Development of Nano Second Pulsed Lasers Using Polarization Maintaining Fibers

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ABSTRACT Pulsed lasers are increasing in their utilization in the laser marking and in the laser micro material processing because it allow us to control input optical pulse energy into the materials. Pulsed fiber lasers have some advantages such as stability, reliability and high brightness over CO_2 lasers or YAG lasers, so that the latters are being rapidly replaced with the pulsed fiber lasers. To improve the processing throughput and to expand the applicable processing materials, it is necessary to increase the output power and to have some properties such as the linear polarized output or the tunability of the pulse width and the repetition rate.

We have developed two types of polarization maintaining pulsed fiber lasers which have a configuration of master oscillator power amplifier (MOPA). One is using the external modulated seed light source for a high power output. The other is using a direct modulated laser diode for a short pulse generation. The seed pulse light is amplified by a polarization maintaining YDF amplifier. We have realized more than 70 W and 13 W output power of 100 ns and 10 ns pulse at 1064 nm, 1 MHz.

1. INTRODUCTION

Recently, the output power of the fiber lasers are becoming higher[1)-3)] so that they are replacing CO_2 lasers or YAG lasers, which have been dominant so far, in the laser material processing such as welding and cutting of metals, marking and scribing on semiconductors or ceramics. Most of these laser material processings harness melting, or changing and converting of substances by heat generated when the light is absorbed into materials. For ceramics, semiconductors, silicon and, especially, resins or composite materials such as plastics, the materials are easily damaged around the processing area due to the heat effect, and therefore the quality of processing deteriorates. It is necessary to control the injected optical energy precisely to improve the quality of the laser material processing, so a pulsed laser which can temporally control the optical energy is used[4), 5)].

A Q-switched pulsed fiber laser can generate several tens of watts at several tens to several hundreds of kHz. The Q-switched pulsed fiber laser is widely used for marking because of its advantages in small size, in simplicity and in maintenance-free.

For marking on metals such as titanium or stainless-steel, the surface of the metals can be colored by controlling processing conditions such as the pulse duration and the pulse energy with a high precision. Therefore processing applications using a pulsed laser, such as printing and decorating on cell-phones or cameras, are expanding.

For pulsed fiber laser, it is difficult to increase the power and the optical pulse energy because of the non-linear effect in the fiber and the input power limitation of the components.

It is necessary to increase average power and to have higher repetition rate in order to enhance the processing throughput and to expand the processing condition. The linear polarized output allows using nonlinear crystal for wavelength conversion.

In this paper, we demonstrate two types of polarization maintaining pulsed fiber lasers which have a configuration of MOPA (Master Oscillator Power Amplifier) as shown in Figure 1. One is using external modulation to obtain a higher average power. The other is using direct modulated laser diode to generate a short pulse less than 100 ns.

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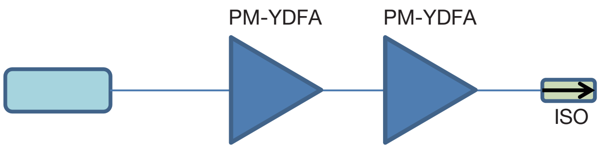

Figure 1 Configuration of pulsed fiber laser. (MOPA : Master Oscillator Power Amplifier)

2. THE PULSED FIBER LASER

There are several methods to generate an optical pulse. Those are principally: a) a Q-switch oscillation that sets an optical shutter like an optical modulator into an optical resonator and oscillating an optical pulse by temporally changing the Q-factor of a resonator. b) an external modulation that cuts out an optical pulse from an output of a CW laser by an AOM (Acousto-Optical Modulator) or a LN ($LiNbO_3$: lithium niobate) optical intensity modulator; c) a direct modulation that directly modulates a driving current of a seed laser and controls the oscillation temporally. Table 1 shows typical examples of optical pulse generation methods of a pulsed fiber laser and their features.

Table 1 Methods of optical pulse generation of a pulsed fiber laser. (Typical examples)

	Q-switch oscillation	External modulation	Direct modulation
Pulse width	Tens of nm up to hundreds of ns	approx. 30 ns or more	Hundreds of ps or more
Repetition rate	Tens of kHz up to 50 kHz	Tens of kHz or more	Tens of kHz or more
Features	High pulse energy	Pulse width and repetition rate are variable.	

With a Q-switch oscillation, an optical pulse oscillation can be obtained by setting the optical switching elements like the AOM into the resonator. The number of components is few and it is easy to make an optical pulse with a relatively high energy. On the other hand, the repetition rate and the pulse width depend on the property of the resonator, so that their values are limited within a certain range.

With an external modulation, the laser oscillation and the pulse generation are physically separated. It is possible to design its characteristics such as the center wavelength, the spectral width, the temporal pulse shape and the repetition rate flexibly by combining them.

With a direct modulation, the driving current of the semiconductor laser is directly modulated to generate optical pulse. It can realize not only almost the same performance as the external modulation but also it can reduce the number of components.

The optical output pulse power from the external or the direct modulation system is smaller than the one from the Q-switch oscillation system. So the optical fiber amplifier is required to have high gain in order to obtain enough power and pulse energy required for the laser material processing. Therefore fiber length used in the optical amplifier tends to be longer, so that it is required to avoid the energy diffusion and the pulse distortion by the non-linear effect.

3. THE DEVELOPMENT OF SEED PULSED LASER

3.1. The External Modulation

The external modulation system consists of basically a CW laser and an external modulator such as the AOM or the LN optical intensity modulator. The system allow design the output pulse characteristics such as pulse shape, pulse duration or repetition rate by the combination of the CW laser and the external modulator.

The AOM generally is used as an optical shutter and can accommodates a relatively high input power, however, there is a trade-off relation that if the operating rate is made higher, the optical aperture becomes smaller. In the fiber inline type, the upper limits of the input power are determined by the power tolerability of collimators used at the input and the output to/from the AOM and by the amount of the coupling loss caused by the size of the aperture. At current status, practical values of the upper repetition rate and input power of the AOM are in the orders of hundreds MHz and a few Watts respectively in the case of tens ns to hundreds ns of optical pulse duration. The LN optical intensity modulator is usually used in high speed optical telecommunication systems. The speed of the system is increasing the order of 10 GHz so that the high speed electric signal generators and the driver IC became available and a pulse generation of several 100 ps became relatively easy.

However, the input power of the LN modulation is ten times lower than that of the AOM so it leads to deteriorate the signal to noise ratio (SNR) by the amplified spontaneous emission (ASE) in the amplifier. It is difficult to design the amplifier because it is necessary to obtain a higher gain to achieve the high output power.

In this paper, we used an AOM modulator to generate an optical seed pulse source of the pulsed fiber laser.

The optical configuration of the external modulated pulsed seed laser is shown in Figure 2. The fiber laser resonator consists of the polarization maintaining double clad Ytterbium doped fiber (PM-YDF), a high reflection mirror (HR) and an output coupler (OC) both made of a fiber bragg grating (FBG)[6]. The FBG is installed in a thermal compensating package to stabilize a center wavelength. The temperature dependences of the center wavelength are shown in Figure 3, as uncompensated in red line and compensated in blue line. With temperature compensation, the center wavelength is nearly-constant from -40 to 80°C.

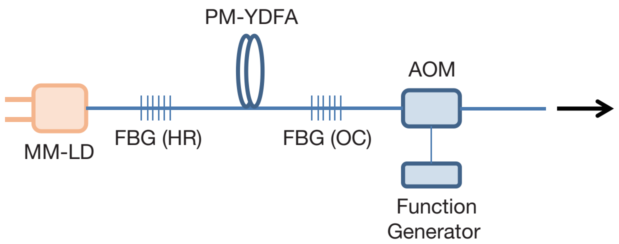

Figure 2 Configuration of external modulated pulsed seed laser. MM-LD: Multi mode laser diode

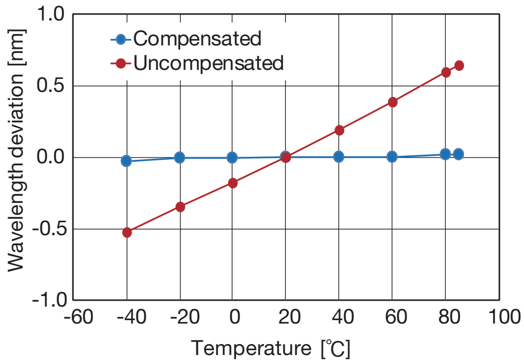

Figure 3 Temperature dependence of center wavelength of FBG. Uncompensated (Red), Compensated (Blue)

The output from the polarization maintaining Ytterbium doped fiber laser is input into the AOM of 150 MHz and is cut out into an almost 100 ns optical pulse. The repetition rate is 1 MHz and the input power is around 1.5 W. The electric signal and the optical pulse shape are shown in Figure 4. An optical pulse of 88 ns is generated from the AOM driven by a rectangular electric signal of 100 ns.

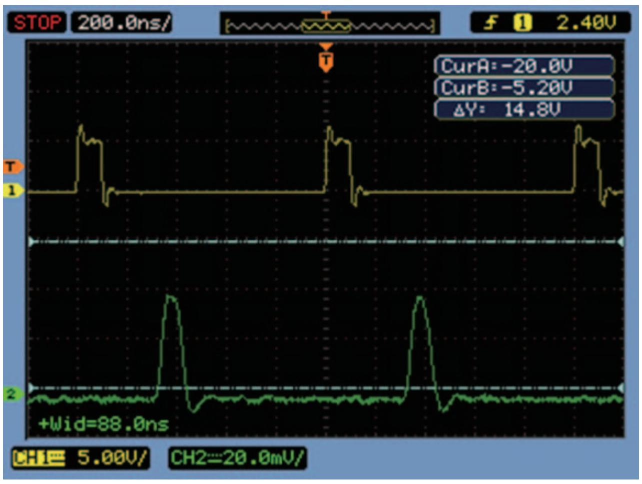

Figure 4 Output pulse shape from external modulated pulsed seed laser. Electric modulation signal (Yellow), Optical pulse shape (Green)

3.2. The Direct Modulation

The direct modulation system generate an optical pulse by the modulation of the driving current of a semiconductor LD directly. It becomes relatively easy to generate a 10 ns or less of optical pulse because a driver IC and a semiconductor LD are commercialy available similar to the external modulator.

Even if the duty ratio is small, the direct modulation system does not need to control drifts at zero level which is required for a LN modulator. Also, there are several advantages available in direct modulating the LD coming from electrical response property, the generation of 100 ns or less pulses, the generation of an arbitrary shape of the optical pulse and the high repetition rate up to GHz.

The temporal pulse shape from the direct modulation of a semiconductor LD is shown in Figure 5.

Figure 5 shows that the optical pulse is well-controlled and that the output is within from 5 ns to 100 ns of pulse width. The pulse peak power is approx. 100 mW.

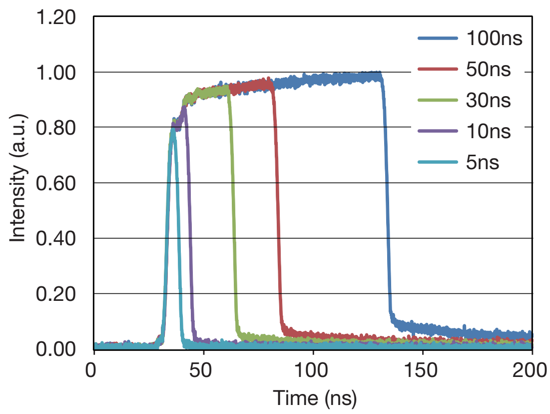

Figure 5 Output optical pulse shape from direct modulate laser diode. (Pulse width: 5 ns–100 ns, repetition rate: 100 kHz)

3.3. The Drive Control Circuit for a Pulsed Laser

We have developed a control board which generates a programmable digital electric signal and controls the driving current of the seed LD and the pumping LD, to control the AOM, the LN optical intensity modulator and the LD. The control block diagram is shown in Figure 6.

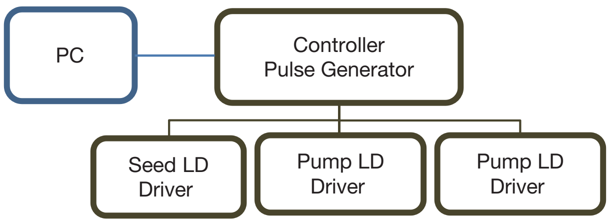

Figure 6 Control block diagram of a pulsed laser control board.

The control board consists of a controller and three laser drivers. The controller has a pulse generator to drive the external modulator or the direct modulated laser diode to generate an optical pulse. The Laser drivers control the LD driving current and the operation temperature.

There are functions that are monitoring each of the optical outputs, the safety features of the controlling output constant and shuting down and performing a routine action safely from an external ON/OFF signal and from the command input from a PC.

4. THE OPTICAL PULSE AMPLIFIER

The output from two-types of developed pulsed seed lasers are amplified in 2-steps polarization maintaining double clad ytterbium doped fiber amplifier as shown in Figure 1. The configuration of an optical pulse amplifier is shown in Figure 7.

The optical input pulse is applied through a tapered fiber bundle (PM-TFB) into the ytterbium doped fiber. The PM-TFB is able to couple up to 18 pieces of Multi-mode laser diode (MM-LD) as a pump light source. In these optical pulsed amplifiers, 1 pc of 10 W and 6 pcs of 25 W MM LD are used as a preamplifier and as a booster amplifier respectively. The pump power of the booster amplifier reaches up to 150 W. Each amplifier has an optimized fiber length and a gain as the non-linear effect becomes smallest to minimize the generation of SRS (Stimulated Raman Scattering) in the fiber.

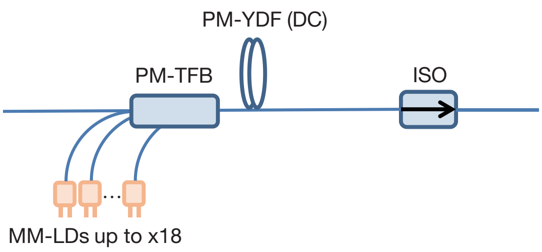

Figure 7 Configuration of the polarization maintaining ytterbium doped double clad fiber amplifier.

4.1. The Amplification of the External Modulated Pulse

The result of the amplified power of external modulated pulsed seed light is shown in Figure 8.

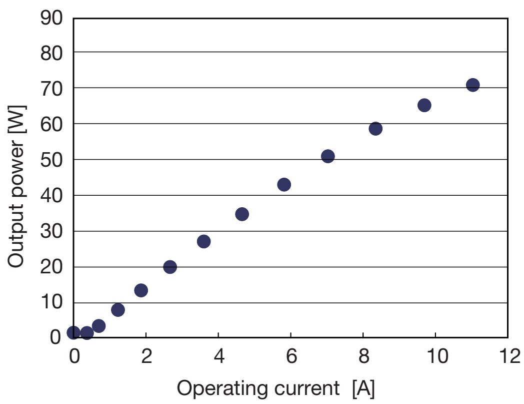

Figure 8 Output power from a MOPA using an external modulation. 100 ns, 1 MHz.

The pulse duration is 100 ns and the repetition rate is 1 MHz. The output is more than 70 W. One of the factors which limits the maximum value of the output power is the increase of the Raman scattering, however the Raman scattering can be minimized to approx. -19 dB against the signal output by the optimizing characteristics of the optical amplifier. The optical spectrum of 70 W output is shown in Figure 9. The conversion efficiency of the pumping light – optical signal power is approx. 45%.

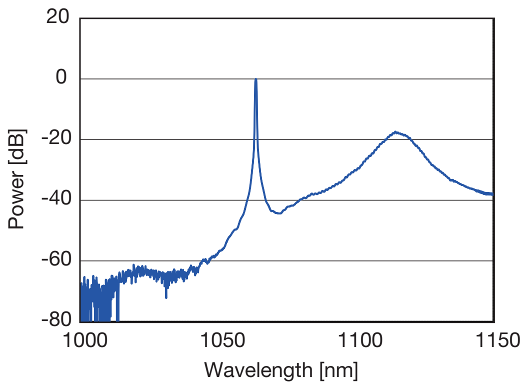

Figure 9 Spectrum of the output from a MOPA using an external modulation (with 70 W output)

4.2. The Amplification of the Direct Modulation

The result of the amplified power of direct modulated pulsed seed light is shown in Figure 10. 10 ns pulse duration, 1 MHz repetition rate and more than 13 W output are achieved. The optical spectrum of 7 W output is shown in Figure 11.

The Signal-SRS ratio of 50 dB or more is achieved by optimizing the gain of a booster amplifier and the fiber length. At this time, the conversion efficiency of the pumping light – optical signal power is approx. 29%.

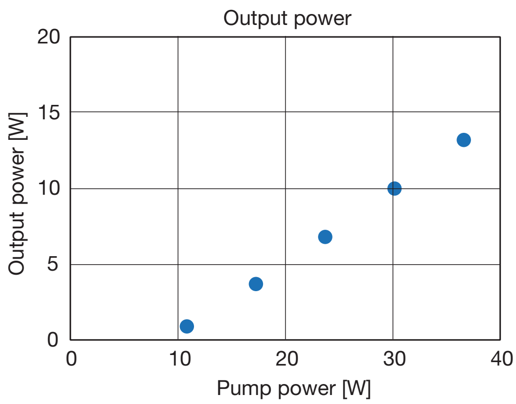

Figure 10 Output power form a MOPA using a direct modulation. 10 ns, 1 MHz.

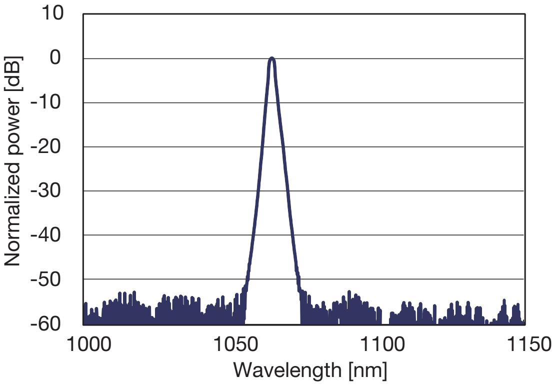

Figure 11 **Spectrum of output from a MOPA using a direct modulation. 10 ns, 1 MHz, 7 W.**

5. THE OUTPUT POWER STABILITY AND THE BEAM PROFILE

The output power stability of the pulsed fiber laser using external modulation is shown in Figure 12. The output power stability is ±1.6% when the output power is 70.5 W. It means that the output of the seed pulse and the optical amplification are stable and also that the polarization fluctuation in the fiber is small. Polarization extinction ratio of the optical output is more than 20 dB.

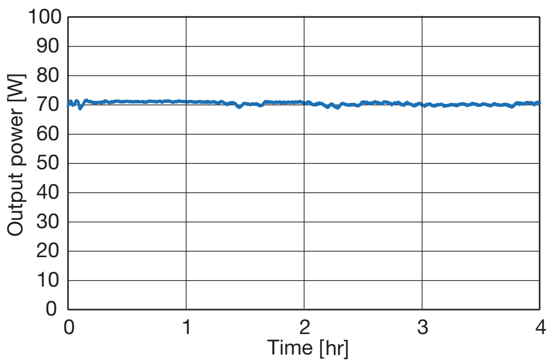

Figure 12 **Power stability of a MOPA using an external modulation.**
4 hours operation.
The deviation from the mean is ±1.6% at 100 ns, 1 MHz and 70 W.

The output beam profile from the isolator is shown in Figure 13. The beam shape has almost a Gaussian profile and an M^2 which shows that the beam quality is less than 1.33. It is a satisfactory performance for a pulsed fiber laser for laser material processing.

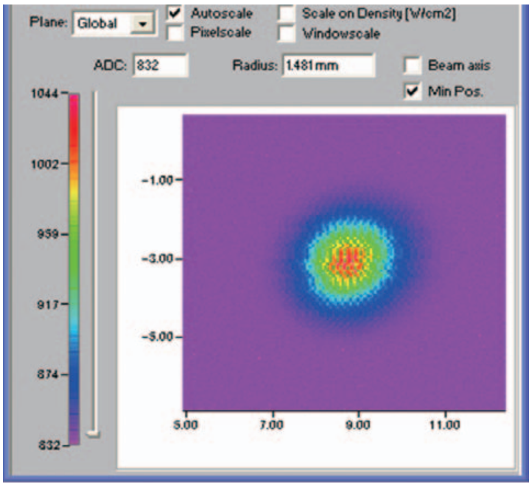

Figure 13 **Beam profile of the output from a MOPA using an external modulation. (100 cm from the isolator)**

6. CONCLUSION

We have developed 2 types of polarization maintaining pulsed fiber lasers using an external modulation and a direct modulation to obtain a high optical output power and a short pulse generation.

We have realized more than 70 W output power with 100 ns, 1 MHz by using an external modulation as a seed pulse source. The output power stability is ±1.6% to the mean value and a polarization extinction ratio of the optical output that becomes more than 20 dB. We have also realized more than 13 W with 10 ns, 1 MHz by using a direct modulated laser diode as a seed pulse source. The booster amplifiers are optimized with respect to its fiber length and its gain to minimize the nonlinear effects in the amplifiers.

The background of this technology comes from technologies in the optical telecommunication system such as high-speed modulation, high power amplification, optimization of nonlinear effect in fibers[7),8)] and stabilizing output power.

These pulsed fiber lasers realized linearly-polarized output by using the polarization maintaining fiber and the splicing techniques. The linearly-polarized output allow us to use wavelength conversion so the wavelength of the pulsed fiber laser can expand the wavelength to 532 nm or 355 nm.

We wish this technology will be a powerful tool to realize new application technology not only in the laser processing application but also in the inspection equipments for the bio-technology and the medical treatment etc. and in an energy field.

ACKNOWLEDGMENT

This research and development has been carried as a part of the “High-power Pulsed Fiber Laser and Processing Technology Project” by NEDO.

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