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DESIGN OF MAGNETOOPTICAL ROTATOR FOR THE SWITCH OF A TWO-WAVE LIGHT FLUX IN FIBER-OPTIC COMMUNICATION NETWORKS

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In the work the possibility of creation of the Faraday rotator based on two planar-oriented magneto-optical film elements for modulating the planes of polarization of the two light beams with wavelengths of 1310 and 1550 nm with angular amplitude of ±45º is shown. An example of using of such rotator in the optical scheme of the switch of a two-wave light flux is examined.
Keywords: magnetooptical rotator, epitaxial ferrite-garnet film, the optical switch, fiber-optic.
PACS: 42.79. ± e

INTRODUCTION

One of the reasons preventing the widespread adoption of an all-optical WDM technology in fiber-optic communication networks is absence of optical switches that can completely replace the existing devices in which the switching is done by converting the light-electricity-light. The solution to this problem on the nearest future is associated with the development of optical switching technologies, which are based on the active optical elements providing passing of a light signal through switching system.

One of such technologies utilizes magnetooptical (MO) material, having Faraday effect, as an active optical element. With the annex to it a pulse magnetic field parallel to a beam of light, there is a modulation of the plane of the polarization of the linearly polarized light that applied to the input of the MO element. Switching of a light flux in such switches is carried out by polarization beam splitters, that adjacent to the output of the MO element [1-3]. Magnetooptical rotators (in this case MO elements with coils of the solenoid magnetizing them) in the mentioned works contained one MO element, which, owing to spectral dependence of coefficient of Faraday provided operation of the switch only on one of lengths of waves of telecommunication spectral range.

The aim of the present work is to check the possibility of creation of the magnetooptical rotator (MOR) based on two planar oriented to its optical axis MO elements, each of which acts on own wavelength. The main essence of a problem consists in receiving out of grown on a 3 inch substrate epitaxial ferrite-garnet film (EFGF) of the MO elements that capable to produce the equal angle rotation of the plane of polarization of light beams with specifically designated for MO elements wavelengths at joint magnetization by one inductor of a magnetic field.

1. STRUCTURE OF THE MOR AND ONE OF POSSIBLE SCHEMES OF THE SWITCH ON ITS BASIS

One of possible optical schemes of the switch of light fluxes with lengths of waves of 1310 and 1550 nm, that can be realized with the help MOR represented in this work is shown in Fig. 1.

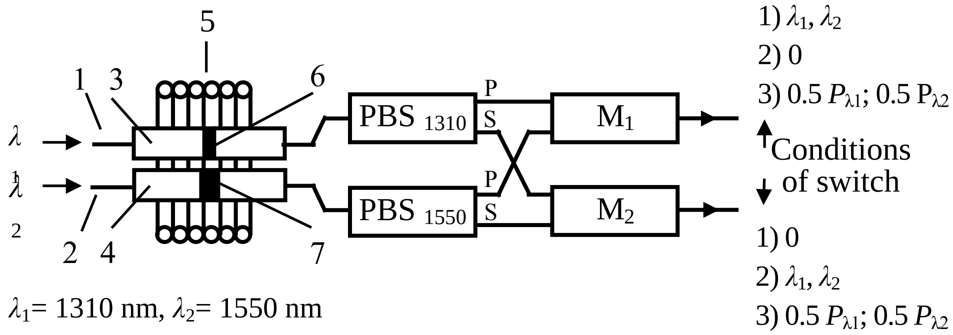

Fig. 1. Scheme of optical switch.

Basic elements of the MOR are the inductor of a magnetic field 5 in the form of the solenoid and the planar MO elements 6, 7 oriented by along its axis, which are made of EFGF. To the inputs of MO elements is summed polarization maintaining optical fibers 1, 2 of the “Panda”. The fibers are connected to the MO elements via by planar glass ferrule 3, 4. From exits of MO elements by means of similar ferrules 3, 4 light fluxes with wavelengths of 1310 and 1550 nm, through polarization maintaining fibers, are supplied in polarization beam splitters PBS_{1310} and PBS_{1550}. The optical signals arriving to their entrances splits on orthogonally polarized S and P components and come to the inputs of the multiplexers M_1, M_2. Where S components of the both of wavelengths are sent to, the M_1 multiplexer, and P components are sent to the M_2 multiplexer.

Distribution of the signals with the wavelengths of 1310 and 1550 nm at the exits of these multiplexers i.e. the switch depends on polarization state of light at the exits of MOR. Therefore, the size of MO elements L_{1310} and L_{1550} for the corresponding wavelengths in the direction of light propagation must be such that, the magnetic saturation field H_S provides rotation of the planes of polarization of either 90°, if unipolar magnetizing device is used, or to ± 45°, if bipolar magnetizing device is used. The need of polarization modulation with such angular amplitude is dictated by the physical mechanism of action of the polarization beam splitters, where one of conditions of complete separation applied to their inputs linearly polarized signals is strictly orthogonal plane of polarization of the signals.

In this work, MOR with bipolar magnetizing device was simulated and investigated. The switch with such rotator can be in three conditions and works as follows.

The fluxes of light, with wavelengths of 1310 and 1550 nm with the equal orientation of the polarization planes, through fiber ports are supplied to the corresponding to them

MO elements of the MOR. When in the solenoid there is no electric current, the planes of polarization at the outputs of the MO-elements are oriented at an angle of 45º to the axis of birefringence of the input fibers of the splitters PBS_{1310} and PBS_{1550}. In this state, the light fluxes, that entering in the polarization splitters by each are divided into two equal fluxes and signals are sent to both wavelengths in the both multiplexer. Thus, in the both output ports of the switch are present the optical signals with both wavelengths, and the operation of the switch is implemented in broadcast mode. Distribution of signals corresponding to this condition between two output ports of the switch is labeled 3 in Fig. 1.

At inclusion of a magnetic field of one of a polarity, i.e. $+H_S$, or $-H_S$, then the Faraday rotation angle, respectively, +45º or -45º. Plane of polarization of the light beams at the output MO elements are oriented, respectively, along one or another of the axes of birefringence fibers. In one of these states of the switch, polarizing splitters directs fluxes of the lights with their respective wavelengths to the respective inputs one of a multiplexers and both flux of the lights come out via its output port, or the corresponding output of the switch. In the second of these states, due to the polarization plane rotation by 90° in the reverse direction, the fluxes of the light via polarization splitters will be directed to the second spectral multiplexer and they come out from second output port of the switch. Corresponding to these states distribution of the signals between the two output ports of the switch in Fig. 1 indicated by numbers 1 and 2.

2. CALCULATION AND FABRICATION OF MO ELEMENTS FOR THE MOR

As it was noted above, in our case, switching between output ports of the switch is carried out by magnetic fields of $+H_S$ and $-H_S$ which provide EFGF magnetization before saturation, alternately, in the direction and against the direction of light propagation inside the films. Thus for each of the operating wavelengths the optical path length $L(\lambda)$ in EFGF layer must be such that the Faraday effect can provide rotation of polarization of light by an angle of $\theta = \pm 45°$. These the longs of the optical paths or in other words the longitudinal dimensions of MO elements are calculated by the formula

$$L(\lambda) = \frac{45^{\circ}}{\theta_F(\lambda)}, \tag{1}$$

where $\theta_F(\lambda)$ – specific Faraday rotation for the used EFGF on operating of wavelengths of the switch.

$\theta_F(\lambda)$ determined by according to the method described in the work [4], which allows to investigate Faraday rotation on different lengths of waves of near infrared range when light passes into the films plane.

The starting material for the manufacture of MO elements of MOR was EFGF with the thickness of 12 μm, consisted of $(BiLuCa)_3(FeGaV)_5O_{12}$, grown the method of liquid phase epitaxy from solution-melt on GGG substrate with a crystal orientation of (111), thickness of about 500 μm end diameter of 76 mm. The specific Faraday rotation of the EFGF at 1310 and 1550 nm was, respectively, 93.4 and 60.9 °/mm. EFGF has a magnetic anisotropy of the "angle phase" with the saturation fields along the axis of easy and hard magnetization intensity of 1 and 30 Oe, respectively.

Based on this EFGF with the help of the method, briefly described in [5] for each of the operating wavelengths were manufactured optical modules OF-EFGF. Optical module OF-EFGF, which is, united in a single design with MO element and optical fiber "Panda". The input and output edges of a films of optical modules are plane parallel, end optically polished so that light extended along an axis of its easy magnetization.

The longitudinal sizes of the MO elements L_{1310} and L_{1550} in optical modules had to satisfy to the values calculated on above given formula, respectively 0.48 and 0.74 mm. These values serve as a guideline for selecting the longitudinal sizes of blanks of EFGF for elements with a stock of length necessary for carrying out technological operations of polishing film edges. It is necessary to note that this technology in our case includes the final polishing operation to minimize the broken layers of EFGF, which can worsen the work of MO element in the device. In the process of finishing polish removes a layer thickness of about 1-2 μm.

In the present study, MOR was made without adjacent to the outputs MO elements of optical fibers (on the right) and the following them remaining components of the switching circuit. Its main feature is the fact that both modules FO-EFGF and magnetizing device are assembled into a single structure with rigidly fixed elements in it. This ensured the permanence conditions of magnetization of both MO elements in the research process. As the magnetizing device, the inductor, in the form of the solenoid coil from a copper wire with a diameter of 0.67 mm. The number of turns in the coil 16, the packing factor is 0.74, along the length of the coil is 11 mm, an inner diameter is 10 mm.

OF-EFGF modules are arranged inside the inductor, so that their optical axes are parallel to the axis of the solenoid coil.

3. RESULTS OF RESEARCH OF THE MOR AND THEIR DISCUSSION

During the research of the MOR measured by the angles of rotation and the degree of polarization of the light at the outputs of modules FO-EFGF during magnetization in direct and the reverse to light the directions and in the absence of the field, as well as optical losses in the modules. Moreover, the response of MOR to magnetic reversal by impulses of a magnetic field with a fixed frequency of 125 kHz was investigated.

Fig. 2 shows a diagram of the experimental setup for studying the MOR.

Radiation of semiconductor lasers 1 and 2 with wavelengths of 1310 and 1550 nm through of connectors 3 is sent into moduls OF-EPFG of the MOR via the corresponding regulators of the planes of polarization of light 4, 5. In our case, these regulators were adjusted so that the planes of polarization coincided with the planes of films. Such orientation was considered reached when the axis of the maximum transmission of the analyzer 9 of polarization coincided with the film plane in lack of a magnetic field. Measured at the same time, the degree of polarization of the light in the output of each MO element of the MOR was not less value 0.98. The analyzer of polarization was supplied with a limb by means of which it was possible to count the turn of the plane of polarization of light with the accuracy of 0.5º. The signal from the polarization analyzer stints on the germanium photodetector 10 connected to the amplifier of photocurrent 11. The amplified electrical signal proportional to the intensity of light on an entrance of a photodetector, was fed to the input of the digital voltmeter 12 in static measurements or vertical channel oscilloscope 14 for dynamic measurements.

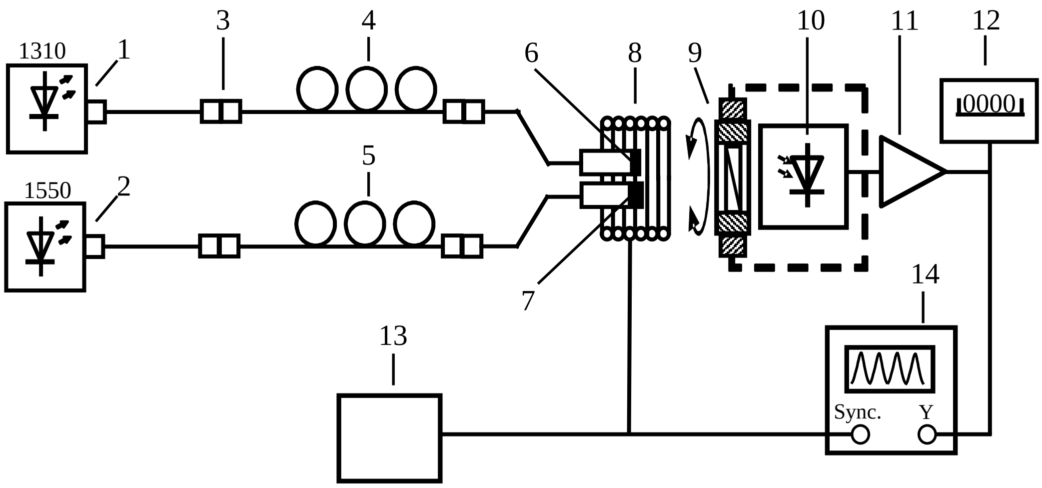

Fig. 2. Diagram of the experimental setup for studying the MOR.

When measuring the rotation angle and the degree of polarization of the light intensity of the magnetic field it was possible continuously change from -20 to +20 Oe in proportion to change of the current, transiting through in the inductor 8 from -1.5 to +1.5 A.

Measurements of angles of Faraday rotation yielded the following results: in the optical channel with a length of wave of 1310 nm the angle of rotation in both directions of magnetization of MO element made average $\theta_{1310} = \pm(45.7 \pm 0.5)°$, in the optical channel with a length of wave of 1550 nm – $\theta_{1550} = \pm(45.2 \pm 0.5)°$. The degree of polarization of the light output of both optical channels was not less than the value 0.98.

When using the MO film in the amplitude modulator or the switch of the light may be deviations from the required angle rotation the plane of polarization by an amount $\pm\Delta\theta$, caused for example by variations λ in the optical network. These deviations can lead to a deterioration modulation depth of the optical signal for the modulator or crosstalk for the switch.

In this regard it should be noted that according to the calculations given in [6] such deviations within the bandwidth of ±40 nm around the wavelength of 1550 nm will make only 0.3 %. Therefore, it is possible to predict that in difference, for example, from EO of modulators based on niobate of lithium, MO the modulator can potentially possess spectrally independent characteristics within the operating band erbium-doped fiber amplifiers, which have, rather equal coefficient of strengthening in the range of lengths of waves of 1520-1570 nm. This can be used to create optical switches for WDM systems using DWDM technology in the wavelength range of 1520-1570 nm.

At studying of a response of MOR on remagnetizing magnetic field the source of a magnetic field was connected to the pulse power 13 (Fig. 2) unit which gave rectangular voltage pulses of 4 μs duration with controlled amplitude variations up to ±5 V at a fixed frequency of impulses of 125 kHz. The signal from the photo diode of the photoreception module through the amplifier 11 arrived on a measuring entrance of an oscillograph 14. At inclusion of a source of a magnetic field and a laser source of one of optical channels at the exit of MOR corresponding to it modulation of the plane of polarization was observed. The analyzer thus remained in the position of fixing 45-degree rotation of the polarization plane of the previous measurements.

Fig. 3 shows the waveform (below) of electric pulses applied to the solenoid, and the waveform (above) of optical pulses registered on each of two outputs MOR. Oscilloscope sweep was 5 μs/div.

The electric pulses supplied to the inductor of magnetic field have amplitude of ±2 V. This is the amplitude of the voltage with which for used in MO a rotator of EPFG there came the magnetization of the saturation, providing a predetermined angle of rotation of polarization, and respectively the maximum amplitude of optical impulses in this experiment.

The received oscillograms show that time of increase and signal falling for each of exits of MOR on two lengths of waves of 1310 and 1550 nm makes 4 μs. That is, per such a time there is a switching the plane of polarization in both optical channels of MOR. Consequently, MOR in the submitted version is able to provide the speed switch of 4 μs.

Some inclination, which is observed on oscillograms at fronts of impulses of the response of the MOR on given impulses of voltage, is explained by existence of a quite considerable inductance of the used solenoid. When using inductors of a magnetic field of other type, for example, the strip line, this time can be reduced considerably. So in work [6] with such inductor of a magnetic field on a surface of MO film was achieved modulation of polarization, at which the time between maxima of intensity made about 1 ns.

Optical insertion losses of the MOR were measured by the substitution method at the disconnected magnetic field. In both long-wave channels they were at the level of 1.5 dB. Here, the main reason of loss is the Fennel reflection at the interface optical fiber-EFGF associated with relatively large difference between the refractive indices of the fiber core (≈ 1.47) and EFGF (≈ 2.2). These losses can be considerably reduced by use of immersion material or applying antireflection coatings on the edges of the film.

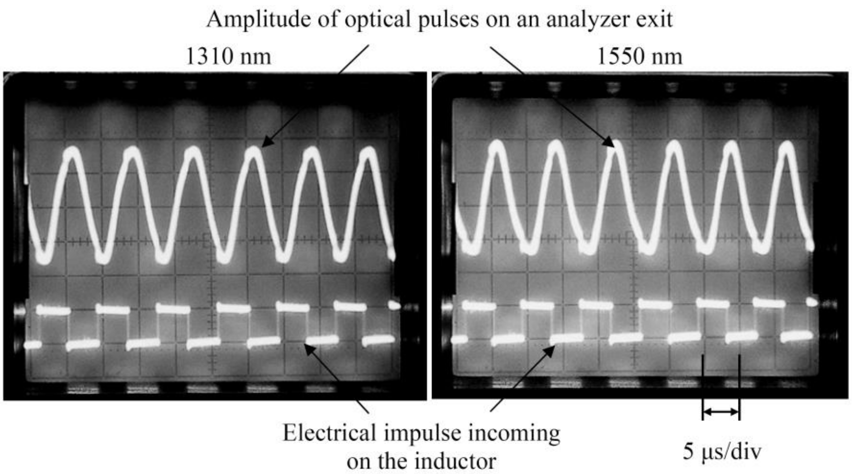

Fig. 3. Oscillograms of the electric signals incoming on the inductor (below) and optical signals on output ports of the switch (above) for wavelengths of 1310 and 1550 nm.

CONCLUSION

Is shown the possibility to practical realization of the two-wave magneto-optical rotator**,** which based on the two planar by oriented on its optical axis MO elements, each of which operates at its wavelength of light.

The method of receiving such elements is shown. MO elements, which were made, demonstrated 45-degree rotation of the polarization plane of light at predetermined wavelengths. This ensures the achievement of the required of the longitudinal dimensions of MO elements at magnetization by their field of saturation being oriented in the forward and backward direction of the light beam in a plane.

The magneto-optical rotator provides simultaneous rotation of the plane of polarization of the two light beams with wavelengths of 1310 nm and 1550 nm on a angle ≈ ±45º. The longitudinal length of MO elements of a rotator in this case was 0.48 and 0.74 mm, respectively. Optical loss of the device does not exceed 1.5 dB.

Such MO rotator, being embedded in a fiber-optical circuit of spectral multiplexers and polarization beam splitters can be used for switching of two-wave light flux in fiber-optical networks [7].

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Басиладзе Г. Д. Розробка магнітооптичного обертача для оптичного перемикача двохвильового світлового потоку у волоконно-оптичних мережах зв'язку / Г. Д. Басиладзе, В. Н. Бержанський, О. І. Долгов // Вчені записки Таврійського національного університету імені В. І. Вернадського. Серія : Фізико-математичні науки. – 2013. – Т. 26 (65), № 2. – С. 109-116.

Показано можливість створення фарадеєвського обертача на основі двох планарно-орієнтованих плівкових магнітооптичних елементів для модуляції площин поляризації двох світлових потоків з довжинами хвиль 1310 і 1550 нм із кутовою амплітудою ±45°. Розглянутий приклад використання такого обертача в оптичній схемі перемикача двохвильового світлового потоку.

Ключові слова: магнітооптичний обертач, епітаксіальна плівка ферит-граната, оптичний перемикач.

Басиладзе Г. Д. Разработка магнитооптического вращателя для оптического переключателя двухволнового светового потока в волоконно-оптических сетях / Г. Д. Басиладзе, В. Н. Бержанский, А. И. Долгов // Ученые записки Таврического национального университета имени В. И. Вернадского. Серия : Физико-математические науки. – 2013. – Т. 26 (65), № 2. – С. 109-116.

Показана возможность создания фарадеевского вращателя на основе двух планарно-ориентированных пленочных магнитооптических элементов для модуляции плоскостей поляризации двух световых потоков с длинами волн 1310 и 1550 нм с угловой амплитудой ±45º. Рассмотрен пример использования такого вращателя в оптической схеме переключателя двухволнового светового потока.

Ключевые слова: магнитооптический вращатель, эпитаксиальная пленка феррит-граната, оптический переключатель.

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