Materials Processing with High Power Diode Lasers †

ABE Nobuyuki*, TSUKAMOTO Masahiro**, and NAKACHO Keiji *

Abstract

Recently, diode lasers with high power and high power density have been developed and offer many advantages such as high conversion efficiency, small size and easy operation. In this report, the beam characteristics of high power diode lasers are discussed and several applications of materials processing with high power diode lasers are investigated, such as welding of steel and aluminum alloy, micro welding, forming and cladding..

KEY WORDS: (High power diode laser) (Welding) (Micro Welding) (Forming) (Cladding)

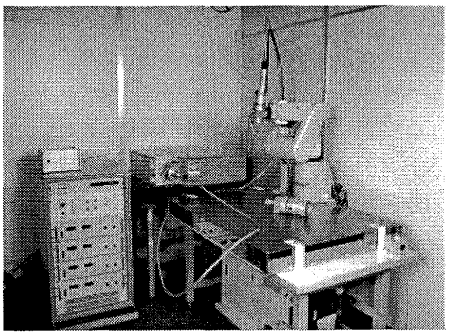
1. Introduction

Diode lasers have superior properties such as a higher conversion efficiency of over 40% and smaller size and lighter weight compared with conventional lasers for materials processing. On the other hand, CO_2 and Nd:YAG lasers have a high power and power density, but, their very low conversion efficiency, such as 1% for Nd:YAG lasers, is a problem not only for a high photon cost but also for environmental pollution. Recently, high power and high power density diode lasers have been developed. In this report, the beam characteristics of high power diode lasers are discussed and some applications of high power diode lasers are introduced..

2. Beam characteristics of high power diode lasers

The authors started the research of beam characteristics and feasibility for materials processing of a 15W class diode laser in 1989 for the 1st stage[1]. For the 2nd stage, a 50W class diode laser system was developed with a beam combination system using wavelength and polarization[2]. The results from these stages proved the possibility of diode lasers for welding of steel sheets, nevertheless their power was still too low. The 2nd stage also proved the possibility of increasing the output power of diode laser systems. By using the beam combination system of the 2nd stage, the authors developed a 2kW class high power and high power density diode laser system for the 3rd stage[3].

Figure 1 shows a photograph of the 2kW diode laser system. Two diode laser stacks with output power of 1kW and wavelength of 807nm were combined with polarization coupling and two 1kW-940nm stacks were also combined with polarization coupling. Two laser beams with different wavelength were combined with wavelength coupling, forming the single beam with high power and high power density. The beam focusing characteristics measured with a beam profiler are shown in **Fig.2**. A $1/e^2$ beam diameter of 966μm and a mean power density of 235kW/cm^2 were achieved at the focal distance of 50.1mm.



Diode laser head Wave length: 807 and 940nm Size: 520×700×220mm Weight: 90kg	Power supply unit Output: 50V, 70A ×4 Size: 553×600×970mm Weight: 160kg
Water cooling unit Size: 560×730×1650mm Weight: 100kg	Focusing unit Focusing distance: 50mm Weight: 0.98, 2kg

Fig.1 A 2kW class high power diode laser system

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*Associate professor

**Assistant professor

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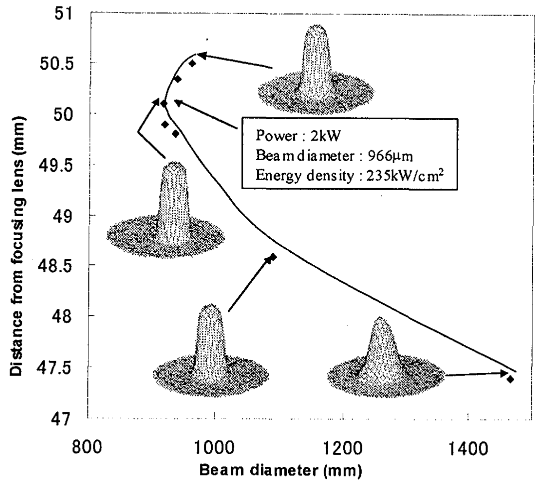

Fig.2 Beam characterstics of 2kW diode laser system

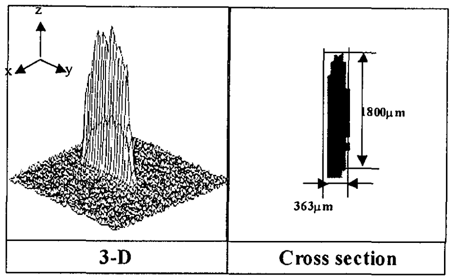

Fig.3 Direct beam profile of 500W diode laser

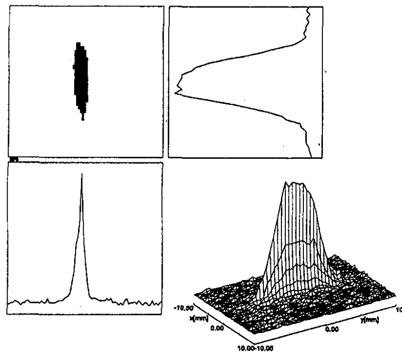

Fig.4 Direct beam profile of 4kW diode laser

In order to examine welding phenomena with the 2kW high power diode laser, bead-on plate welding was performed on mild steel plate at the focal point. Strong laser plasma formation was observed beyond an output power of 900W although the power density was relatively low compared with CO_2 and Nd:YAG lasers. This is because the beam profile of the diode laser was not a Gaussian type but a top-hat type. This strong laser plasma caused a severe damage to the protection glass because of the short focal length of the diode laser system. An assist gas nozzle which is usually used for high power CO_2 laser welding and a large gas flow rate of 70l/min suppressed the laser plasma and prevented the damage of the lens.

Although diode lasers have an advantage of high conversion efficiency, they also have a drawback of low beam quality. This low beam quality arises from their short focusing length, when they are used at a high power density. This short focusing length limits their ability for high power density welding even though laser plasma can be suppressed by assist gas.

On the other hand, diode lasers can be used with direct irradiation conditions without an optical fiber, even if the power density is low. **Figure 3** shows a direct beam profile of a 500W diode laser system. An elliptical beam with a beam size of 363μm x 1800μm and a power density of 84.8kW/cm^2 was obtained at a focal distance of 62.4mm. **Figure 4** also shows a direct beam profile of a 4kW high power diode laser system. An elliptical beam with a beam size of 1mm x 12mm and a power density of 37kW/cm^2 was obtained at a work distance of 46mm.

Even if the power density of direct diode lasers is lower than that of optical fiber coupled diode laser, heat conduction type welding is possible when these elliptical beams are used along the direction of their long axis, or large area irradiation is possible when they are moved along their short axis direction. The characteristics of diode lasers as heat source are placed between arc heat sources and conventional laser heat sources. The conversion efficiency of diode laser is low compared with arc heat sources but power density is superior. On the other hand, the conversion efficiency of a diode laser is high compared with conventional lasers although power density is low. Furthermore, the focusing distance of a diode laser is shorter than other lasers. Considering these characteristics, application fields of diode lasers should be concentrated to the fields which do not require high power density, such as thin plate welding, joining of plastics, brazing, forming, hardening and surface modification.

3. Materials processing with high power diode lasers

3.1 Welding of thick steel plates

Figure 5 shows butt-welding of SUS304 stainless steel plates of 5mm in thickness at a welding speed of 0.24m/min[4]. A parallel bead without defects was obtained. **Figure 6** shows the welding characteristics of the diode laser for SUS304 stainless steel. The data of CO_2 and Nd:YAG laser are also shown. These characteristics are comparable with those of conventional lasers. Diode lasers which have been thought to be unsuitable for materials processing have now developed to a power of 2kW and a power density of 235kW/cm^2 and comparable welding characteristics with conventional lasers for materials processing.

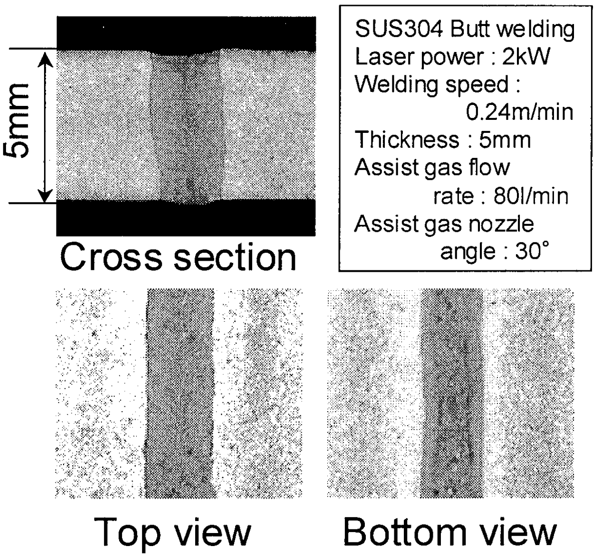

Fig.5 Butt welding bead of 5mm thick steel plate

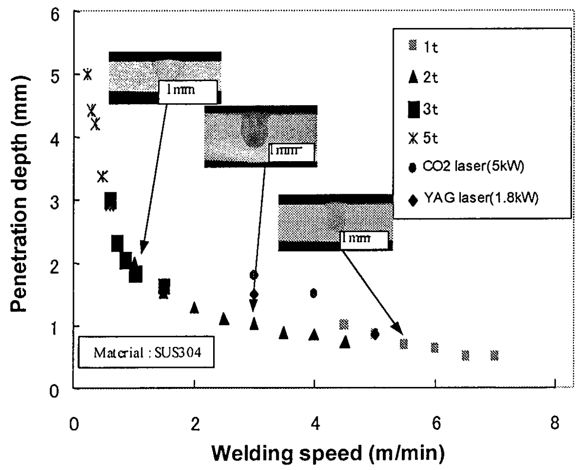

Fig.6 Welding characteristics of 2kW diode laser

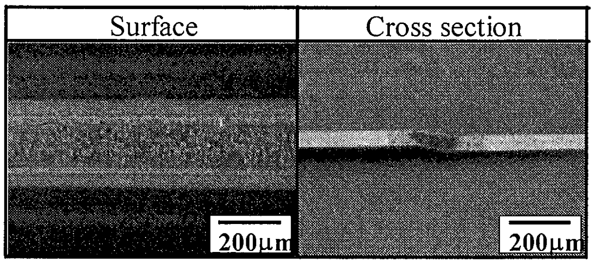

Fig.7 Butt welding of 50µm ultra thin plate

3.2 Welding of thin plates

Figure 7 shows a weld bead of 50µm thick SUS304 thin plates with a laser power of 100W at a welding speed of 3m/min. A sound bead was obtained and no plasma formation observed. As thin plate welding does not induce the laser plasma, it is a good application field for diode lasers which have the drawback of short focusing distance.

3.3 Laser forming of thick steel plates

Figure 8 shows laser forming of 5mm thick SUS304 plate which was irradiated 30 times at 1.5m/min with a diode laser power of 1kW[5]. A 5mm thick SUS304 plate was bent in U-shape after these irradiations were repeated in 18 lines with 5mm separation. The laser forming process has many advantages as it is performed on a defocused point, it can use long work distances. As it is a non-melting process, it is free from laser plasma. As diode lasers have short wavelengths compared with other lasers for materials processing, the absorption coefficient is higher and as diode lasers are easily controlled, the precise input heat control is possible. These advantages make laser forming a good application field for diode lasers.

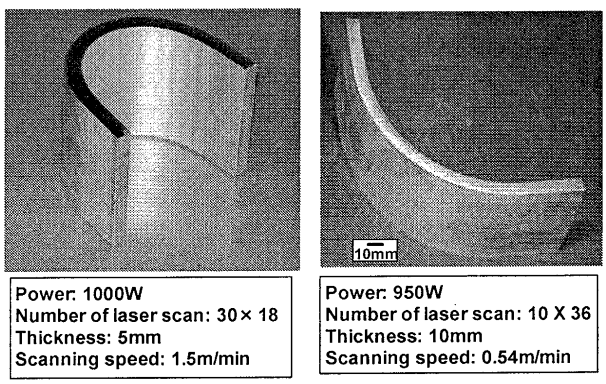

Fig.8 Diode laser forming of thick plate

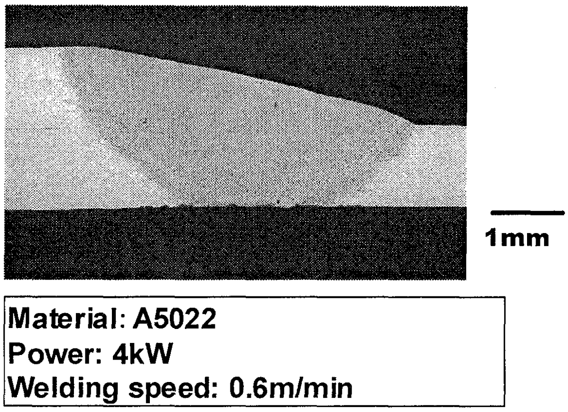

Fig.9 Welding of aluminum alloy

3.4 Welding of aluminum alloys

Aluminum alloys were successfully welded with a diode laser of an output power of 4kW, a power density of $37kW/cm^2$ and a beam size of 1mm x 12mm[6]. Bead on plate welding of 12m/min and lap-fillet welding of 3m/min were performed. **Figure 9** shows the lap-fillet weld bead of aluminum alloy AA5022. As the absorption coefficient of aluminum alloy matches the wavelength of diode lasers, welding can perform effectively. Furthermore, thermal conduction welding does not induce spattering or laser plasma, so producing a smooth and sound weld bead.

3.5 Laser cladding

Figure 10 shows micro cladding with 500W direct diode laser. A Ni-base self-fluxing alloy of 600µm in thickness was cladded onto mild steel plate. Low power and low power density makes a very quiet cladding process without metal vapor or spattering.

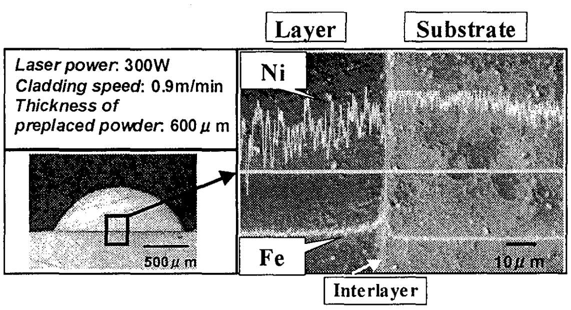

Fig.10 Micro cladding with diode laser

4. Conclusion

Diode lasers have been believed to be unsuitable for materials processing, due to their low output power and low brightness. However, recently, they have been powered by the improvement of laser diode itself and the development of stacking technology, to deliver an output power of 2kW and a power density of $235kW/cm^2$, for example. Such a laser can weld 5mm thick SUS304 at a welding speed of 24cm/min, which is comparable with conventional lasers for materials processing.

Application fields of diode lasers have been spreading to welding, cladding, surface hardening, material removal, forming, soldering, brazing, joining of plastics etc. In this report, ultra thin plate welding, laser forming, aluminum welding are described as appropriate applications for diode lasers.

References

1) N. Abe and Y. Kunugita: Trans. JWRI, 26(2), 1997, 89.
2) N. Abe, Y. Kunugita and S. Miyake; Proc. 17th Int. Congress on Application of Lasers and Electro-Optics, Orlando (1998, Laser Institute of America), G95.
3) N. Abe, R. Higashino, M. Tsukamoto, S. Noguchi and S. Miyake; Proc. 18th Int. Congress on Application of Lasers and Electro-Optics, San Diego (1999, Laser Institute of America) A236.
4) N. Abe, R. Higashino, N. Nakagawa, M. Tsukamoto, S. Miyake, S. Noguchi and M. Hayashi; Proc. 19th Int. Congress on Application of Lasers and Electro-Optics, Dearborn (2000, Laser Institute of America), A16.
5) N. Abe, N. Nakagawa, M. Tsukamoto, K. Nakacho, M. Sogabe, S. Miyake and S. Noguchi: Proc. 20th Int. Congress on Application of Lasers and Electro-Optics, Jacksonville (2001, Laser Institute of America), D607.
6) N. Abe, A. Morikawa, K. Maeda and K. Namba: Proc. 21st Int. Congress on Application of Lasers and Electro-Optics, Scottsdale (2002, Laser Institute of America), 504.