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GENERATION MODE STABILITY OF A FIBER RING LASER *

A.S. Gnatenko & Yu.P. Machekhin♦

Kharkiv National University of Radio Engineering and Electronics, 14, Lenin Ave, Kharkiv, 61166, Ukraine

♦Address all correspondence to Yu.P. Machekhin E-mail: foet@kture.kharkov.ua

To provide DWDM systems with a single source of radiation, it is possible to use a fiber femtosecond laser operating in the mode of generation supercontinuum. Functioning of a fiber ring laser operating in the mode of a train of ultra-short pulses is determined by the presence of liquid crystal polarizers being part of the resonator. Understanding of the control mode conception for passive mode locking by means of the liquid crystal polarizers is possible upon stable laser operating conditions. Therefore, it is purposed to study the conditions of sustainable modes of the ultra-short pulse fiber ring laser.

KEY WORDS: *fiber laser, non-linear amplification factor, coefficient of dispersion*

1. INTRODUCTION

Application of lasers in the informational technologies is based upon their permanent upgrading and development. Using of fiber lasers has become a separate, independent trend in the informational technologies. As a rule, those lasers, the active medium of which is formed by the one-mode quartz fiber doped by erbium ions, are operating in the 1.55 μm band.

Investigations of the fiber lasers capable of providing physical communication channels for DWDM (dense wavelength division multiplexing) systems on the basis of the frequency plan recommended by the ITU (International Telecommunications Union) standards [1] have been performed during recently. The traditional approach providing for drafting of the frequency plan is based on applying semiconductor lasers, where each of the lasers provides for generation within a specified frequency interval. But, of course, a large number of semiconductor lasers with power-supply units and systems for controlling the radiation frequency results in a substantial increase of the system costs. Implementation of the ITU frequency plan becomes possible due to application of the discrete spectrum of the supercontinuum generated in the fiber ring laser.

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A femtosecond fiber laser operating in the supercontinuum generation mode can be used for providing one source of radiation to the DWDM systems. Operation of the fiber ring laser working in the ultrashort pulse train mode is determined by availability of the liquid crystal (LC) polarizers included into a cavity. Understanding the techniques for controlling passive mode synchronization with the help of LC polarizers is possible under the condition of a stable operating mode of the laser.

The objective of this paper is investigation of the conditions for establishing the stable pulse generating mode in the fiber ring laser.

2. CONSTRUCTION OF A FIBER RING LASER

The basis for construction of the laser under investigation is formed by the well-known [2] scheme of a fiber ring laser (FRL) (Fig. 1). The fiber ring cavity and the active medium of the laser concerned are based on the SMF28 fiber with the negative value of the group velocity dispersion (GVD) having the length of 3.7 m and one-meter long section of one-mode erbium-doped quartz fiber with the positive value of GVD. The cavity includes: the multiplexer (WDM), which provides for the input of radiation from the semiconductor pump laser, the pump laser itself is operating at the wavelength of 980 nm. The GVD of SMF28 is estimated as -0.023± 0.005 ps^2/m. The GVD of the fiber extension used for the input is -0.007± 0.005 ps^2/m, and GVD of the erbium-doped fiber is 0.075± 0.005 ps^2/m [3,4]. Total GVD in the cavity is estimated as -0.013 ± 0.005 ps^2/m. While calculating GVD in the cavity, the parameters of the discrete optic elements were omitted because their total value is practically equal to zero.

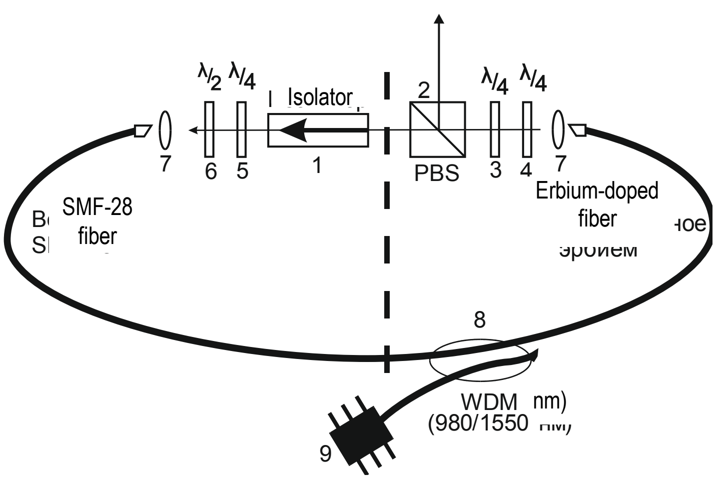

FIG. 1: Block diagram of the fiber ring laser:1– insulator; 2–PBS; 3,4,5 – $\lambda/4$ plates; 6 – $\lambda/2$ plate; 7 – lens; 8 – multiplexer; 9 – pumping diode

$$\widetilde{F}(t,\varsigma) = A(t)e^{-i\omega\varsigma}, \tag{2}$$

where ω is constant but the function $\widetilde{A}(t)$ is the complex field amplitude and it can be put down as

$$\widetilde{A}(t) = a(t)e^{i\phi(t)}, \tag{3}$$

where $a(t)$ is the real field amplitude and $\phi(t)$ are the real values of the phase as the function of *t*.

For non-linear systems the phase has the following form [7]:

$$\phi(t) = \phi_0 + d\ln(a(t)), \tag{4}$$

where d is the phase modulation parameter known as the chirp parameter [9] in the non-linear optics, ϕ_0 is an arbitrary phase, for the sake of simplicity it is recommended to accept that $\phi_0 = 0$.

After substitution into (1) (2) and (3) it is obtained

$$\begin{gathered}\omega \cdot a(t) = ig_1 \cdot a(t) + \\ +\left(\frac{\beta_2}{2} + i\rho\right)\left(\frac{\partial^2 a(t)}{\partial t^2} + 2i\frac{\partial a(t)}{\partial t}\frac{\partial \phi(t)}{\partial t} - a(t)\left(\frac{\partial \phi(t)}{\partial t}\right)^2 + a(t)i\frac{\partial^2 \phi(t)}{\partial t^2}\right) + \\ +(D_r + iD_i)a(t)^3\end{gathered} \tag{5}$$

From the equation (5) it can be obtained the system of two equations, composed of its real and imaginary parts:

$$\begin{cases} g_1 \cdot a(t) + \beta_2 \dfrac{\partial a(t)}{\partial t}\dfrac{\partial \phi(t)}{\partial t} + \dfrac{\beta_2}{2}a(t)\dfrac{\partial^2 \phi(t)}{\partial t^2} + \rho\dfrac{\partial^2 a(t)}{\partial t^2} - \rho a(t)\left(\dfrac{\partial \phi(t)}{\partial t}\right)^2 + D_i a(t)^3 = 0 \\ -\omega \cdot a(t) + \dfrac{\beta_2}{2}a(t)\left(\dfrac{\partial \phi(t)}{\partial t}\right)^2 - 2\rho\dfrac{\partial a(t)}{\partial t}\dfrac{\partial \phi(t)}{\partial t} - \rho a(t)\dfrac{\partial^2 \phi(t)}{\partial t^2} + D_r a(t)^3 = 0 \end{cases} \tag{6}$$

For the convenience of putting down it is performed the substitution: $a(t) = a$, $\dfrac{\partial a(t)}{\partial t} = a_t{}'$, $\dfrac{\partial^2 a(t)}{\partial t^2} = a_{tt}{}''$.

The equation (10) has the form of a differential equation with separable variables. Its solution will be

$$a(t)=\sqrt{\frac{g_1}{\rho d^2-\rho-\beta_2 d}}\cdot\sqrt{\frac{3d(4\rho^2+\beta_2^2)}{2(\beta_2 D_i-2\rho D_r)}}\sec h\left(\sqrt{\frac{g_1}{\rho d^2-\rho-\beta_2 d}}\cdot t\right). \quad (11)$$

From the expression (11) there can be determined the stability conditions. The pulse is excited only when the parameters of optical non-linear system (see Fig. 1) in our case, have the following values: the linear amplification is $g_1>0$, the dispersion coefficient is $\beta_2<0$ to avoid pulse broadening, the non-linear amplification factor is $D_i>0$, and the phase self-modulation coefficient is $D_r<0$. At the above parameters the fiber ring laser have the stable pulse, which is similar to the Gaussian one (see Fig. 2).

4. CONCLUSIONS

The model of the fiber ring laser based on the erbium-doped active fiber is developed. It is developed and investigated the mathematical model of the fiber ring laser on the basis of the Ginsburg-Landau complex equation (1). Numerical analysis of the equation (1) is performed, and the stability conditions for the optical non-linear system shown in Fig. 1 – the linear amplification is $g_1>0$, the dispersion coefficient is $\beta_2<0$ to avoid pulse broadening, the non-linear amplification factor is $D_i>0$ and the phase self-modulation coefficient is $D_r<0$ – are determined as the result of the above analysis. These conditions provide for the possibility of obtaining stable pulses similar to the Gaussian shape. Subsequently, the above conditions will also be investigated with the purpose of obtaining ultrashort pulses that will be attained by means of receiving passive mode synchronization due to active and passive media and rotation of wave plates.

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