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LETTER

Optical switch by direct modulated laser diode using fiber laser for pulse picking

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Abstract

A new method of direct modulating a pre-amplifier laser diode as an optical switch is proposed. To modulate the laser diode with lower repetition rate, the repetition rate in the kilohertz region can be achieved using a source laser of 100 MHz without electro-optical modulators (EOM) or acousto-optical modulators (AOM). Using a direct modulated laser diode, an ON/OFF ratio (extinction ratio) of 25 dB was demonstrated in this study.

1 | INTRODUCTION

Ultrashort pulses can be advantageous for high efficiency and flexibility for laser system. A duration of 200 fs with peak power of ∼2.5 kW has been reported [1, 2]. Since mode locking is used for the laser system, the repetition rate is given by the cavity length. The repetition rate of 100 MHz can be easily obtained; however, it is difficult to produce the repetition rate below 100 MHz with extra cavity length. A repetition rate in the kilohertz region is required for a regenerative amplifier, or fluorescence lifetime measurements, for example. In order to produce the repetition rate in the kilohertz region, pulse pickers such as electro-optical modulators (EO), acousto-optical (AO) modulators or Mach–Zehnder modulators are often used [3–5]. However they require large size and high cost, and restrict the choice of repetition rate.

Q-switch lasers, for example, have shown great successes due to their simple and stable schemes. We previously proposed slower Q-switched YAG method to reduce its repetition rate and to increase its power. The system was used as a laser source for a pulsed laser deposition (PLD) system [6]. Only the Q-switch is modulated with lower repetition rate than the original repetition rate of flash lamp (slower Q-switched system) in order to obtain high energy fluency. Although the duration time became slightly wider (from 10 ns to 13 ns), the fluency becomes enough to produce an ablation on the target in the system, and a variety of high quality epitaxial films [7–10] including graphene [11, 12] and even nanoparticle [13] have been reported. In this presentation, we propose a new method for pulse picking using a fiber laser with directly modulated pre-amplifier laser diode as an optical switch. For underwater communication, for an example, the wavelength of 400–550 nm is used; however, low power of laser and slow optical switching remains the optical communication speed less than a few MHz. With the direct modulation method, optical communication of ∼100 MHz can be realized. An optical switch for mode-locked operation uses a saturable absorber mirror (SAM) with a lifespan, and the reflectance of the element varies widely. The direct modulation method can offer a long life and stability of performance.

2 | EXPERIMENTAL

An all polarization-maintaining (PM) fiber mode-locked laser contains a passively mode-locked oscillator and a fiber pre-amplifer. The laser oscillator is based on a Fabry Perot (FP) cavity configuration with wavelength 1030 nm at repetition rate of 98 MHz. And an extended cavity length of approximately 210 cm produced 35 MHz from the oscillator. A PM fiber Bragg

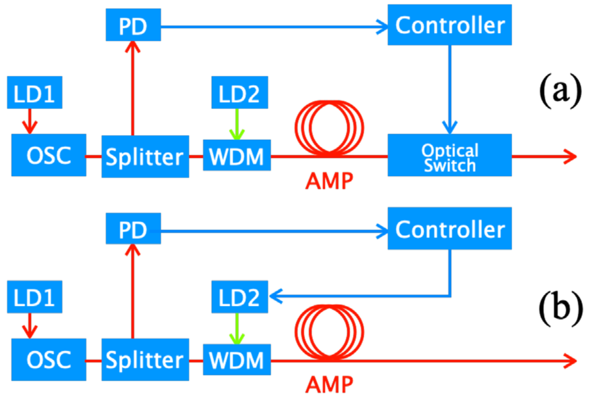


FIGURE 1 Schematic of pulse picking laser system. (a) Regular pulse picking system with optical switch and (b) direct modulating pumping LD system

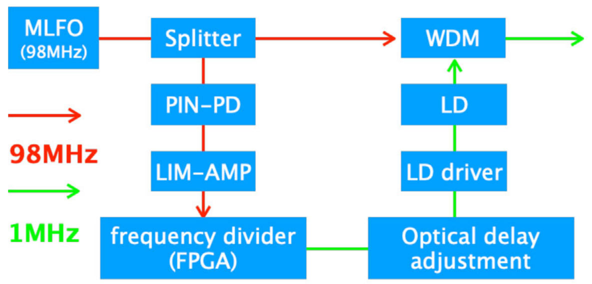
grating (FBG) is used as the output mirror of the FP cavity, and the FBG has a reflection peak wavelength of 1030 nm with bandwidth (FWHM, full width at half maximum) of 0.8 nm. The 1030 nm laser oscillator (OSC) used a 30 cm PM Yb-doped gain fiber powered by a 980 nm laser diode (LD) via a PM wavelength division multiplexer (WDM). As an end reflector of the FP cavity, a saturable absorber mirror (SAM) directly butt-coupled was used for self-started passive mode-locking of the fiber laser.

In order to reduce the repetition rate, some ratio of the laser is directed out by optical PM coupler for producing a delayed gate signal for pulse picking. A fiber-based acoustic optical modulator (AOM), for example, is typically used for a pulse picker with the delayed gate signal (Figure 1a). In this study, the pumping LD was modulated by a controller with 50% duration of pulse width at 1 MHz without any optical switch such as EO (Electro-Optical) or AO (Acousto Optical) modulator, as shown in Figure 1b.

3 | RESULTS AND DISCUSSION

The 1030 nm laser generated by the oscillator showed a power of 10 mW with a pulse width of 6 ps and with a frequency of 98 MHz, pumped by a 980 nm laser diode (LD2 in Figure 1). In this study, the modulated LD2 was used as an optical switch, as shown in Figure 1b.

Figure 2 shows the detail of the pulse picking system. A PIN photodiode (PIN-PD) was used to detect a laser pulse from the Mode-locked Fiber Oscillator (MLFO, 300 mW@100MHz) via a beam splitter followed by a limiting amplifier (LIM-AMP) for waveform shaping. The LIM-AMP was required for use of the frequency divider comprised of Field-Programmable Gate Array (FPGA). The FPGA generated a frequency of 1 MHz out of the original 98 MHz. With the optical delay adjustment, the laser diode (LD) was stimulated by a LD driver with the the reduced source of 1 MHz, and the Wavelength Division Multiplexer (WDM) multiplexed the original and the reduced carriers onto single fiber (3 mW@1MHz) followed by another AMP (300 mW@1MHz).



MLFO	Mode-Locked Fiber Oscillator	homebrew
PIN-PD	PIN Photo Diode	DET08CFC/M (TRHOLABS)
LIM-AMP	Limiting Amplifier	homebrew
FPGA	Field-Programmable Gate Array	homebrew
LD	Laser diode	3CN01378JL (3SP Technology)
WDM	Wavelength Division Multiplexer	HPMIWDM-0398-F-S-F-222-LLL-1-C6 (Optizone)

FIGURE 2 Detail of the pulse picking. A PIN photodiode (PIN-PD) was used to detect laser pulse from Mode-locked Fiber Oscillator (MLFO, 300 mW@100MHz) via beam splitter followed by a limiting amplifier (LIM-AMP) for waveform shaping. The LIM-AMP was required for use of the frequency divider comprised of Field-Programmable Gate Array (FPGA). The Wavelength Division Multiplexer (WDM) multiplexed the original and the reduced carriers onto single fiber (3 mW@1MHz) followed by another AMP (300 mW@1MHz)

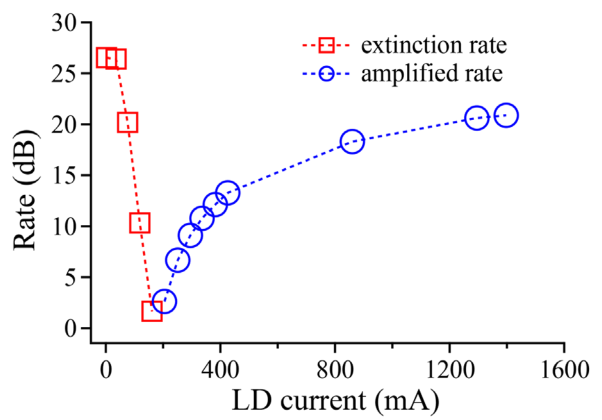


FIGURE 3 Extinction and amplified ratio with 1030 nm laser at 98 MHz. The extinction ratio of 25 dB was achieved

One important factor for an optical switch is the ON/OFF ratio (extinction ratio), which is expressed as the ratio of two optical power levels of a digital signal generated by an optical source, for example, a laser diode. Typical extinction ratio for commercial products using AO or EO modulations are ranging from 15 to 45 dB [14, 15]. Figure 3 shows the extinction ratio as a function of applied LD (LD2 in Figure 1b) current in this study. Without using typical AO or EO modulator, an extinction ratio of 25 dB was achieved by the direct modulated LD system. The direct modulation method showed the practical extinction rate could be produced without using AO or EO modulators.

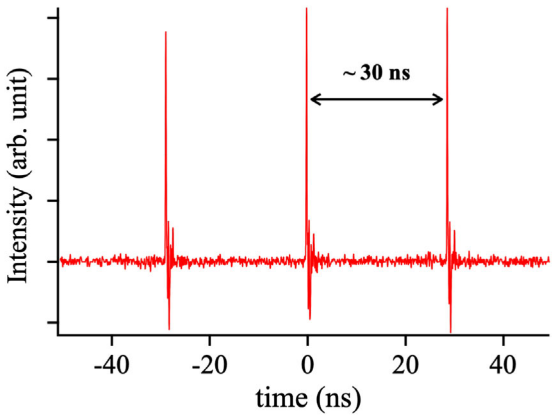


FIGURE 4 Reduced repetition rate with an extra length cavity. The repetition rate changed from 98 MHz to 35 MHz

With 98 MHz repetition rate, the 1030 nm laser modulated by pre-amplifier (LD2) showed a slow rise profile and did not reach its maximum power of the source laser. In order to properly modulate the LD, the repetition rate of the source laser was reduced with an extra cavity length employed in the OSC. Figure 4 shows a reduced source laser repetition rate of 35 MHz instead of 98 MHz with an additional 70 cm to the cavity length. Using the reduced repetition rate of the source laser, LD modulated by pulse width can generate pulse width modulation with the further low frequency. With an additional pre-amplifier, the original power of 5 mW was amplified to 450 mW. Pulse width modulation as a burst mode is in progress.

In order to generate a short pulse, the mode-locked technique is usually used for femto-second and pico-second pulsed laser, and to pick up favorable repetition rate, changes of cavity length or pulse picking by EO or AO switch is usually used. The direct picking can be a simple and low cost method to change the repetition rate without EO or AO switch.

4 | SUMMARY

We proposed a new method of direct modulated pre-amplifier laser diode as an optical switch. The method directly modulated pre-amplifier with feedback of photodiode output from source laser, and showed the capability of signal generation with extinction ratio more than 25 dB.

AUTHOR CONTRIBUTIONS

Satoru Kaneko: Writing - original draft. Manabu Yasui: Methodology. Masahito Kurouchi: Methodology. Robert York: Investigation, methodology. Yuna Hagiwara: Methodology. Masaru Nakamura: Conceptualization.

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CONFLICT OF INTEREST

The authors have declared no conflict of interest.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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REFERENCES

1. Schlauch, T., et al.: High peak power femtosecond pulses from modelocked semiconductor laser in external cavity. Electronics Lett. 44(11), 678–679 (2008)
2. Schlauch, T., et al.: Femtosecond passively modelocked diode laser with intracavity dispersion management. Opt. Express 18(23), 24316–24324 (2010)
3. van Hoek, A., Visser, A.J.W.G.: Pulse selection system with electro-optic modulators applied to mode-locked cw lasers and time-resolved single photon counting. Rev. Sci. Instrum. 52, 1199 (1981)
4. Balzer, J.C., et al.: Modelocked semiconductor laser system with pulse picking for variable repetition rate. Electronics Lett. 47(25), 1387–1388 (2011)
5. de Vries, O., et al.: Acousto-optic pulse picking scheme with carrier-frequency-to-pulse-repetition-rate synchronization. Opt. Express 23(15), 19586 (2015)
6. Kaneko, S., Shimizu, Y., Ohya, S.: Preparation of bisrcacuo multilayers by use of slower q-switched 266 nm yag laser. Jpn. J. Appl. Phys. 40, 4870–4873 (2001)
7. Kaneko, S., et al.: Structural modulation on multilayered bismuth cuprate observed by x-ray reciprocal space mapping. J. Appl. Phys. 97, 103904 (2005)
8. Kaneko, S., et al.: Strain-amplified structural modulation in bi-cuprate high tc super superconductor. Phys. Rev. B 74, 054503 (2006)
9. Kaneko, S., et al.: Large constriction of lattice constant in epitaxial magnesium oxide thin film: Effect of point defects on lattice constant. J. Appl. Phys. 107(7), 073523.1–073523.3 (2010)
10. Kaneko, S., et al.: Crystal orientation of epitaxial oxide film on silicon substrate. Appl. Surf. Sci. 586, 152776–1–5 (2022)
11. Kaneko, S., et al.: Layer-by-layer growth of graphene on insulator in co_2 oxidizing environment. ACS Omega 2, 1523–1528 (2017)
12. Kaneko, S., et al.: Carbon clusters on substrate surface for graphene growth - theoretical and experimental approach. Sci. Rep. 12, 15809 (2022)
13. Kaneko, S., et al.: Optimizing coverage of metal oxide nanoparticle prepared by pulsed laser deposition on nonenzymatic glucose detection. Talanta 84, 579–582 (2011)
14. Wan, P., et al.: Pulse shaping fiber lasers for free-space and lidar application. Proc. SPIE 7817, 7810K–1 (2010)
15. Ruske, J.P., et al.: Integrated optical ultrashort-pulse picker with high extinction ratio. Electronics Lett. 39(20), 1442 (2003)

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