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# Materials Processing Characteristics of a 2kW Class High Power Density Direct Diode Laser System †

**Nobuyuki ABE*, Ritsuko HIGASHINO**, Masahiro TSUKAMOTO***, Shuichi NOGUCHI**** and Shoji MIYAKE*******

Abstract

*A 2kW class high power density direct diode laser materials processing system was developed and its processing characteristics were examined. By using a wavelength and polarization coupling method, an output power of over 2kW, a beam diameter of 0.96mm and a power density of 235kW/cm² were achieved at the focal point. The processing characteristics of the high power density direct diode laser were evaluated for stainless steel and mild steel. Strong laser plasma formation was observed at a power density of over 100kW/cm². By suppressing this plasma with assist gas, full penetration single pass welding was successfully achieved for a 5mm thick SUS304 stainless steel plate at a welding speed of 0.24m/min, with a parallel bead shape and no welding defects. High speed welding of 1mm thick thin mild steel plate was also achieved at a welding speed of 4m/min.*

**KEY WORDS**: (High power) (Diode laser) (Welding) (Materials processing) (Beam characteristic)

## 1. Introduction

Laser beams are considered to be one of the best tools for the thermal processing of materials because of their ability to finely focus energy. Lasers typically used for thermal processing include $CO_2$ and Nd:YAG lasers. Although offering high power and high power density, however, their conversion efficiency from electrical energy to optical energy is too low; it is only about 10% for $CO_2$ lasers and about 3% for Nd:YAG lasers. Therefore, high power lasers of these types are quite large. In contrast, diode lasers have a much higher conversion efficiency that can reach over 40%, and they can be made very small and light. A 2kW class high power density direct diode laser materials processing system was developed and its processing characteristics were examined. By using a wavelength and polarization coupling method, an output power of over 2kW, a beam diameter of 0.96mm and a power density of 235kW/cm² were achieved at the focal point. The processing characteristics of the high power density direct diode laser were evaluated for stainless steel and mild steel. Strong laser plasma formation was observed at a power density of over 100kW/cm². By suppressing this plasma with assist gas, full penetration single pass welding was successfully achieved for a 5mm thick SUS304 stainless steel plate at a welding speed of 0.24m/min, with a parallel bead shape and no welding defects. High speed welding of 1mm thick thin mild steel plate was also achieved at a welding speed of 4m/min.

However, from the first time diode lasers emitted light in 1962, they have been developed only for the communications field because of their low output power, low brightness and poor beam properties. No thought has been given to their application to materials processing. In recent years, however, high power diode lasers have been developed, achieving a sufficient power level for practical use. From the early 1990's, the use of diode lasers for soldering, welding, cutting, drilling and marking has been investigated in the U.S.A., Germany and U.K. In Japan, soldering research was also performed using a 10W diode laser that combined 12 diode lasers by optical fiber coupling[1] and 13W soldering equipment[2]. Such systems have not come into practical use due to their high price, low power and low power density. In 1993, a high power 50W class diode laser was developed, and welding and cutting were performed using this system[3]. In 1996, many applications were tried such as marking/engraving

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natural stone (marble and granite), marking ceramic tiles, sealing tile grout, cutting and marking glass, marking/engraving wood, stripping paint and lacquer, and welding metallic wire using a 60 W diode laser[4]. However, the power density of the laser was only 3kW/cm$^2$, and welding of thick steel plates could not be performed.

The authors believe that direct diode lasers will be the next generation of materials processing lasers, especially for welding, and thus have been developing high power density direct diode laser systems and studying the materials processing characteristics in a three-stage project. In the first stage, a 10W class diode laser system was examined[5]. At a diode current of 35A, a maximum output power of 12W was obtained at the end of the optical fiber, which was reduced to 7.5W after passing through the focusing lens and protection glass. The 1/e$^2$ beam diameter was 182μm, and a mean power density of 25kW/cm$^2$ was obtained at the focal point. A 0.06mm thick mild steel plate was welded at a focal distance of 25.6mm with a welding speed of 2mm/s. The authors concluded that the direct diode laser has the potential to be applied to materials processing, especially welding. In the second stage, a 50W class direct diode laser materials processing system was developed[6]. In order to generate more power and a higher power density, the effectiveness of a combination method employing polarization coupling and wavelength coupling was examined using 4 diode arrays: two pairs of 15W diode arrays, one pair with an 810nm wavelength and another pair with a 950nm wavelength. The two beams produced by the two pairs of diode arrays through polarization coupling were combined by wavelength coupling into a single beam. At a diode current of 31.5A, a maximum output power of 48W was obtained at the focusing lens, which was reduced to 38 W after passing through the focusing lens and protection glass. The 1/e$^2$ beam diameter was 264μm, and a mean power density of 60kW/cm$^2$ was achieved at the focal point. This system welded 0.4mm thick SS400 mild steel with a penetration depth of 0.2mm at a welding speed of 1mm/s. The results of the second stage showed the ability to effectively combine the beams from 4 diode arrays into a single beam using polarization coupling and wavelength coupling. The effect of the higher power density was also shown on the penetration depth and bead shape.

## 2. High Power Density Diode Laser Material Processing System

### 2.1 2kW Diode Laser System

In the third stage, the authors developed a 2kW class high power, high power density diode laser materials processing system. **Figure 1** shows a drawing of the system. The 2kW diode laser used was a JOLD-2000-CAXF-100A (JENOPTIK Laser Diode). Four 1kW diode stack modules (one pairs with an 807nm wavelength and another pair with a 940nm wavelength) were combined using the same method as for the second stage.

The beam delivered through the optical fiber was focused with a focusing unit installed on 5-axis robot. A protection glass was set in front of the focusing lens to prevent the lens from being damaged by spatter or mist. **Figure 2** shows a photographic overview.

**Figure 3** shows the output power dependency on the diode module current. At a diode current of 57A, an output power of 2kW was achieved after passing through the focusing unit.

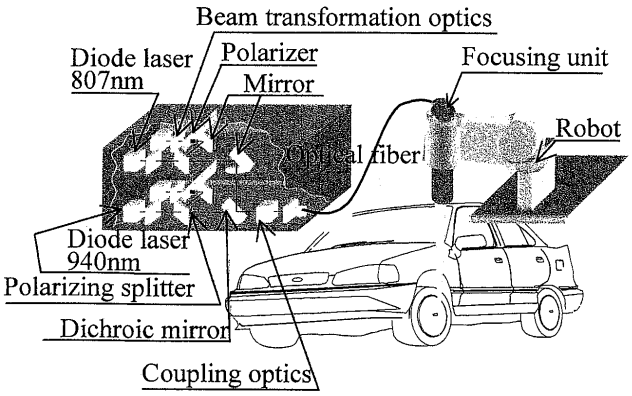


**Fig.1** 2kW high power density diode laser system

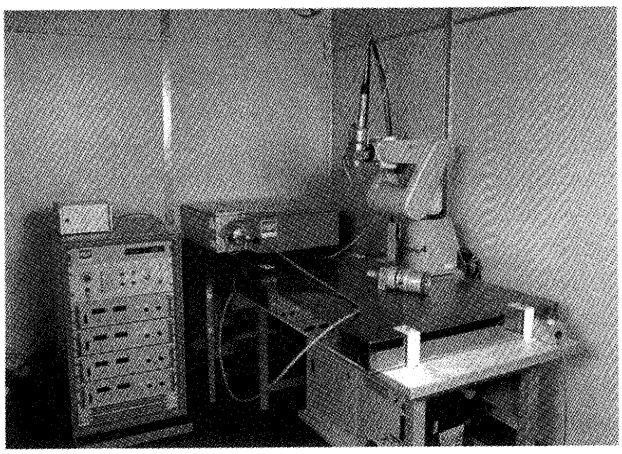

**Fig.2** 2kW HPDL materials processing system

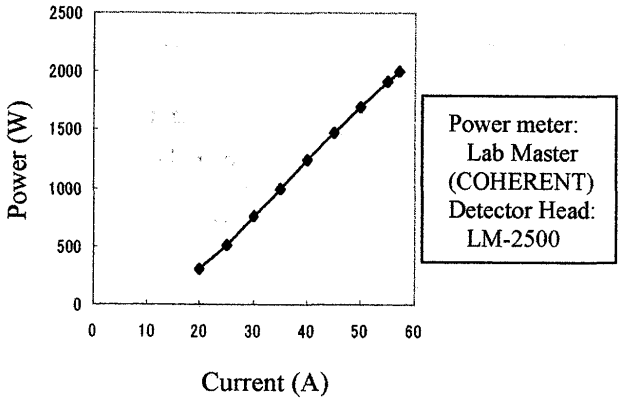


**Fig.3** Output power dependency on diode module current

2.2 Beam Profile

The beam profile and mean power density were analyzed using a UFF100 laser beam analysis system (Prometec Corp.). **Figure 4** shows the beam profile at different working distances along the beam axis. The minimum beam diameter was obtained at the working distance of 50.1mm. **Figure 5** shows the beam profile at the focal point; it has a top- hat shape. The $1/e^2$ beam diameter was 966μm, and a mean power density of 235kW/cm$^2$ was achieved. This energy density was five times higher than that of the 50W system studied in the second stage.

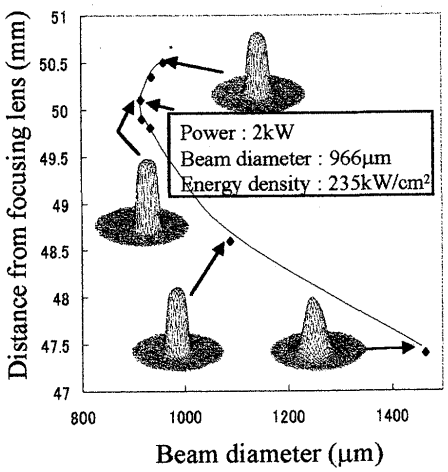


**Fig.4** Beam focusing characteristics along the beam axis

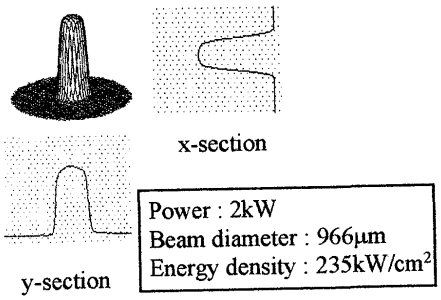


**Fig.5** Beam profile at the focal point

## 3. Processing Characteristics of the High Power Density Diode Laser

3.1 Laser Plasma Phenomena

In order to examine the diode laser's characteristics for materials processing, bead-on plate welding and butt-welding were performed using both SS400 mild steel and SUS304 stainless steel.

Strong plasma formation by the high power density beam was observed. **Figure 6** shows the amount of laser plasma at various laser power levels. When the power exceeded 700W, laser plasma appeared; such a plasma had never been seen in the 10W and 50W systems. With increasing laser power, laser plasma formation became stronger. Bead-on plate welding without assist gas resulted in serious damage to the protection glass. The use of assist gas, however, effectively suppressed the laser plasma. The assist gas changed the laser plasma formation. **Figure 7** shows the laser plasma at various assist gas flow rates. The laser plasma was completely suppressed at a He gas flow rate of over 70 l/min. **Figure 8** shows the penetration depth dependency on the assist gas flow rate at a welding speed of 3m/min for bead-on plate welding of 3mm thick mild steel. As the flow rate increased, the penetration depth also increased, reaching a maximum penetration depth of 1.3mm at a gas flow rate of 60 l/min. **Figure 9** shows the penetration depth dependency on the assist gas nozzle angle. The assist gas nozzle angle had minimal effect on the penetration depth at welding speeds of 1 and 3m/min. At a welding speed of 5m/min, a nozzle angle of 40 degrees was more effective than other angles.

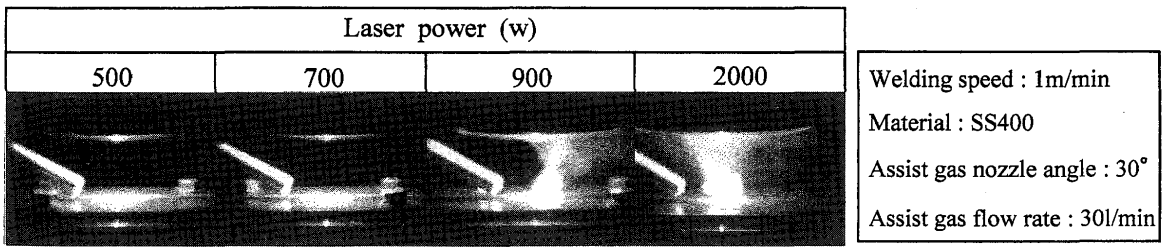


**Fig.6** Laser plasma generation by high power density diode laser

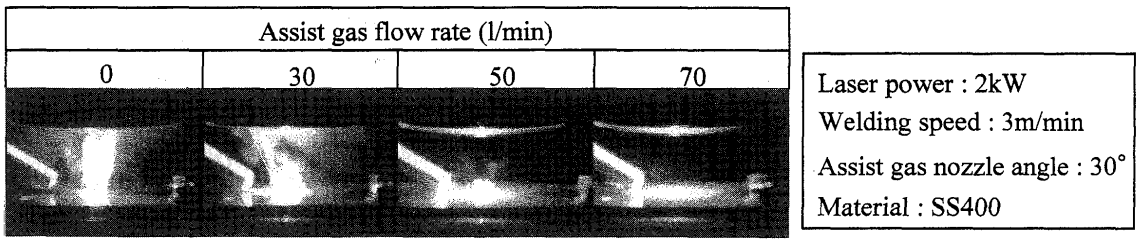


**Fig.7** Effect of assist gas flow rate on suppression of laser plasma

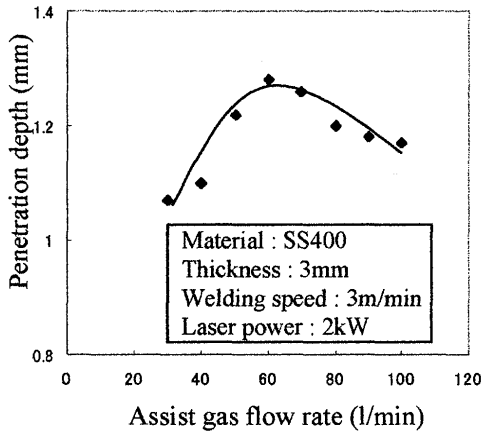


**Fig.8** Assist gas flow rate dependency on penetration depth

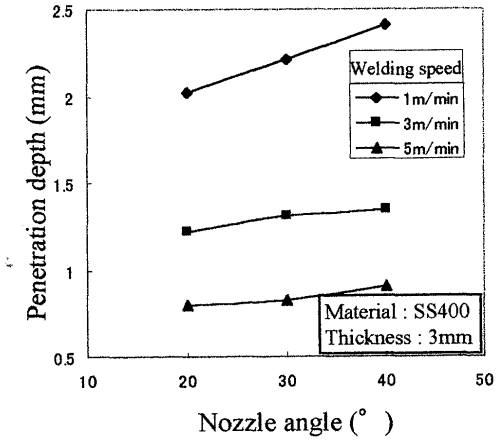


**Fig.9** Assist gas nozzle angle dependency on penetration depth

3.2 Welding Characteristics

**Figure 10** shows the relationship between the welding speed and penetration depth for bead-on plate welding of 3mm thick SS400 mild steel at an output power of 2kW. With decreasing welding speed, the penetration depth increased and a penetration depth of 2.3mm was achieved at an output power of 2kW and welding speed of 1m/min. For 1mm thin SS400 mild steel, full penetration welding was achieved at a welding speed of 4m/min.

**Figure 11** shows the relationship between the welding speed and the penetration depth for bead-on plate welding of 3mm thick SUS304 stainless steel at an output power of 2kW. With decreasing welding speed, the penetration depth increased to over 5mm at a welding speed of 0.24m/min. **Figure 12** shows the butt-welding bead of 5mm thick SUS304 stainless steel at an output power of 2kW. Full penetration butt welding of 5mm thick SUS304 stainless steel was achieved at a welding speed of 0.24m/min. The bead showed a parallel bead shape with no welding defects.

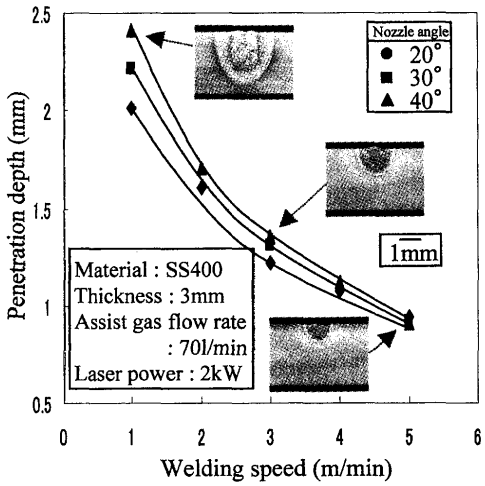


**Fig.10** Welding speed dependency of SS400 mild steel on penetration depth at various assist gas nozzle angles

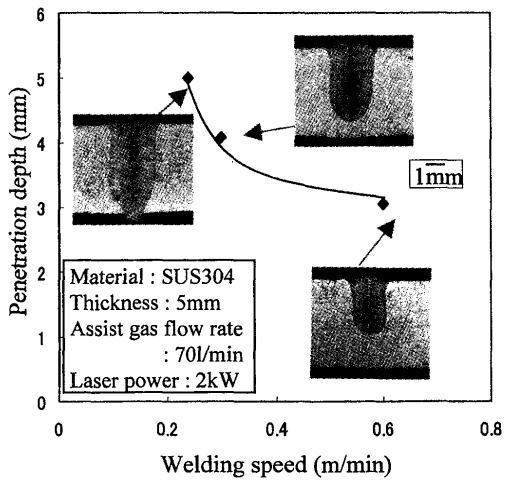


**Fig.11** Welding speed dependency of SUS304 stainless steel on penetration depth

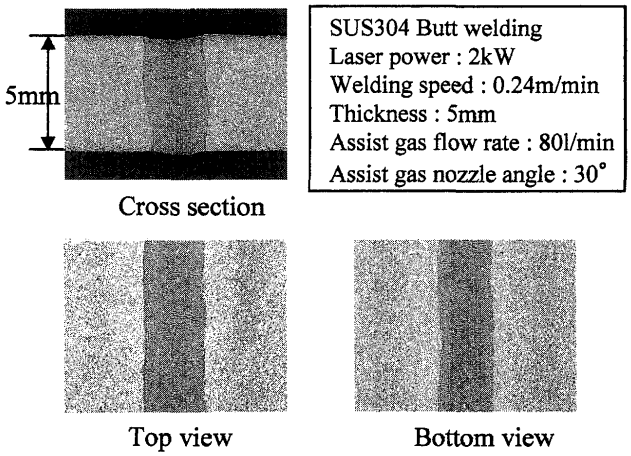


**Fig.12** Butt-welding bead of 5mm thick SUS304 stainless steel plate

## 4. Conclusions

A 2kW class direct diode laser materials processing system was developed. An output power of 2kW was achieved, with a beam diameter of 966μm and a power density of 235kW/cm$^2$ at the focal point. When the processing characteristics of the high power density direct diode laser were examined for mild steel and stainless steel plates, strong plasma formation was observed at high power densities. This plasma was effectively suppressed by assist gas. Full penetration single pass welding was successfully achieved for 5mm thick stainless steel plate at a welding speed of 0.24m/min, with a parallel bead shape and no welding defects.

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