Nanosecond Pulse Erbium-Doped Fiber Laser based on Evanescent Field Interaction with Lutetium Oxide

IOP Conf. Series: Materials Science and Engineering **854** (2020) 012038 doi:10.1088/1757-899X/854/1/012038

Nanosecond Pulse Erbium-Doped Fiber Laser based on Evanescent Field Interaction with Lutetium Oxide

A A A Jafry[1], R A M Yusoff[1], N Kasim[1,*], S N M Rifin[1], A R Muhammad[2], and S W Harun[2]

[1] Department of Physics, Faculty of Science, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[2] Department of Electrical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

Email: k.nabilah@utm.my *

Abstract. The mechanism of evanescent field interaction is established between lutetium oxide (Lu_2O_3) and light on the surface of D-shaped optical fiber. The D-shaped optical fiber was prepared using rotating wheel technique with the improved two times polishing method. The side-polished fiber sample owns a remaining fiber diameter of 70 µm and polishing length of 1400 µm. Lutetium oxide was deposited onto the D-shaped optical fiber as a pulse initiator inside an erbium-doped fiber laser cavity. A Q-switched with operating wavelength of 1565 nm was generated. Stable pulses were recorded as the pump power raised from 146 to 162 mW with pulse width as short as 450 ns and repetition rate of 0.967 MHz. As the pump power varied, output power of 120 to 160 µW which corresponds to pulse energy of 124 to 166 pJ were obtained.

1. Introduction

Q-switched laser is one of the attractive techniques to compress and initiate the pulse in nanosecond to microsecond time domain. The avalanche applications of Q-switched laser including corrective eye surgery, tattoo removal technique and laser cutting technology had attracted enormous research effort in this area [1, 2]. Since the introduction of semiconductors saturable absorber mirrors (SESAMs) in 1992, the performance of Q-switched laser had been improved to several order of magnitude. SESAMs is able to generate pulses as short as 10 femtosecond due to its ability to produce regular pulse train in the laser cavity [3]. However, SESAMs possess narrow operating bandwidth which is in the range of 800 to 1600 nm, making it incompatible for longer near-infrared wavelength. The mechanism of pulses generation in SESAMs is also complex as it requires precise alignment of laser setup which will induce large signal loss inside the laser configuration. Therefore, an all-fiberized laser cavity is introduced as it manipulates the mechanism of saturable absorption inside the laser configuration. To date, few materials are utilized as a saturable absorber (SA) in the laser cavity.

Among materials, lutetium oxide (Lu_2O_3) exhibit nonlinear absorption of approximately 4%, non-saturable absorption of 13% and saturable intensity of 32.03 MW/cm^2 in 1.55 µm region. Therefore, lutetium oxide had been utilized as SA in erbium-doped fiber laser (EDFL) cavity for the generation of Q-switched and mode-locked [4, 5]. Lu_2O_3 which is used as a host material in laser, scintillator for X-ray imaging and production of ceramic possessed a wide absorption in near-infrared bandwidth [6-8]. Lu_2O_3 is proved to be an efficient additive to host materials (thulium, ytterbium and erbium) for rare-earth doped fiber laser as they are able to emit pulsed lasers in the 1- , 1.55- and 2-µm region [9-11]. In

IOP Conf. Series: Materials Science and Engineering **854** (2020) 012038 doi:10.1088/1757-899X/854/1/012038

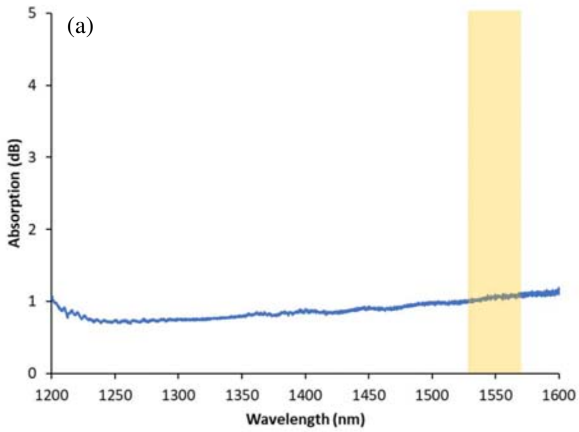
addition, Lu_2O_3 has a high thermal expansion and high melting temperature which is important to withstand high intensity laser illumination from laser pump.

In recent years, Q-switched laser is generated via the incorporation of a thin film inside an all-fiberized laser cavity. Researchers are able to initiate ultrafast pulse laser in the range of ps to sub-fs pulse duration in EDFL cavity [12]. However, thin film possesses a low damage threshold as most of them are produced using a polymer matrix as a host such as polyvinyl alcohol (PVA) and poly-methyl methacrylate (PMMA). PVA and PMMA has a melting temperature of approximately 200 °C and 160 °C, respectively, making them vulnerable to high intensity laser pulses. Here, we demonstrate a D-shaped optical fiber coated lutetium oxide as a SA in EDFL cavity. Our SA device has a long nonlinear interaction length and high optical damage threshold which makes it superior for the generation of Q-switched [13]. Nanosecond pulse erbium-doped fiber laser is induced via evanescent field interaction between Lu_2O_3 and light on the surface of the D-shaped optical fiber.

2. Preparation and characterization of D-shaped fiber-Lu_2O_3

The D-shaped fiber was prepared using polishing wheel technique, similar manner to Ahmad et al. [14]. An amplified spontaneous emission (ASE) source was launched onto the single-mode optical fiber (SMF-28) with output power meter (Thorlabs) connected to another end. Two fiber holders were used to clamp both ends of the single-mode optical fiber, ensure less vibration during polishing process. The waist region of the single-mode optical fiber was then placed onto the rotating wheel of the polisher. Approximately 2 mm long buffer was removed before polishing process. After 15 minutes of polishing process, a D-shaped fiber with 1400 µm long and 70 µm thick was produced.

The Lu_2O_3 solution was prepared by mixing isopropyl alcohol (IPA) with 99.99% pure Lu_2O_3 nanopowder purchased from Shanghai Xinglu Chemical Technology Co., Ltd. The process starts by stirring 50 mg of Lu_2O_3 nanopowder with 50 mL of IPA at room temperature for 24 hr. The mixture was then ultrasonicated for 6 hr at room temperature. A 3 µL of the prepared solution was drop onto D-shaped fiber for SA optimization. The linear absorption spectrum of the SA was shown in Figure 1 (a). The graph indicates ~1 dB absorption in 1565 nm wavelength, an optimum value for Q-switched generation. The modulation depth of prepared D-shaped fiber-Lu_2O_3 was measured using twin-balanced detector technique. Figure 1 (b) displayed a nonlinear absorption spectrum of SA device with 4% saturable absorption, 13% non-saturable absorption, and 32.03 MW/cm^2 saturable intensity.



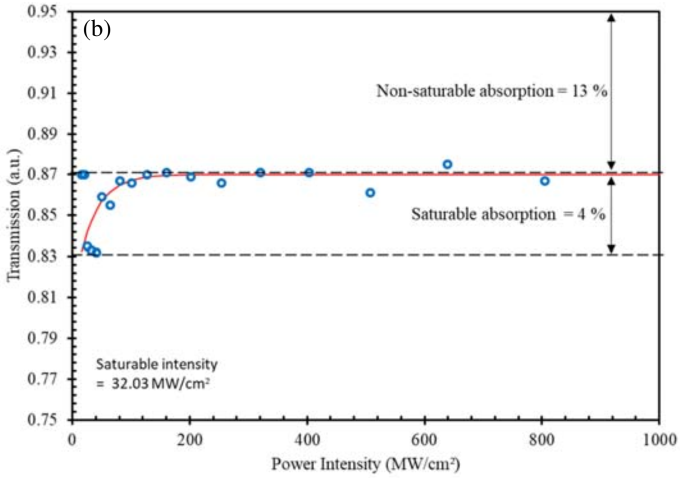


Figure 1. Optical properties of D-shaped fiber-Lu_2O_3; (a) linear absorption spectrum within the span of 1200 to 1600 nm, and (b) nonlinear absorption profile measured using twin-balanced detector technique.

3. Erbium Doped Fiber Laser Ring Cavity

The laser cavity was setup as drawn in Figure 2. A laser diode pump with 980 nm wavelength was launched onto the 980/1550 nm wavelength division multiplexer (WDM) as a wavelength-dependent beam splitter. The output port of the WDM was further connected to a 2.8 m erbium-doped fiber as a gain medium. The gain medium has an absorption coefficient of 23 dB/m, a core diameter of 4 μm, a cladding diameter of 125 μm and a numerical aperture (NA) of 0.16. Next, the light was converged to an optical isolator thus ensure unilateral light generated. The light was then allowed to propagate towards the D-shaped fiber-Lu_2O_3 as a SA device. The SA was connected to the 90/10 optical coupler with 90% of light cycled back to a 1550 nm port of WDM. A 10% of light was used for analysis purposes. An optical spectrum analyzer (Anritsu, MS9710C) with resolution of 0.05 nm and an optical power meter (Thorlabs) was used to characterize the output signal. A 350 MHz digital oscilloscope (Gwinstek, GDS-3352) and 9 kHz-7.8 GHz radio frequency spectrum analyser (Anritsu, MS2683A) connected via a 1.2-GHz InGaAs photodetector were used for temporal characteristics analysis.

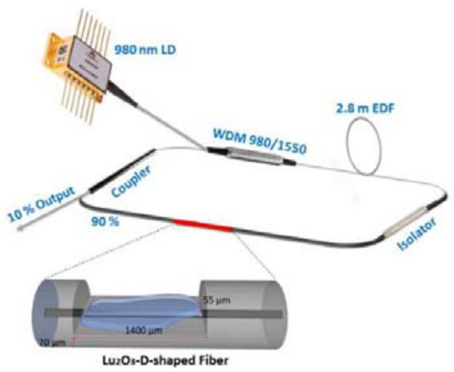


Figure 2. Experimental setup for nanosecond pulse generation in EDFL using Lu_2O_3-D-shaped fiber as saturable absorber.

4. Result and Discussion

IOP Conf. Series: Materials Science and Engineering **854** (2020) 012038 doi:10.1088/1757-899X/854/1/012038

A nanosecond pulse laser was generated at a threshold pump power of 146 mW. The optical spectrum analyzer measured a nanosecond pulse with a center wavelength of 1565 nm and a 3dB spectral bandwidth of 0.594 nm as depicted in Figure 3 (a). As the pump power raised from 146 to 162 mW, stable pulses observed. However, further increasing the input pump will causes the pulses to mitigate and eventually disappeared. Figure 3 (b) shows an oscilloscope trace of the nanosecond pulse generated at threshold pump power of 146 mW. The captured spectrum obtained a pulse width of 450 ns and a pulse period of 1034 ns. The signal was further analyzed using a radio frequency spectrum analyzer (RFSA) as shown in Figure 3 (c). The RFSA depicted a fundamental frequency with many harmonics within 6 MHz frequency span. The signal-to-noise ratio (SNR) of 46.24 dB was observed at a repetition rate of 0.967 MHz.

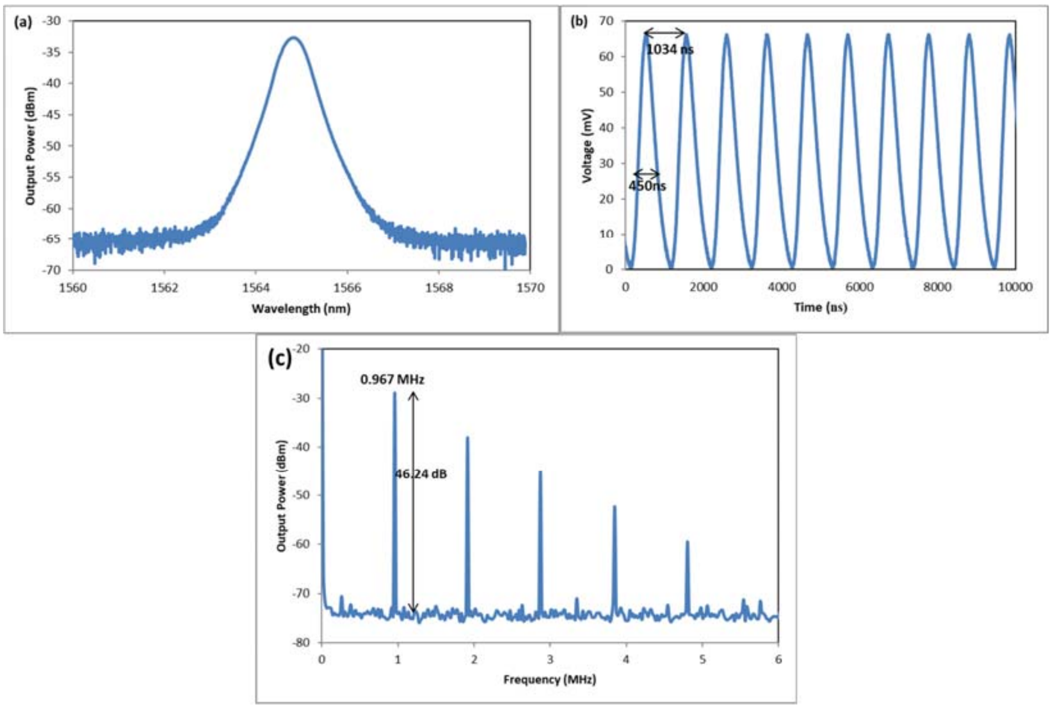


Figure 3. Spectral and temporal performances of the Q-switched laser; (a) output spectrum, (b) typical oscilloscope trace, (c) and RF spectrum at 146 mW pump power.

The signal was further investigated within the variation of multiple input pump power. The graph of repetition rate and pulse width against pump power was shown in Figure 4 (a). A nearly uniform pulse width and repetition rate was captured within 146 to 162 mW pump power. At a minimum attainable pump power, Q-switched generated obtained a pulse width of 450 ns and a repetition rate of 0.967 MHz. The graph of output power and pulse energy against pump power was also plotted in Figure 4 (b). A typical Q-switched behaviour was observed as the output power and pulse energy increased linearly with the increment of pump power. The Q-switched possesses an output power of 120 to 160 µW as the pump power raised within 146 to 162 mW. The laser generated exhibit pulse energy of 124 to 166 pJ within the same range of pump power.

(a) **(b)**

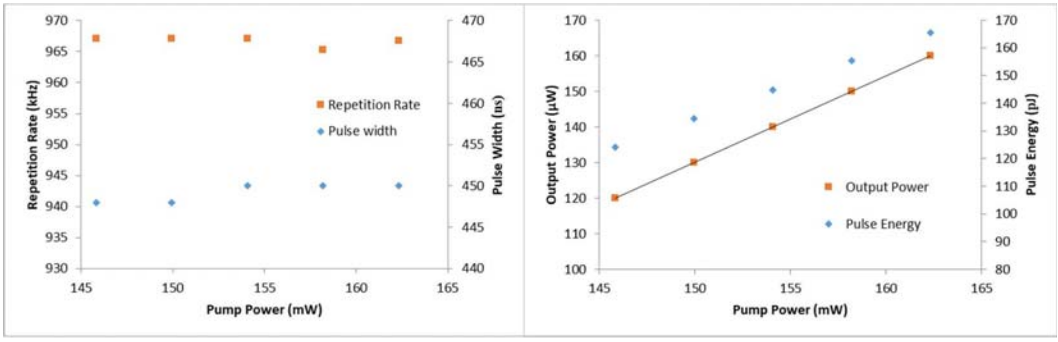


Figure 4. Q-switching performance; (a) repetition rate and pulse width against pump power (b) output power and pulse energy against pump power.

5. Conclusion

We present nanosecond pulse generation with Lu_2O_3 deposited onto D-shaped fiber as a pulse generator for EDFL cavity. The D-shaped optical fiber prepared using a rotating wheel technique owns a polishing length of 1400 nm and a diameter of 70 µm. The mechanism of the evanescent field between Lu_2O_3 and light was exploited to generate Q-switched in the EDFL cavity. With the appropriate amount of Lu_2O_3 deposited onto D-shaped optical fiber, stable Q-switched initiated within 146 to 162 mW. The generated pulses exhibit the highest repetition rate of 0.967 MHz corresponds to the shortest pulse width of 450 ns. SNR measured was 46.24 dB indicating the stability of the laser. The maximum output power and pulse energy generated was 160 µW and 166 pJ, respectively, at a maximum attainable pump power of 162 mW.

6. Acknowledgements

This research is fully supported by Fundamental Research Grant Scheme (FRGS), R.J130000.7826.4F928 and Research University Grant (RUG), Q.J130000.2654.16J01. The authors fully acknowledged Ministry of Education (MOE), Malaysia and Universiti Teknologi Malaysia for the approved fund which makes this important research viable and effective.

References

[1] Okamoto Y, Kitada R, Uno Y, Doi H. Cutting of Solid Type Molded Composite Materials by Q-switched Fiber Laser with High-Performance Nozzle. *J Adv Mech Des Syst Manuf.* **2(4)**:651-60.

[2] Shah S, Alster TS. Laser Treatment of Dark Skin An Updated Review. *Am J Clin Dermatol.* **11(6)**:389-97.

[3] Keller U, Weingarten KJ, Kartner FX, Kopf D, Braun B, Jung ID, Fluck R, Honninger C, Matuschek N, DerAu JA. Semiconductor saturable absorber mirrors (SESAM's) for femtosecond to nanosecond pulse generation in solid-state lasers. *IEEE J Sel Top Quantum Electron.* **2(3)**:435-53.

[4] Jafry AAA, Kasim N, Munajat Y, Yusoff RAM, Rusdi MFM, Mahyuddin MBH, Harun SW, Arof H, Apsari R. Passively Q-switched erbium-doped fiber laser utilizing lutetium oxide deposited onto D-shaped fiber as saturable absorber. *Optik.* **193**:162972.

[5] Baharom MF, Rahman MFA, Latiff AA, Wang P, Harun SW. Lutetium (III) oxide film as passive mode locker device for erbium-doped fibre laser cavity. *Opt Commun.* **446**:51-5.

[6] Martin T, Douissard PA, Seeley Z, Cherepy N, Payne S, Mathieu E, Schuladen J. New High Stopping Power Thin Scintillators Based on Lu2O3 and Lu3Ga5-xInxO12 for High Resolution X-ray Imaging. IEEE *Trans Nucl Sci.* **59(5)**:2269-74.

[7] Martinet C, Pillonnet A, Lancok J, Garapon C. Optical, structural and fluorescence properties of nanocrystalline cubic or monoclinic Eu : Lu2O3 films prepared by pulsed laser deposition. *J*

IOP Conf. Series: Materials Science and Engineering **854** (2020) 012038 doi:10.1088/1757-899X/854/1/012038

Lumines. **126(2)**:807-16.

[8] Vetrone F, Boyer JC, Capobianco JA, Speghini A, Bettinelli M. NIR to visible upconversion in nanocrystalline and bulk Lu2O3 : Er3+. *Journal of Physical Chemistry B*.**106(22)**:5622-8.

[9] Chen XT, Zhao SZ, Zhao J, Yang KJ, Li GQ, Li DC, Qiao WC, Li T, Zhang HJ, Feng TL, Xu XD, Zheng LH, Xu J, Wang YG, Wang YS. Sub-100 ns passively Q-switched Nd:LuAG laser with multi-walled carbon nanotube. *Opt Laser Technol*. **64**:7-10.

[10] Lagatsky AA, Antipov OL, Sibbett W. Broadly tunable femtosecond Tm:Lu2O3 ceramic laser operating around 2070 nm. *Optics Express*. **20(17)**:19349-54.

[11] Xu ZH, Lin JY, Sun YG, Ding F, Fan HT, Shi S, Fang QH, Bi YF, Gao Y. Facile Synthesis and Down-Conversion Emission of RE3+-Doped Lutetium Oxide Nanoparticles. *J Nanosci Nanotechnol*. **18(4)**:2850-5.

[12] Hasan T, Sun ZP, Wang FQ, Bonaccorso F, Tan PH, Rozhin AG, Ferrari AC. Nanotube-Polymer Composites for Ultrafast Photonics. *Adv Mater*. **21(38-39)**:3874-99.

[13] Park NH, Jeong H, Choi SY, Kim MH, Rotermund F, Yeom DI. Monolayer graphene saturable absorbers with strongly enhanced evanescent-field interaction for ultrafast fiber laser mode-locking. *Optics Express*. **23(15)**:19806-12.

[14] Ahmad MT, Rusdi MFM, Jafry AAA, Latiff AA, Zakaria R, Zainuddin NAM, Arof H, Ahmad H, Harun SW. Q-switched erbium-doped fiber laser using silver nanoparticles deposited onto side-polished D-shaped fiber by electron beam deposition method. *Opt Fiber Technol*. **53**:101997.