Development of a 50W Class Direct Diode Laser System for Materials Processing and its Processing Characteristics †

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Abstract

A 50W class high energy density diode laser system was developed by the optical combination of four 15W diode arrays. The beam diameter at the focal point was 264 μm and a mean energy density of 60kW/cm² was achieved. Cutting and welding characteristics were investigated for mild steel. Mild steel plates 0.1mm thick could be cut at a cutting speed of 6mm/s and a penetration depth of 0.2mm on a 0.4mm thick specimen was achieved at a welding speed of 1mm/s without surface treatment or an assist gas.

KEY WORDS: (High Power Diode Laser)(High Energy Density)(Welding)(Cutting)

1. Introduction

Laser beams are generally considered to be one of the best tools for the thermal processing of materials because of their ability to finely focus energy. In thermal processing, the most commonly used devices are CO_2 and Nd:YAG lasers, which are noted for their ability to generate high power levels. However, CO_2 and Nd:YAG lasers are unable to efficiently convert electrical energy to optical energy because they are indirectly driven by the energy sources utilized, such as electrical discharge or flash lamps. Therefore, high power lasers of this type are quite large. Diode lasers, in contrast, are substantially more compact and also highly efficient in converting electrical energy to optical energy because they are directly driven by electrical current. The low output power and brightness of diode lasers, however, has largely restricted their use to the fields of information and communications. Diode lasers are generally regarded as a poor tool for materials processing and very few reports on their use in this field have been published. A 1996 UMIST[1)] study of a 60W diode laser used in materials processing noted that the diode laser was primarily limited to the engraving of marble and the marking of granite because of its low energy density of 3kW/cm². Recently, however, research into high power diode lasers has been progressing and is now attracting a good deal of interest. In response to this trend, we have begun our own development project at the Research Center for Ultra High Energy Density Heat Sources, JWRI, Osaka University, aimed at producing a high energy density diode laser system suitable for use in the thermal

Phase 1: **Study of the beam characteristics of a direct diode laser suitable for materials processing, and successful cutting of mild steel plates with a 10W class direct diode laser.**

Phase 2: **Development of a 50W class diode laser system with a high energy density of 50kW/cm², development of a multi-diode laser beam combination system, and evaluation of the system's ability to weld and cut steel plates.**

Phase 3: **Development of a 3kW class high power direct diode laser system with an energy density of 200kW/cm², and study of its application for materials processing including welding, cutting and drilling of steel plates.**

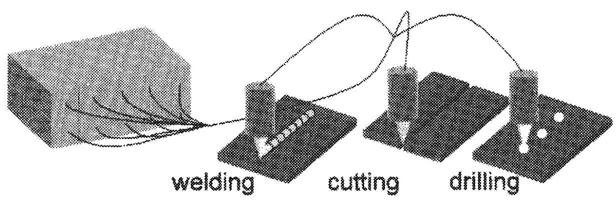

Fig.1 Project stages and objectives for the develop-ment of a high power, high energy density direct diode laser system for materials processing.

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processing of materials. Our project is divided into three phases as illustrated in **Fig.1** below. This paper will describe the results so far obtained in Phase 1 and Phase 2 of the project.

2. Characteristics of a 10W Class Direct Diode Laser System

In recent years, diode laser arrays with an output power of 10W and a focus diameter of 180 μm have become available. Although the beam power of these lasers is still relatively low, we decided to examine direct diode lasers' potential for future application to materials processing. Phase 1 of our project dealt with ascertaining the beam characteristics of a 10W class diode laser designed for materials processing[2].

The diode laser used was an OPC-D010-910-HBPS produced by Opto Power Corporation. The 12 laser beams generated by the elements in the diode bar were gathered into a single beam by a beam shaping unit and then run through a 250 μm diameter optical fiber. An Optical Re-Imaging Unit (ORU) focused the output power from the diode laser module via the optical fiber at a convergence ratio of 1:2 at 70% power throughput and a focal distance of 25.6mm. A 1mm thick cover glass was set in front of the terminal glass of the ORU to prevent contamination of the lens by spatter or mist.

The output power was measured at the end of the optical fiber, after the ORU, and behind the cover glass, respectively. **Figure 2** shows the output power dependency on the diode current. When the diode current was 35A, a maximum output power of 12W was obtained at the end of the optical fiber. The power output decreased to 7.5W, however, after the beam passed through the ORU and the cover glass.

The beam profile and mean energy density were analyzed using a UFF100 laser beam analysis system (Prometec Corporation). **Figure 3** shows the beam profile at different working distances after passing through the ORU and the cover glass. The $1/e^2$ beam diameter was 182 μm, and a mean energy density of 25kW/cm^2 was obtained at the focal point. The beam cross section was elliptical and spread out slightly. We attributed this to the limitations of the beam shaper unit. The energy density decreased sharply as the distance from the focal point increased.

In order to examine the direct diode laser's potential for materials processing, thin mild steel plates (0.01 - 0.1mm thick SS400) were cut at a focal distance of 25.6mm at cutting speeds of 2 - 22mm/s. The experimental apparatus is shown in **Fig.4**.

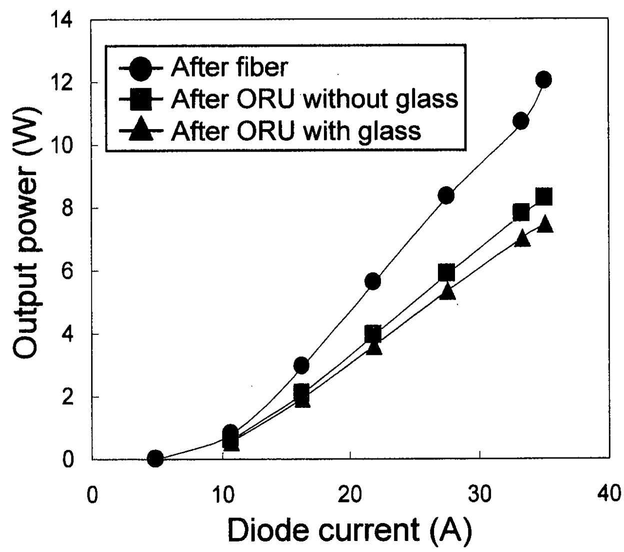

Fig.2 Output power dependency on diode current.

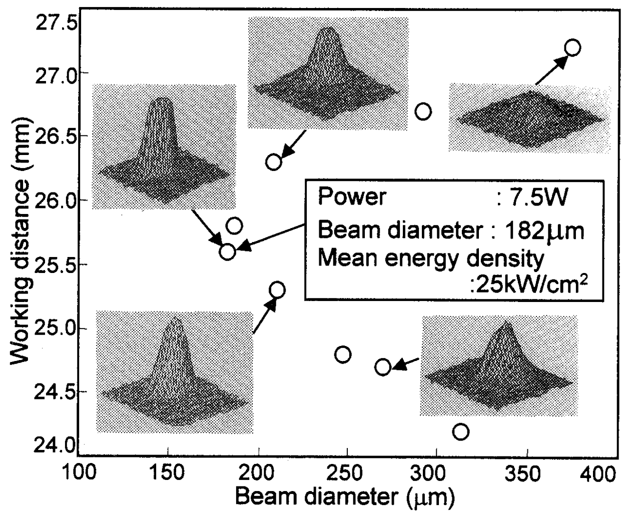

Fig.3 Beam profiles along the beam axis of a 10W class diode laser.

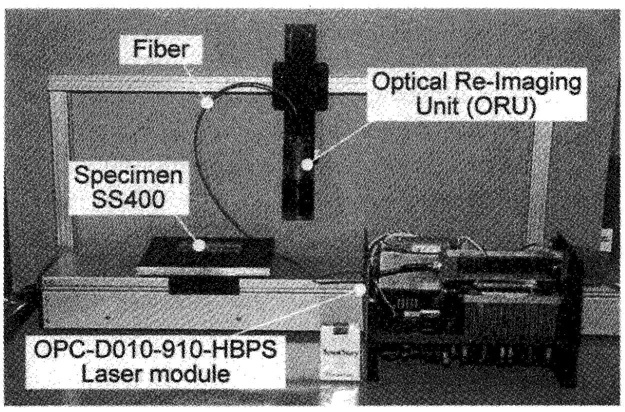

Fig.4 Experimental apparatus for a 10W class direct diode laser system.

Figure 5 shows the maximum cutting thickness as a function of the cutting speed. A 0.06mm thick steel plate was cut using an output power of 7.5W and a cutting speed of 2mm/s without either surface treatment or an assist gas. **Figure 6** shows the relationship between the cutting width and cutting speed, and also the surface appearance of some specimens after cutting. The cutting width became wider as the cutting speed decreased. The cutting width of the thinner specimens was wider than that of the thicker plates, and the cutting edge borders of all of the specimens turned black. We concluded, therefore, that a 10W system has the ability to be used for cutting, but the laser output and energy density are too low to be of practical use for materials processing.

3. Development of a 50W Class Direct Diode Laser System

3.1 Beam characteristics of a 50W class direct diode laser system

In order to increase both power and energy density, we developed a 50W class direct diode laser system to examine the effectiveness of combining the beams from 4 diode arrays into 1 beam using both polarization coupling and wavelength coupling as shown in **Fig.7**. Three mirrors, two polarizing beam splitter cubes, two quartz polarization rotators and a dichroic mirror were prepared for optical combination of the four 15W diode arrays with a beam shaper. The wavelengths of the two pairs of 15W diode arrays were 810nm and 950nm, respectively. A quartz polarization rotator was set up on the exit aperture of one of the diode arrays in each pair. For each pair of diode arrays, the splitter cube reflects the beam polarized 90° by the rotator at a right angle, while at the same time letting the reflected beam from the other diode array pass through. In this way the beams produced by each pair of diode arrays are combined at the splitter cubes. The beams that exit the splitter cubes each have different wavelengths (810nm and 950nm) and approach the dichroic mirror from different directions. The 950nm beam passed through the dichroic mirror, while the 810nm beam is reflected at a right angle, with the result that they combine into a single beam. An achromatic lens then focuses the combined beam at a focal distance of 21.1mm.

Figure 8 clearly shows that the beam diameter of each laser beam, after passing through each optical component, was largely unchanged throughout the process of converting the four individual beams into one beam. However, Fig.8 also shows that the laser

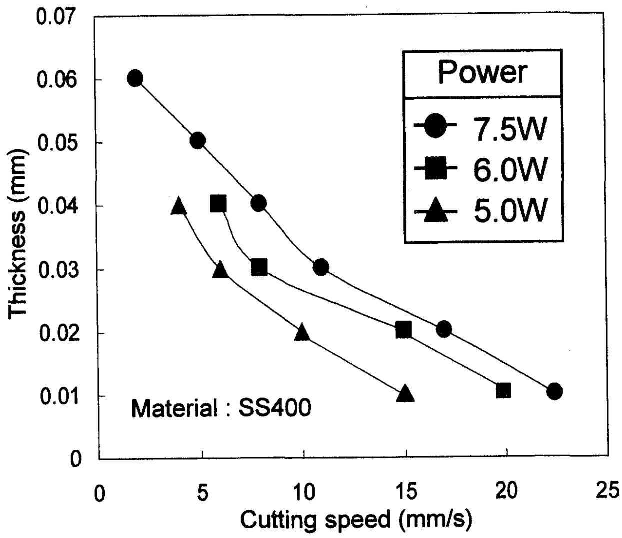

Fig.5 Cutting thickness dependency on cutting speed.

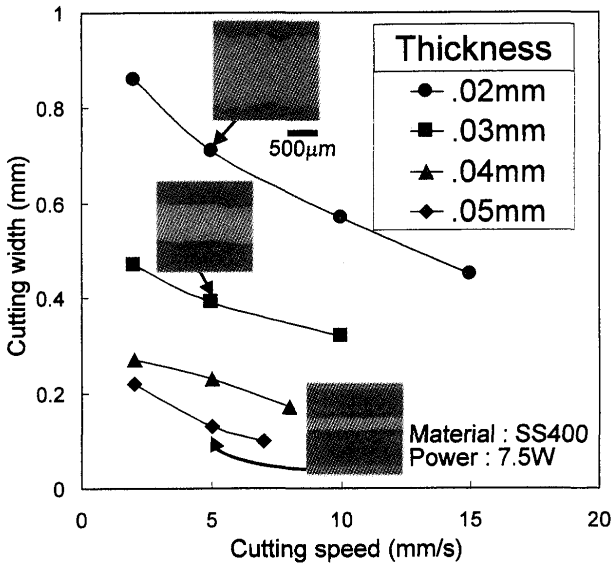

Fig.6 Cutting width dependency on cutting speed.

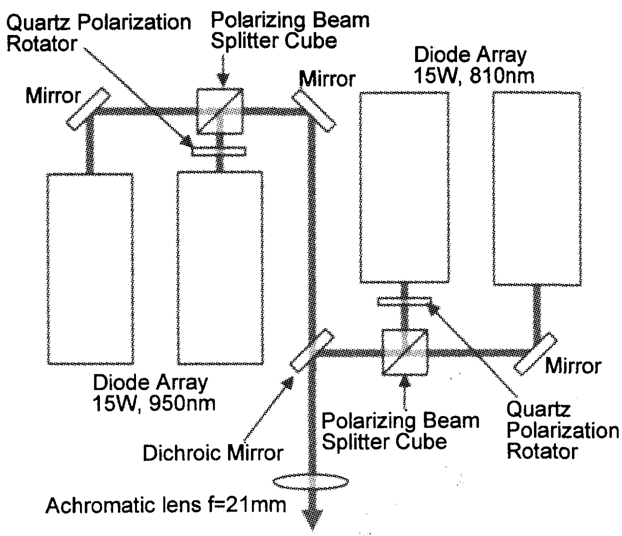

Fig.7 Diagram of the 50W class direct diode laser combination system.

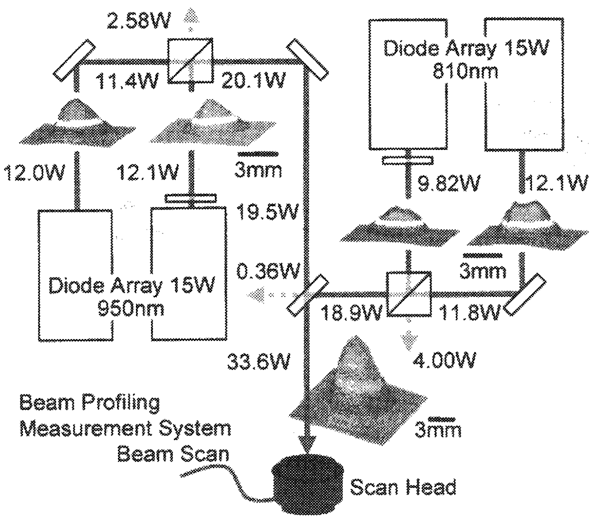

Fig.8 Beam profile measurements.

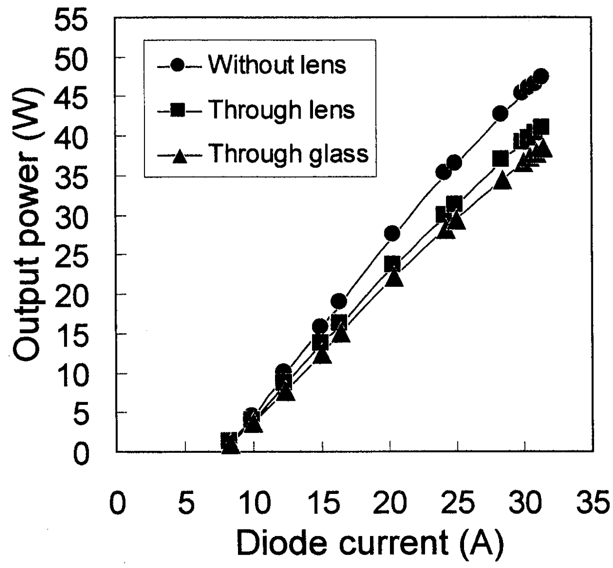

Fig.9 Output power dependency on diode current.

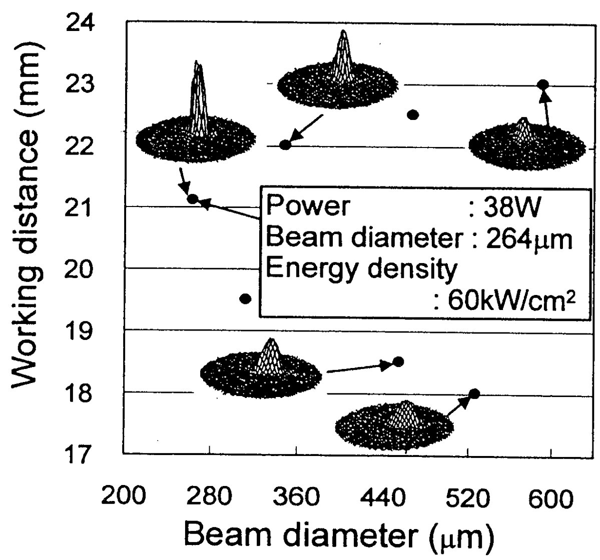

Fig.10 Beam profile of the 50W class diode laser system.

power levels do not combine effectively. We believe that this is mainly because the polarization ratio of each diode laser is not 100%, as only 73% of the total power output survives the process of conversion into one beam. **Figure 9** shows the output power dependency on the system's diode current. When the diode current was 31.5A, a maximum output power of 48W was obtained before focusing. This level decreased, however, to 38W after passing through the achromatic lens and cover glass. **Figure 10** shows the beam profile of this system along the beam axis. The $1/e^2$ beam diameter was 264 μm, and a mean energy density of $60kW/cm^2$ was obtained at the focal point. The tiny peaks which appeared around the main beam were probably caused by insufficient beam alignment.

3.2 Processing characteristics of a 50W class direct diode laser system

In order to investigate the system's potential for application to materials processing, cutting and bead-on plate welding were performed using SS400 mild steel (0.01 - 0.4mm thick). **Figure 11** shows the maximum cutting thickness in relation to the cutting speed for the 50W system with an energy density of $42kW/cm^2$ (the results of the 10W system with an energy density of $25kW/cm^2$ have also been plotted for comparison). The 50W system was able to cut a 0.1mm thick mild steel specimen at a cutting speed of 6mm/s without any assist gas, while the maximum cutting thickness for the 10W system was 0.06mm. The cutting width became narrower as the cutting

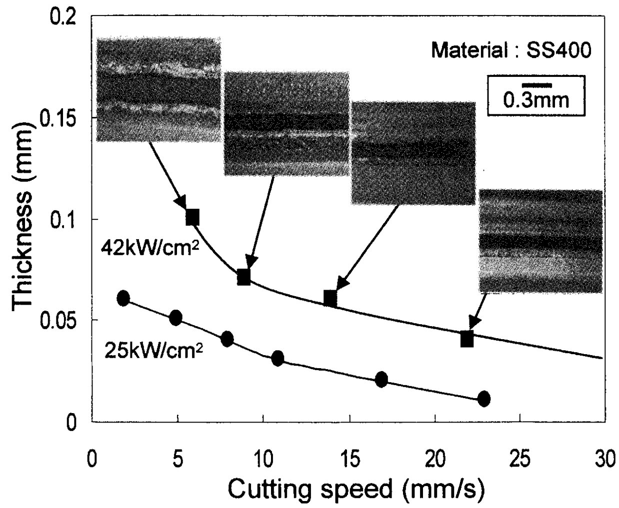

Fig.11 Comparison of maximum cutting thickness dependency on the cutting speed for $25kW/cm^2$ and $42kW/cm^2$ beams.

speed increased. **Figure 12** is a comparison of the surface appearance of the specimens cut using the 10W and 50W systems. The 50W system was able to cut a 0.04mm specimen at a cutting speed of 21mm/s. This cutting thickness was obtainable at more than double the cutting speed of the 10W system for the same thickness specimen. The cutting width of the 50W system was narrower and the black-colored cutting edge was also narrower.

Figure 13 shows the relationship between the welding speed and penetration depth. The weld beads were formed by bead-on plate welding of 0.4mm SS400 mild steel at an output power of 34W. When the welding speed was reduced to a rate of 0.2mm/s, a penetration depth of 0.16mm was achieved at a power level of 34W. A comparison of the weld bead cross sections obtained with the 50W system and 10W system is shown in **Fig.14**. A penetration depth of only 0.02mm was obtained with the 10W system on a specimen of 0.06mm SS400 mild steel at a welding speed of 5mm/s. In contrast, the 50W system achieved a penetration depth of 0.2mm on a 0.4mm specimen of SS400 mild steel at a welding speed of 1mm/s. This difference is attributable to both the increased output power and higher energy density at the focal point.

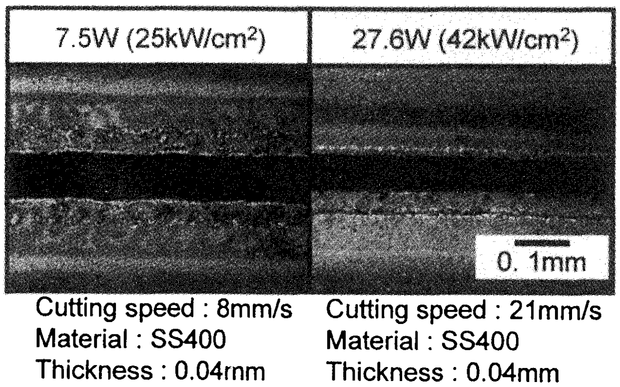

Fig.12 Comparison of cutting surface appearance after cutting with 25kW/cm² and 42kW/cm² beams.

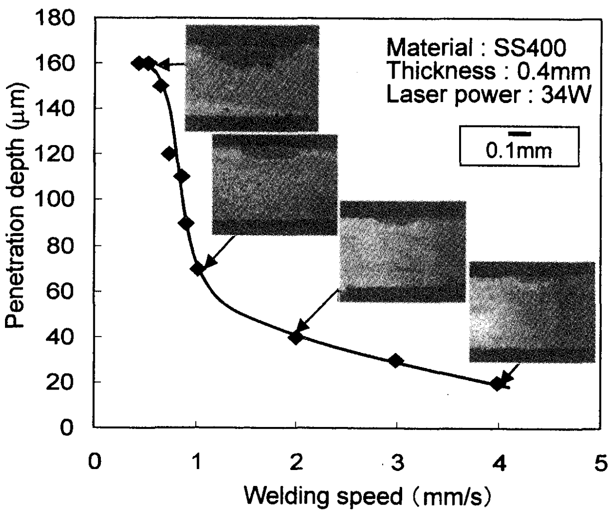

Fig.13 Penetration dependency on welding speed.

4. Conclusion

In order to develop a diode laser system for materials processing, we examined a single-bar type low power system before developing a combination type 50W class diode laser system with an energy

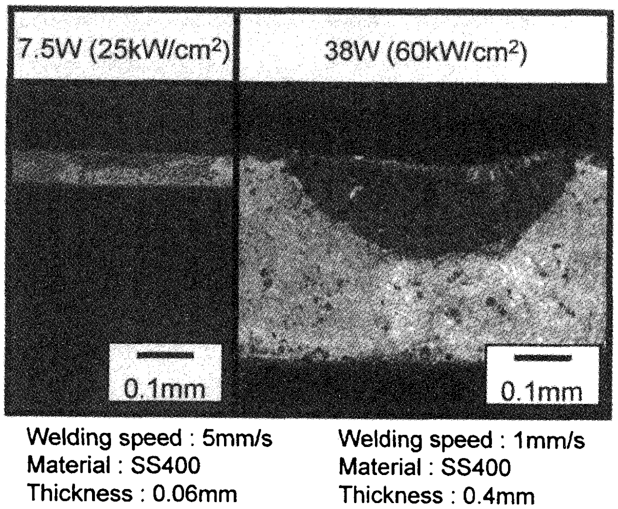

Fig.14 Comparison of weld beads for 25kW/cm² and 60 kW/cm² beams.

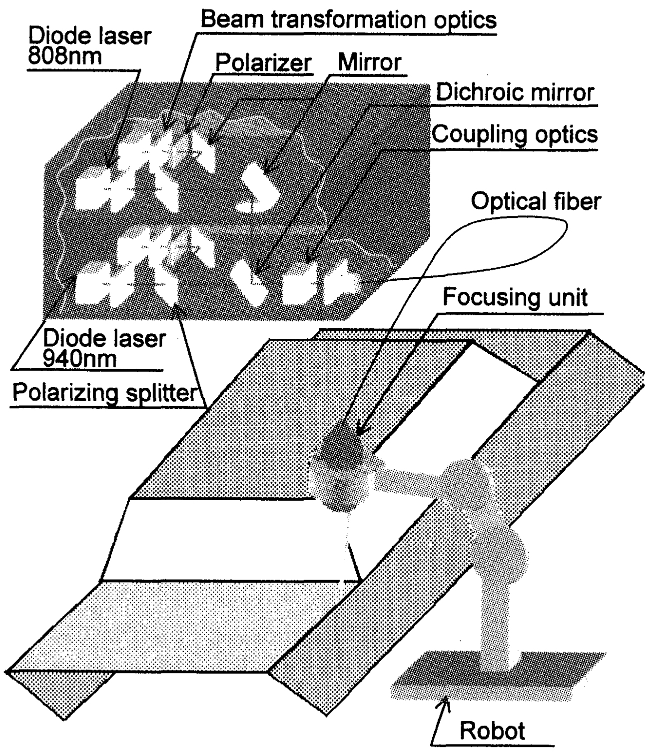

Fig.15 3kW class high power direct diode laser sys-tem.

density of 60kW/cm^2. After studying the 50W system's thermal processing characteristics and comparing it with the performance of the low power system, we found that this type of beam combination system functions successfully and the 50W system is able to more effectively weld and cut mild steel plates. Therefore, we are now planning to develop a 3kW class high power direct diode laser system using wavelength and polarization combination of four 750W diode stacks for our final phase of development. **Figure 15** shows the design of this system.

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