High-Efficiency Linearly Polarized Fiber Laser

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Recently, high-power visible light sources by frequency doubling have attracted great interest in display and medical applications. In order to realize these light sources, linearly polarized light sources that have high output power, high energy-conversion efficiency, narrow spectral width and high polarization extinction ratio are required. We have studied a linearly polarized fiber laser for frequency doubling. We evaluated the characteristics of the prototype and confirmed that it was suitable for frequency doubling.

1. Introduction

High-power visible laser sources in the color range between green and orange have attracted great interest in display and medical applications. High-power laser emission in this color range is typically generated with bulky dye lasers or gas lasers. But, the size of these lasers is impractically large for the applications mentioned above. Also, it is difficult to generate the visible wavelength directly from a solid-state gain medium.

One of the promising ways to realize the visible laser in green to orange range (wavelength of 500-600 nm) is frequency doubling of near-infrared lasers that emit light of 1000-1200 nm wavelength[1)]. In frequency doubling, an input light of 1000-1200 nm (fundamental light) wavelength is converted into a visible light of 500-600 nm wavelength by second harmonic generation in a crystal such as periodically poled lithium niobate (PPLN). The main challenge in popularizing frequency-doubled lasers is the improvement of the energy efficiency of the entire light source system that is supported by the efficiency increase of both the frequency doubling and fundamental light emission. In order to achieve high-efficiency second harmonic generation, the fundamental light is required to have high power, high spatial coherency and high temporal coherency. Linear polarization is also required because the crystals for frequency doubling are anisotropic.

A near-infrared wavelength radiation is typically generated with YAG lasers or fiber lasers. Fiber lasers are believed to be suitable for frequency doubling because they have high spatial coherency, high output power and high energy-conversion efficiency. Also, they are compact, maintenance-free, optical-alignment-free and have high heat dissipation efficiency.

An ytterbium-doped fiber laser is an attractive candidate for such a near-infrared laser because it can emit laser light in 1000 and 1100 nm wavelength region at a high energy-conversion efficiency. One advantage of ytterbium-doped fiber lasers is the fact that high power and reliable pump lasers are widely available. Therefore, it is easy to obtain a high output power. Accordingly, high-power ytterbium-doped fiber lasers have been actively investigated and used in material processing applications[2)]. We have also developed the 10-W pulse fiber laser[3)] and the 100-W CW fiber laser[4)] for these applications.

Also, we have investigated the ytterbium-doped fiber laser at 1000-1200 nm for frequency doubling. For example, an ytterbium-doped polarization maintaining solid photonic bandgap fiber for yellow–orange lasers by frequency doubling has been already proposed[5)].

In this paper, we focused on the efficiency of a linearly polarized ytterbium-doped fiber laser as a fundamental light source for frequency doubling.

2. Optical circuit configuration

Figure 1 shows the schematic diagram of the linearly polarized fiber laser. The laser consisted of a gain fiber, an end-pumped combiner, two pump sources and a pair of fiber Bragg gratings. A double clad polarization maintaining ytterbium-doped fiber (DC-PM-YbDF) was employed as a gain fiber. The laser cavity was formed by a pair of fiber Bragg gratings

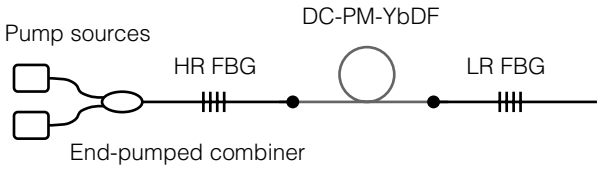

Fig. 1. Configuration of linearly polarized fiber laser.

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Panel 1. Abbreviations, Acronyms, and Terms.

PPLN—Periodically Poled Lithium Niobate
YAG—Yttrium Aluminum Garnet
DC-PM-YbDF—Double Clad Polarization Maintaining Ytterbium-Doped Fiber
FBG—Fiber Bragg Grating
PANDA—Polarization Maintaining and Absorption Reducing

(FBG). One of them was used as a high reflector (HR FBG) and the other was used as an output coupler (LR FBG).

The pump light from the end-pumped combiner was launched into the inner cladding of the DC-PM-YbDF via the HR FBG. And the pump light propagated in the inner cladding and was absorbed in the active core over the entire fiber length. The unabsorbed pump light was dumped at the end of the DC-PM-YbDF. Once ytterbium ions in the fiber were excited by the pump light, spontaneous emission light was generated in the core. This light was increased in intensity as it went back and forth between the HR FBG and the LR FBG, and the laser oscillation finally occurred. The laser light was extracted from the laser cavity through the LR FBG.

In order to form the laser cavity, the reflection band of the HR FBG and the LR FBG must overlap. We used a narrow-band LR FBG to realize a narrow linewidth fiber laser. The laser oscillation wavelength depends on the reflection wavelength of the LR FBG.

The fibers were single modal at the laser oscillation wavelength. Therefore, the laser operates on a single mode. The fibers had also the same refractive index profile to achieve low splice losses. Figure 2 shows the cross-sectional schematics of the fibers. Unlike the conventional PANDA fiber, the distance between the two stress applying parts was short to create the large polarization dependence of bending loss. Thus, only the light in the low bending loss polarization undergoes significant gain. The laser oscillation occurs only in the low bending loss polarization. Thus, by only coiling fibers, single-polarization laser oscillation is realized. No additional optical component such as a polarizer is needed.

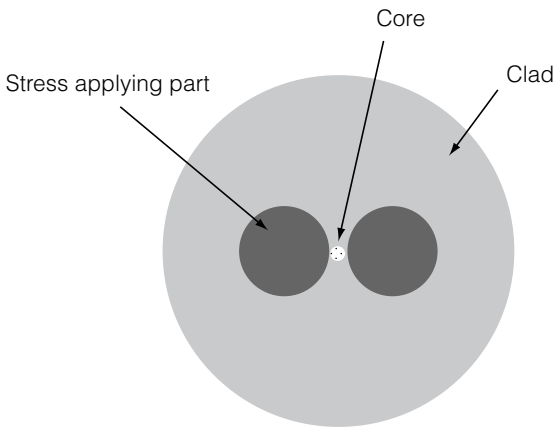

Fig. 2. Schematic diagram of cross section of fiber.

We made a prototype of the linearly polarized fiber laser with the above-mentioned configuration. Fiber length of DC-PM-YbDF and reflectivity of FBGs were designed optimally.

3. Optical performance and characteristics

Figure 3 shows the relationship between pump power and output power. The pump wavelength was 915 nm. The laser output increased linearly with the launched pump power and showed no evidence of roll-over even at the highest output power, which was limited only by available pump. The laser gave an output of 12.8 W for a launched pump power of 19.6 W. We expect to achieve a higher output power on increasing the pump power. Figure 4 shows the relationship between pump power and conversion efficiency. The conversion efficiency was increased with launched pump power and reached 65.1% at the pump power of 19.6 W. The wall-plug efficiency of laser was approxi-

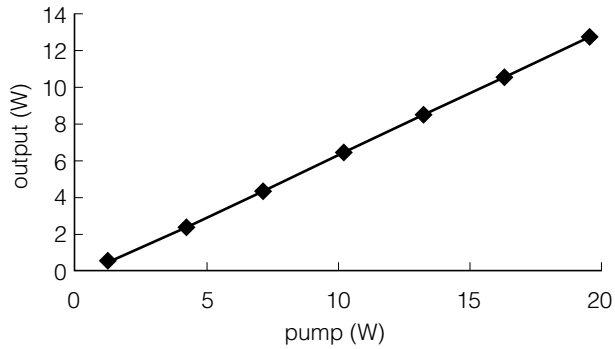

Fig. 3. Relationship between pump power and output power.

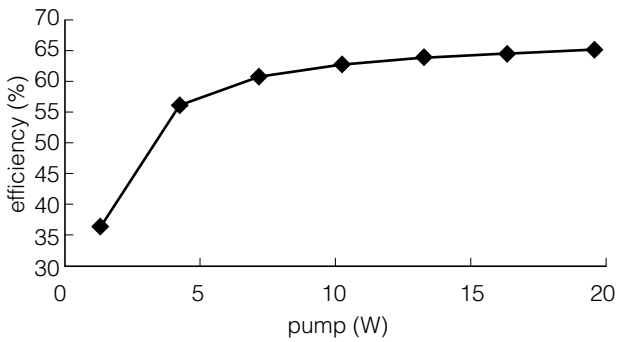

Fig. 4. Relationship between pump power and conversion efficiency.

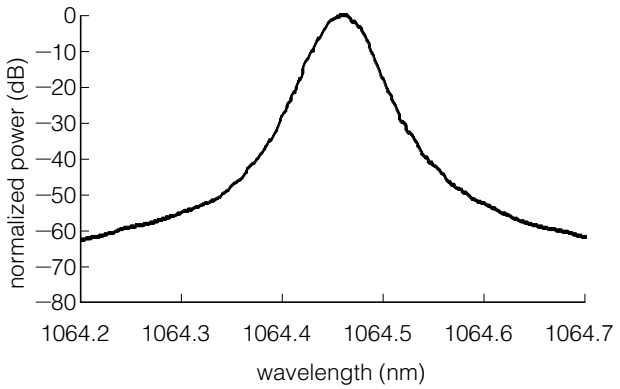

Fig.5. Measured spectrum of output light.

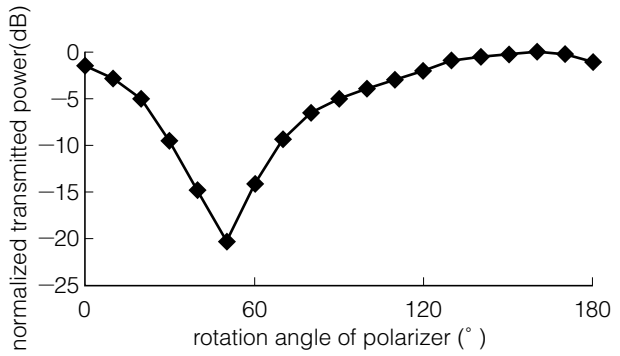

Fig.6. Relationship between the angle of polarizer and normalized transmitted power.

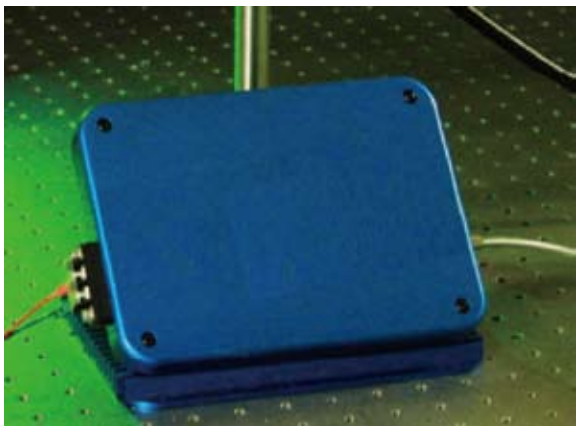

Fig.7. Overview of prototype.

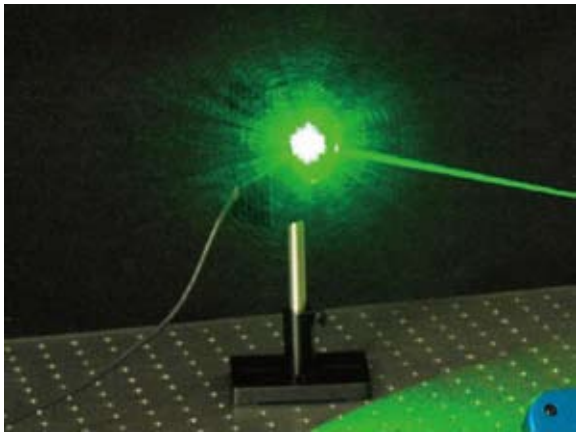

Fig.8. Green light generation.

mately 31 %.

Figure 5 shows the measured output spectrum for the pump power of 19.6 W. The laser wavelength was 1064.46 nm. The spectral width was 0.03 nm. In general, the spectral width less than 0.1 nm of the incident light is desirable for efficient frequency doubling. The spectral width of our laser was narrow enough to frequency double efficiently.

We measured the polarization extinction ratio of the output light. Figure 6 shows the relationship between the angle of a polarizer and the transmitted power. The polarization extinction ratio of the output light was about 20 dB. For efficient frequency doubling, the high polarization extinction ratio of the incident light is desirable because frequency doubling is most efficient in a single linear polarization and the orthogonal polarization power is lost and unavailable. In our laser, the other polarization power was less than 1% of the total output power. The decrease in the efficiency is negligible.

Figure 7 shows the prototype of the linearly polarized fiber laser. This fiber laser contained all optical devices shown in Fig. 1. The dimensions were L 200 mm × D 150 mm × H 30 mm. We can reduce the size of this laser. Figure 8 shows the generation of green light using this laser and a frequency-doubling device. In the experiment, 2 W of green light was generated at 10 W of output power of the fundamental light.

4. Conclusion

We have studied the high-efficiency linearly polarized fiber lasers. In the prototype, the output power was 12.8 W, the wall-plug efficiency was 31%, the spectral width 0.03 nm and the polarization extinction ratio 20 dB. It was suitable for frequency doubling. Also, we could successfully generate a green laser beam using the manufactured fiber laser.

References

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