Mode locking in a fiber femtosecond laser using liquid crystal cells

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***Abstract*— In this paper, we present the configuration of erbium-doped fiber laser. The laser operates in passive mode locking. Usually in existing schemes fiber ring laser using mechanical adjustment mode locking by rotating in the space of the wave plates. In our optical system, we propose to use voltage-controlled liquid crystal cells, to replace conventional polarization controllers (quarter-half-wave plate) inside the laser cavity. Using this innovation, freed from the mechanical adjustment mode locking, we plan to obtain the pulse width of the order of hundreds femseconds and an average power output of the order of tens milliwatts.**

***Keywords*— fiber laser; femsecond; liquid crystal; polarization; wave plate.**

I. Introduction

The key idea for using of lasers in information technology is their continuing improvement and modernization. Application of fiber lasers in information technology has become a free-standing and separate scientific field.

Nowadays are carried out studies of fiber lasers that are capable of physical channels for DWDM systems based on the frequency plan which is recommended by the ITU [1]. The traditional approach, which ensures the formation of the frequency plan based on the use of semiconductor lasers, each of which provides the generation of a specific frequency range. However, a large number of semiconductor lasers with power supply units and control systems of radiation polarization with mechanical control, leads to a significant increase in the cost of the system. Therefore, the aim of this work was to study and develop a femtosecond fiber laser using liquid crystal (LC) polarizers in the resonator.

Modern fiber femtosecond lasers with passive mode locking are not only short pulse duration (typically 500 fs), and a pulse repetition frequency (from tens up to hundreds MHz), but also availability of optical components, and importantly relatively small dimensions. Typically, mode−locking in fibre lasers is achieved using nonlinear polarization rotation (NPR) effect [2-3]. NPR in combination with intracavity polarization beam splitter works as an artificial saturable absorber. When pulse propagates inside the cavity its centre experiences different polarization rotation than its slopes. Polarization beam splitter assures that the pulse centre propagates with smaller losses than the slopes which favours pulse mode operation over CW and leads to shortening the pulse that circulates inside the cavity. For mode-locking is required to polarization inside the resonator are correctly oriented, which is usually achieved by recruiting a quarter and half-wave plates. Once the orientation of the plates is set so that mode locking is obtained, and assuming stable environmental conditions, no further adjustments are needed in order to maintain pulse operation of the laser. However, any temperature drift, the fluctuations of the pump power, laser on-off can affect the mode-locking. As a result, in practice, a set of quarter-wave and half-wave plates inside the cavity to be adjusted from time to time manually or automatically (e.g., using stepper motors). This is a significant drawback of the method NPR mode locking, as it requires constant maintenance (manual adjustment plate) or an increase in the total cost of the laser (automatic adjustment of the plate). Passive mode locking using a saturable absorbers - this is another method which has been widely studied and applied [4-5]. But usually, such lasers also require proper adjustment of polarization inside the resonator to receive the mode locking. Although some configurations based on polarization maintaining fiber (PP) have been demonstrated [6], which has a significant drawback high cost of fiber. Also, these lasers have a much output longer pulses and lower power. Thus, we define a method NVP mode locking as the main method for generating femtosecond pulses with considerable difficulties that are associated with the need to control intra-cavity polarization state, which is necessary to obtain and maintain mode locking. Therefore, we propose that the wave plate to use the LC polarizers, which are no worse than wave plates and are already widely used as part of many devices: optical tweezers [7], microscopy [8] or the formation of pulses [9]. But the main advantage for us is that the birefringence of the LC may be changed by a relatively small electric field, which can easily turn the LC cell into variable retarders or complete polarization controller [10]. In this paper, we propose to control the polarization inside the resonator using the LC cell in erbium-doped fiber laser femtosecond mode-locked. Set of four cells automatically, using no high voltage adjust mode locking. It also discusses the advantages and disadvantages of this new configuration. Understanding the control mode passive mode locking using the LC polarizers possible if stable operation of the laser. In more detail the conditions of stable operation has been described in [11]. Theoretical study of the stable operation of the laser is to study the complex Ginzburg-Landau equation:

$$i\frac{\partial F(t,\varsigma)}{\partial\varsigma}=ig_1F(t,\varsigma)+(\frac{\beta_2}{2}+i\rho)\frac{\partial^2F(t,\varsigma)}{\partial t^2}+ (D_r+iD_i)F(t,\varsigma)\left|F(t,\varsigma)\right|^2, \quad (1)$$

The stationary solution of equation (1) has the form:

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

$A(t)$ is a complex-valued function and can be written as:

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

Next, we use:

$$\phi(t)=\phi_0+d\ln(a(t)) \quad (4)$$

where d – phase modulation parameter known in nonlinear optics as chirp parameter [12], ϕ_0 – an arbitrary phase, for simplicity it has been suggested to take ϕ_0.

On substituting equations (2-4) into equation (1) and its solution can be determined as:

$$a(t)=\sqrt{\frac{g_1}{\rho d^2-\rho-\beta_2 d}}\cdot\sqrt{\frac{3d(4\rho^2+\beta_2^2)}{2(\beta_2D_i-2\rho D_r)}}\cdot \sec h(\sqrt{\frac{g_1}{\rho d^2-\rho-\beta_2 d}}\cdot t) \quad (5)$$

Pulse exists when linear gain is as follows - $g_l>0$, the dispersion coefficient is equal to $\beta_2<0$, it was specified in section 2, the coefficient of nonlinear gain is $D_i>0$ and phase modulation coefficient is equal to $D_r<0$. With these parameters, we have a stable pulse similar to the Gaussian, see Fig. 1. $D_i>0$ nonlinear extension coefficient depends on the

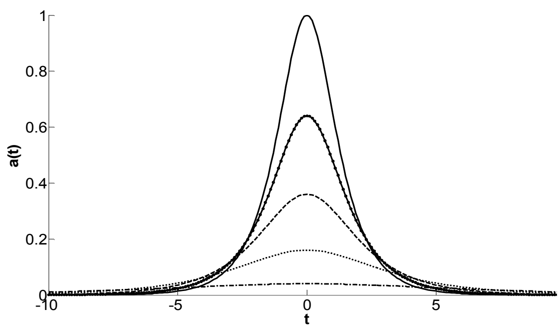

Fig1. Dependence of pulse amplitude versus time

position of the wave plates, thereby rotating of the wave plates can increase the impulse amplitude and also the duration, which is required to achieve passive mode locking.

II. PASSIVE MODE LOCKING WITH LC CELLS

Fig.2 Image of liquid crystal polarizer

In this study, we will use a nematic liquid crystal developed in Minsk, Bellary. The birefringence of 1.5 micrometers was Δn = 0.35, anizotropy permittivity was 17 at a frequency of 1.5 kHz. LC cells were obtained by a sandwich of two glass plates with electrodes are coated polyimides for homogeneous orientation of the liquid crystal material. The active area of the electrodes was 150 mm2, and the distance between the plates was from 5 to 10 microns, Fig.2.

As mentioned in the introduction, the method of NPR mode locking best choice for ultrashort pulse generation and optical frequency comb fiber lasers. The lasers based on NVP [typical optical circuit shown in Fig. 3] mode locking is obtained when the polarization state within the resonator is properly aligned.

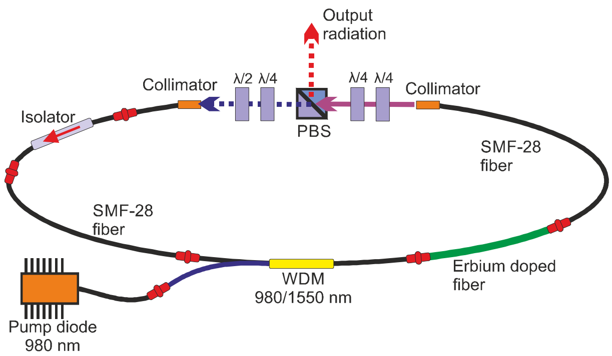

Fig.3 . Picture of a fiber ring laser with wave plates

This is usually achieved by a set of wave plates which may be rotated around its axis. In practice the number of wave plates depends on many factors and can vary. In some examples, the two full polarization controller (CP) (before and after the polarization divider cubes (PBS)) [13], in some schemes in the correct position the fiber ensures that mode locking is obtained with one of the CP (placed before PBS) [14]. Other examples include two [15], three [16] or four [17] wave plates. However, the biggest problem is not the number of wave plates, and the mechanism of their regulation. In most cases, the position of these plates must be adjusted manually. Since any motion of the fibers, temperature, or even switch button pump can lead to loss of mode locking, these changes require constant supervision. There are examples of systems where the wave plate is adjusted with motorized holders or electronic control provisions fibers [18-19], but this increases the cost of the device. We propose to use the LCD cell voltage-controlled, instead of the wave plates. The optical scheme is shown in Fig. 4. The laser fiber ring resonator and active medium both are formed on the basis of SMF28 fiber (with negative group-velocity dispersion - GVD) which is 3.7 m in length and of 1m Er-doped fiber. The resonator structure consists of: a multiplexer (WDM) which provides beaming input of a diode pumping laser, the pumping laser itself operates at the wavelength of 980 nm. GVD of the SMF28 is measured with value of 0,023 ± 0,005 ps / m. GVD of the fiber nub for the input is measured with value of 0,007 ± 0,005 ps / m, and GVD of the erbium fiber is measured with value of 0,075 ± 0,005 ps / m [20-22]. The total GVD of the laser design corresponds to -0,009 ± 0,005 ps / m. This condition contributes to the passage of light in the ring resonator of a femtosecond order pulse compression , and it is not distorted. Thus, we will get the output radiation of femtosecond duration of the order.

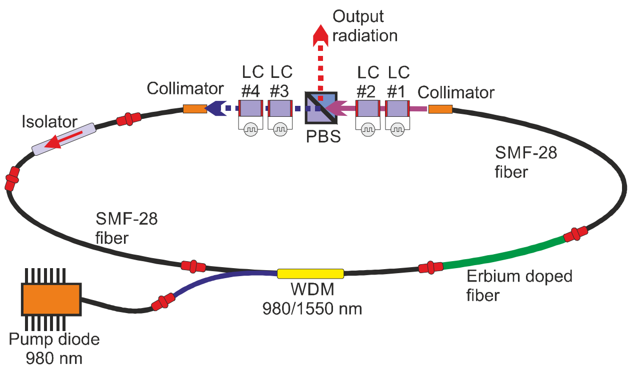

Fig.4 . Picture of a fiber ring laser with liquid crystal polarizators

Liquid crystal cells # 1, # 2 provides full control of the polarization of light to PBS. Two additional wells were located after a polarizing cube to control the polarization after the PBS. Maybe eventually we give up four cells and simplify the single-cell before and after PBS. The pump source we use a laser diode with a wavelength of 974nm, a maximum output power of 330 mW, Fig.5.

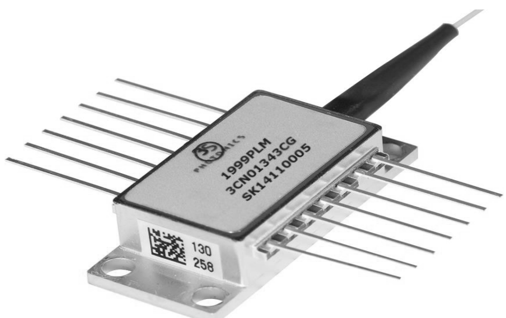

Fig. 5. Laser pump diode

Amplification part consists of an erbium-doped fiber 100 cm. Also, we have developed current control system of the pumping diode and thermal stabilization system (control peltier element). When connecting the pump laser to the system stabilization and control the current pump laser operated stably and output the 330 mW, which corresponds to its passport data, the measurement was carried out with a power meter company OPHIR. It was also studied the spectral composition of light, Fig. 6. The result was a stable multimode structure that was observed during the time change or shift of spectral components. These results demonstrate the effective and correct operation of the system of thermal stabilization, since a change or fluctuation in temperature of the laser diode, there is a change or shift of the emission spectrum.

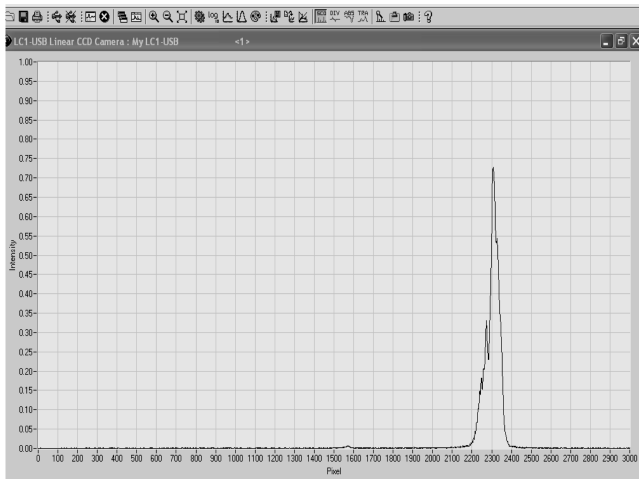

Fig. 6 Picture of the spectral characteristics for the diode pumping

Current control system of the pump laser diode can is universal, because adding an external transistor circuit can be achieved currents up to 20 A, and if the scheme include multiple NCP3065 chip in parallel, the currents can reach more than 60 A. For example, the pump current of 80 A, we have included in the system of three parallel circuits, respectively, increases the size of the system in connection with the use of such a large current inductors and transistor, but the system was stable. Ease of implementation and effective operation makes it possible to use our system to control the pumping of high-power semiconductor laser diodes, as well as all types of diode-pumped lasers. The voltage on the LC cell is controlled by a pulse generator developed by us, that can control not only the signal amplitude, and frequency. Also, most likely at the laser output will need to put additional collimator for collection beam, which will be delivered to the spectrum analyzer and durable device for measuring pulse characteristics later.

III. Conclusion

The main problem of passive mode locking laser is a constant adjustment of the polarizers to provide a stable, trouble-free operation of the laser. This contributes to the development of polarization controllers for the automatic control mode-locked. Usually this is done mechanically, for example by rotating the wave plates in the space [23]. To get rid of this, we propose to replace the wave plate for LC polarizers, which differ inexpensive cost. A similar method of mode locking laser with LC has been recently proposed in [24], where the LC cell was used to run mode locking. But in the scheme mode locking are also configured manually. We assume that presented in this paper laser configuration, in which the polarization setting by using the LC cells that need to take full control of the polarization. Thus we can always quickly restore mode locking even when the physical change or impact on the laser.

We believe that our work provides a good reason for further research in this direction. We hope that with the characteristics of the laser will not be worse than the typical constructions of earlier: the optical spectrum of > 20 nm, pulse repetition rate > 20 MHz, pulse duration < 200 fs and an average power output of the order of tens milliwatts. И Most importantly, the four LC cell with a relatively low voltage (0 to 10V), with a frequency of 1.5 kHz, there is no need to use wave plates, saturable absorbers and other retarders. The pulse generator to control LC cell was made by us with the chip NE555. Thus, the device with all the optical components and electronic support is relatively expensive in comparison with existing femtosecond lasers and easy to implement and configure. And this is the key priorities for the use of modern devices. It has been said the main advantages of our configuration consists in the simplicity of scheme, low cost and quick setting operation of the laser.

But also in the study are likely to be disadvantages, which are as follows: we do not know how many will serve an LC cell. In our experiments, we will not use high output power, so the problems with it will not. We will try to raise the power characteristics of the laser in the future, but do not know how will behave LC cell at high power. We will explore this later. Также неизвестно как будут вести себя ячейки при изменении окружающей среды с критическими температурами. At this stage, we developed a stand, whose work is carried out at room temperature. All the alleged deficiencies will be tested in further studies.

In this paper, we proposed a scheme fiber ring femtosecond laser that operates in passive mode locking. This mode is achieved by introducing into the resonator of LC cells, and they control the polarization. Polarization is controlled by a voltage applied to the LC cell. T Also, it can be assumed that the laser can operate in different modes of synchronization modes. This laser should generate pulses of less than 200 fs, which corresponds to more complex same structures, with an average power output of 10 to 20 mW.

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