1,55 mkm fiber laser with electronic controlled mode-locking

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***Abstract* —A projection of an erbium-doped active-fiber laser is offered in this research paper. Mode synchronization method — the nonlinear evolution of mode polarization, is used to ensure the duration of femtosecond pulses. The basis of this method uses liquid crystal controllers polarization, which is controlled by an electrical signal. The proposed scheme and method for obtaining ultrashort pulses are free from the unstable operation of the laser.**

Keywords — fiber laser, polarizer, liquid crystal cell, mode locking.

I. Introduction

The conditions for obtaining ultrashort optical pulses were created in the middle of the last century due to the development of laser physics and technology. The sources of generation of femtosecond pulses were implemented on the basis of a titanium-sapphire laser. Further practice of obtaining femtosecond pulses was created on the basis of lasers with other active elements. One of such lasers was a fiber laser based on quartz fiber activated by erbium ions. The development of fiber lasers was carried out in two directions: lasers with a linear resonator configuration and with a ring resonator configuration. Femtosecond lasers based on both designs were created. However, the conditions of mode locking can be based on different mechanisms. One of the latest mode locking mechanisms is based on the nonlinear control of the longitudinal modes polarization in a ring fiber laser. The main problem of using the method for controlling the nonlinear polarization of longitudinal modes in order to get the mode locking is the use of mechanical methods for controlling polarization. Recently there have been attempts to use non-mechanical methods for controlling the mode polarization. The relevance of the proposed studies becomes clear following the established trends in the search for mechanisms controlling the mode polarization. The relevance of the research work lies in the need to study liquid crystal (LC) cells, which in turn are controlled by electrical signals and are devoid of mechanical control parts, in the capacity of controllers polarization in order to ensure mode locking using nonlinear evolution polarization method (NPE) in a ring fiber laser and to obtain ultrashort pulses. It should be noted that there are works in which the use of a single LC polarization controller is shown to trigger the NPE in an erbium fiber laser, where the fiber itself was tuned so that one element can control the polarization. However, this projection did not allow compensating for changes in the birefringence of the fiber over time or for the influence of the environment. Thus, both the development and implementation of more advanced mechanisms for starting the mode-locking regime based on the fiber laser NPE remain a live issue today.

II. Studies of the fiber laser with electronic controlled mode-locking

Fiber lasers with mode locking obtained due to the nonlinear polarization evolution (NPE) of the emission, are unique optical sources with parameters implemented in a wide range of both pulse durations and energy for various forms of these pulses [1], are very much in demand in information science and in other fields. The pulse generation was realized shorter than 36 fs [2], 4 μJ pulse energy was obtained (without additional amplifiers) [3] in such lasers. Therefore, the NPE mode locking method is the best choice for obtaining an ultrashort pulse and generating a comb of the optical frequencies in fiber lasers. The polarization state of the beam inside the laser resonator may vary depending on the radiation intensity when interacting with the material, in lasers with NPE. In combination with a polarizer, the nonlinear rotation of the polarization can be configured as a saturable absorber, where the reduction of optical losses in the resonator with increasing radiation intensity is used to stimulate the formation of an output laser pulse [4]. The NPE mechanism is very flexible due to having a wide bandwidth, which ensures the shortest possible pulse duration, and is also resistant to damage or long-term degradation of optical elements. To achieve the required loss with saturation, it is necessary to control the polarization of light in a nonlinear medium. This is usually accomplished by using one or more controllers polarization (wave plates) that rotate to achieve the desired polarization state. For this, motorized polarization rotators [5-6] were proposed and demonstrated [7] for automatic mode locking. Alternatively, polarization control can be accomplished by applying force (fiber bending) to the fiber in order to control birefringence [8]. It was also demonstrated that thermodynamic polarization regulators can be used for mode self-locking [9]. However, motorized elements and those based on thermal effects can be slow, requiring considerable time

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the theoretical and experimental curve of the dependence of the emission polarization rotation angle on the voltage applied to the LC cell.

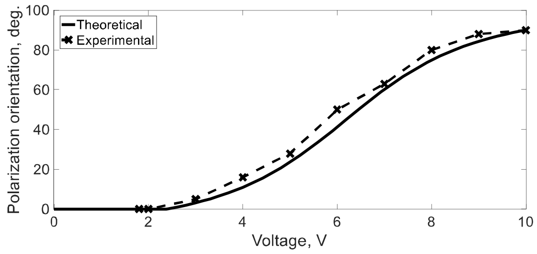

Fig.5: Dependence of the emission polarization rotation angle on the voltage applied to the LC cell

Fig. 5 shows that there is a cutoff voltage, which in our case is 2.2-2.5 V, in nematic planar LC cells. It follows from the theoretical curve that the polarization angle in space varies from 0 to 90 ° with applied voltage from 2.2 to 10 V. When a voltage of more than 10 V is applied, the LC cell "is saturated" and the polarization rotation angle changes very little, while an electrical breakdown of the LC layer may occur if the voltage is applied more than 10 V. The experimental curve, Fig.5, practically coincides with the theoretical one; the cause of the minimal difference may be the error of measuring devices or calculation methods. In an experimental study, a voltage of different amplitude (from 0 to 10 V) was applied to the LC cell in the form of a meander with 1 kHz frequency.

Solving equation (3) together with the Oseen-Frank equation, we obtain the following:

$$I(U) = \left[1 - \sin(2\alpha 1)\sin(2\theta(U))\right]/2 + \\ + \left[\cos(2\alpha 1)\cos(2\theta(U))\cos(2(\alpha 1 + \theta(U) - 2\alpha 2 + \Delta\phi))\right]/2, \quad (4)$$

After studying the equation (4), it can be concluded that the maximum values of the emission intensity transmission through the laser optical system will appear under 3.9 V, 7.1 V and 10 V voltage applied to the LC cell, at a fixed position of the quarter wave plates relative to the axis of the LC cell, namely 80 and 90 °, Fig. 6

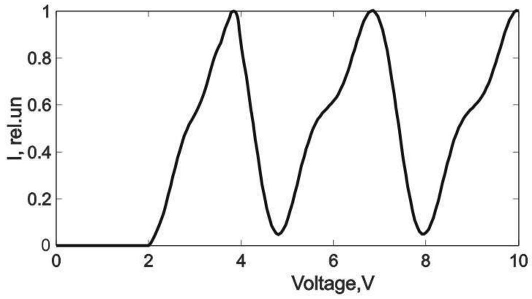

Fig.6: The dependence of the intensity of the emission passing through the optical system of the laser on the voltage applied to the LC cell.

Thus, the conducted studies prove that the LC cells can be used as polarization controllers to provide mode locking in ring fiber lasers.

CONCLUSIONS

A new method of mode locking using NPE in ring fiber lasers is described in this research paper. The proposed ring fiber laser scheme can completely replace existing lasers of this type and semiconductor emission sources for information transmission, which provide the frequency plan recommended by ITU in DWDM systems. We also analyzed the dispersion characteristics of the fibers, which are used in the construction of lasers of this type, and the lengths of the fibers for the implementation of a ring laser were quantified. In Section 4, the stability of polarization was analyzed for the NPE realization in the proposed laser scheme by solving the nonlinear Ginzburg-Landau equation. And also the theoretical and experimental electro-optical properties of LC controllers polarization were investigated by numerically solving the Oseen-Frank equation, the theoretical results obtained largely coincide with the experimental ones. The work fully demonstrated the possibility of controlling the emission polarization by an LC controllers polarization, for the NPE realization in ring fiber lasers.

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