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Optical Switching by Thermocavitation for the Implementation of an All-Fiber Pulsed Laser

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Abstract. A new optical switching for the generation of laser pulses based on the phenomenon of thermocavitation is reported. Thermocavitation bubbles were induced within a glass cuvette filled with a saturated solution of copper nitrate dissolved in water. Two optical fibers were submerged into the solution, very close to the region where the vapor bubble was generated. Once the bubble is generated it expands rapidly and the incoming laser light transmitted through the optical fiber is reflected at the vapor-solution interface and reflected into the fiber, which is coupled to an erbium-doped fiber ring laser and the laser pulse was extracted from the ring cavity and detected by a fast photodetector. The generation of the laser pulses is based on the change of the optical reflection coefficient at the end surface of the glass fiber by the expansion and collapse of the bubble, which behaves like a mirror with variable reflectivity. For both pulses, the repetition rate obtained was in a range of 118 Hz to 2 kHz at 1560 nm, with a pulse width ranging from 64 to 57 μs, which can be controlled by adjusting the laser power to in-duce thermocavitation bubbles.

Keywords: Optical switch, thermocavitation bubbles, pulsed laser.

1 Introduction

The basic scheme of a resonator for a fiber optic laser is the linear scheme, where the mirrors are deposited at the ends of the fiber [1]. But there are also resonators in ring configuration without mirrors, instead a coupler is used as the output port to extract the light emitted [2]. The modulation techniques for the generation of light pulses can be carried out in two different ways: i) Q-switching [2] and ii) Mode-Locking switching [3] which are divided in active and passive methods. In active methods the losses are

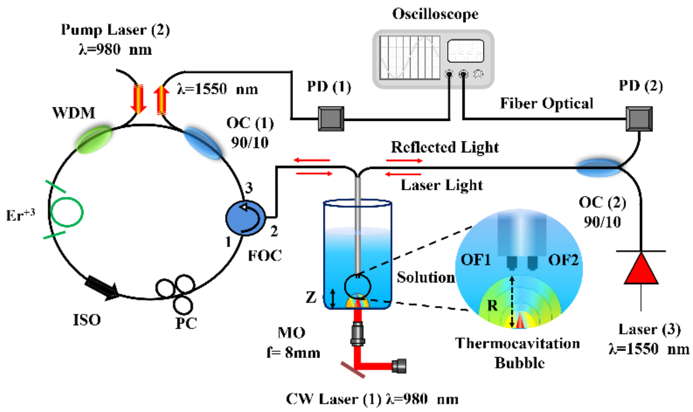

Fig.1. Scheme of the thermocavitation-based pulsed laser and experimental setup known as a fiber optic hydrophone (FOH).

modulated with elements external to the cavity with a control element [4] and passive methods, referring to internal elements that automatically modulate losses [5].

The phenomenon of thermocavitation is present when a highly absorbent solution is irradiated with a continuous wave (CW) laser. Where the absorbed light heats the solution to its critical limit, that is, the temperature at which an explosive liquid-gas phase transition occurs [6,7].

The precise moment when superheated water explosively turns into steam, producing a rapidly expanding bubble, which finally collapses, emitting an acoustic wave. In this work, it is precisely the growth dynamics of the thermocavitation bubble the main factor that causes the losses and the control of the laser cavity, acting as a mirror of variable reflectivity in time.

2 Experimental Setup

The thermocavitation is generated by a CW near infrared laser with λ = 980 nm (Laser (1)) where the output beam is collimated, reflected, and focused with a microscope objective (f = 8 mm) into the saturated solution of copper nitrate (13.78 g per 10 ml of water) which is contained inside a glass cuvette as shown in Fig. 1.

To carry out the generation of light pulses, the experimental setup of a pulsed all-fiber laser in a ring configuration with a total length of ~ 42 meters was used, see Fig. 1 (left section). The system was pumped by an LDC 205C laser with a wavelength λ = 980 nm (Laser 2), used 12 m of single-mode optical fiber doped with erbium as active medium, an WDM (NPM07000165), isolator (M11 / 81202003), polarization controller (FPC030) and an circulator (FOC) (S/N: A8038188), where the Port 1 of the FOC is connected to the laser cavity, while the optical fiber coming from port 2 was cleaned, cut, and introduced into a metal tube and subsequently, immersed in the working solution, close to the region where thermocavitation is created.

Consequently, the light reflected inside the fiber enters the circulator again through the same port 2 and exits through port 3, which is connected to a 90/10 optical coupler

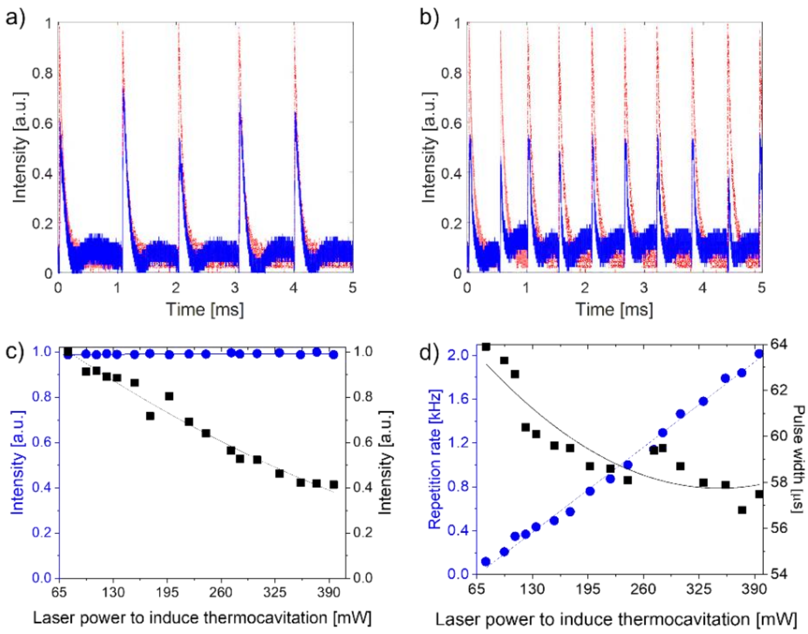

Fig. 2. Light pulses at the exit of the laser cavity (Red-Dotted) and the acoustic hydrophone (Blue-Continuous) varying the power to induce thermocavitation bubbles. a) 282 mW and b) 375 mW. c) Variation of intensities of the pulses extracted from the laser cavity (Blue-Circles) and those from the FOH (Black-Square), as well as in d) The repetition frequency (Blue-Circles) and the temporal width of the pulse (Square-Black) varying the power to induce thermocavitation.

(CWD07014557) (OC (1)) to close the laser cavity, where only 10% of the energy is extracted in the form of pulses, which were analyzed with the help of a photodetector (PD (1)) and observed with an oscilloscope.

The right section of the experimental setup corresponds to the well-known fiber optic hydrophone (FOH) see Fig. 1 [8], which was implemented in this work in order to verify that each pulse at the output of the pulsed all-fiber laser corresponded to a single thermocavitation event. The experimental setup uses an infrared laser with a wavelength of λ = 1550 nm (Laser 3), sending the light beam to a 90/10 coupler (CWD07014557) (OC (2)) where 90% of the light is sent to port one.

Simultaneously both fibers (OF1 and OF2) detect the change in refractive index due to the glass-vapor interface caused by the growth of the thermocavitation bubble, which expands rapidly, causing the laser light to incoming transmitted through it is reflected.

3 Results

Figure 2 (a, b) shows the temporal characteristics of pulses, here the optic fiber laser (Red-Dotted) and the pulses detected by the fiber optic hydrophone (Blue-Continuous), were measured as a function of the laser power to induce thermocavitation (282 y 375 mW), using a power pump 235 mW to the laser ring.

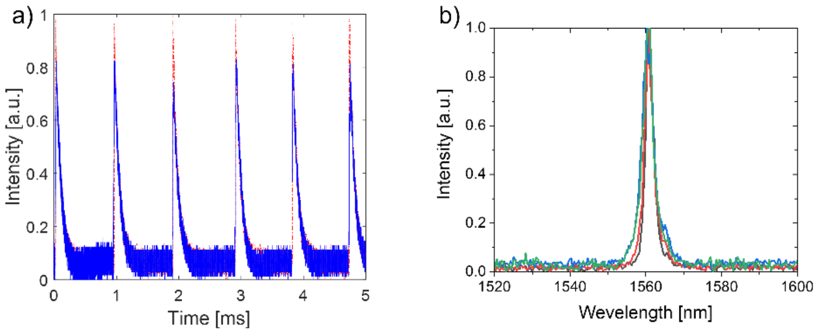

Fig. 3. a) Pulses at the output of the fiber optic laser (Red-Dotted) and the FOH (Blue-Continuous) at the pumping power of 272 mW. b) Spectra of the pulses at the exit of the cavity.

Both signals were observed simultaneously on the same oscilloscope, each pulse captured by the photodetector corresponds to a single thermocavitation event.

In the Fig. 2c shows the variation of normalized intensities captured by the oscilloscope of the pulses at the exit of the laser cavity (Blue-Circles), which remain practically constant. As well as the signals captured by FOH (Black-Boxes) which tend to decay, both signals detected as a function of the variation of the power to induce thermocavitation from 75 mW to 395 mW.

In Fig. 2d the repetition rate of the light pulses detected by the PD (1) that corresponds to the output of the laser cavity, which increases from 118 Hz to 2 kHz (Circles-Blue). while the temporal width decreases moderately from 64 to 57 μs (Squares-Black) both characteristics depending on the laser to induce thermocavitation.

To observe the variation of the temporal characteristics of the cavity output pulses when the pumping power is varied, the laser power to induce thermocavitation was set at 272 mW, as well the focusing distance $Z = 30$ μm.

Fig. 3a shows the temporary traces of the pulses at the exit of the cavity (Red-Dotted) and those detected by FOH (Blue-Continuous) at a pumping power of 199 mW, it was noted that the amplitude and the frequency is practically constant to the changes of variation in the bass drum power, so there is no need to show more sequences of pulses, the only alteration that the pulses present is in the temporal width with a decrease from 69 to 60.4 μs. In Fig. 3b the output spectrum is shown, which is centered 1560 nm. More in detail about the pulses at the laser output, see the reference [9].

4 Conclusions

In this paper, we present a mechanism for the generation of laser pulses using the phenomenon of thermocavitation. Thermocavitation is due to the high laser light absorption by a homogeneous solution at a specific wavelength, which enables the focal point to reach superheated conditions (~300° C). Here, vapor bubbles were induced using a CW laser at 980 nm (which is an inexpensive energy source) focused into a saturable solution of copper nitrate dissolved in water. Here the losses are caused by time-varying reflectivity due to the dynamic growth of a thermocavitation bubble.

These reflectivity changes are detected by an optical fiber, which is coupled to a simple erbium-doped fiber ring laser. The amplitude of the laser pulses is greater and constant when they pass through the ring cavity, compared what the pulse is obtained from the fiber optic hydrophone setup. Control over the pulse repetition rate is realized by adjusting the laser power to induce thermocavitation, obtaining a repetition rate from 118 Hz to 2 KHz, with a pulse width that change from 64 to 57 µs.

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