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Faouzi Bahloul, Aymen Bel Hadj Taher, Mohamed Salhi, François Sanchez, Rabah Attia. Pulse Evolution in Microstructured Optical Fiber Ring Laser. Colloque International TELECOM'2013 & 8ème JFMMA, Mar 2013, Marrakech, Morocco. hal-03208330

HAL Id: hal-03208330

https://hal.univ-angers.fr/hal-03208330

Submitted on 26 Apr 2021

PULSE EVOLUTION IN MICROSTRUCTURED OPTICAL FIBER RING LASER

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Abstract: We have numerically studied the characteristics of the pulse evolution with the symmetrized split-step Fourier method in an actively mode-locked ring fiber laser. The characteristics of the multiple pulses are investigated with various cavity parameters. The numerical results show that stable pulses can be obtained when the parameters of the ring are suitably chosen. The Microstructured Optical Fiber Ring Laser shows good performance as an optical pulse source, since it generates a stable pulse train with a pulse width of 2ps and a tunable repetition rate.

Key words: Ring Laser (RL), Microstructured Optical Fiber (MOF), Nonlinear Schrödinger Equation (NLSE), Split Step Fourier Method (SSFM).

I. INTRODUCTION

Fibers lasers, which utilize an optical fiber doped with rare earth elements such as erbium or ytterbium as the active gain medium, have been widely investigated in the recent years. Pulsed fiber lasers have key advantages including high peak power and short pulse duration. Mode locked fibers laser have found applications in many areas as communication, material processing, biological metrology and medicine [1]. Microstructured optical fibers (MOF) have attracted much attention since the first demonstration of optical guidance in a MOF in 1996 [2]. MOFs have shown potential for many practical applications, due to their novel optical properties and have been in the focus of research over the recent years. Light guidance in MOF is provided by a periodic arrangement of holes, acting as a cladding, running along the full length of the fiber. A potentially unlimited range of geometric arrangements permits control of optical properties as dispersion nonlinearity and birefringence [3].

The cavity design of the actively mode-locked Erbium doped fiber laser is schematically shown in Figure 1. The cavity comprises Erbium doped fiber, microstructured optical fiber, optical modulator and bandpass filter. An isolator was used to maintain the unidirectional traveling wave in the laser cavity. The pulse is outputted after the optical modulator using a 90:10 output optical coupler.

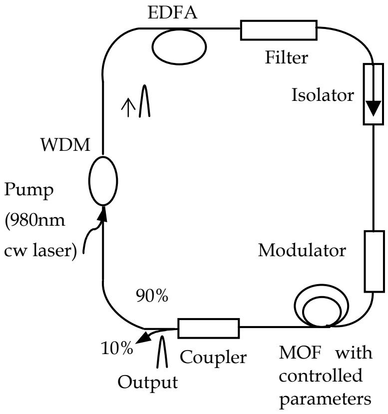

Figure1: Set up of the fiber ring laser

In this work, we propose a model of Microstructured Optical Fiber Ring Laser (MOFRL). The output pulse is dependent upon the parameters of the different components of this laser. We study the influence of the various properties of the MOF and the repetition rate on dynamics of pulses propagation. We demonstrate the influence of the parameters on the formation of the different pulses.

Finally, we numerically simulate the pulse propagation in a MOFRL. By means of the extended nonlinear Schrodinger equation taking into account the roles of MOFs and EDFA, we obtain stable pulse generation regime.

II. Fiber Laser Model

The cavity is modeled as a sequence of different elements. For the numerical modeling we use a simple scheme of a ring fiber laser, which consists of a doped fiber, microstructured optical fiber, optical modulator, bandpass filter, isolator and output coupler. This laser model allows including the dominant effects into the simulations and is still close to reality. In addition, our approach allows to treat each element separately. The cavity is schematically represented in Fig. 2. The optical isolator is also considered and easily implemented by the computational procedure.

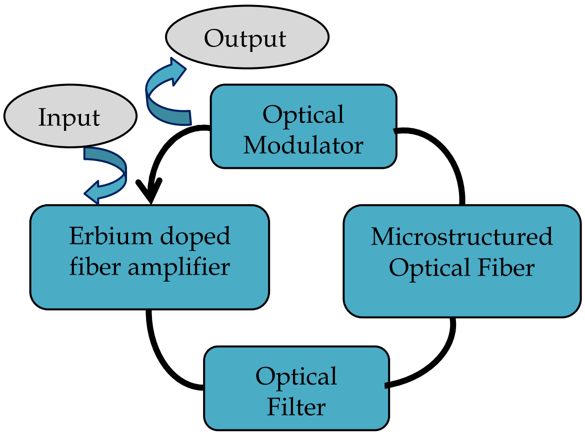

Figure2: General schematic of the fiber laser model

Every round trip, we simulate the pulse propagation in fibers separately by solving the NLSE using the split-step algorithm. Then, the pulse is calculated after the optical modulator and band pass filter using their transfer functions.

The optical pulse propagation through the MOF is governed by the nonlinear Schrödinger equation [4]:

$$\frac{\partial E}{\partial z} + j\frac{\beta_2}{2}\frac{\partial^2 E}{\partial T^2} - \frac{\alpha}{2} = j\gamma|E|^2 E$$

where

E is the complex envelop of the electric field.

z is the propagation distance.

β_2 accounts for the second order fiber dispersion.

α and γ are the loss and nonlinear parameters of the fiber, respectively.

T is the delayed time ($T=t-z/v_g$), vg is group velocity.

In EDFA the nonlinear Schrödinger equation becomes as follow [5]:

$$\frac{\partial E}{\partial z} + j\left(\frac{\beta_2}{2} + j\frac{g}{2\omega_g^2}\right)\frac{\partial^2 E}{\partial T^2} - \frac{g-\alpha}{2} = j\gamma|E|^2 E$$

The saturated gain has the following expression [6]

$$g = \frac{g_0}{1+\frac{E_p}{E_s}} ,$$

where

g_0 is small signal gain.

E_p is the instantaneous pulse energy.

E_{sat} is the saturation energy.

ω_g is the spectral gain bandwidth.

The optical filter has a Gaussian profile and can be described by the following transfer function [7]:

$$H(f) = \alpha_F \, e^{\left(-\frac{1}{2}\left(\frac{f}{B_0}\right)^2\right)} ,$$

where

α_F is the insertion loss.

B_0 is half of the (1/e) bandwidth of the filter.

The optical modulator can be modeled by the transmission function [7]:

$$T = \alpha_m \cos^2\left(\frac{\pi}{4}\left(\Delta_m \cos(\omega_m t) + 1\right)\right) ,$$

where α_m is the insertion loss.

$\Delta_m=2V_m/V_\pi$ is the modulation depth.

V_π is the voltage applied on the modulator that causes a π phase shift in one arm of the integrated optical interferometer.

V_m is the amplitude of the modulating signal.

$\omega_m = 2\pi f_m$ is the angular modulation frequency.

III. Results and discussions

We have used Symmetrized Split Step Fourier Method (SSSFM) for solving Schrödinger equations modeling the propagation of the pulse in the fiber ring laser. We have taken into account the nonlinear effects and the dispersion.

The method considers the dispersion and nonlinearity as independent effects. A MATLAB program is written to simulate the performance of an actively mode locked fiber ring laser. Pulse characteristics and shape at each round trip of ring laser was recorded and analyzed. The pulses were plotted together in time domain. This gives an idea of how the pulse evolves as a function of the number of rounds trips.

Numerical simulations of the laser operation are undertaken to give a qualitative behavior and a physical description of the multipulses generation. They are carried out by considering an initial Gaussian pulse and propagating it through the various components shown in Figure

2. Table 1 presents the parameters used in the numerical simulations.

TABLE I

PARAMETERS VALUES USED IN THE SIMULATIONS

MOF	EDFA	Modulator
$L=20m$	$L=15m$	$f_m = 30GHz$
$\alpha=0.2dB/km$	$\alpha=0.5dB/km$	$V_m=1.8V$
$\gamma=0.0019/w/m$	$\gamma=0.003/w/m$	$V_{pi}=6V$
$\beta_2=-21ps^2/km$	$\beta_2=-19ps^2/km$	$V_b= 0V$
	$g_0=8m^{-1}$	$\alpha_m=1$
	$E_{sat}=1pJ$	
	$\omega_g=15.7ps^{-1}$	

The peak power of the injected Gaussian pulse is 1W and the duration (FWHM) is 6ps as shown in Figure 3.

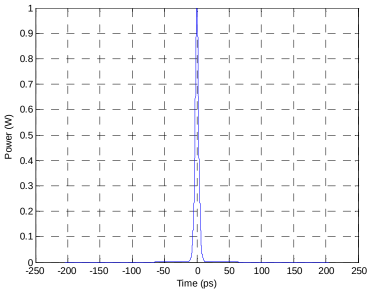

Figure 3: Input pulse peak power 1W and the duration (FWHM) is 6ps.

We distinguish two regimes: the transient and the steady-state. After 2000 trip rounds, we obtain stable equidistant pulses separated by a time equal to the period of the optical modulator and with 0.3W peak power (Figures 4-5).

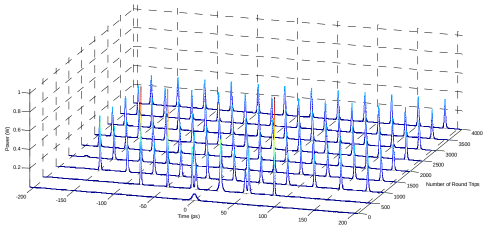

Figure 4: Numerically calculated pulse evolution in actively ring fiber laser: $g_0=8m^{-1}$ and $E_s=1pJ$.

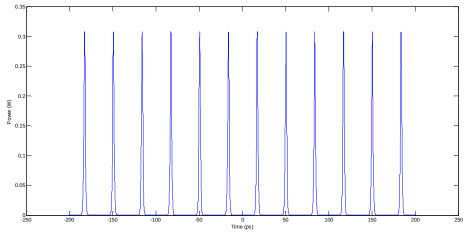

Figure 5: Output pulses with 0.3W peak power and 2ps duration.

With a fixed gain in the amplifier and saturation energy, multi pulses can be generated with different forms. The results are shown in Figures 6-7. A number of solitons were found to circulate along the laser cavity with random spacing. In the time domain, the random pulse pattern repeated with the round-trip time period. It represents a pseudo periodic regime.

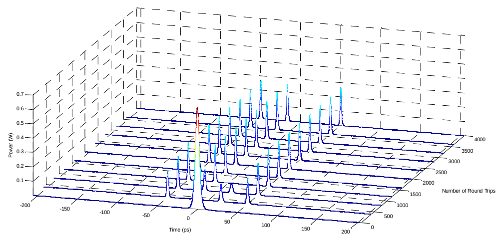

Figure 6: Numerically calculated pulse evolution in actively ring fiber laser $g_0=2m^{-1}$ and $E_s=1pJ$.

By suitably adjusting the small signal gain and the saturation energy, stable ultrashort pulse can be generated with tunable repetition rate.

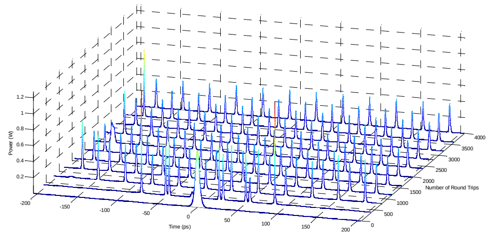

Figure 7: Numerically calculated pulse evolution in actively ring fiber laser: $g_0=2m^{-1}$ and $E_s=5pJ$.

If we take the same parameters as the last simulation and we change the nonlinear parameter of the MOF $\gamma_{MOF} = \gamma_{SMF} = 0.0012/w/m$ we obtain the temporal output pulses as described in Figure 8. We remark that we have only 4 pulses every round trip. We demonstrate a simple method of generating 30-GHz repetition-rate pulse trains from a MOFRL. By adjusting the non linear coefficient of MOFs, pulse trains are obtained with different forms.

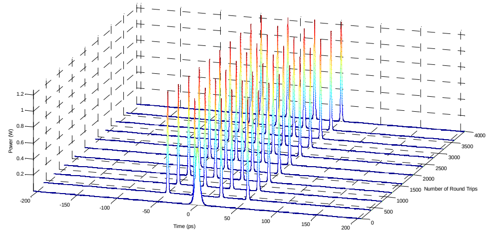

Figure 8: Numerically calculated pulse evolution in actively ring fiber laser, $\gamma_{MOF}=0.0012/w/m$

Finally, the pulse will be kept stable in a Gaussian or a hyperbolic secant-like shape, with a repetition rate dominated by the modulator and EDFA characteristics. This is also in agreement with many experiments involving the general ring mode-locking fiber laser [8-9].

IV. Conclusion

We have obtained stable multipulses by numerical simulation using MOFRL. We note that the pulse evolution is more sensitive to the EDFA characteristics than the other parameters of the cavity. We numerically predict the transient region and we show that a stable pulse train is generated with a pulse width of 2ps and a tunable repetition rate.

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