LOGIC GATES AND CIRCUITS WITH ELECTRICAL AND OPTICAL INPUTS FOR THIN FILM AND ORGANIC ELECTRONICS

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1. Introduction

A new type of logic gates with both electrical and/or optical inputs and electrical outputs is proposed for possible application in (large area) thin film and organic electronics.

2. Device structure

The proposed logic gates and circuits are based on a semiconductor active layer with high resistivity grown on an isulating or semi insulating substrate. The active layer can acts as a conductive channel between source and drain electrodes, similarly to thin film transistors or photoresistors, as shown in Fig. 1.

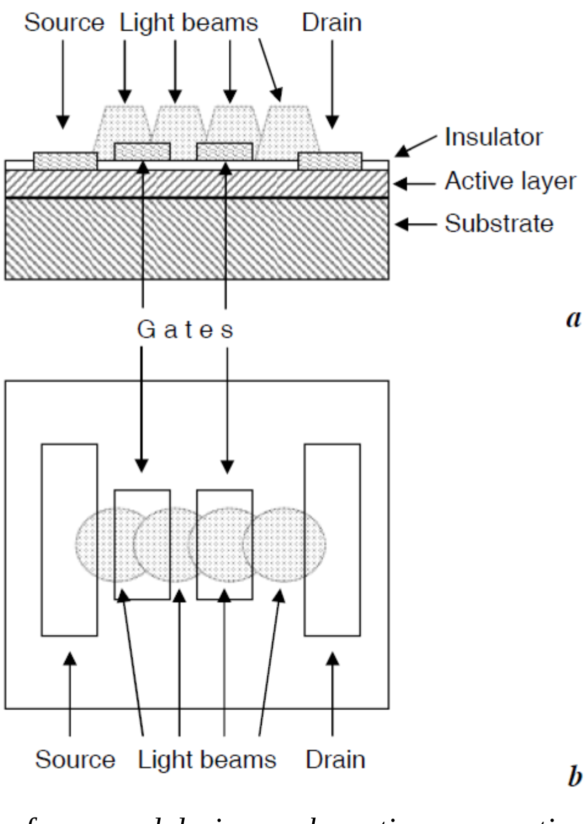

Fig. 1: The structure of proposed devices: schematic cross-section (a) and topology (b) of a transfer gate with 4 optical and 2 electrical inputs

The active layer is covered by an insulator layer, which is transparent for input optical signals (light beams). Free charge carriers are generated in conductive channels by the optical signals with appropriate photon energy. The spots of adjacent light beams overlap and beam spots form a geometrical band, which determine the width of the conductive channel. But the second adjacent spots are far from each other, more far, than the diffusion length of generated charge carriers.

Metal gates, which are electrically conductive and transparent or semitransparent for optical signals, are formed on the top of the upper insulator layer. Gates overlap the whole width of the conductive channel of the device. (If the substrate is transparent for optical signals, they can be introduced from bottom side. In this case gates should not be transparent for light.) Conductive channels can be closed under the gates by an appropriate voltage value applied to a gate. So, gates are input ports for electrical signals. In principle, the device can be formed on a Metal-Semiconductor (MS) structure without an upper insulator layer as well instead of a Metal-Insulator-Semiconductor (MIS) structure described above. In this case Schottky gates can be used for electrical inputs.

Another possibility is to form electrical gates below the conductive channel on the substrate directly. In this case gates should not be transparent optically either.

The channel is conductive between source and drain only, if all optical signals are switched on and such a potential is applied to all electrical gates, which does not close the channel. Different logic gates can be constructed with both electrical and/or optical inputs and electrical outputs.

If the top insulator (mono- or multi)layer can store electrical charge (Si_3N_4, Al_2O_3, SiO_2/Si_3N_4, etc.), the channel can be closed by the appropriate charge amount stored in the top layer. This charge can be injected into the top layer by voltage pulses applied to one or more gates. The charge can be erased by voltage pulses of opposite sign and the channel will be conductive again. As the injected charge can be stored for a long time, non-volatile memories can be constructed, which can be programmed electrically and read optically with electrical output signal. Further on, logic functions can be realized as well by these non-volatile memory devices.

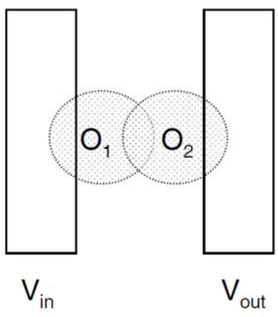

Fig. 2: Transfer AND gate with two optical inputs

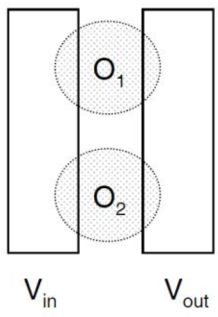

Fig. 3: Transfer OR gate with two optical inputs

3. Logic gates and arrays

Different logic gates and arrays can be realized by using the proposed device idea and structure. The structure presented in Fig. 1 is a transfer AND gate, which realizes the logic function $V_{out}=O_1{*}O_2{*}O_3{*}O_4{*}\underline{E}_1{*}\underline{E}_2{*}V_{in}$ where O_1, O_2, O_3, and O_4 are the optical input signals, and $\underline{E}_1$ and $\underline{E}_2$ are the inverted electrical signals. (For non-inverted electrical signals that potential is considered, which closes the channel.)

In the case of two optical inputs two simple logic functions can be realized: transfer AND gate $V_{out}=O_1*O_2*V_{in}$ (see Fig. 2) and transfer OR gate $V_{out}=(O_1+O_2)*V_{in}$ (see Fig. 3). In the case of one optical and one electrical inputs $V_{out}=O_1*\underline{E}_1*V_{in}$ function can be realized only (see Fig. 4). If these transfer gates are inserted in the driving part of a passive load inverter, where the power voltage (logic high level) value is the voltage, which is necessary to gates to close the channel, the inverted values of the above functions can be realized. Loading resistor value should equal the geometric mean value of resistances of closed and open transfer gate. As a resistance ratio between the open and closed states of the transfer gate of 1:100 can be easily reached, the deviation of high and low logic states from their nominal values is lower, than 10%. The power voltage should be chosen such that 90% of its value would safely close the channel.

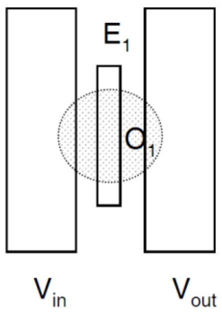

Fig. 4: Transfer AND gate with one optical and one electrical inputs

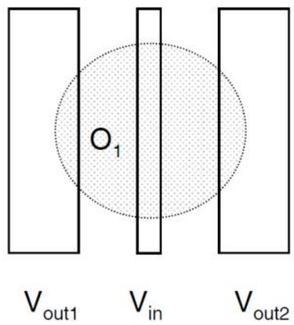

Fig. 5: Transfer gate with one optical input and two electrical outputs

Controled signal branching to more outputs can be realized either. Two possible topologies of a transfer gate with one optical input and two electrical outputs are presented in Figs. 5 and 6. The O_1 optical signal opens the channel from the input to both outputs. The topology of a transfer gate with three optical and two electrical inputs and two electrical outputs is shown in Fig. 7. The logical functions are as follows: $V_{out1}=O_1*O_2*\underline{E}_1*V_{in}$ and $V_{out2}=O_1*O_2*\underline{E}_2*V_{in}$. So, the input signal can be transferred to one or to the other output or to both of them.

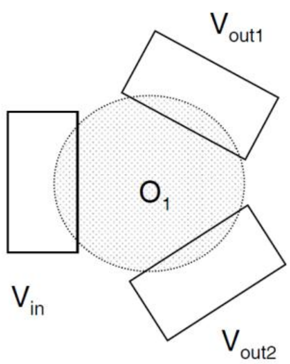

Fig. 6: Another possible topology of a transfer gate with one optical input and two electrical outputs

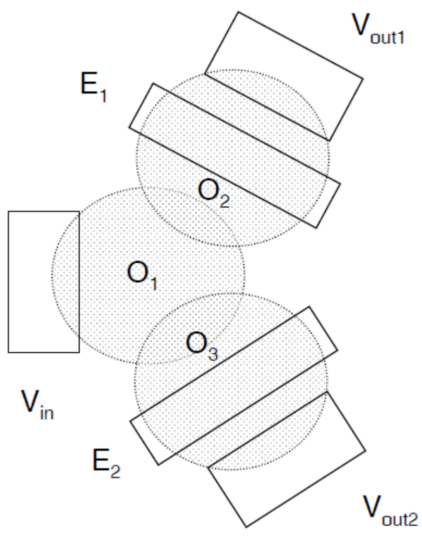

Fig. 7: Transfer gate with three optical and two electrical inputs and two electrical outputs

4. Possible applications

As the response time between the optical input signals and the electrical output signals is relatively long (it depends on the generation/recombination rates), and the minimum channel width is expected in μm range (a few optical wavelengths of input signals), the proposed logic devices and arrays can find application in such special fields only, where the optical input signals is necessary or advantageous in thin film or wide band gap semiconductor circuits. Possible fields of application are the (large area) thin film and/or organic electronics, e.g., control circiuts for solar cell arrays, where the operating speed and device dimensions are not critical, but the price is very important.

5. Summary

A new type of logic gates with both electrical and/or optical inputs and electrical outputs has been proposed. The possible realization of different logic functions is demonstrated. The possible application fields are briefly discussed.

Acknowledgement

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