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Recent developments in new laser systems used for material processing

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1. Introduction

In the development of high power laser systems for material processing some general trends can be pointed out. First, there is a trend to develop low cost laser systems by high volume production lots and all by cheaper components like turbine blowers, switch-mode power supplies etc. Furthermore, new laser concepts e. g. diffusion cooled CO₂-lasers are able to reduce the costs. Another very important trend is that a higher beam power is requested by the customers. Welding applications which have been done two or three years ago with a 5 kW laser system should be done now with 10 kW beam power. One reason is that the production speed is very important and influences the production costs. Working with higher processing speeds requires a more stable beam power and position. This leads to closed control loops to control process parameters like beam power. As multi-kilowatt Nd:YAG-laser systems are on the market now, there is a strong trend to use robot systems with fibers, even if the CO₂-laser with similar power is cheaper than the Nd:YAG-laser). The whole system including laser source, beam guiding and robot (gantry) could be cheaper when using a Nd:YAG-laser with a fiber for the beam guiding. In addition to these trends concerning CO₂- and Nd:YAG-lasers, high power diode laser systems are being developed at the moment. Diode laser systems can be used for pumping Nd:YAG-lasers or for direct applications in material processing. In the last case they will be used mainly for hardening, soldering, melting surfaces and maybe spot welding in the next years.

	Laser Diodes	Nd:YAG	CO₂
Efficiency	30 - 60 %	1 - 3 %	5 - 10 %
Wavelength	0.78 - 0.83 μm	1.064 μm	10.6 μm
Power	multi-kW	up to 3 kW	up to 20 kW
Lifetime	20.000 - 100.000 h	10.000 h	10.000 h
Maintenance	maintenance free	each 200 h (lamps)	each 500 h
Price/Watt	200 - 400 DM/Watt	300 - 1000 DM/Watt	200 - 400 DM/Watt
Fiber Delivery	possible	possible	not possible
Voltage	up to 100 V	up to 1000 V	up to 10 kV
Watts per Lasing Volume	1000 Watt/cm ³	50 Watt/cm ³	1 Watt/cm ³

Table 1 Comparison of Laser Beam Sources

Table 1 shows a comparison of laser diodes, Nd:YAG- and CO₂-lasers. Important is the very good overall efficiency of the diodes. A problem at the moment are the high watts per lasing volume. This leads to a heating of the diodes themselves. Therefore, the most important work which is carried out at the moment is to increase the cooling efficiency. If the price of the diodes is reduced as we could expect from fig. 1, it will be about \$ 10 per watt beam power in the next years. The change from CO₂- or Nd:YAG-lasers to diode lasers can be compared with the development of the transistor in the electrical industry and the change from valves in TV or radio to transistor technology.

2. Diode laser systems

To generate high power laser diode radiation, there are mainly three different ways possible: first stacking of diodes to a closed packed 2-dimensional array, second lens multiplexing and third fiber multiplexing. Fig. 2 and 3 demonstrate the different possibilities.

To conduct the diode laser radiation into a fiber, micro-optics have to be used. These micro-optics can be corrected micro-optics with 3-4 elements, grin lenses, spherical optics or aspherical optics. The total power contained in the special angle of radiation is demonstrated in fig. 4. The example shows the diode, the numerical aperture of 0.7 and a cylindrical grin lens

with a diameter of 1.5 mm. The dotted-broken line indicates that e. g. under an divergence angle of 23° with a cylindrical grin lens only 22% of the total beam power is contained. This is also the maximum beam power which can be focussed into a hundred micrometer fiber diameter. If a higher percentage of beam power should be coupled into a fiber of hundred micrometer diameter, the micro-lens has to change from quartz to a high index material and the best possibility is to use aspherical optics.

Fig. 5 shows an arrangement of fiber coupling to conduct the radiation of a diode array into a single fiber. Cylindrical and elliptical micro-lenses are used to parallelize the different beams and the single beams are focussed into the fiber with a bigger lens.

When using a lot of fibers (fiber bundle) and for each diode array (focussed into one fiber) a separate power supply, the laser diode offers a totally new possibility in laser technology. By focussing the laser light coming out of the different fibers to the workpiece, it is possible to shape the integral beam profile by controlling and changing the output power of the different diode units. This allows a controlled beam profile adapted to the process which opens new possibilities in the case of hardening, remelting, soldering etc. A scheme is demonstrated in fig. 6.

Fig. 7 shows the different laser applications as a function of the power density which is necessary and the interaction time for the process. The laser diode intensity is limited at the moment to 10^6 W per cm^2 and this means all applications below this power density can be done with laser diodes in future.

3. Nd:YAG-Lasers

Another application for laser diodes is the pumped Nd:YAG-laser. The advantage is higher overall efficiency and, resulting from this, the heat input into the Nd:YAG-crystal is lower and this leads to a better beam quality. However, this good beam quality will be reduced again if the beam guiding fiber is used. This is demonstrated in fig. 8, where the beam quality at the entrance into the fiber and the output quality of the beam at the end of the fiber is plotted. With lower fiber diameters higher output beam quality can be reached. It is indicated that a strong bended fiber will reduce the quality of the outgoing beam, too. 2 and 2,5 kW Nd:YAG-lasers with a beam quality allowing a deep welding process are on the market now.

Fig. 9 demonstrates a 3 kW Nd:YAG-laser system which is commercially available and is built up by six 500 W systems which are pulsed. By combining the six laser heads with two fast beam multiplexers it becomes possible to bring the radiation of beams into one fiber, one after another, so that at least 3 kW continuously come out of the fiber. The effect is that the 3 kW system has a beam quality of a 500 W Nd:YAG-laser system which is definitely higher than the quality of a conventional 2 kW system.

4. CO₂-Lasers

The costs and the volume of CO₂-lasers have dramatically been reduced in the last years. In the last five years there was a reduction of costs of more than a factor 2. Fig. 10 shows the laser volume per kilowatt output power as a function of the years. The development of diffusion cooled laser systems will be responsible for a reduction of volume and costs which will be higher than indicated in fig. 10.

Fig. 11 demonstrates that in principle two possibilities are being developed at the moment. These are anular and slab geometries. Therefore, the beam has to be guided between the two plates or the two tubes which are the electrodes.

The first commercially available diffusion cooled laser system in the kilowatt range was presented by Rofin Sinar at the Laser Conference 1993. Fig. 12 shows a cost comparison of an axial-flow DC-excited CO₂-laser in the kilowatt range and a diffusion cooled RF-excited laser. The size of the diffusion cooled laser can be approximately the half of the axial-flow DC-excited laser. The costs can be approximately 30% lower including the more expensive RF power supply.

The use of switch-mode power supplies for DC-excited transverse flow systems can reduce the price of the systems by approximately 20% to 30% and, in addition to that, leads to the possibility to pulse the systems with for example 2 or 3 kHz.

Fig. 13 shows a totally controlled laser system. In a lot of applications like cutting, welding and drilling the process can be controlled by adapting the beam power in the range of a 10th of a millisecond. This can be easily done by Nd:YAG-lasers and laser diodes but it is more difficult when using CO₂-

lasers. Therefore, a RF-excited CO_2 -laser has a very big advantage compared with DC-excited laser systems due to the possibility to adapt the output power to the interaction phenomena of the process in a very short time.

5. Conclusion

The direct application of high power laser diodes will find a market in the field of surface treatment in the near future. Diode pumped Nd:YAG-lasers will find a market if the price for laser diodes decreases. The advantages are higher efficiency and better beam quality of the Nd:YAG-laser. We can expect that the market for CO_2 -lasers will develop to smaller and cheaper systems with higher beam power, which offers the possibility for a totally controlled process.

Fig. 1 Laser Diode Power and Price Development

Fig. 2 Laser Diode Combination

Fig. 3 Laser Diode Combination

Fig. 4 Beam Shaping of HPDL's for Fiber Coupling

Side view

Top view

Fig. 5 Arrangement of Fibre Coupling for a Single Fiber

Fig. 6 Diode Arrangement to Control the Beam Profile (FhG-Patent)

Fig. 7 Laser Materials Processing

Fig. 8 Fiber Transmission-Beam Quality

Fig. 9 Combination of Six Laser Heads with Two Fast Beam Multiplexers

Fig. 10 Development of laser power and laser volume

Fig. 11 Comparison: Anular-Slab Geometry

Fig. 12 Cost Comparison

Fig. 13 On-line Control in Laser Beam Machining