High-power pulsed fiber lasers and their evolution

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Fujikura has achieved an output power of 30 W from a Q-switched pulsed fiber laser with a pulse width about 100 ns for the first time in the world. Following the achievement, we commercialized a 70 W output pulsed fiber laser . In the article, we describe our activities on high-power pulsed fiber lasers, and introduce our 70 W output products. Fujikura's advanced and original functions of pulsed fiber lasers for more precise and complicated material processing are also described.

1. Introduction

In comparison with high-power pulsed Neodymium-doped yttrium-aluminum-garnet (Nd:YAG) lasers, high-power pulsed fiber lasers (i) provide a higher quality beam that is easily constricted, (ii) are smaller, lighter and air-cooled, and (iii) need no maintenance. With these advantages, lasers of this type have contributed to fine and higher-speed processing with laser markers, along with size reduction and facilitation of maintenance. High-power pulsed fiber lasers have already attained the mainstream position in laser marking.

Fujikura started the development of Q-switched-operation pulsed fiber lasers early, and became the first in the world to attain an average power of 30 W from a fiber laser with 100 ns-wide pulses[1)]. Subsequent efforts for increasing average output resulted in commercialization of the world's highest power of 70 W from commercially available fiber lasers.

The following article gives a historical overview of Fujikura's development of high-power pulsed fiber lasers and describes several unique characteristics intended for processing applications with higher precision or in more complicated situations.

2. Power enhancement of pulsed fiber lasers

Fujikura's pulsed fiber lasers started with 30-W models and proceeded to 50- and then 70-W products. Figure 1 shows the appearance of the 70-W air-cooled pulsed fiber laser, and Table 1 shows its typical specification[2)].

This product is based on the master oscillator-power amplifier (MOPA) configuration in which the laser light is produced by a master oscillator (MO) and then amplified by a power amplifier (PA) consisting of a pre-amplifier and a main amplifier. The MO generates a pulsed light with a pulse width of about 100 ns and a pulse repetition frequency of 60-120 kHz, which is then amplified by the high-gain amplifier to give a beam with a high output power while maintaining a high level of beam quality.

Several components such as a pump combiner, a fiber Bragg grating (FBG), high-power laser diode (LD) modules for pumping, and an optical isolator are in-house products. The high-quality garnet crystal used in the isolator was also self-developed. Thus, Fujikura's own technologies related to optical fibers and optical components assured the high reliability and low cost of the pulsed fiber lasers.

In an earlier stage of the development aiming at a power of 30 W, major problems were (i) photo-darkening of Yb-doped core fiber, (ii) low resistance to light reflected by a work to be processed, and (iii) deterioration of optical characteristics due to the nonlinear optical effects. These were solved, respectively, by (1) development of photo-darkening suppression technology[3), 4)], (2) development of a Raman shifter[3), 5)] and a pump combiner[3), 6)] with a structure of our own, and (3) optimization of structural parameters of the fiber system for power amplification. However, (ii) the resistance to reflected light and (iii) influences of the

Table 1. Typical specifications of 70 W output air-cooled pulsed fiber laser product.

Item	Typical specification
Center wavelength	1085 nm
Rated power	70 W max.
Beam quality M^2	2.0 max.
Pulse repetition frequency	50 - 100 kHz
Pulse width	100 - 200 ns
Pulse energy	1 mJ max.
Peak power	5-10 kW
Interface	Analogue/Digital, RS-232
Dimension	W310 × H181 × D416mm
Mass	15 kg

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Panel 1. Abbreviations, Acronyms, and Terms.

M^2—Em squared (Beam quality)
Nd:YAG—Neodimium-doped Yttrium Aluminum Garnet
MOPA—Master Oscillator-Power Amplifier
MO—Master Oscillator
PA—Power Amplifier
LD—Laser Diode
ASE—Amplified Spontaneous Emission
FBG—Fiber Bragg Grating
PANDA—Polarization-maintaining AND Absorption reducing

nonlinear optical effects remained problematic in further increase of output power. The measures taken for power increase to 70 W are described below.

Light reflected from a work may, if returning into the fiber laser, be amplified in the power amplifier and damage the optical components. Particularly, self-oscillation of the PA, triggered by the reflected light, will generate light pulses with high peak power and can cause serious damage of the combiner and pumping LDs. Optical amplifiers with high gains, and therefore MOPA fiber lasers with higher power, are more susceptible to this effect. The amplified spontaneous emission (ASE) components in the reflected light may also cause self-oscillation of the PA.

An optical isolator is a common measure to prevent reflected light from entering the PA, but a normal polarization-independent isolator is not sufficient because ASE light has a broad wavelength spectrum. Therefore, an original filter to screen the ASE light was added to the 70 W pulsed laser. The PA consists of a pre-amplifier and main amplifier to enhance the output power. The resistance to reflected light was improved by suppressing self-oscillation of the PA induced by the reflected light through modified design of the Yb-doped optical fiber used in the two amplifiers, thus optimizing their respective gains.

Fig. 1. Appearance of 70 W output air-cooled pulsed fiber laser product.

The nonlinear optical effects in optical fibers always present problems against power increase of lasers, because they become more significant for the temporal and spatial power density of light travelling in a fiber. The effects can be mitigated by extending the pulse duration to lower the temporal power density. Instead of simple extension of the resonator length, which leads to rippled temporal waveform due to the superposition of pulse components after different numbers of circulation in the resonator, a multiplex resonator system is used for adjusting the resonator length to increase the pulse duration.

The configuration of the master oscillator is schematically shown in Fig. 2. The multiplex resonator consists of a Fabry-Perrot resonator with two resonator mirrors and a ring resonator therein. The ring resonator is constructed with a optical coupler. The branching ratio of the coupler and the length of the ring resonator influence the characteristics of the master oscillator. Conseguently, these parameters were optimized with the temporal waveform and controllability of the pulsed light generated by the master oscillator.

3. Development toward high-precision and complicated processing

In addition to its traditional laser marking applications, Fujikura approaches the market of material pro-

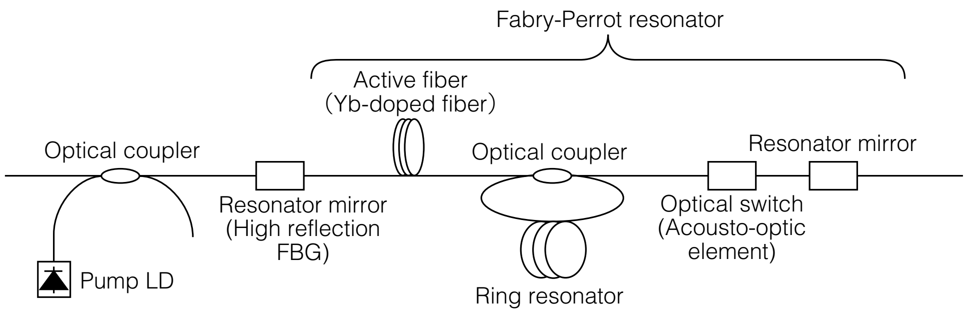

Fig. 2. Schematic configuration of master oscillator.

cessing with higher precision and complexity. Based on our optical fiber and component technologies, we have developed pulsed fiber lasers with distinctive features. Specifically, linear polarization of the laser light and high-speed pulse picking are described below along with the features of the pulsed fiber lasers with these functions.

3.1 Linear polarization of laser light

Polarization is one of the factors that characterize the laser light. In polarized light, the electric (and magnetic) field vibrates in a particular plane only. Polarization of light may have marked effects on its interaction with a substance. Thus, efficiency and product quality in laser processing of materials depend upon the polarization state of the light. In cutting of a crystal, for example, the cutting velocity and the quality of cut surface are affected by the polarization direction of the laser light with respect to the crystal orientation. Controlling the polarization of the laser light is therefore a prerequisite for stable and high-precision processing.

The processing efficiency depends also on the wavelength of the laser light because of the wavelength dependency of the light absorption of the material. For example, some processing-resistance materials, such as high-strength glass, silicon, and other semiconductors, or copper, show higher processing efficiency for UV and visible light. For cutting, drilling, or patterning of these materials, therefore, a wavelength converter (nonlinear optical crystal) is used. The shorter wavelengths also contribute to the working precision through finer conversion of the beam. Since the efficiency of wavelength conversion is highly dependent on the polarization direction of the incident light, the laser used with a wavelength converter must oscillate a single liniarly-polariged light.

The configuration of the new single-polarization pulsed fiber laser is schematically shown in Fig. 3. The linearly polarized laser light is obtained by a fiber polarizer based on the PANDA (Polarization maintaining AND Absorption reducing) type polarization-maintaining optical fiber. The polarizer is provided before the main amplifier, and the polarized light is amplified in the power amplifier. To maintain the polarization in the PA, the PANDA-type fiber is used for the Yb-doped active fiber and in the pump combiner.

3.2 High-speed pulse picking

Pulse lasers are used not only to make simple dots or lines on the material surface, but also for more complicated processing. Pulse picking (on-off switching of individual pulses in the pulsed laser light of a frequency of several ten to several hundred kHz) and control of pulse output power are useful functions for such applications. Although the power of a fiber laser can be controlled through the intensity of the pump light, this does not guarantee stable processing, because of the time delay until the pulse intensity, as shown in Fig. 4, is stabilized. This problem is overcome by picking of individual pulses by an external high-speed light switch such as an acousto-optic element using tellurium dioxide medium. The pulsed light from a fiber laser is combined with the acousto-optic element through a lens and, after switching, re-combined with a fiber through a lens. The intensity of the signal light can also be modulated by varying the diffraction efficiency of the laser light through varying the power of the high-frequency signal applied to the acousto-optic element.

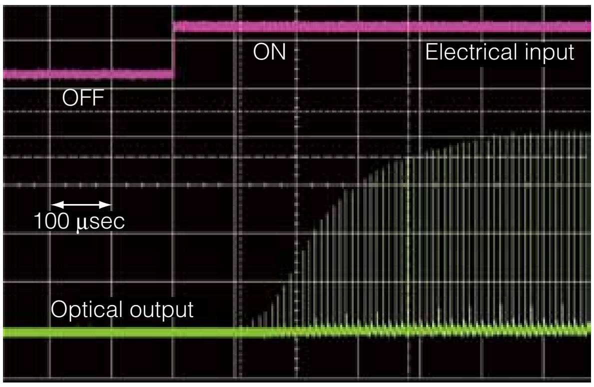

Fig. 4. Change of output signal at On-Off switching.

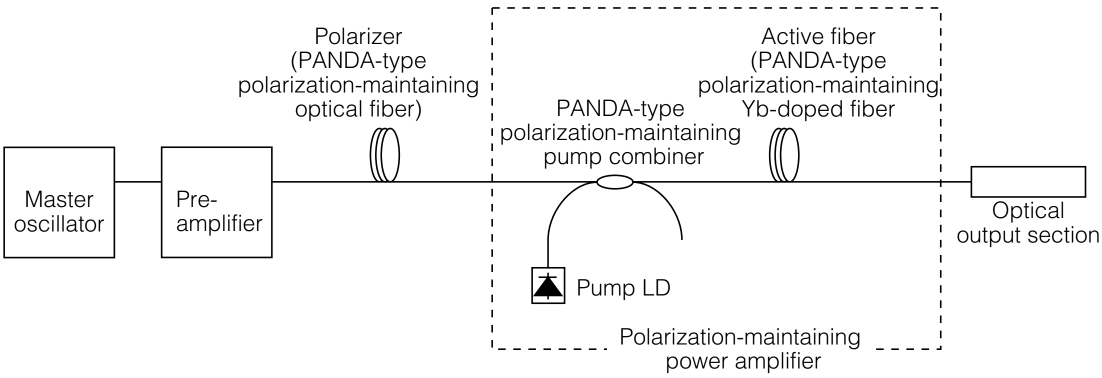

Fig. 3. Schematic configuration of linearly polarized pulsed fiber laser.

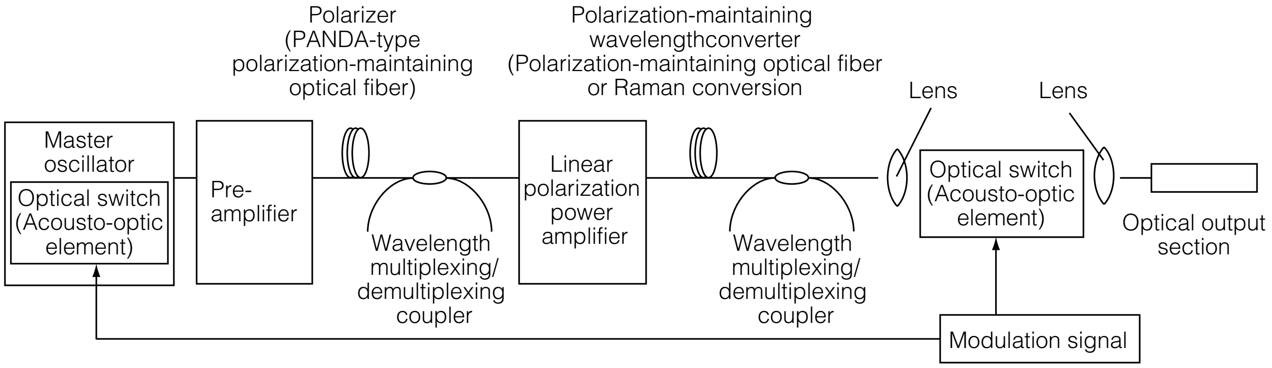

Fig. 5. Schematic configuration of linearly polarized pulsed fiber laser with high-speed pulse picker.

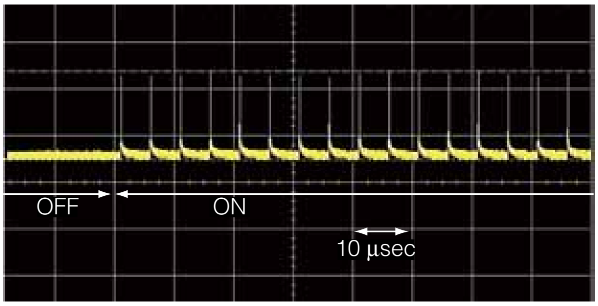

Fig. 6. Change of output signal at On-Off switching.

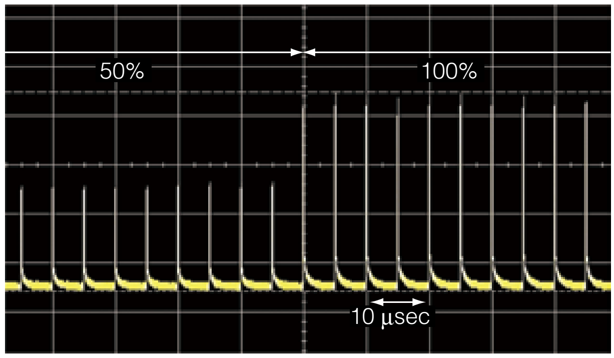

Fig. 7. Change of output signal during intensity modulation from 50% to 100% output.

3.3 Configuration and features

The newly developed linearly polarized pulse fiber laser has a polarization-maintaining wavelength converter with a structure similar to that of the Raman shifter[3] after the linear polarization power amplifier. The converter decreases the wave frequency by producing Stokes light due to the stimulated Raman scattering, one of the nonlinear optical effects, in the fiber. A wavelength multiplexing/demultiplexing coupler after the converter acts as an optical isolator to prevent reflected light from re-entering the optical circuit. The configuration of this fiber laser is schematically shown in Fig. 5.

The fiber laser achieved an average output power of 7 W and a polarization extinction ratio of 25 dB or more. Figures 6 and 7 show oscilloscope images of the pulse series from the laser as converted to electric signals by a photoelectric converter. For a pulse repetition frequency of 200 kHz, on-off switching in less than 10 μs was achieved as shown in Fig. 6. Similarly, intensity modulation (50% to 100% output power) with an interval less than 10 μs was possible as shown in Fig. 7. The switching and modulation were readily controlled through the signal fed to the acousto-optic element, and individual pulses were able to be picked. Synchronous pulse picking on plural numbers of fiber lasers is also possible through the input signal terminal for control of the pulse picking by an external signal. Functions described above are expected to extend the applications of the linearly polarized pulsed fiber laser to complicated material processing with high precision.

4. Conclusion

This article describes development efforts for high-power pulsed fiber lasers for laser marking and reports linear polarization and high-speed pulse picking technology for complicated processing applications with high precision. Fujikura will continue the development of pulsed fiber lasers with novel functions on the basis of our optical fiber and component technologies.

Reference

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