5-kW Single-mode Fiber Laser

Yuya Takubo,[1] *Shinya* Ikoma,[1] *Keisuke* Uchiyama,[1]
Masahiro Kashiwagi,[1] and *Kensuke* Shima[2]

Single-mode fiber lasers, which have high output power and good beam quality, are demanded in various fields of materials processing. In this report, a 5-kW single-mode fiber laser is demonstrated. Stimulated Raman scattering (SRS), which is a major problem in high power fiber lasers, is well-suppressed in the fabricated laser even with the 20-m-long delivery fiber. Such long delivery fiber is suitable for practical processing fields. In addition, the processing experiment of a pure copper with the laser is carried out. The high processing quality and the tolerance to the back reflection light are confirmed.

1. Introduction

Fiber lasers are expanding their market penetration due to their advantages such as high beam quality, high energy conversion efficiency, and small footprint. In particular, high power single-mode fiber lasers have received a lot of attention by their extremely high beam quality. They can be applied to high speed remote processing using a galvanometer scanner, fine processing, and processing of materials with high electrical and thermal conductivity, such as aluminum and copper.

Although a single-mode fiber laser can realize various materials processing, it is not easy to increase its output power. The main challenge of a high power single-mode fiber laser is how to suppress stimulated Raman scattering (SRS), which is one of nonlinear optical phenomena. As SRS is triggered by the laser light in a fiber and the laser light energy converts to Stokes light of SRS, the destabilization of output power is caused by SRS. In addition, laser diode modules for pumping a fiber laser may be broken by back-reflected Stokes light from a material under processing. Therefore, a single-mode fiber laser is difficult to be applied to the processing of highly reflective materials, such as aluminum and copper. Furthermore, since SRS is more likely to occur when the propagation length of the laser light in a fiber becomes longer, the delivery fiber length is limited in a high power single-mode fiber laser. Since a delivery fiber of more than 20 m is demanded in practical manufacturing scene, a fiber laser with a high tolerance to SRS is required.

We have developed SRS-suppressed high power single-mode fiber lasers. We have successfully demonstrated the processing of pure copper with a 3-kW single-mode fiber laser with 20-m-long delivery fiber [1]. We have also carried out a high speed remote processing using a galvanometer scanner and our single-mode fiber laser [2].

In this report, we demonstrate the 5-kW single-mode fiber laser. The Stokes light of SRS is suppressed to 45 dB below the laser output power, even with the delivery fiber of 20 m. We also report the processing results of pure copper using our 5-kW single-mode fiber laser and a galvanometer scanner.

2. Characteristics of 5-kW single-mode fiber laser.

Figure 1 shows the schematic diagram of our 5-kW single-mode fiber laser. The laser is a single-stage Fabry-Perot system consists of pump laser diode modules, pump combiners, fiber Bragg gratings (FBGs), an ytterbium-doped fiber, and an endcapped delivery fiber. The pump lights are combined by pump combiners and input to the laser cavity. The laser cavity consists of a high reflection FBG (HR-FBG), an ytterbium-doped fiber, and an output coupler FBG (OC-FBG). The laser light propagates through the 20-m-long delivery fiber and is emitted from the end cap.

Figure 2 shows the plots of the output power versus launched pump power and the beam profile at the focus position. We have achieved 5 kW output power

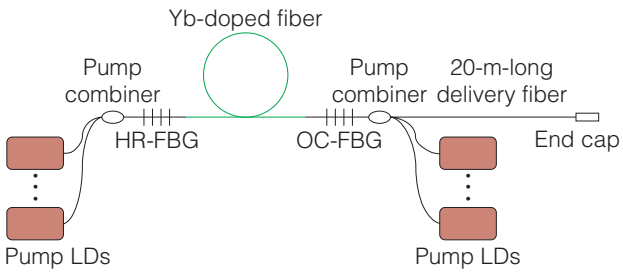

Fig. 1. Schematic diagram of the 5 kW single-mode fiber laser.

1 Laser and Photonics Research Department of Advanced Technology Laboratory
2 Fiber Laser Research Department of Advanced Technology Laboratory

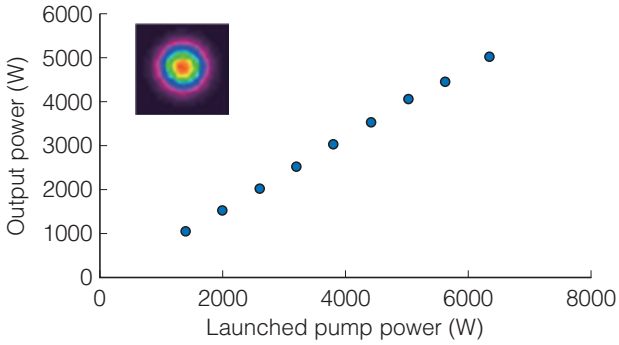

Fig. 2. Output power of the 5 kW single-mode fiber laser and the field pattern at the focal point.

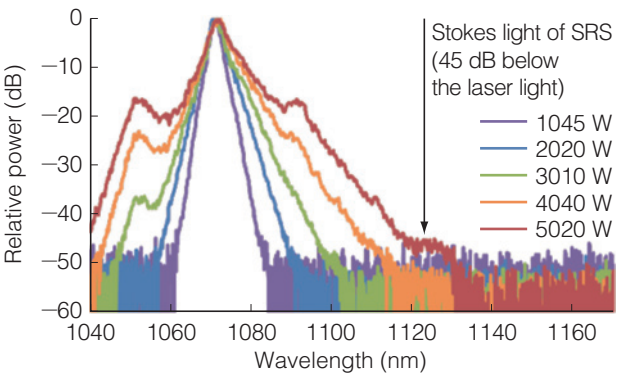

Fig. 3. Output spectra of the 5 kW single-mode fiber laser.

at the pump power of 6.3 kW; the slope efficiency was 80%. The laser has a Gaussian beam profile and the M-squared factor is 1.3.

Figure 3 shows the output spectra of the single-mode fiber laser. The oscillation wavelength is 1070 nm. The Stokes light of SRS is suppressed less than 45 dB from the output power. Even with the 20-m-long delivery fiber, the Stokes light is well suppressed. On the other hand, the side peaks are observed beside the oscillation wavelength. We assume that it is triggered by another nonlinear optical phenomenon, four-wave mixing. As the phase matching condition needs to be achieved for four-wave mixing, it is less likely to occur in back-reflected light from the processed samples. Therefore, four-wave mixing in a high power single-mode fiber laser is thought to be less harmful than SRS.

3. Application to materials processing

In order to evaluate the performance of the 5-kW single-mode fiber laser, we carried out the bead-on-plate processing tests using a galvanometer scanner. Figure 4 shows the experimental setup. The laser light is focused on the surface of the copper plate. The scanning area of the galvanometer scanner is 150 mm x 150 mm and the working distance is about 300 mm. The beam diameter at the focusing point is 38 μm.

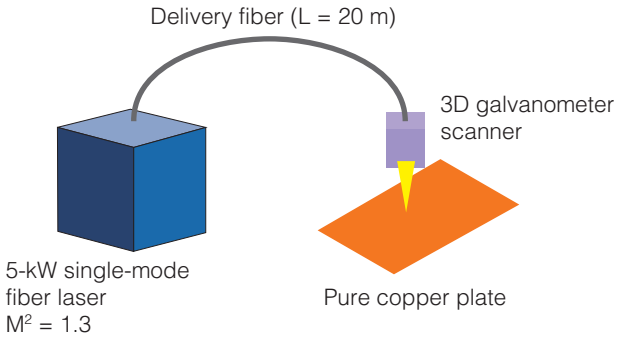

Fig. 4. Schematic configuration of processing test setup.

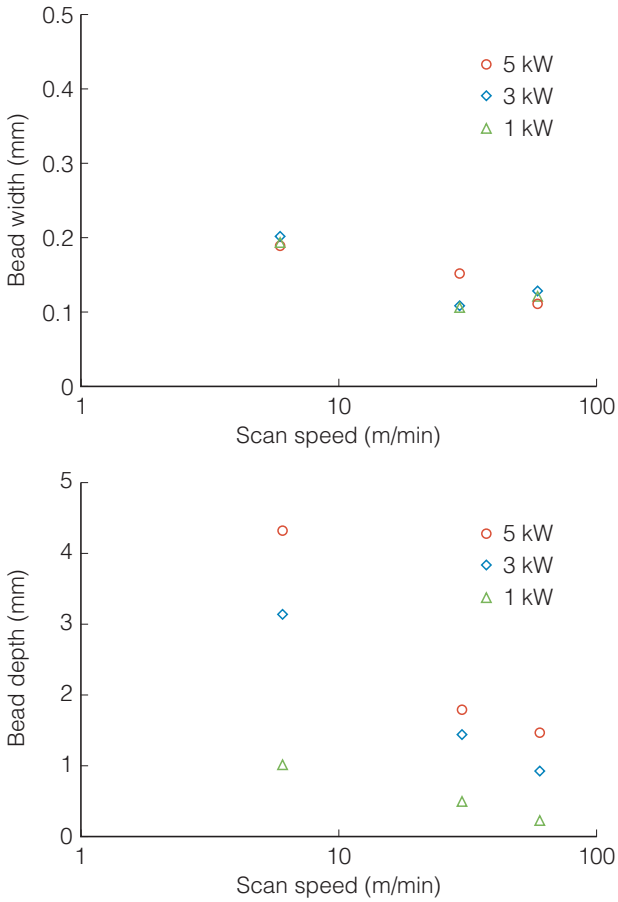

Fig. 5. Test results of bead-on-plate using 5 kW single-mode fiber laser. (a) Scan speed dependence of bead width. (b) Scan speed dependence of bead depth.

Figure 5 shows the plot of the bead width and the bead depth versus the scanning speed of the galvanometer scanner at the output power of 1 kW, 3 kW, and 5 kW. The change of the bead width is not observed in response to the change of the output power, whereas the bead depth becomes deeper when the output power becomes higher. The bead depth is 4.32 mm at the output power of 5 kW and the scanning speed of 6 m/min. The aspect ratio, which is the bead depth divided by the bead width, is approximately 22 at the same condition.

Fig. 6. Cross-section of processed copper plate by 5-kW fiber lasers. (a) By 5-kW single-mode fiber laser. (b) By 5-kW multimode fiber laser.

Figure 6 shows the cross-sectional images of the copper plates processed by the single-mode fiber laser and the mult-mode fiber laser at the output power of 5 kW and the scanning speed of 6 m/min. The aspect ratio of the copper processed by the multimode fiber laser is about 6.3. The processing by the single-mode fiber laser can achieve much higher aspect ratio.

The destabilization of the output power did not occur during the processing test, and the laser was not broken by the back-reflected Stokes light of SRS. The great tolerance of the 5-kW single-mode fiber laser to the back-reflection was confirmed through the processing tests of the pure copper plates.

4. Conclusion

We developed the 5-kW single-mode fiber laser with the M-squared factor of 1.3. In the developed laser, the Stokes light of SRS is well-suppressed less than 45 dB below the laser light power, even with a 20-m-long delivery fiber.

The bead-on-plate processing test of the pure copper was carried out using the developed fiber laser and the galvanometer scanner. The aspect ratio of the processed copper was about 22 at the output power of 5 kW and the scanning speed of 6 m/min. The 5-kW single-mode fiber with 20-m-long delivery fiber will bring a lot of benefits to the materials processing field. We will proceed further with the development of high power single-mode fiber lasers with the long delivery fiber.

Reference

1). S. Ikoma, H. K. Nguyen, M. Kashiwagi, K. Uchiyama, K. Shima, and D. Tanaka, “3 kW single stage all-fiber Yb-doped single-mode fiber laser for highly reflective and highly thermal conductive materials processing”, Proc. SPIE 100830, 10083Y, 2017.

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