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Observations of plume spectra during CO_2 laser irradiation†

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KEY WORDS: (Laser induced plume) (Continuum emissions) (Line emissions) (Assist gas) (Penetration depth)

Welding quality depends on the conditions of the molten pool and the beam hole produced with high power lasers in laser welding. If the molten-pool and beam-hole conditions are directly observed, we can find a defective part in process of welding. But it is not easy to observe them. During laser irradiation a plume is induced and expands from beam hole to outside. Plume light is easily observed since its intensity is very strong. When the characteristics of the plume are related to the molten-pool and beam-hole conditions, observation of the plume can become important for high quality laser welding. In this note, we describe the relation between plume light spectra and penetration depth of the bead.

Our experiments were performed with a 15 kW class CO_2 laser and a stainless steel target (SUS304 plates). CO_2 laser, welding and observed directions are indicated in Fig. 1 and the experimental setup is shown in Fig. 2. The CO_2 laser beam was focussed onto the stainless steel target with a concave mirror of f=700 mm. The focal spot diameter was about 0.9 mm. Thickness of the stainless steel target was 10 mm and the welding speed was 60 cm/min. Our setup has two directions for spectral measurements and observations of target and plume. For spectral measurements the plume light from +1 mm height above the target in Fig. 1 was collected by two concave aluminum mirrors and guided into an optical fiber and to a spectrometer coupled to a CCD. The field of view was within a circle of diameter 2 mm at the target position. Spectral resolution was 3 nm. Laser power was varied in each experiment, at 1, 2 or 3 kW and laser intensity was $2x10^9$, $4x10^9$, or $6x10^9$ W/m^2 at the target. The flow rate of assist gas was 0 l/min. Observed spectral regions were between 400 nm and 800nm. Figures 3(a), 3(b) and 3(c) indicate the relationships between laser power and plume spectra at 1, 2 and 3 kW laser power, respectively. Continuum emission is indicated in Fig. 3(a), whose spectral peak

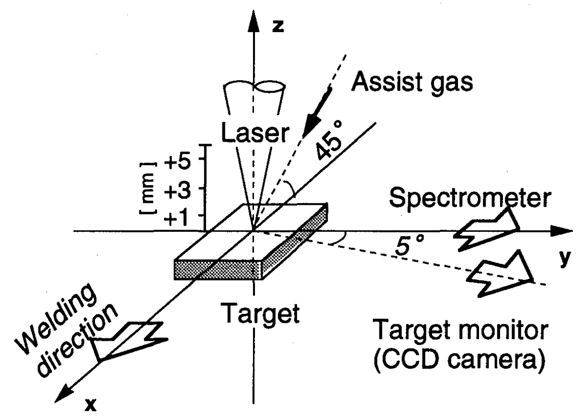

Fig. 1 Schematic configuration of laser, welding and observed directions

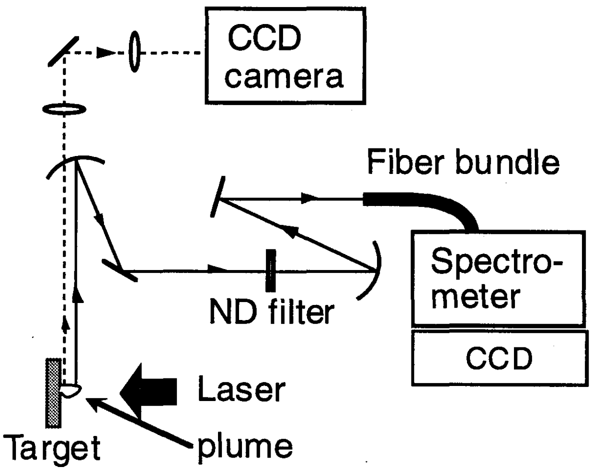

Fig. 2 Experimental setup

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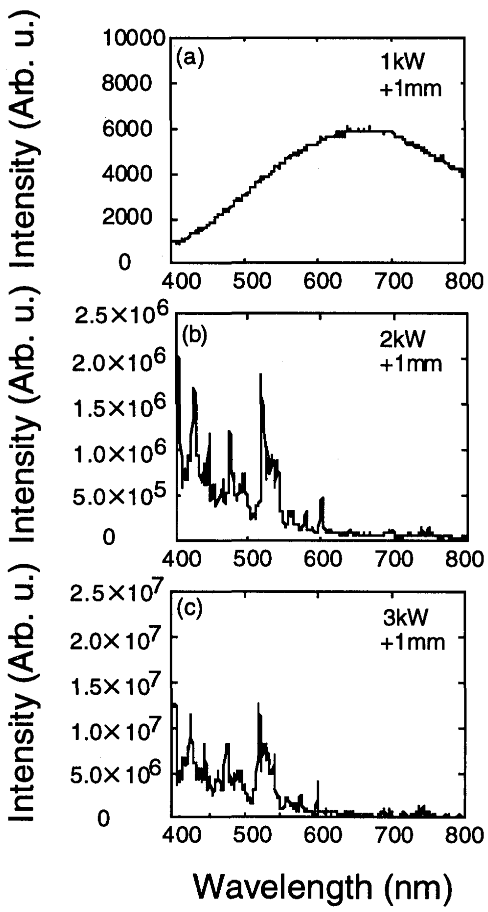

Fig. 3 Plume spectra depended on laser power

is at about 670 nm. In Figs. 3(b) and 3(c) strong line emissions are shown and these intensities are 10^2 times and 10^3 times stronger than those of continuum emission shown in Fig. 3(a). The spectrum in Fig. 3(b) is very similar to that in Fig. 3(c). At 1 , 2 and 3 kW laser power, penetration depths were 0.50, 1.20 and 2.50 mm, respectively. When the penetration depth was 0.50 mm, line emissions were not observed. To investigate the effect on plume spectra and penetration depth of flow rate of the assist gas, flow rate was changed from 0 *l*/min to 40 *l*/min (0, 20 or 40 *l*/min). The laser power was 1 kW in each experiment and observed spectral regions were between 300 nm and 800 nm. The results for 0, 20 and 40 *l*/min are shown in Fig. 4(a), 4(b) and 4(c), respectively. Continuum emission was observed in the case of 0 and 20 *l*/min flow rates. Penetration depths were 0.53 mm for both 0 *l*/min and 20 *l*/min cases. For 40 *l*/min the penetration depth was 0.70 mm. As Fig. 4(c) indicates, line emissions were generated on the continuum emission in the short wavelength regions. The difference in penetration depth between 20 *l*/min and 40 *l*/min flow rates was 0.17 mm. It was assumed that the line emissions shown in Fig. 4(c) indicate the variation of 0.17 mm in penetration depth.

In summary, we have investigated the behavior of plume light spectra and penetration depth. From 2 kW to 3 kW laser power, line emissions were generated and their spectral shapes were similar. These results suggest that the phenomena which caused the line emissions were stable although the penetration depth for 3 kW was about two times deeper than for 2 kW. For 1 kW laser power, line emissions were caused with assist gas at 40 *l*/min. Possible interpretations are that incident laser power could enter more in the beam hole at 40 *l*/min than for 0 *l*/min or 20 *l*/min, resulting in 0.17 mm deeper penetration depth.

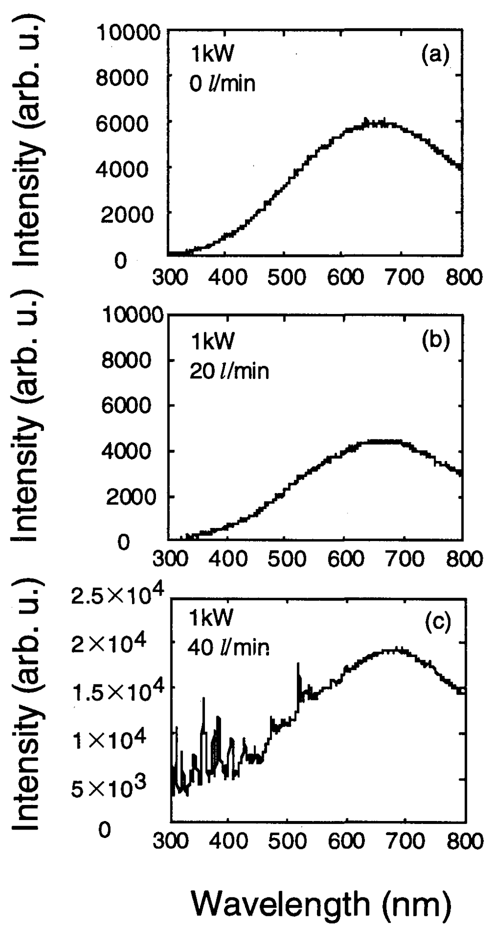

Fig. 4 Plume spectra depended on flow rate of assist gas