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Magneto-Optical Waveguide Logic Gates and their Applications

Shukhrat Egamov *, Abduvali Khidirov, Mirzokulov Khotam Bakhtiyor ugli

Tashkent University of Information Technologies, Samarkand Branch, Samarkand, 140100, Uzbekistan
* Corresponding author: Shukhrat Egamov, Samarkand, 140037, Uzbekistan, Email: s_egamov@mail.ru
ORCID Author 1: 0000-0002-3454-6867, ORCID Author 2: 0000-0001-8146-3987, ORCID Author 3: 0000-0003-1236-5464

ABSTRACT: The results of studying the possibilities of the properties of magneto-optical qubits obtained using the Faraday rotation effect are presented. Waveguide geometries have been chosen for the design of various information processing and transmission devices based on new concepts creating key elements of logic gates, with new architectures applicable to different fields of science and industry. A mechanism for controlling magneto-optical qubits could be implemented for modeling of several magneto optical logic elements in waveguide forms, including simultaneous parallel *AND, XOR* and other procedures The proposed device can be used to create a wide range of information processing and transmission components founded on new strategies.

KEYWORDS: Faraday rotation, Magneto optical waveguide, Magneto optical qubits, Logic gates

1. Introduction

Today, cyberspace is becoming a hub of the most advanced successes and approaches of modern technology. In the virtual world, it is no longer possible to process terabytes of data with ordinary computers and supercomputers. Therefore, countries around the world are actively researching the use of new strategies to develop quantum computing and artificial intelligence systems.

Quantum information processing has fundamental advantages in the fields of computing, communication security and ultra-precise measurements, but ways to make real devices are still being explored.

In this article, we present the results of the prospective study of applying the properties of magneto optical (MO) qubits in different fields of science and technology, and the design of various applications for processing according to new principles using logic elements with new architectures, devices that store and transmit information.

Main objective of this work is to present main properties of logic gates created using magneto-optical (MO) features of photons appearing in organic Plexiglas waveguide with a reasonable Verdet constant in the visible range influenced by external magnetic field. The logic *XOR* and *AND* operations are performed simultaneously in a same waveguide and can be detected with minimal peripheral electronics. Operation of the waveguide MO half adder (HA) was studied experimentally by means of the magnetic field modulation given by a low-frequency generator. *XOR* and *AND* logic operations are created to obtain *Carry out* and *Sum* outputs on separate channels using waveguide *X* geometry. Variety of designed magneto optical logic gates can be directly applied for fiber optics communication purposes in future as a tool for processing and transmitting information.

2. Faraday Rotation and Magneto-Optical Qubits

The development of quantum information management capabilities requires high quality control of the propagation trajectory and interference of qubits with polarization encoding of photons, which are used to process and transmit information. These conditions can be implemented much more easily with the help of microminiaturization of the classical optical architecture, switching to the use of 3-D and 2-D configurations of optical (and, accordingly, magneto-optical) waveguides with appropriate transparency windows [1-3].

The magneto optical Faraday effect was chosen as the main foundation for creating the magneto-optical qubits, observing their evolution, and recording interactions in an optical waveguide. The Faraday effect, like the vast majority of other magneto-optical phenomena, arises essentially as a consequence of the Zeeman effect and is associated with the features of the polarization characteristics of Zeeman optical transitions and with the laws governing the propagation of polarized light in a medium with dispersion. [4-6]. The specificity of magneto-optical effects is that in a magnetic field, in addition to the usual linear optical anisotropy, which represents itself in a medium under the action of an electric field or deformation, circular anisotropy arises associated with the nonequivalence of two directions of rotation in a plane perpendicular to the field. This important circumstance is a consequence of the axiality of the magnetic field.

Consider the propagation of linearly polarized light along the field. First of all, we note that linearly polarized light can be represented as a superposition of left-handed and right-handed circularly polarized waves, with both polarizations existing simultaneously with the same probability (Figure 1).

If light propagation through the MO material coincides with the direction of the applied field *H*, then a circular magnetic birefringence which is called the Faraday effect is observed, The Faraday effect for a given frequency of incident light is given by

$$\alpha_F = rdH \quad (1)$$

where α_F is the Faraday rotation angle of the polarization plane, *r* is a characteristic of the substance and a function of the wavelength, *d* is the length of sample, *H* is the external magnetic field [6]. When the field direction is changing α_F sign also changes to the opposite, i.e. the Faraday effect is odd in magnetization.

The simplest way to measure the Faraday rotation angle of the incident light's polarization is shown in Figure 1a. If no magnetic field is applied, the observer sees a dark field when the polarizer *PL* and analyzer *AN* are crossed (their axes are mutually orthogonal). If a magnetic field is applied to the sample, then the viewing field becomes clear.

The dark field can be obtained again by turning the analyzer clockwise or counterclockwise, depending on the applied magnetic field along or against the direction of light propagation. In the absence of a field and crossed polarizer *PL* and analyzer *AN*, we observe a blackout in the observer's view field at the exit. When the magnetic field is active (Figure 1a), the plane of light polarization rotates and in order to obtain darkening again, it is necessary to turn the analyzer by some angle to the right, which will be equal to the Faraday angle α_F. When changing the direction of the magnetic field we get a left rotation, that is, counterclockwise.

To measure the Faraday rotation by the modulation photometric method, is chosen geometry in which the angle between the polarizer and the analyzer is set to $\pi/4$ radians, in contrast to the visual one, in which the angle between the axes *PL* and *AN* is $\pi/2$ (Figure 1b) while alternating magnetic field is applied. The modulation photometric method of measuring Faraday rotation is more convenient to check α_F more precisely.

We can use the MO Faraday rotation effect to build logic devices using a bulk Plexiglas waveguide that has a fairly large specific Faraday rotation and low absorption in the visible spectrum.

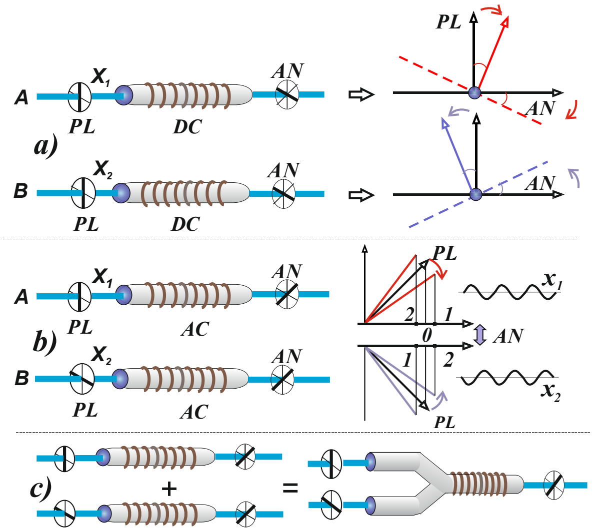

Figure 1: Observation of the Faraday effect: a) in the presence of a fixed magnetic field parallel (above) and antiparallel (below) to the direction of the incident light – right and left rotation; b) the behavior of the variable intensity component of the detected light for two orthogonal polarizations, respectively; c) combining two signals in one Y shape waveguide

A novel of MO waveguide half adder (HA) has been developed and experimentally tested. A diagram of the simplest MO HA used to test experimentally the operability of *XOR* and *AND* logic elements is shown in Figure 2. In such a geometry we were able to measure a Faraday rotation angle of about 0.25°/cm at a magnetic alternating field strength of 100 Oersted and a wavelength of 440 nm. It has been proven that by using this configuration and the appropriate electronics to measure the output signal , we can easily get a match to the truth table values for our gates without the extra switchings as in traditional electronics..

The concept of "magneto optical qubits" is presented briefly in [1]. Another option of MO qubits has been proposed in [7], where the implementation of single qubit quantum gates exploits the longitudinal and polar magneto optic Kerr effect in the reflection geometry. For longitudinal Kerr effect the magnetic field is located on planes of incident light polarization and the surface of an opaque sample.

One of the main benefits of MO qubits over optical qubits in transparent waveguides is opportunity to increase the coherence time of qubit by six or more orders of magnitude. It allows the creation of quantum computing devices models with minimized troubles. The simplest classical logic *AND*, *XOR* and *NOT* gates including HA and adders. It also opens a choice to create *C-NOT* (*Controlled NOT)* quantum gate using basic digital logic concepts.

Quantum behavior of photons formal features of one and two input signals can be described via proposed magneto optical qubit generator (MOQG) properties.

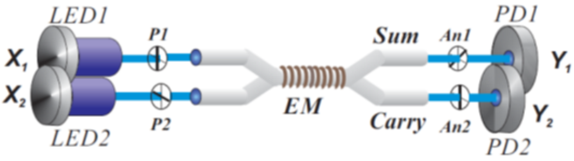

Figure 2: Schematic representation of HA (peripheral electronics not shown): *LED1* and *LED2* are light-emitting diodes (*λ= 440 nm*), X_1 and X_2 signals with *HP* and *VP* light polarization orientations, *EM* is an electro-magnet; *Sum* is the summing waveguide channel; *Carry* is the transfer channel; *An1* and *An2* are analyzers; *PD1* and *PD2* are photodiodes for detecting output signals.

Suppose that signal *A* is represented by a beam of photons of a certain wavelength Therefore we can spatially separate them into two different rays with A_x and A_y orthogonal polarizations. This means we can get two different bits from the same photon source. If we connect these two rays together, we get a new state that can be called the bra vector *|A>*. Under the influence of an alternating magnetic field, *|A>* begins to oscillate with a declination amplitude equal to the Faraday rotation angle α_F. As shown in the lower right corner of Figure 3, different alternating parts of the *|A>* eigenvalues can be obtained by changing the orientation of the output analyzer. It is important to note that with the help of waveguides we can easily detect AC and DC different currents, separate them and measure signals simultaneously induced in the PDs.

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The variable part of the signal changes as a function of $\sin 2\pi\nu t$ (ν is the frequency of the alternating magnetic field) when the analyzer is oriented along the *X* axis (P_x) and accordingly as $-\sin 2\pi\nu t$ when the analyzer is oriented along the *Y* axis (P_y). The alternative component is zero when the analyzer is parallel to A_{XY}, i.e. oriented in the *XOY* plane at $\pi/4$ angle to the *X* or *Y* axis. This means that we can in fact propose the concept of MOQG with the geometry plotted in Figure 3. Any logical qubits containing device can be called a quantum register, which is more meaningful than a classical one. It is clear that instead of the classic bit with a value of *1* (the presence of an input signal *A*) or *0* (no signal) we can obtain a magneto optical quantum bit with values between *+1* and *–-1* depending on the orientations of the analyzer at the output.

The initial state of a photon can be expressed as: polarization $\boldsymbol{p}$ index, spatial s index, orbital angular momentum m index and wavelength λ [2, 3]. In our particular case, we can determine the photon's polarization and its spin number as $S = \pm 1$, just to define the MO quantum logic devices basic principles.

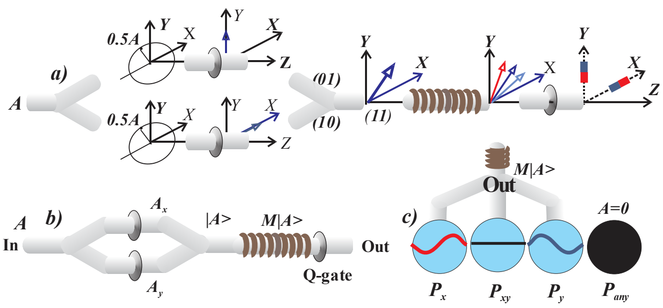


Figure 3: Processes im MOQG. a) obtaining orthogonal polarizations of MO qubits b) overall view of MOQG for one qubit, c) AC and DC signals for different orientations of output analyzers

Polaroid films (shown as discs in Figure 2) separate the incoming X_1 and X_2 optical signals into mutually orthogonal polarizations. In the upper HA channel, we get a qubit state similar to an "entangled" photon. This is expressed by the $\boldsymbol{X_1}$ and $\boldsymbol{X_2}$ vector sum just before the magnetic field is applied. The resulting angle of $\boldsymbol{y_1}$ vector between *X* and *Y* axis is equal to $\pi/4$ radians in the *XOY* plane *(Carry channel)*. Then Y_1 will oscillate around its initial state due to Faraday rotation during applied magnetic field.

In a *Carry out* channel the output polarizer is oriented in the *X*-direction of the passing beam polarization. When such geometry is chosen, we just register a non-zero signal if both X_1 *and* X_2 signals are generated in the *Carry out channel.* Each of X_1 and X_2 signals entering the magnetic field region due to the Faraday effect to be considered as distinct oscillating vectors in the *XOY* plane. Here we cannot operate with **A** and **B** vector sum directly because here they are not coherent.

Changes in the state of a photon (or another similar objects) can be described using operators. The waveguide branch of the "Removal" channel after the magnet coil is routed to the bottom right to the "*Sum*" channel and acts as a *CNOT* gate. Subsequently, the received MO signals are analyzed in the summation and transfer channels with properly aligned polarizers and recorded by photodetectors. Elementary calculations reveal that the truth table conditions for this model of quantum MO HA are fully satisfied, as it was in case of the classical version of MO HA.

3. Magneto Optical Waveguide Logic Gates

Numerical logic (Boolean algebra) deals only with binary possible numbers or two variable values that correspond to Boolean values*: 0* and *1*. Thus, digital logic circuits can be functionally analyzed and synthesized using logical algebra, truth tables, and other tools that can represent a relationship between *1* and *0* while logic operations are produced [8, 9].

Boolean values of *0* or *1* are called binary numbers or bits. Set a variable with more than two values with an *n* – bits' set express 2 different values. The value of the output signal at a given point in time is called a combinatorial scheme. It is uniquely determined by the logic circuit summing the values of the input signal without data storage digital circuits [9].

These circuits can be fully described by a data sheet listing all combinations of input signals and their corresponding output values in a form of truth table. Note that a useful theorem has been proved in logical algebra: any logical function can be represented by a superposition of three functions: logical addition or disjunction *(OR),* logical multiplication or conjunction *(AND),* and negatiion (*NO*).

Just three basic schemes that implement the *AND, OR* and *NOT* functions are sufficient to construct any combination scheme. Figure 4 shows the logic gate flags above and the corresponding truth tables. Truth tables for above operations are expandable to any number of inputs. The functions performed by the schema are defined as follows:

If all inputs are *1*, *AND* element produce only *1* at output. Logical function performed by *AND:*

$$Y = X_1 \bullet X_2 \bullet \ldots \bullet X_m. \qquad (2)$$

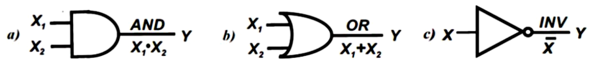
If at least in one of the electronic inputs *1* is presented *OR* circuit at the output generates only *1*. The logical function performed by the OR element:

$$Y = X_1 + X_2 + \ldots + X_m. \qquad (3)$$

If logic *NO* operation is applied than output signal value will be inverted in regard to input one. Ones ttransform to zeros and vice versa. *NO* logic element (inverter) is indicated as: $Y = \overline{X}$. Consider another way to build gates that are coded and directly compatible with data transmission via fiber optic lines of communications. We are able to use the MO Faraday effect to realize various logic widgets with organic compound such as Plexiglas waveguides, which have good transparency and sufficiently big specific Faraday rotation [1, 4].

The classic HA consists of two inputs with X_1 and X_2 signals and two outputs where sum channel Y_1 *(Sum)* and transmission channel Y_2 *(Carry)* including a truth tables are presented in Figure 5.

The key element that are used as the MO waveguide is a Plexiglas sample that prevents light from absorption and scattering losses during propagation. The electromagnet is a multilayer copper wired coil.



X_1	X_2	$Y=X_1 \cdot X_2$
0	0	0
1	0	0
0	1	0
1	1	1

X_1	X_2	$Y=X_1+X_2$
0	0	0
1	0	1
0	1	1
1	1	1

X	Y
0	1
1	0

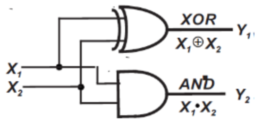
Figure 4: Basic logic elements and their truth tables:
a) AND; b) OR; c) NO

Let's take a quick look at how logic gates can be designed using MO waveguides. The main purpose of the design is its operation ib modulo 2. binary counter mode. However, it has been found that a waveguide of this configuration can be adapted to operate in other modes. The functions of the remaining details needs no explanation (See Figure 2).

The basic binary coding of input signals should be done by pulse modulation of light, i.e. the *LED* comply with *ON* — "*1*", *OFF* — "*0*" during operations.

Additional explanations should be given to the physical properties of the input and output signals. The encoded data in the form of electrical signals, is converted into video pulses and transmitted to the *LEDs*, which in turn are converted into optical radiation with pulses of specific duration. These *A* and B rays are then converted to linear polarization by going through the *HP* (horizontal) and *VP* (vertical) polarizers

a)



b)

X_1	X_2	$Y_1=X_1 \oplus X_2$	$Y_2=X_1 \cdot X_2$
0	0	0	0
1	0	1	0
0	1	1	0
1	1	0	1

Figure 5: a) Symbol of the half-adder, and b) the truth table

Qubits containing logical device can be considered as a more informative quantum register compared with the classical one [6]. Now we can call them Boolean variables X_1 and X_2 or as basic vectors |*0*> and |*1*> , orthogonal to each other. They pass through one or other input of the waveguide, as shown in (4) [5].

$$X_1 = \begin{pmatrix} 1 \\ 0 \end{pmatrix}; \quad X_2 = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \qquad (4)$$

Expressing a simple optical qubit as a vector in Hilbert space, for example |0> and |1> (see above: (4)), and place it in an alternating magnetic field, the spin degeneration disappears and the photon's polarization properties will change. The descriptive vector begins precession with the magnetic field frequency around the initial equilibrium state. The maximum angle of precession is proportional to the angle of Faraday rotation in the waveguide material.

To describe these forced oscillations due to Faraday effect and measure its properties it is convenient to introduce a new vector with corresponding eigenvalues. It should be noted that the same quantum laws still applicable to these new MO "particals" as to their precursors – photons.

The action of the changing magnetic field leads to conversion of optical signal into magneto-optical due to the Faraday effect. Therefore, instead of the purely optical signals *X1* and *X2*, it makes sense to consider magneto optical signals that occur when entering the waveguide domain with an electromagnetic coil (Faraday domain: Figure 6).

When the magnetic field is active, the optical signals passing through the analyzer with a certainly oriented direction will get an additional intensity component. This generated variable component intensity value depends on mutual orientation of the input and output polarizers.

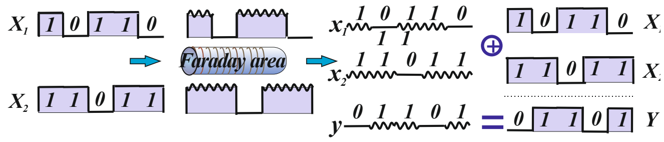


Figure 6: Development of processed signals.

The *Y* data signal captured by a photodiode are amplified and transformed into electrical *y* signals acceptable for further data processing, storage or transmission. In contrast to the classic case of an MO gate, instead of dealing with discrete *0* and *1* signals, here we are dealing with segments of sinusoids that serve as the processed signals.

It was experimentally determined that the angle of rotation of the polarization plane of the incident light at a 440 nm wavelength is about 15 min/cm while 100 Oe variable magnetic field is applied.

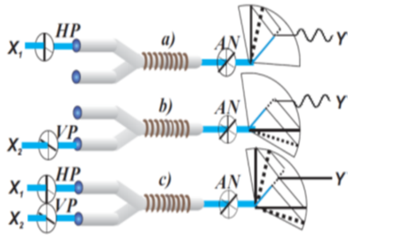
All possible combinations of the X_1 and X_2 input signals and relating output values summated in the *Sum* y_1 and *Carry y2* channels are shown in HA's truth table in Figure 5

Classic HA can be easily adjusted in combined mode without additional switching operations that are considered as follows.

The processes in the Sum and Carry channel are passing as follows [10]. Two optical signals *A* (X_1) and *B* (X_2) generated by LEDs fall into Y -shaped waveguide as shown in Figure 7. Then they pass through a polarizing filter placed between the light source and the waveguide and are converted into X_1 and X_2 signals. polarized horizontally *(HP)* or vertically *(VP)* respectively. In general, entering X_1 and X_2 signals are in nature purely optical. Their electrical transformation to logic *"1"* has the order of magnitude from tens to hundreds of millivolts and expressed as potential (video) signals.

Due to the Faraday effect, the polarization plane of the transmitted light rotates in *XOY* plane to α_F angle and is changed by the application of a sinusoidal alternating current to the coil. The intensity of the beam that passed throughthe analyzer is detected by the *PD1*photodiode, as shown in Figure 2.

The total detected outcoming photocurrent further can be separated into DC and AC components. The angle between polarizer and analyzer is mostly adjusted to *π/4.*



X_1	X_2	$Y=X_1 \oplus X_2$
0	0	0
1	0	1
0	1	1
1	1	0

Figure 7: Schematic of the MO *XOR* logic element for two binary signals processing in the *Sum* waveguide channel: *a) X1 = 1, X2 = 0, Y = 1; b) X1 = 0, X2 = 1, Y = 1, c) X1 = 1, X2 = 1, Y = 0.* On the right side (from top to bottom) – symbol of *XOR* logic gate and the truth table

Let 's consider the case of X_1 *(HP)* and X_2 *(VP)* signals separately. In the absence of a magnetic field for both cases (Figures 6a and 6b) we find that the photocurrent is equal to ½ of initial beam intensity I_0 according to Malus' law (horizontal line on the right side of the image). The magnetic field generated in a coil leads to the Faraday rotation in the waveguide. For small values of α_F (Figures 7a, 7b and 7c respectively), the photocurrent depends on the material constant and variable components:

$$I_{ph}=k(I/2+I\alpha_F \sin\Omega t) \quad (5)$$

where *k* is the scaling factor, I_{ph} is the intensity of the incident light, α_F is the Faraday rotation in radians, *Ω* is the generated magnetic field frequency, $I\alpha_F \sin\Omega t$ is the variable part of detected light intensity.

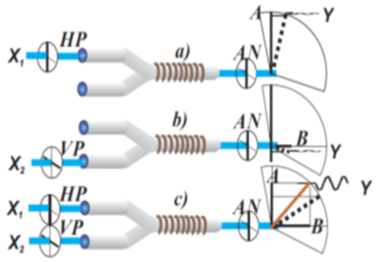
Processes taking place for different options for incomimg signals during *XOR* MO logic gate operations are displayed separately in figure 7. In this geometry the output signal *y* behavior is similar to one ib sum channel of a classic semiconductor logic circuit. Variable part of resulting intensity are represented by sinusoids. The phase difference arisen after modulation between *X1* and *X2* is equal to π radians.

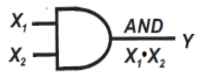
Identical to *XOR (exclusive or)* gate architecture and sinilar set of elements was chosen for the *AND* gate. *The* angle between the polarizer and the analyzer in this case should be adjusted to zero or *π*/2 radians (Figure 8).

It implies that X_1 and X_2 in the *AND* gate after the polarizers have the same polarization and similar arrangement as in Figure 7, but here the analyzer is oriented perpendicular to the X_1 signal polarization or parallel to X_2. In both cases (Figure 8a and 8b) in the presence of a signal (only X_1 or just X_2 alone), the output variable signal will be negligible.

This can be demonstrated more precisely by a simple trigonometric transformation of small Faraday rotation angles. When both signals are present we get a sinusoidal response which can be defined as a default value of *1*.

To perform both *XOR* and operations in the same waveguide, we can switch configuration from the Y- to the X-waveguide configuration as shown in Figure 2





X_1	X_2	$Y=X_1 \cdot X_2$
0	0	0
1	0	0
0	1	0
1	1	1

Figure 8: Diagram of the magneto-optical logic *AND* gate, for processing two binary signals in the *Carry out* channel: *a)* $X_1=1$, $X_2=0$, $Y=0$; *b)* $X_1=0$, $X_2=1$, $Y=0$, *c)* $X_1=1$, $X_2=1$, $Y=1$. On the right side from top to bottom: logic *AND* gate symbol and the truth table.

Now we will discuss some other features of the MO waveguide logic gate which seems to be very efficient for future applications.

Taking into account that there are no special designations for magneto-optical waveguides yet, it is proposed to depict them schematically as in Figure. 9b.

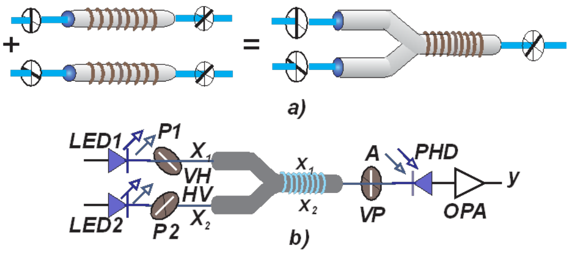


Figure 9. The main designations of the elements proposed for hybrid chips with magneto-optical logic gates. Example of the waveguide binary counter

X_1, X_2 – are input optical signals; *LED1, LED2* – light emitting diodes of channels *1* and *2* (inputs); *P1, P2* – polarizers of input channels *1* and *2* installed orthohonal to each other; *A* – output analyzer; *EM* – electromagnet-modulator; *PHD* – photodetector (silicon photodiode); Op-amp (*OPA*) – an operational amplifier or other electronics for amplifying (measuring) and fixing the output signal.

Using these notations, we will give an explanation of the *INVERTER* operation. Let's say that we want to use the device in Figure 9 to invert the binary information entering channel 1. It is assumed that binary coding is carried out using amplitude modulation, that are successive video pulses. *LED* is *ON* – "*1*", *OFF* – "*0*".

Note that the data originally encoded as an electrical signal (usually in ASCII standard) is converted into video pulses and transmitted to *LED*, which converts them into light radiation pulses

This signal then passes through the polarizer, gets *H* or *V* polarization depending on chosen geometry of the input part of the waveguide. Under the influence of the changing magnetic field, the optical signal is converted into a MO one. After passing through the analyzer, the derived output signal gets an additional variable intensity component under magnetic field influence leading to MO Faraday rotation. This signal is detected by the photodiode. Variable part of light intensity is transformed into the electrical signal, amplified and can be used further for processing or storage information.

To make the inverter work, turn on the counter in *exclusive or* mode. According to Figure 7, let x_1 be the input signal ***y***, and the result of the inversion will be $\bar{y}$. For simplicity we have choosen the expression ***10110.*** The result of the inversion should be the expression ***01001.*** It is easy to guess that for this auxiliary channel x_2 must permanetly operate in the ***111111*** mode. The principle of operation of a magneto-optical inverter is clear from Figure 10

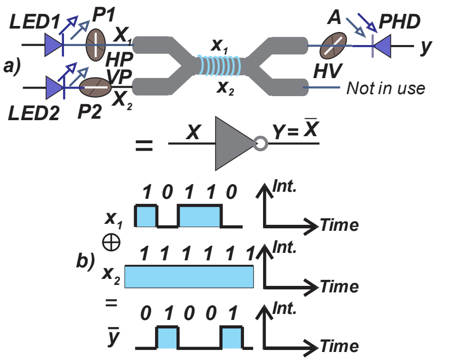


Figure 10. Magneto optical NOT logic gate *(INVERTER):* a) schematic diagram; b) time dependences of input and output signals for a magneto-optical inverter. Input signal $x_1=y=10110$, output signal $\bar{y}=01001$

The dynamic *ERASE* operation is also easily accomplished with minor changes to the configuration shown in Figure 9. To smooth the signal, it is proposed to remove the polarizer in the x_2 channel and leave the *LED* to work in a constant mode. The operation principle of the magneto-optical "*ERASE*" logic gate is clear from Figure 11.

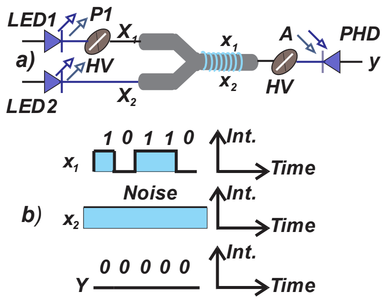


Figure 11. Dynamic magneto-optical *ERASE* logic gate: a) schematic diagram; b) time dependences of the input and output signals for the magneto-optical " *eraser* ". Input signal $x_1=10110$, output signal $y=00000$.

The analyzer at the output of the waveguide should be installed parallel or perpendicular to the polarizer of the input channel x_1. In principle, in the presence of only one plane-polarized beam, the rotation of the polarization plane at the output with mutually parallel or orthogonal orientations of the polarizer and analyzer cannot be fixed with the modulation technique, so the use of 2 channels may seem redundant. However, we take into account the fact that device parts should preferably be unified and interchangeable.

Let us now consider how the *COPY* magneto-optical gate works. To create this device, we will use the main configuration shown in Figure 9. The information signal enters as usual through the upper channel x_1, through the second x_2 the light from the constantly working *LED* passes, as in the first two cases (in *inverter* and *erase modes*).

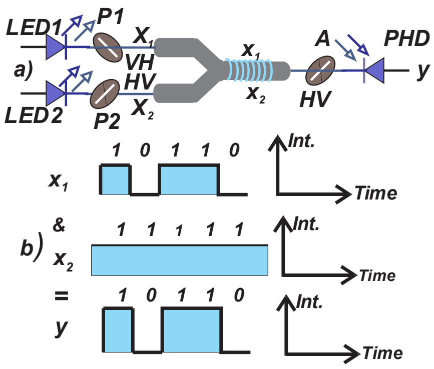


Figure 12: Dynamic magneto-optical waveguide logic gate *COPY*. a) schematic diagram; b) time dependences of the input and output signals for the magneto-optical *"copier"*. Input signal x_1 *=10110,* output signal *y=10110*

In order to be fulfilled the truth table, we apply the *AND* gate mode operation of the MO waveguide for two signals. To do this, we set the input polarizers for x_1 and x_2 mutually perpendicular to each other, and in the output channel y, the position of the analyzer is chosen parallel to either x_1 or x_2, that is, the geometry of the previously considered half-adder for the Carry out channel is selected.

It should be noted that these two positions of the analyzer are characterized by the fact that if the analyzer is parallel to the polarizer for channel x_1 and the phase shift of the output alternating signal is taken equal to zero, then when rotated by 90°, that is, when the analyzer is parallel to the polarizer x_2, the phase shift will be 180°. This property is used for tuning, calibration, and other ancillary operations before making accurate measurements of the Faraday effect for scientific purposes.

A schematic diagram of a hybrid magneto-optical waveguide chip assembly for use in *COPY* operations is shown in Figure 12

It is easy to see that at the output we get not only a repetition of the form and content of the input signal, but also its amplification. This circumstance will turn out to be very important, since the transmission and processing of any signal is accompanied by one or another degree of attenuation, which does not allow building a large number of cascades without noise and signal attenuation, therefore it seems that the proposed version of the *"copier"* in the future, when switching to optocoupler circuits, will be in great demand.

As for the magneto-optical waveguide *shift register*, at this stage, the options for its implementation currently are not competitive.

The fact is that for reliable functioning of above mentioned shift register, it is necessary to solve the issues of designing compatible delay lines, selecting a suitable electronic element base, adding synchronization mechanisms, etc., therefore, in this paper, the results of the study of the *shift register* are not considered.

4. Conclusion

The proposed quantum information processing method fundamentally changes the situation on the basic components of logic devices. Thereby we have no need for expensive bulky parts like high quality mirrors, transparent plates, crystal polarizers, phase plates, optical benches and powerful light sources. Obvious advantages of the of fiber optics and integrated optics are in fact that all processes take place in a single wave-transmitting waveguide with size of the order of a fraction of a square centimeter [11-14].

Photons with their unique properties are very convenient carrier of information. Thus they actively can be applicable for designing various logic devices based on different physical phenomena [15-18]. Photons with magnetooptical features also seems very flexible for future applcations. It makes sense to actively continue the ongoing research on the application of the results in the areas of artificial intelligence, communication technologies and cryptography.

Conflict of Interest

The authors declare no conflict of interest.

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SHUKHRAT EGAMOV He has PhD degree in physics and mathematic from the Moscow State University. His research activity is mainly associated with Samarkand State University. Currently he is a member of Tashkent University of Information Technologies' team. He has published more than 30 articles.

KHIDIROV ABDUVALI has done his bachelor's degree from Tashkent University of Information Technologies in 2010. He has done his master's degree from Tashkent University of Information Technologies in 2012. More than 12 articles have been published.

MIRZOKULOV KHOTAM has done his bachelor's degree from Samarkand branch of Tashkent University of Information Technologies in 2014. He has done his master's degree from Tashkent University of Information Technologies in 2016. He has completed his PhD degree in technical science from the Tashkent University of Information Technologies in 2020. More than 20 articles have been published.