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OPTIMIZATION OF SPECIALIZED COMPUTER SYSTEMS BASED ON OPTICAL MODULATORS FOR PERFORMING COMPLEX MATRIX OPERATIONS

A specialized computer systems based on optical modulators for performing multidimensional matrix operations is studied. The optical modulator cell schemes for improving their dimensions and operation rate are optimized.

Keywords: *specialized computer systems; optical modulator; matrix operations; absorption coefficient; electro-absorption modulator; double-diode.*

Introduction

Optoelectronic computer systems are proving their advantages during last 30 years. These systems are characterized by high data rate, parallelism, low power consumption, etc. The usage of matrix form of data communications (including images) allow to realize a parallelism principle of optoelectronic systems. The matrix form of data can be present as well using optical modulators. After analysis of [1, 2], it became that for optoelectronic specialized computer systems semiconductor modulators are the best solution as they have high integration degree and semiconductor material can change its optical properties by the influence of different factors (voltage, optical radiation, temperature etc.). The latter property of semiconductor material is used for modulation of input beam on the modulator.

Optimization of specialized computer systems for implementation of element-wise operation of matrixes multiplication

One of directions of systems with optical transparants application is realization of matrix operations, i.e. the work with information of picture type. Until recently, only execution of simple matrix operations by the systems of this type, such as addition, multiplication , rotation etc, with the matrixes of the limited sizes (dimension 10^2x10^2 [1]) are studied. However, there is a problem of rapid processing of large size matrixes.

It is suggested to use specialized systems with optical transparants for implementation of sequence of matrix operations. Thus every matrix operation will be executed serially on separate optical transparant. Namely, the set of optical transparants which will work as logical elements and execute these operations is used. As a result of series connection of such transparants it will be possible to perform complex matrix operations in specialized computational systems.

The scheme of optical transparent cell on the basis of electro-absorption modulator (EAM – Electro-Absorption Modulator) [3], operating as NAND- logical element is already known. Electro-optical scheme of such element is presented in Fig. 1.

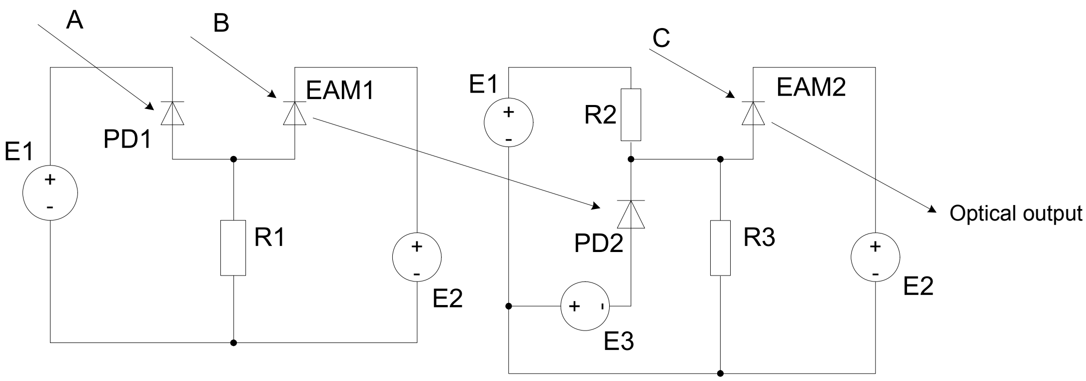

Fig.1. Electro-optical scheme of NAND logical element

In Fig.1 A and B are information signals, C is constant optical signal, EAM1 and EAM2 are electro-absorption modulators, PD1 and PD2 are photo receivers.

Advantages of this logical element as compared with the same elements on S-SEED-devices (Symmetric Self-Electro-Optic Effect Device) [4] is absence of input paraphase signals, that enables to decrease both the sizes of the element and connections between its components and transparants which can be built on them. In addition, in such element NAND the problem of different by levels of input and output signals, which exists in generations of optical modulators OCOG1-OCOG-4 (Optically Controlled Optical Gates) [5] is solved. In NAND element, which is presented in Fig.1 input and output signals will have identical wavelength, intensity and signal amplitude. It is due to the fact that input signals A, B and C are identical by all above-mentioned parameters. Equality of input and output signals of this optical logical element will allow to construct systems with series connection of such elements in which an output of one element can be the input of the following and so on.

In other words, Fig.1 shows one cell of optical transparant which will execute the operation of cell-to-cell multiplication with inverting . All modulator will have the form , shown in Fig.2.

$\overline{\&}$	$\overline{\&}$	$\overline{\&}$	$\overline{\&}$
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Fig.2. Optical modulator on the basis of logical elements NAND

However, the drawbacks of this scheme (see Fig.1) are three sources of supply and considerable number of scheme elements which results in the increase of its size and price.

For improvement of characteristics of specialized computational systems, namely reduction of their size (at the expense of reduction of the number of elements) and cost, as well as increase of operation rate, it is suggested to optimize the scheme of optical transparent cell on the basis of logical element NAND, shown in Fig.1.

Optimized scheme of logical element NAND is shown in Fig.3.

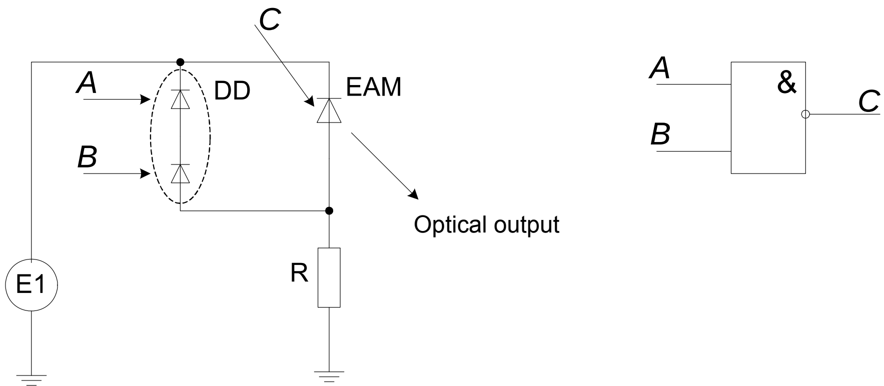


Fig.3. Optimized electro-optical scheme of logical element NAND

It operates in the following manner. Information signals A and B arrive on the surface of double-diode DD [5], and signal C – is constant optical signal, by levels coinciding with signals A and B. Thus, double-diode DD will be open only in case if optical radiation A and B will fall on it (in other words A and B will be equal to 1). Then current across DD will grow and yields the reduction of voltage on EAM modulator.

In Fig.4 the graphs of dependence of absorption factor of semiconductors with quantum wells on applied voltage on different wavelengths are shown [6]. It is evident from the graphs , that voltage reduction on EAM results in the increase of its absorption factor . Therefore it becomes non-transparent and constant optical signal C does not pass through it, as a result we obtain zero on the output of NAND element.

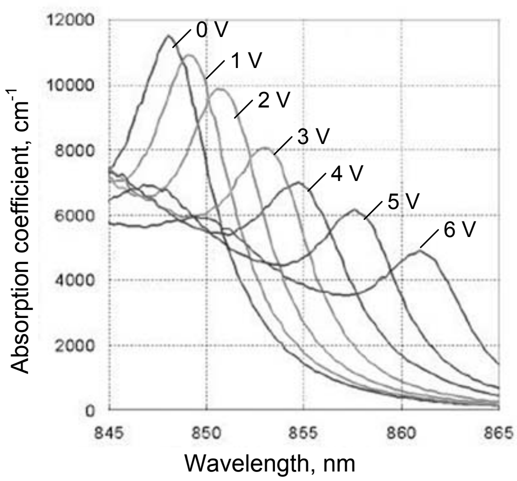


Fig.4. Graphs of absorption factor dependence of semiconductor with quantum wells on the applied voltage [6]

In all other cases (when even one of information signals equals zero) the double-diode DD is not open, voltage on EAM does not change and constant optical signal C passes through it, and on the output we get logical “1”. Thus this scheme (see Fig.3) confirms truth table for NAND element.

In comparison with the scheme of logical element NAND, shown in Fig.1, optimized scheme contains fewer elements. As a result the rate of implementation of this Boolean operation increases and the sizes of logical element, which are important enough at the construction of modulators on their basis, diminish.

Optimization of the specialized computer systems for realization of matrixes addition operation

On the basis of logical element NAND (see Fig.1) it is possible to execute other matrix operations. Structural diagram of by- element addition operation , carried out by certain connection scheme of NAND elements, will have the form ,shown in Fig.5

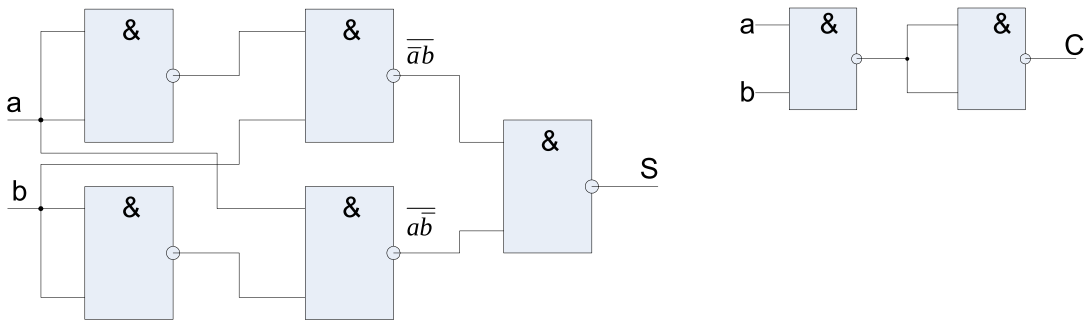


Fig.5. Structural diagram of operation of optical signals addition on the example of one cell
S – modulo 2 sum; C - carry bit

However this scheme has the same disadvantages, as the scheme , shown in Fig.1. In addition, it is rather bulky, due to the fact that it contains many NAND elements. In Fig.6 electro-optical circuit of addition operation on the basis of logical elements NAND, shown in Fig.1, is suggested

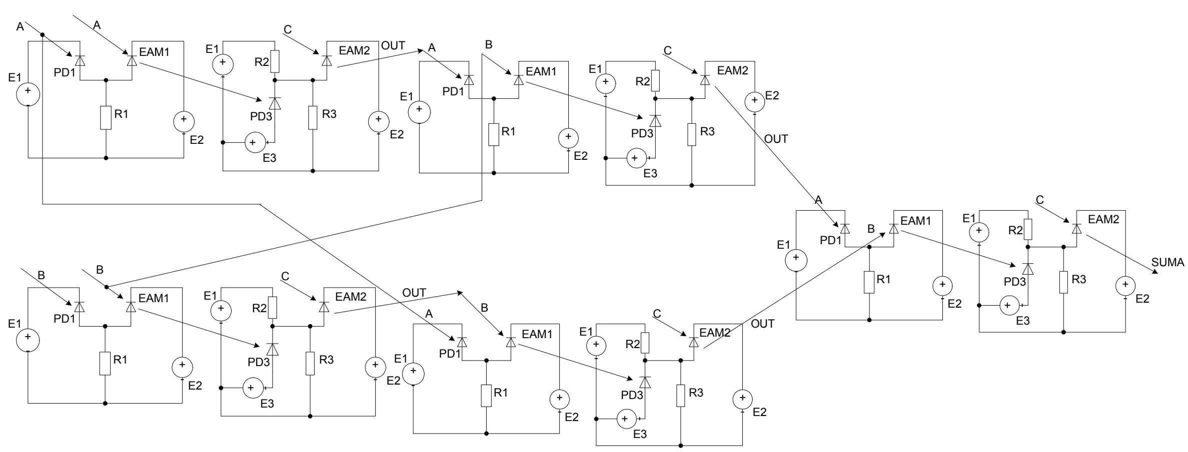


Fig.6. Electro-optical circuit of addition operation realization on the basis of logical elements NAND

It is suggested to optimize the scheme of addition operation , decreasing its dimensions, number of elements and increasing operation rate. Optimized addition scheme of two optical signals for specialized computer systems on the example of one cell is presented in Fig.7.

Scheme , presented in Fig.7, operates in the following manner. When single signals arrive at inputs A and B currents across photodiodes PD1 and PD2 are identical and that is why voltage on EAM 1 does not change and it transmits constant optical signal C. Similar situation occurs in the second parallel section of the scheme with EAM2. Accordingly, two single signals arrive on double-diode DD, and further situation is similar to the situation of element multiplication (see Fig.3), that is why at the output we will obtain zero.

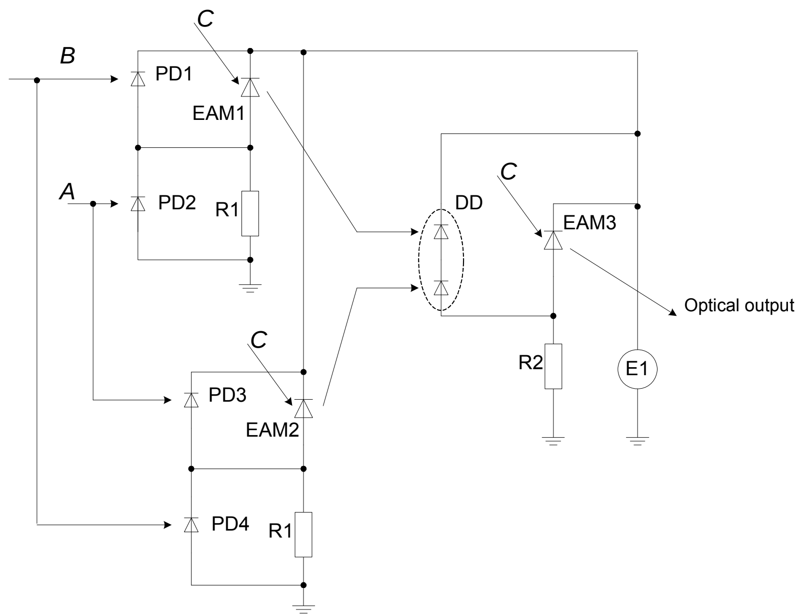
The same way zero input signals A and B do not change voltage at EAM1 and EAM2, does not change voltage on EAM 1 and EAM 2 , leading to in zero signal at scheme output.

When at the input of the scheme information signals A= 0 and B=1, then voltage at EAM 1drops, increasing its radiation absorption coefficient (see Fig.4), and at the output of EAM 1 zero signal is available . Zero signal A at the second parallel section of the scheme increases voltage at EAM2, increasing its transmission, and at the output of EAM 2 there is constant optical signal.

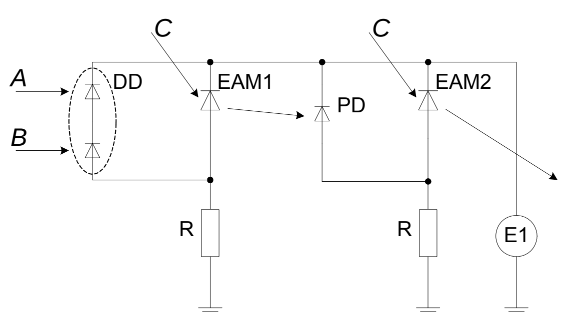
Zero and nonzero input signals at double-diode result in a nonzero signal at the output of the whole scheme.

In case when at the input of the scheme information signals A=1 and B=0, then voltage at EAM2 drops, resulting in the increase of radiation absorption, and at the output of EAM2 zero signal is present. Zero signal B on the first parallel section of scheme increases voltage at EAM1, increasing its transmission, and at the output of EAM1 there is constant optical signal C=1. Nonzero and zero input signals on double-diode DD result in a nonzero signal at the output of the whole scheme.

Consequently, operation of the scheme shown in Fig.7, confirms truth table of modulo 2 sum .



a)



b)

Fig.7. Optimized electro-optical scheme of two signals addition operatin: electro-optical scheme of – modulo 2 sum operation (a) and carry bit (b)

As compared with the circuit of logical element of modulo 2 sum, shown in Fig.6, the optimized circuit contains far less elements. It will allow to increase the rate of this Boolean operation and considerably decrease the dimensions of the element of modulo 2 sum , what is important for construction of the transparent on its basis.

Comparison of characteristics of optical transparents for realization of complex matrix operations

Optimization of electro-optical schemes of logical elements NAND and modulo sum of 2 for implementation of operations with large dimensional matrixes in specialized computer systems resulted in decreasing of scheme elements amount, that allowed to decrease its sizes. Another important parameter of such schemes is the rate of operations realization.

Let us estimate separately frequency of operations realization for optimized logical element NAND (see Fig.3) and optimized logical element modulo sum of 2 (see Fig.7).

Frequency of operations realization is on logical element NAND, shown in Fig.3, will be calculated by the formula [3]

$$f_{NAND} = \frac{\sqrt{3}}{2\pi \cdot R\left(C_{DD} + C_{EAM}\right)}, \quad (1)$$

where R is resistance of the scheme; C_{DD} is capacity of double-diode; C_{EAM} is capacity of electro-absorption modulator.

Accordingly, time of this Boolean operation realization will be:

$$\tau_{NAND} = \frac{1}{f_{NAND}}. \quad (2)$$

Time of operations realization is calculated similarly for logical element modulo sum of 2 with a carry bit, shown in Fig.7:

$$\tau_{\oplus} = \frac{1}{f_1} + \frac{1}{f_{NAND}}, \quad (3)$$

where f_1 is operation frequency of the first parallel area with EAM 1:

$$f_1 = \frac{\sqrt{3}}{2\pi \cdot R_{\Sigma}\left(C_{PD1} + C_{PD2} + C_{EAM1}\right)} \quad (4)$$

Table 1 contains the comparison of realization rate of Boolean operations mentioned-above on the basis of existing and optimized schemes.

Table 1

Comparison of realization rate of Boolean operations NAND and modulo sum of 2

Modulator type	Realization rate of Boolean operation for two matrixes of 10240 x 10240 pixels size	
	Boolean operation NAND	Boolean operation of modulo sum of 2
Modulator on the basis of existing scheme	422 ns	1,27 μs
Modulator on the basis of the optimized scheme	107 ns	426 ns

From Table.1 it is seen , that the optimized schemes have higher rate of Boolean operations execution. Thus, processing rate in optimized schemes is higher approximately 2 times for the Boolean operation NAND and approximately 3 times for Boolean operation of modulo sum of 2. In addition, optimized scheme of transparent cell which executes Bolean operation NAND (see Fg.3) contains approximately two times less elements, and scheme for operation modulo
sum of 2 – approximately three times less elements.

These characteristics influence in a positive manner on specialized computer systems based on optical transparants that enables to process more efficiently large dimensional data arrays and reduce overall dimensions of such systems

Conclusions

Using semiconductor structures, the schemes of specialized computer systems with optical transparents are elaborated for realization of complex matrix operations, a number of parameters for the improvement of their characteristics is optimized. Namely, quantity of elements in the schemes of logical elements NAND and modulo 2 sum is reduced, all these measures resulted in reduction of logical elements dimensions, and in growth of the rate of Boolean operations realization for large -dimension matrixes. Operation of multiplication of two matrixes of 10240 x 10240 with inverting is executed during 107 ns, and operation of addition of similar matrixes – during 426 ns. The obtained results 2-3 times exceed characteristics of existing specialized computer systems on the basis of logical elements by operation rate and number of scheme elements.

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