The Features of the Blue-IR Hybrid Laser and the Copper Processing Technique

– High Quality Copper Welding by Using the Blue-IR Hybrid Laser –

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ABSTRACT In the laser welding of copper materials, we have developed a Blue-IR hybrid laser that can greatly improve the processing quality compared to the processing with only a near-infrared fiber laser. By combining an efficient heat input to the copper material with the blue laser and a local heat input with the fiber laser, the molten pool can be stabilized, which is difficult with only the fiber laser, and while suppressing the generation of processing defects such as spatters and blowholes, a welding method which can obtain deep penetration has been achieved.

1. INTRODUCTION

Momentum for vehicle electrification, such as increasing the ratio of Electrified Vehicles (xEV) in new vehicle sales worldwide and establishing laws and regulations to accelerate the transition from internal combustion engine vehicles to xEV, is increasing in order to achieve the CO_2 reduction targets set forth in the Sustainable Development Goals (SDGs), and efforts by each original equipment manufacturer (OEM) are accelerating. Along with this, demand for the products that make heavy use of copper materials, such as motors and batteries, which are electromechanical components of xEV, is increasing, and innovation in the manufacturing process is also required. In addition, in consideration of the declining birthrate and aging population especially in developed countries, there is an increasing desire for labor saving and automation in factories. Therefore, Laser processing, which has features such as non-contact, local heating, high speed, high precision and low distortion, is attracting attention as a solution that achieves high production efficiency.

In this respect, expectations for the laser welding of pure copper are increasing, but there were problems with the stability of penetration welding and the welding quality because the absorption ratio of copper near 1000 nm, which is the fundamental wave of fiber lasers, is quite low, and because the heat is difficult to accumulate locally due to its high thermal conductivity. To address these issues, we have developed a Blue-IR hybrid laser that combines a visible light semiconductor laser and a near-infrared fiber laser in order to achieve a high-quality welding of pure copper, and have established a welding technology that reduces spatter generation and provides stable and deep penetration compared to that of the conventional welding using only a fiber laser.

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2. LASER WELDING OF COPPER MATERIALS

2.1 Copper Processing With a Near-Infrared Fiber Laser and Its Problems

Figure 1 shows the wavelength dependence of the absorption ratio of copper. As can be seen from this figure, the absorption ratio of a copper material in the near infrared region is very low at 4 to 5%. Therefore, since

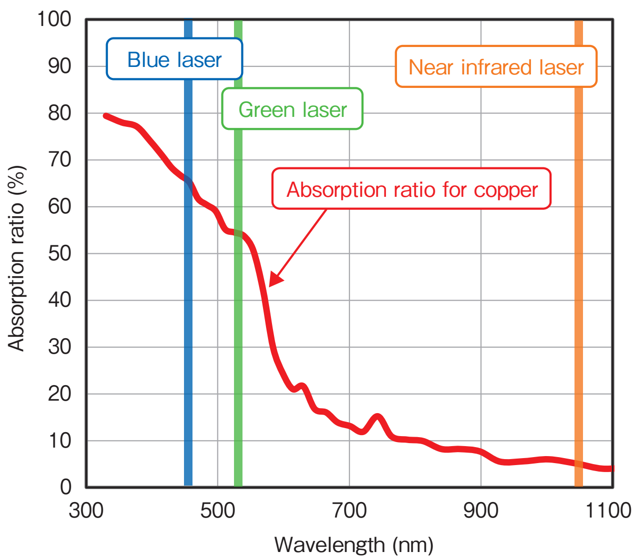

Figure 1 Wavelength dependence of the optical absorption of copper.

most of the irradiated light is reflected, it is necessary to irradiate light with a very high-power density so that a large amount of heat input can be obtained in order to obtain a molten state. On the other hand, once melted, its absorption ratio rises to 10 to 20%[1), 2)], and the light energy used for melting becomes excessive energy and is incident on the processing point. Due to this excessive energy input, the temperature of the molten metal rises sharply, copper evaporates, and the keyhole is induced by the evaporation recoil pressure. At this time, it is thought that spatters are generated because the shape of the keyhole is disturbed by the vapor pressure of the metal vapor.

In addition, since the thermal conductivity of copper is very high at 400 W/mK, the amount of heat input by laser irradiation instantly diffuses to the surroundings. For that reason, the temperature at the processing point repeatedly fluctuates, and as a result, the molten state becomes unstable. Therefore, when a copper material is being processed with only a fiber laser, deep penetration can be obtained, but the bead on the surface is disturbed as shown in Figure 2 (a), and the melting depth are not uniform as shown in Figure 2 (b).

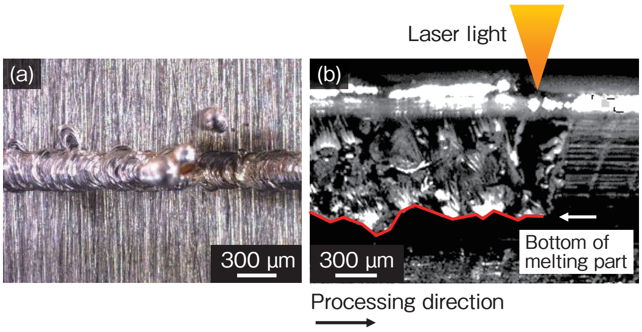

Figure 2 Processing quality of the IR laser welding. (a) surface, (b) cross-section.

2.2 Copper Processing With a Blue Semiconductor Laser

As is clear from Figure 1, the absorption ratio of copper for visible light lasers such as a blue laser is 55 to 60%, which is extremely high compared to an Infra Red (IR) laser. Therefore, more efficient heat input than with an IR laser is expected. However, at present, it is difficult to enter light into a minute fiber core of about several tens of µm like a fiber laser, and as a result, the beam spot expands and the heat conduction type melting mode is used. In order to obtain keyhole-type melting with a visible light laser, the power density of about 2 to 2.3 MW/cm^2 is needed.

In the case of the heat conduction type melting, the heat absorbed on the surface is isotropically conducted, resulting in a wide and shallow penetration, and it is difficult to obtain deep penetration as in the case of processing with a fiber laser. Especially in a material with a high thermal conductivity such as copper, the absorbed thermal energy tends to spread to the entire workpiece, and the problem of the penetration depth becomes more significant. Figure 3 shows a schematic drawing of the thermal conduction type melting and the keyhole type melting in the copper processing. As shown here, in the processing with a visible laser, it is stable but the melting depth is shallow, and in the processing with a fiber laser, the melting depth is deep but defects such as spatters and blow holes are present.

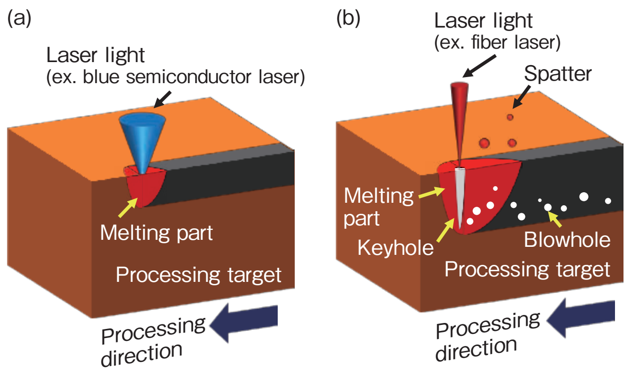

Figure 3 Schematic drawings of the copper welding. (a) thermal conduction type, (b) keyhole type.

2.3 Copper Processing With a Blue-IR Hybrid Laser

We have developed the Blue-IR hybrid laser BRACE, which combines a blue laser and a fiber laser in order to perform high-quality copper welding while obtaining deep penetration (Figure 4). As a blue light source, it is equipped with a direct diode laser module jointly developed with Nichia Corporation. The concept is to form a stable molten pool by an efficient heat input to a wide area with a blue laser, and to achieve deep penetration with a fiber laser that is good at local heat input. This Blue-IR hybrid laser is combined with an optical head or a galvanometer scanner to build a processing optical sys-

Figure 4 Blue-IR hybrid laser, BRACE.

tem, then, actual processing is performed. Figure 5 shows the photographs of the setup of optical system for processing.

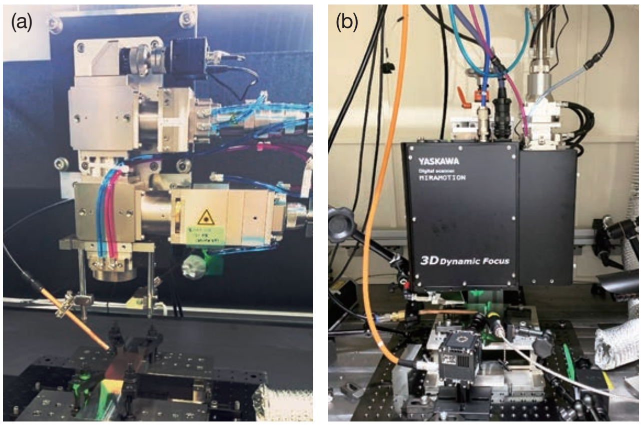

Figure 5 Optical setup for laser welding combination with (a) an optical head (made by Laserx Inc.) and (b) a galvanometer scanner (made by YASKAWA Electric Corporation).

Figure 6 shows the processed surface when a copper bead-on-plate processing is performed with the Blue-IR hybrid laser. As it is clear from the comparison with Figure 2 (a), a very beautiful bead with no turbulence, spatter marks, or blowholes was obtained. Figure 7 is a snapshot of the results of the in-situ observation of the molten metal cross section during processing by applying glass to the end face of the copper plate and processing its vicinity the copper side. As shown in Figure 2 (b), the melting depth was non-uniform when processing with only a fiber laser, but stable penetration was obtained with the Blue-IR hybrid laser, and the bottom depth of the molten pool was almost uniform.

Figure 8 is snapshots of the surface melting state during processing taken with a high-speed camera. It can be seen that in the processing with the Blue-IR hybrid laser, the size of the molten part increased as the melting width increased, compared to the processing with a fiber laser. Looking at the keyhole aperture, the area of the reflected light image from the aperture was large, and the keyhole aperture diameter was widened during the processing with the Blue-IR hybrid laser. It is considered that the widening of the keyhole aperture makes it easier for the thermally evaporated copper vapor to escape, which helps reduce spatters.

Figure 9 shows the processed images of the in-situ observation of the molten metal cross section during laser processing taken with a high-speed camera. From this figure, the shapes of the molten pool during processing with a fiber laser and processing with the Blue-IR hybrid laser can be estimated. As can be seen from Figure 9 (a), in the processing with a fiber laser, the length from the processing front to the rear end was short, and a sharp and deep molten pool was formed. On the other hand, in the processing using the Blue-IR hybrid laser shown in Figure 9 (b), the tail of the molten pool was longer than that formed by the processing with a fiber laser, and the front part of the molten pool was also slightly overhanging to the forward, resulting in the enlargement of the entire molten pool. By expanding the molten pool

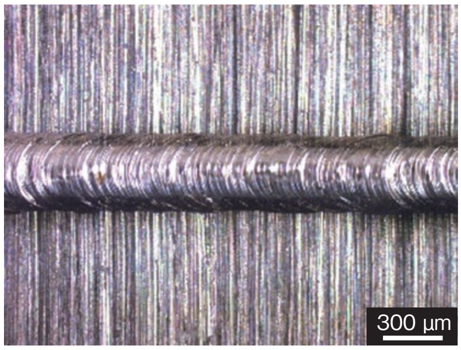

Figure 6 Welding bead on a copper plate processed with the Blue-IR hybrid laser.

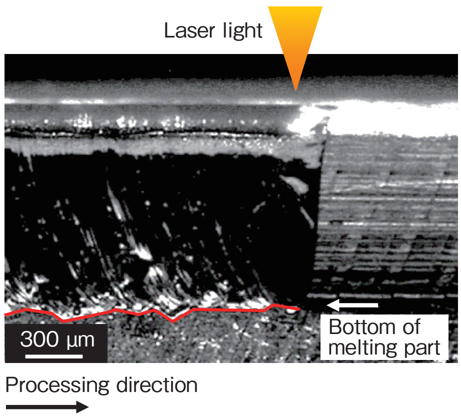

Figure 7 Snapshot of the in-situ observation of the welding cross section processed with the Blue-IR hybrid laser.

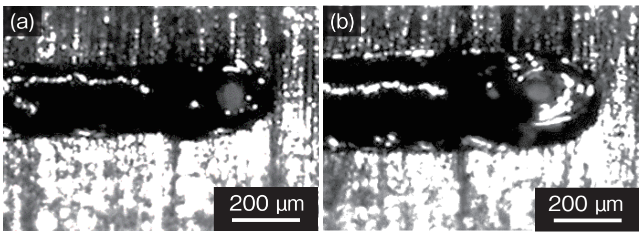

**Figure 8 Snapshot of the in-situ weld surface observation with a high-speed camera.
(a) fiber laser, (b) Blue-IR hybrid laser.**

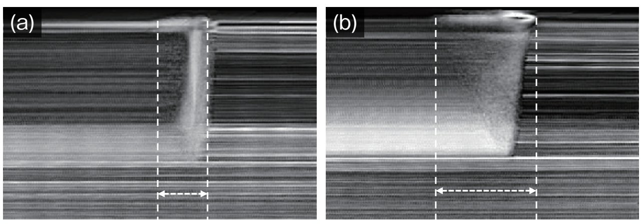

**Figure 9 Cross-sectional shape of the molten pool.
(a) fiber laser, (b) Blue-IR hybrid laser.**

in this way, the turbulence of the molten metal flow caused by the evaporation recoil pressure generated on the inner wall of the keyhole can be relaxed, which leads to the stable behavior of the molten metal and the improvement in the uniformity of the melting depth.

As described above, the effect of the coaxially irradiated blue laser expands the molten pool and stabilizes the internal heat convection, and the expansion of the keyhole aperture allows the metal vapor to be discharged well to the outside of the keyhole, and the vapor pressure inside the keyhole can be reduced. Therefore, the generation of spatters can be suppressed and a stable molten pool can be obtained in the processing with the Blue-IR hybrid laser, resulting in a high-quality processing.

Figure 10 shows photographs that visualizes the trajectories of the spatters generated when a bead on plate processing with a length of 44 mm was performed on an oxygen-free copper plate with a thickness of 2 mm using a fiber laser and the Blue-IR hybrid laser. The processing conditions were a fiber laser output of 1 kW, a blue laser output of 150 W, and a processing speed of 200 mm/s. As it is clear from the comparison between Figure 10 (a) and Figure 10 (b), the generation of spatters was significantly reduced in the processing with the Blue/IR hybrid laser, which was one of several compared to the processing with a fiber laser.

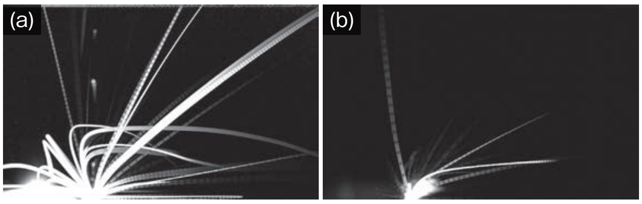

Figure 10 Trajectories of the spatters generated in copper welding. (a) fiber laser, (b)Blue-IR hybrid laser.

3. CONCLUSION

This paper briefly explains laser welding of copper materials, and reports that the Blue-IR hybrid laser stabilizes the molten pool, suppresses welding defects such as spatters that occur during processing with a near-infrared fiber laser, and provides a deep welding depth.

In the future, we will deepen our understanding of the melt-solidification phenomenon in laser processing and promote its elucidation, and also develop welding technologies for various components such as batteries and motors to provide optimal processing solutions based on physical explanations of the phenomenon to our customers.

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