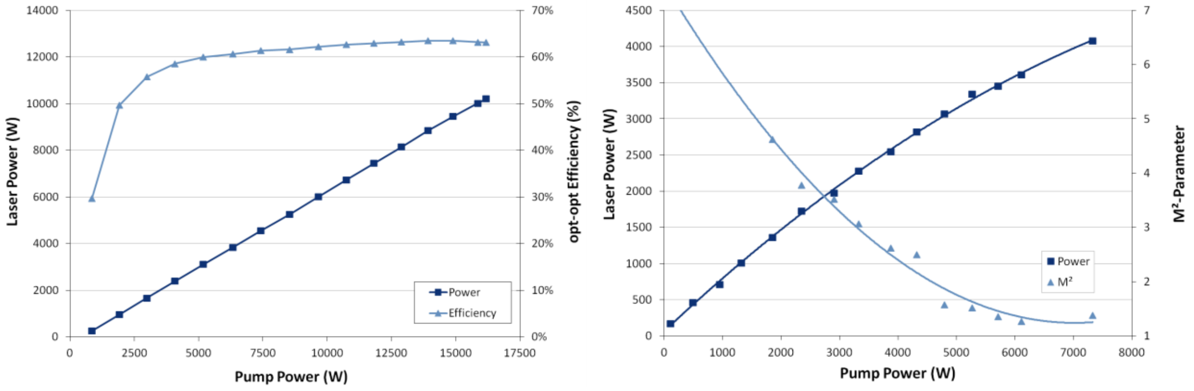

Fig. 4: 10 kW, M² = 110, pumped at 940 nm, pump power limited (left), 4 kW, M² = 1.38 from a single disk, pumped at 969 nm, pump power limited as well, new record (right).

Calculations from Giessen in 2006 indicate that 30 kW from one disk are, in principle, possible. In summary, it is foreseeable that average power scaling of the laser disk will continue. We have demonstrated 4 kW single mode disk lasers, up to 10 kW out of a single disk and hence the possibility of scaling the power of disk lasers in the range of several tens of kilo watts. This will pave the way towards disk lasers with even further reduced cost and will open up more industrial laser applications with high brightness demands.

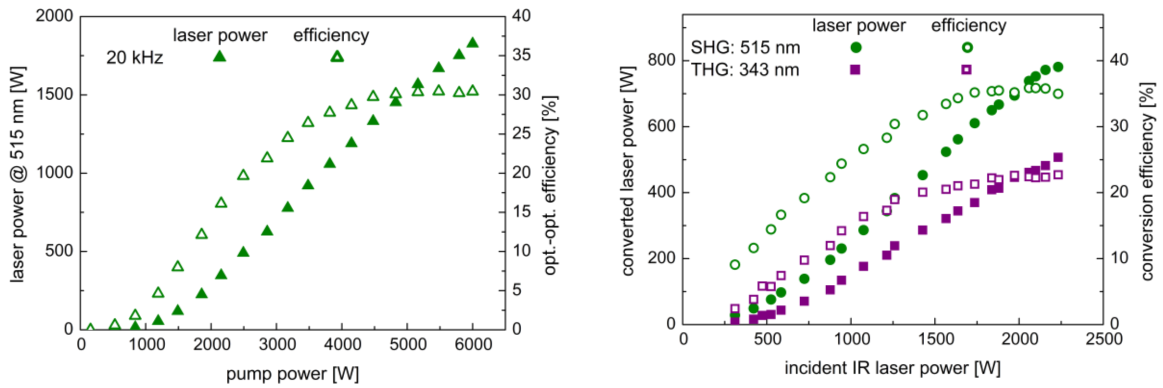

Fig. 5: Output power and opt.-opt. efficiency of a q-switched thin disk laser with intracavity second harmonic generation at a frequency of 20 kHz (left), Output power and conversion efficiency of a cavity-dumped thin-disk laser with external second and third harmonic generation at a frequency of 20 kHz (right).

4. Conclusion

We have shown that the disk laser technology is a versatile platform for high average power and high beam quality. Due to its unique architecture disk lasers are an ideal choice for 24/7 industrial laser applications: They combine flexibility, high reliability, and low cost. Therefore they suit perfectly to today's industrial demand.

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