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Analysis of Crosstalk in HgCdTe based Vertical Photoconductive LWIR Detector Arrays

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Abstract: HgCdTe is a well known material for Infrared detection applications because of its special properties like high absorption coefficient, adjustable bandgap and moderate dielectric constant etc. Vertical PC detectors of HgCdTe are very easy to fabricate as compared to the other detectors with the desired uniformity and therefore, these detectors may be proved better choice if the cost and the yield are considered. The proposed vertical PC detector design improves the fill factor of the detector array and allows the access of individual elements without the need of integrated circuit for their readout. The structure virtually does not have any optical crosstalk due to diffusion current, but suffers from the electrical crosstalk because of the networking of its element. This paper presents an analysis of the crosstalk for the focal plane array (FPA) of vertical PC detectors. We demonstrate that the networking reduces the detectivity by a factor strongly dependent on the number of rows and columns in the FPA. *Copyright © 2013 IFSA.*

Keywords: Crosstalk analysis, HgCdTe, Infrared, LWIR detectors, Photoconductive detector.

1. Introduction

The need of the hour is the development of scalable and low-cost imaging technologies and arrays that meet the focal plane architecture requirements while optimizing power, speed, noise, resolution, spectral response, and fill factor of the infrared (IR) FPA. Such FPAs find several military and civilian applications in IR detection and thermal imaging. In the presented work photoconductive (PC) LWIR detector structure is discussed and analyzed for possible use as a low cost IR detector for low end civilian applications.

There are fundamental limitations of the PC detectors and their FPA, like high power dissipation and low impedance as compared to the photovoltaic (PV) detectors. These shortcomings have limited the scope of PC detector up to only the first generation scanning arrays. However HgCdTe based PV detectors are very difficult to fabricate and are very expensive. Therefore being simple in principal and easy to fabricate, the PC detectors will be preferable if its shortcomings can be overcome or minimized. To get the optimized PC array structure suitable for staring detector arrays, vertical PC IR detector array has been proposed [1] and investigated in details for its pros and cons [2]. A vertical PC device has been simulated for a wavelength of 10.6 µm in our recent work [3], wherein we showed that the vertical PC has merit and can be integrated in form of two dimensional staring arrays with external discrete circuit for the readout [4]. The FPA architecture for vertical PC and the read out circuit are chosen so as to minimize the fabrication steps and optimizing the detector parameters [1, 3, 4]. Such technique gives another advantage that the readout circuit is kept outside the cooled area and therefore the power dissipated in the biasing and readout circuit does not load the cooling system, improving the cost effectiveness, reliability and ruggedness of the system.

A vertical PC detector array although seems to address all the shortcomings of the PC detectors as staring IR imagers, it has the limitation of the interconnects. For *N*×*M* array, we need to have 2.*N.M* connections to bias all the elements that become practically very difficult and not feasible for even a moderate sized FPA, like 64×64 array. Therefore, we propose to use the method of row-column interconnection scheme, wherein all the elements have one of their ends connected to a row and other end to a column, simplifying the interconnections from 2.*N.M* to only *N*+*M*. The implementation of the scheme integrated with the PC detector array and its implications are discussed in this paper. Using circuit simulations of this connection scheme, we have shown that the sharing of interconnect lines results in a strong electrical crosstalk that poses a limit on the size of the array as this crosstalk is a strong function of the number of elements in rows/columns.

2. Device Structure and Proposed Array Scheme

Vertical PC IR detector is chosen as the substitute of the conventional horizontal photoconductor, which eliminates its basic drawbacks [1]. Fig. 1 shows the basic structure of the single PC element of n-type HgCdTe in vertical n+-n-n+ configuration. The dimensions of detector are chosen to be 10×25×25 μm. The bias field is applied vertically through n+-n blocking contacts.

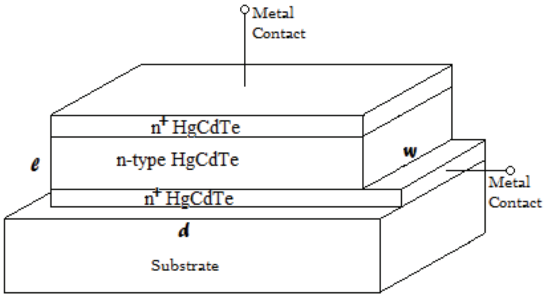

Fig. 1. Structure of Vertical PC LWIR detector.

An N×M array of this basic element is grown on the semi-insulating CdZnTe substrate. All the bottom n^+ region are connected column-wise and the top n^+ regions are connected row-wise for all the elements. This scheme results in a 2D PC detector array connected in such a way that each element has one of its ends connected to a row line and other end connected to a column line, as shown in Fig. 2.

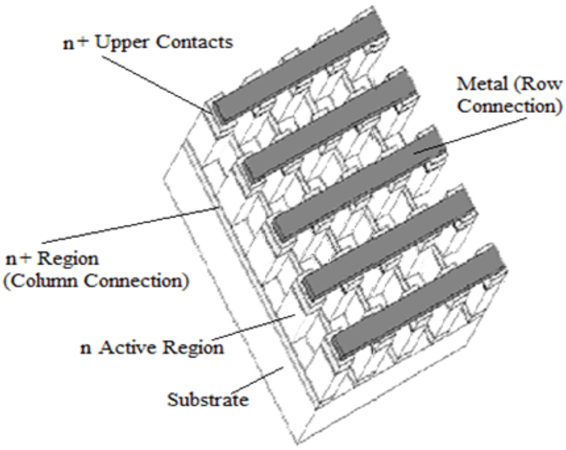

Fig. 2. Structure of Vertical PC LWIR detector array.

If the material is chosen properly the device can be illuminated from any of the top and bottom layers. By the virtue of the design of the structure itself, it does not require hybridization using indium bump bonding.

3. Crosstalk

The proposed structure of PC IRFPA has a few basic advantages. Since the electron–hole pairs are generated only in the mesa isolated active layer of n-type HgCdTe sandwiched between two n+ layers, there is no diffusion current out of the detectors so no crosstalk occurs because of the diffusion of minority charge carriers to adjacent elements. Thus, by the virtue of the structure of FPA there is virtually no crosstalk.

The seemingly simplified FPA structure however contributes the networking effect. Networking effect is the unwanted phenomenon in which, while taking measurements for one detector, all other detector form a complex network parallel to the detector under consideration resulting in a strong electrical crosstalk [5]. The PC detectors act as variable resistors, i.e., the detector resistance changes when there is incident radiation falling on it. Due to the inherent linearity in the resistive circuits, the analysis becomes a lot easier and the electrical crosstalk can be analyzed using superposition and compensation network theorems [6].

4. Theoretical Model for Crosstalk Analysis

In this section a theoretical model is formed to analyze the structure for crosstalk because of networking. This model deals with the effective resistance of the network for extracting the actual resistances in 2D array of networked resistors. The biasing is done by applying a constant current source between the nodes where the measurements are to be done. The voltage developed across these nodes and the current in individual element are related linearly. In this paper, a network array of 5×5 elements is considered. Fig. 3 shows the resistive array. The value of these resistances will change with illumination.

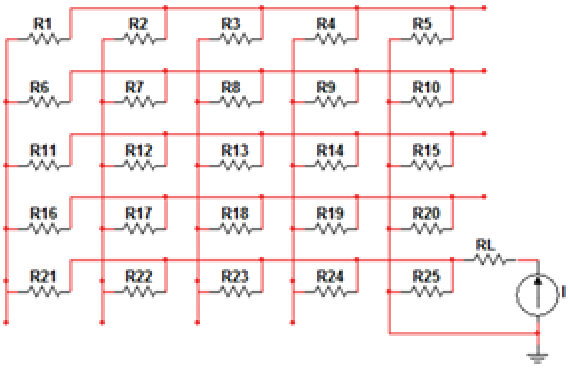

Fig. 3. Schematic diagram of 5×5 PC array in network configuration.

Initially, for bias point analysis we assume that all the elements in the array have equal resistances (say, R) at the set operating temperature (usually ~80 K for HgCdTe detectors). This is a quite reasonable assumption as in imaging arrays, uniformity is of utmost importance and has to be maintained in the design. The little variation in the values of detector element resistance comes only through the process variation. Because of the networking effect existing in the array due to row and column connections, the uniformity of entire array is lost after basing.

The elements of the array may be divided into four regions based on circuital symmetry as shown in the Fig. 4. These regions are described as follows:

a) Region-1 Consists of the element directly connected to the bias source.
b) Region-2 Consists of the elements having only one direct connection to the bias source, i.e., elements that are in the same column where the bias source is connected. This covers (N-1) elements for a *N*×*M* array.
c) Region-3 Consists of the elements having only one direct connection to the bias source, i.e., elements that are in the same row where the bias source is connected. This covers (M-1) elements for an *N*×*M* array.
d) Region-4 Consists of elements having no direct connection to the bias source. This region thus contains (*N*-1)×(*M*-1) elements for a *N*×*M* array.

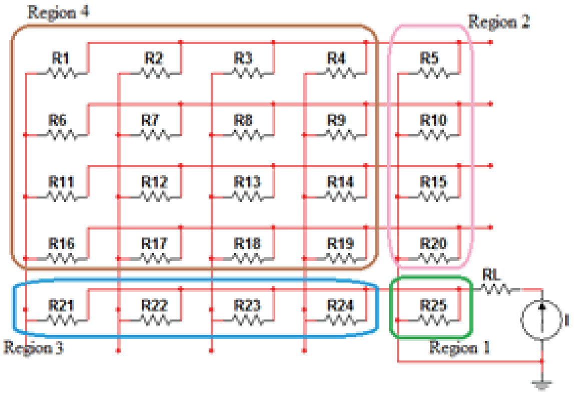

Fig. 4. Schematic divided into regions based on circuital symmetry.

It may be noticed that due to the circuital symmetry, all the elements lying in a particular region will carry the same current.

5. Bias Point Analysis

Let us assume that the element R_{25} is being biased by applying a current source of current 'I' between the nodes c_5 and r_5, as shown in Fig. 5. The rows are marked by 'r' and columns are marked by 'c' in this figure. Suppose the current flowing through the elements of region 1, 2, 3 and 4 are I_1, I_2, I_3 and I_4 respectively. The current has several paths to flow from the node c5 to r5. For example, the current flowing through the direct path, i.e., through element R25 will be I_1.

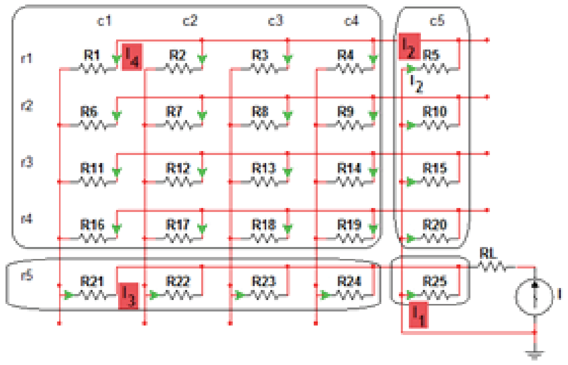

Fig. 5. Current distribution through the array.

The total current I is given by

$$I = I_1 + (N-1)I_2 \tag{1}$$

Also

$$I = I_1 + (M-1)I_3 \tag{2}$$

The current I_4 is related to currents I_2 and I_3 as

$$I_4 = \frac{I_2}{(M-1)} \tag{3}$$

$$I_4 = \frac{I_3}{(N-1)} \tag{4}$$

For an $N \times N$ array, where $M=N$, we have

$$I_2 = I_3 \tag{5}$$

Now, for the current flowing from c5 to r5 through direct path (path1) and through another path (path 2), indicated in Fig. 6, will produce same potential difference. Therefore, we have:

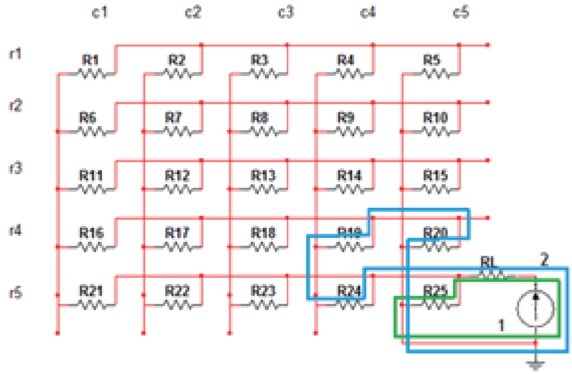

Fig. 6. Two alternate paths for the current in array: 1 is the direct path, 2 is indirect path.

$$I_1 \times R25 = I_3 \times R24 + I_4 \times R19 + I_2 \times R20 \tag{6}$$

But,

$$R1 = R2 = \ldots = R25 = R \tag{7}$$

So

$$I_1 \times R = I_2 \times R + I_4 \times R + I_2 \times R \tag{8}$$

$$I_1 = 2I_2 + I_4 \tag{9}$$

From equation 4, 5 and 9

$$I_1 = \frac{(2N-1)I_2}{N-1} \tag{10}$$

From equation 1, and 10

$$I_1 = \frac{(2N-1)I}{(N)^2} \tag{11}$$

and

$$I_2 = \frac{(N-1)I}{(N)^2} \tag{12}$$

Also

$$I_3 = I_4 = \frac{1}{(N)^2} \tag{13}$$

Deducing the ratio of currents from equations 10, 11 and 12

$$I_1 : I_2 : I_3 = (2N-1) : (N-1) : 1 \tag{14}$$

This indicates that the amount of bias current flowing through the elements of different regions have different values, which is again a function of the number of elements in the array. As the size of array increases, the dissimilarity of the bias current increases, resulting in large non-uniformity in the array of otherwise uniform detectors.

The above analysis also allows to extract the equivalent resistance between two nodes of the array. Assuming the resistance across r5 c5 to be R_{eq}, the potential drop as measured while biasing will be:

$$R_{eq} \times 1 = R \times I_1 \tag{15}$$

This implies that

$$R_{eq} = R\frac{(2N-1)}{N^2} \tag{16}$$

6. Simulation for Illuminated Case

When the resistances are same (for no illumination case), the $N \times M$ elements will have potential drops through them in the ratio given in Eq.(14). The resulting voltages at various nodes will be as depicted in Fig. 7 for I = 1 Amp.

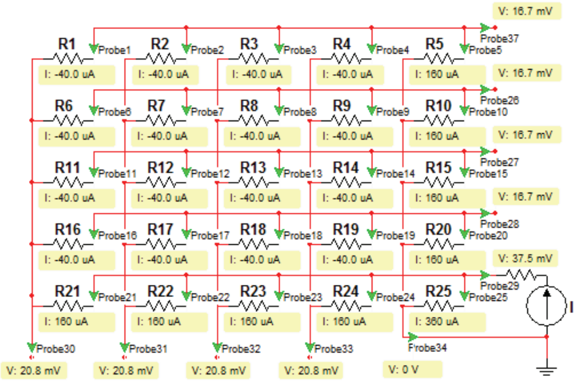

Fig. 7. Simulated Current and Voltage values for Resistances of equal value.

The values of the sensor resistances have been taken to be 104.11 ohms in this simulation, based on our previous work of device simulation [3]. The potential drop across any element can be found by taking difference of the voltage between its corresponding column and row.

The resistance of the element will change due to the incident radiation. This change in resistance will affect the apparent potentials of not only the element in illumination but also all other elements in the array. The apparent change in the potentials will be the functions of the actual change in all of the element resistances [5, 6].

Let us assume that the resistance of an element changes by an amount ΔR. To analyze the amount of crosstalk introduced in other elements because of change in resistance of the other element the resistance of R_{15} is changed. Due to change in this resistance, the voltage across the corresponding row and column also changes. This leads to change in the voltages V_{11} to V_{NM} .The corresponding change in the voltages is depicted in the simulation shown in Fig. 8.

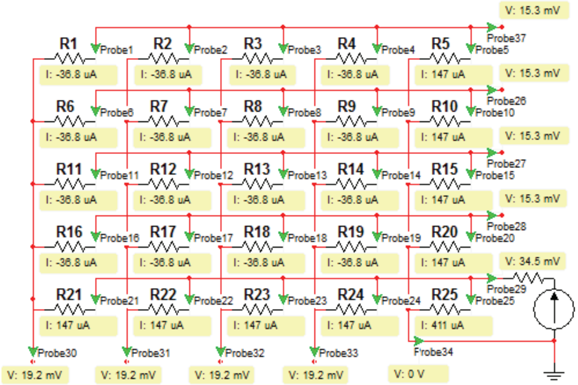

Fig. 8. Simulated Current and Voltage values for changed value of R_{25}.

For a simple case, the change in resistance is depicted as change in voltage for the corresponding row and column. The value of resistance for the element R_{25} is reduced (say by 20 %) and the voltages for the row 5 and column 5 have changed as inferred from the equations. The effect of change in resistance value of R_{25} can also be seen on the voltages in other rows and columns in Fig. 8.

Thus, we see that there is a change in voltage across an element of the FPA for two cases first is because of biasing of any other elements and second is because of change in the resistance values of other elements due to illumination. Low resistance of the photoconductive detector imposes a major issue of concern for the proposed structure. Fig. 9 depicts the change in voltage of an illuminated element R_{25} because of change in resistance in some other element (R_{13}).

7. Conclusions

We have presented a method of using vertical HgCdTe based photoconductors as staring infrared sensor. We have proposed the connection row-column interconnection scheme and investigated the resulting electrical crosstalk due to such interconnections. Using circuit simulation of 5×5 array of these detectors, we have shown that the electrical crosstalk may severely affect the imager performance and needs to be resolved.

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