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Silicon Photodetectors Matrix Coordinate Bipolar Functionally Integrated Structures

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In this paper a new approach for solving the detection and coordinate the detection of radiation in the optical range of 0.3-1.1 microns, based on the use of so-called bipolar functionally integrated structures (BI-FIS) in pixels photodetector arrays is discussed. Variants of new technical solutions based on photodetectors matrix pixel BI-FIS structures are shown. Their effectiveness and scope are evaluated.

Keywords: Detector, The detector coordinate functionally integrated structures.

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1. INTRODUCTION

An important and urgent problem of modern science and technology is a fast coordinate registration of the optical spectrum of the radiation in the range of 0.3-1.1 microns. Registration of such radiation is necessary for the solution of many scientific problems, such as elementary particle physics, in systems ranging, managing stationary and moving objects, sensing clouds and control the terrain, in optical communication lines. Moreover, this list is constantly being updated with new tasks with extremely high quality requirements of Radiation Detection and application areas. For the radiation detecting of this spectral range high-silicon matrix photodetectors with high-PIN-diodes (or bipolar transistors) in the cells of the external low-voltage and amplifies and processes signals electronic devices are commonly used. Thus the photodetector and external control electronics are made on different crystals, because their implementation in a single IC design intractable due to the difference in the voltage supply and the structure of the active regions. This circumstance does not allow to get the highest possible quality of registration conventional photodetectors, especially for such parameters as speed, integration and coordinate precision, and to satisfy the ever-increasing requirements of modern photodetectors.

2. EXPERIMENTAL PROCEDURES

In recent years, new design element base of integrated circuits [1-3], called functionally integrated structures (FIS) and allowing a large extent solve the above problems were created.

FIS are widely used in a number of areas of microelectronics, in particular:

– Power electronics (devices IGBT) [4];

– VLSI dynamic memory (p-MOS capacitive memory cell) [5];

– Sensors and LEDs in the external action [6-12];

– In the CCD [13].

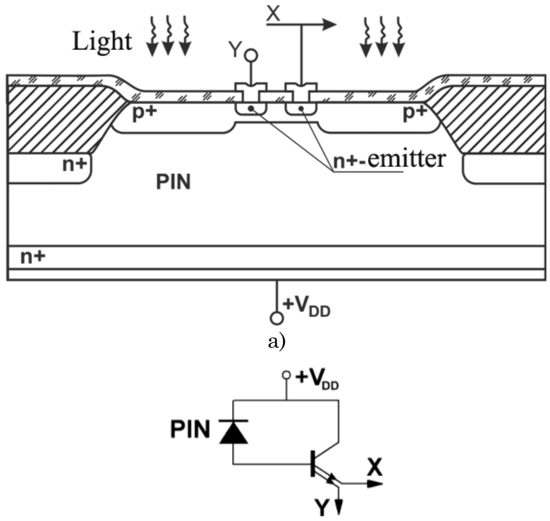
It should be noted that these and many other FIS were obtained as inventions. However, recently there have been heuristics methods [1] and the methods of computer synthesis of FIS structures [2-3]. Among the heuristic methods the most effective methods are:

– Pooling of equipotential regions (MOEO);

– Method of forming virtual domains (MFVO).

Among the methods of computer synthesis of the most popular method that uses an undirected graph as a mathematical model of the FIS structure. Consider some of the options designs FIS having promise as a new element base for the matrix of pixel coordinate photodetectors. Int is shown the structure of the pixel matrix of the coordinate of the photodetector [14, 15], in which are functionally integrated bipolar 2-emmiterny transistor and high-PIN-diode. This FIS was obtained by MOEO (see Fig. 1).

In this integrated structure of the collector region of the bipolar transistor *n*-type at the same time is an area *i*-type of PIN-diode and p+ region is – the transistor base the *p*-type region of PIN-diode. At the same time, in spite of the relatively complex equivalent electric circuit pixel its design is very simple and can be considered as one-dimensional, that allows to describe it by construction of simplified circuit diagram (see Fig. 1b).



a)

b)

Fig. 1 – FIS 2D bipolar transistor and PIN-diode: a) the structure of the cell; b) equivalent circuit

The basic principles of cell are as listed below. When a high voltage V$_{DD}$ is supplied to the area n^+-type PIN-diode in the *i*-layer, a region of the space-charge region (SCR), is produced and it which gives the main contribution of the carriers generated by the radiation into, the photocurrent I_{ph}. This photocurrent at the same time is the base current of the transistor, which increases in β times, whereby through the emitter of the transistor and the corresponding address lines X and Y will leak currents I_{e1} and I_{e2} will leak:

$$I_{e1} = I_{e2} = \frac{1}{2}\cdot\beta\cdot I_F, \tag{1}$$

where β – gain of the base current of the bipolar transistor; I_e – photocurrent.

Given that such matrix with such pixels can be produced by standard bipolar VLSI technology, using the topological rate LT = 1.0 mm area of 5 × 5 mm, with the value of the gain $\beta = 80\text{-}120$. So at the output of the matrix there are currents I_{e1} and I_{e2} almost by two orders of magnitude higher than the photocurrent I_{ph}, This circumstance allows to reduce the charge exchange T_c parasitic capacitances J_V through pixels resistance R_{pix}, formed by X and Y coordinate lines:

$$T_C = C_{pix}\cdot n\cdot\frac{R_{pix}}{B_Y}, \tag{2}$$

where T_C – charge exchange parasitic capacitances $cP = S_{pix}\cdot n$; S_{pix} – the specific capacity of a single pixel; n – number of pixels in the row (column); $R_{pix} \approx 1$ MW – the resistance of the pixel.

For a rectangular matrix of 100 × 100 elements and the area $S = 1\ \text{cm}^2$ specific parasitic capacitance is $\text{SP} \approx 0{,}5\ \text{pF}\cdot\text{m}^{-2}$. Hence, charge exchange $T_C \approx 4$ ns. (see Fig. 2)

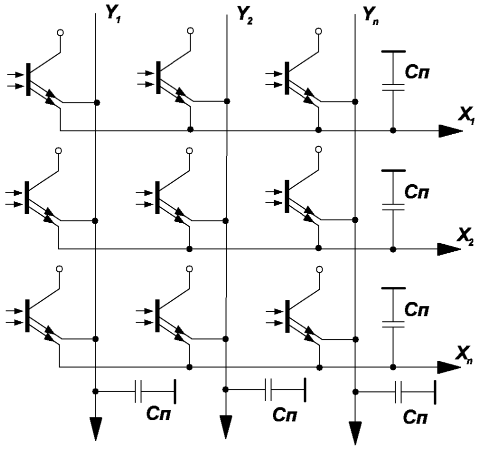


Fig. 2 – Equivalent circuit diagram of a matrix photodetector with twoemitter transistors

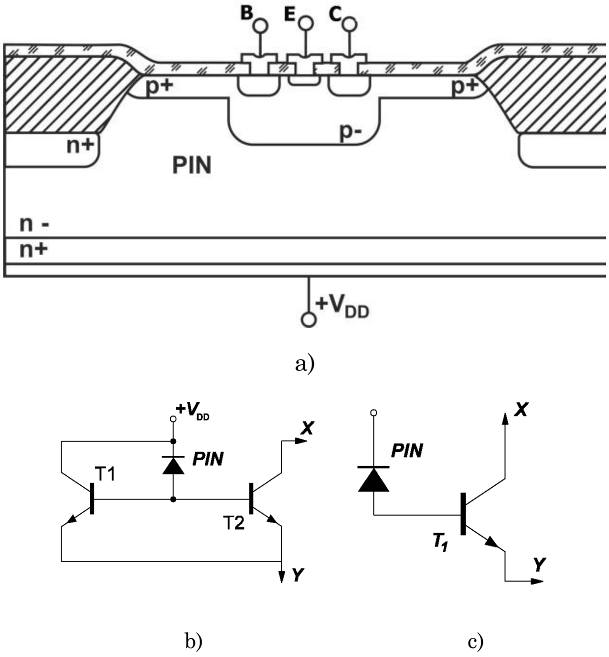
Speed bipolar T_{pix} pixel is determined by the transit time through the HMO of collector p-n-junction PIN-diode, the value of which, in the extreme case, is equal to the thickness of the silicon wafer (300-400 microns), and the drift velocity of charge carriers $v_{dr} \approx 1{,}5\cdot 10^7\ \text{cm c}^{-1}$:

$$T_{pix} = \frac{d}{v_{\partial p}}, \tag{3}$$

where d – the thickness of the silicon wafer; V_{dr} – the drift velocity of the charge carriers.

Speed of such pixel T_{pix} is about 2 ns. Figure 3a shows a diagram of a functionally-integrated photodetector pixel with «isolated» p-n-transition of collector (ICP) [16]. The base of the bipolar transistor and p-PIN – diode is also integrated into this structure, however, the collector region is n-type in the base region. The base is isolated from the n-region PIN-diode by p-n-junction and forms a region of n^+-type emitter the horizontal bipolar n-p-n transistor. This FIS was also obtained by MOEO. Figure 3b shows the equivalent circuit diagram of a pixel. Note that in this structure the vertical n-p-n transistor T_1 is parasitic, and to minimize its impact the p-base region is deep performed – however pixel structure can be represented by the simplified equivalent circuit (see Fig. 3c). ICP-pixel works similarly, except that the photocurrent is amplified and preferably distributed over the coordinate lines of a horizontal and not vertical transistor.

This case, the horizontal transistor may have a low supply voltage, thus increasing its speed, which is determined by the transit time of the charge carriers.



a)

b) c)

Fig. 3 – Pixel with “isolated” collector: a) structure; b) equivalent circuit; c) simplified equivalent circuit

Through the base, which is defined as:

$$t_{\partial p} = \frac{W}{2\cdot D_n\cdot N}, \tag{4}$$

where W – width of the base region; D_n – the electron diffusion coefficient; N – factor of the field.

For typical designs of the transistors the time is no greater than 1 ns. Figure 4 shows the circuit diagram of coordinate photodetector with such pixels. Figure 5a shows the FIS of pixel collector, isolated by space charge region [17], in which the n-region of the bipolar transistor and the high-PIN-diode also functionally integrated. However, they may have the different potentials as the section is divided by a "virtual" dielectric HMO "deep" p^+

region and the *n*-collector region, *n*-layer PIN-diode. Figure 5b shows, respectively, its simplified and detailed equivalent electrical circuits. This FIS was obtained by the method of forming virtual regions.

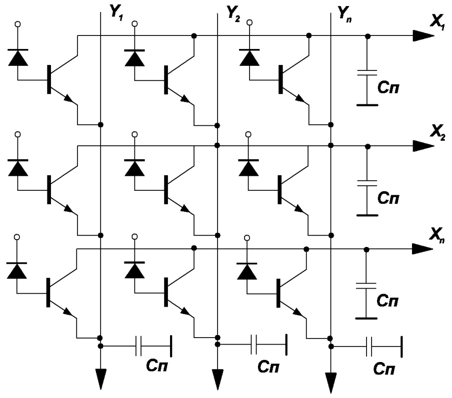
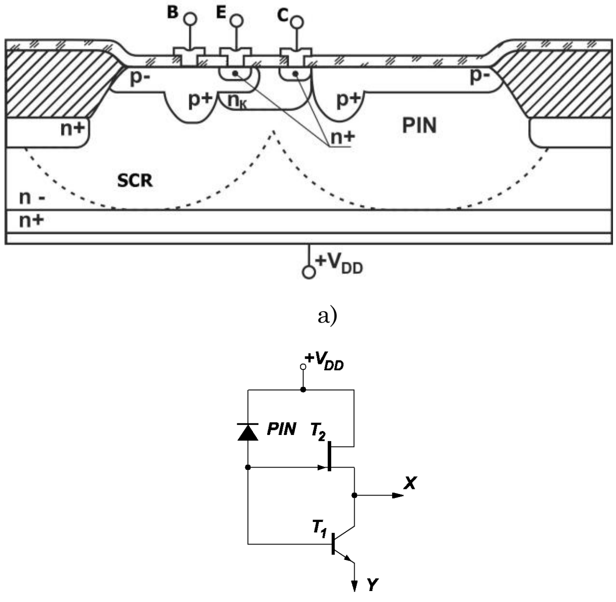


Fig. 4 – Equivalent circuit diagram of a matrix photodetector with the ICP



a)

b)

Fig. 5 – Pixel with an isolated area of the HMO collector: a) structure; b) equivalent circuit

3. RESULTS AND DISCUSSION

The advantages of the photodetector with twoemitter pixels are simple design and manufacturing technology. The disadvantage is a relatively low breakdown voltage of the bipolar transistor, that, compared with PIN-diode, limits the IPF of approximately up 100-150 microns.

The advantage of the photodetector with the ICP-pixels is the ability to maximize the HMO characteristic of PIN-diode (400 microns). The disadvantages are the large pixel sizes and, consequently, lower position resolution and the availability of additional current of the parasitic transistor, which increases the power of the matrix.

The advantage of the photodetector with AIMS-pixels is the ability to get maximum performance at maximum deep HMOs disadvantages are large pixel size and complex manufacturing technology.

In connection with the foregoing, each of the options considered may have its best (optimum) the scope, for example, the detection of deep and not deeply penetrating radiation.

4. SUMMARY

The article describes the new versions of the technical solutions for the construction pixels coordinate photodetectors containing functionally integrated structures based on bipolar transistors.

It is shown that the coordinate matrixes based on bipolar FIS have a high speed. Their position resolution determined by the size of the bipolar structure and no more than 5-10 microns at a rate of 1 micron topology.

The possible scope of the matrix – the detection of optical radiation in the range of 0.3-1.1 microns and ionizing particles (electrons, protons, α-particles, “soft” X-rays and etc.) is suggested.

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