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Electrical characteristic signatures for non-uniformity analysis in HgCdTe photodiode arrays

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HIGHLIGHTS

- ▶ Presented a theoretical approach of modeling non-uniformity in HgCdTe Photo-diode arrays.
- ▶ Identification of characteristic signatures in dynamic resistance–voltage curves.
- ▶ Correlation and sensitivity analysis of the signature parameters with the input/design physical parameters.
- ▶ Analysis of 2D distribution of signature parameters in response to the parameter variations.
- ▶ Statistical approach to identify the root cause of the non-uniformity in the arrays.

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ABSTRACT

In this paper we present a method of analyzing the performance non-uniformity of HgCdTe photodiode arrays for infrared imaging applications. For quantifying the characteristic behavior of various photodiodes, we have parametrized the dynamic resistance verses voltage signatures in such a way that the obtained signature parameters have some relevance with different physical parameters. We also estimated the sensitivity of the proposed signatures on physical parameters using statistical technique. These characteristics signatures may be used to quantify the non-uniformity of the HgCdTe photodiodes in IR imaging arrays and its analysis. The method presented here is based on theoretical calculation of MWIR HgCdTe photodiodes. However, the method is generic and may be implemented on any other type of diode arrays for theoretical or experimental analysis of their non-uniformity.

1. Introduction

Mercury Cadmium Telluride (HgCdTe) has been the dominant material for fabricating high performance infrared (IR) detectors in the complete useful range of IR radiations for a last few decades due to its tunable band-gap and high sensitivity and for that reason it continues to be the material of choice for future generation of IR detectors also [1–4]. However, being fragile and defect prone material, controlling its properties over a large area is a challenging task. Therefore, maintaining a reasonable uniformity in an imaging array of HgCdTe photodiodes requires in-depth characterization and detailed analysis of the non-uniformity and corrective measures in an iterative manner.

The variations in the electrical properties that govern the current conduction mechanisms of a photodiode are responsible for the pixel-to-pixel non-uniformity in a photodiode array, which is highly undesirable from image quality point of view [3,4]. These variations may be examined by various physical and electrical characterizations of the spatially distributed photodiodes as well as their underlying material. However, it is a long and time consuming process to extract all the important parameters of material and device and to examine their variations required for process optimization.

In this paper, we propose a method to quickly analyze the performance as well as performance non-uniformity in HgCdTe photodiode arrays using signatures of dynamic resistance–voltage (*R–V*) characteristics. Here, we describe these signatures and their quantitative measure for MWIR (Mid Wave IR, i.e., 3–5 µm wavelength band) photodiode arrays, but the method adopted is equally applicable to other types as well. The selected signature parameters are simple and easy to extract during the measurement itself. To establish and analyze the correlation of these signatures with the device/material parameters theoretically, we varied various parameters randomly in pre-defined limits in a sample space of 10,000 cases and evaluated *I–V* and *R–V* characteristics for each case based on the 1-D models, well reported in literature [5–13]. Then we extracted the signature parameters and examined their

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correlations with a number of input design parameters. Although, the presented analysis is theoretical, it may be utilized for experimental study for quick statistical analysis of non-uniformity in fabricated HgCdTe photodiode arrays.

2. Electrical characteristics of HgCdTe photodiode

The major known dark current mechanisms in an HgCdTe photodiode are: (i) thermal diffusion of carriers, (ii) generation–recombination (*G–R*) in space charge region, (iii) trap-assisted tunneling (TAT), (iv) band-to-band tunneling (BTB) and (v) surface leakage through ohmic shunt. All these mechanisms have been extensively investigated and are well reported in literature [5–13]. In the case of MWIR HgCdTe diodes, BTB current has been found negligibly small in the voltage range of interest and therefore has been ignored in the present analysis. The characteristic behaviors of these mechanisms are illustrated in Fig. 1a and b for a typical set of design parameter values.

The total current and therefore the overall dynamic resistance of a photodiode depend on various parameters that govern different current conduction mechanisms. In a typical photodiode, the forward biased region is dominated by the *G–R* and diffusion currents up to a certain forward voltage and then diffusion current becomes the most dominant one, until the series resistance starts limiting the current flow with increasing forward bias. In reverse bias region, at near zero bias *G–R* is the dominant current mechanism until the TAT takes over at some moderate reverse bias voltage. At high reverse bias, TAT becomes the only dominant mechanism in MWIR HgCdTe photodiodes.

When either a device or a material parameter changes, it affects some conduction mechanisms and results in the changes in some specific parts of the *I–V* and *R–V* characteristics. For example, if trap density becomes higher, the TAT mechanism may take over the *G–R* at relatively lower reverse bias voltage. Similarly, if the shunt resistance becomes lower, it starts dominating the total current in complete reverse bias region. In general, current–voltage (*I–V*) characteristics and *R–V* characteristics both contain the similar information as both of them are basically the results of a single electrical measurement. We have selected only the *R–V* characteristics for our analysis because being the derivative of *I–V*, it shows comparatively more prominent changes for the parameter variations.

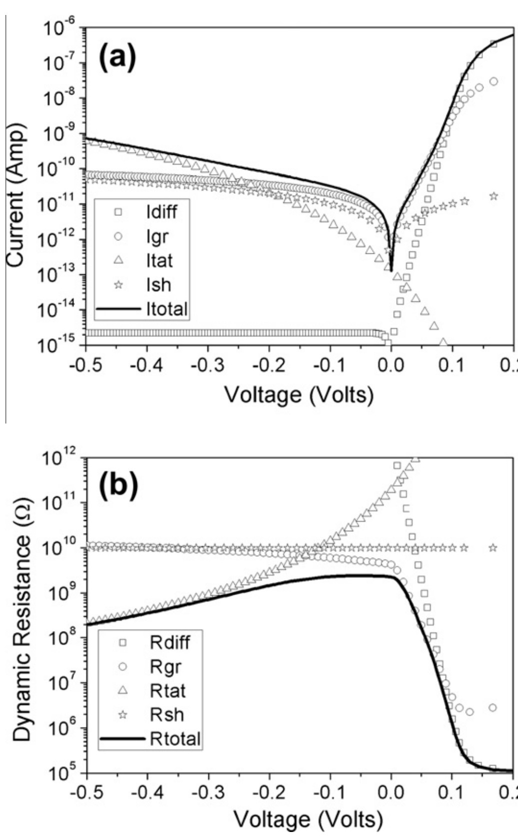

Fig. 1. Electrical characteristics of a typical MWIR HgCdTe photodiode, (a) *I–V* characteristics and (b) *R–V* characteristics.

3. Identification of characteristic signatures

In our earlier work, we had examined the sensitivities of various physical parameters on the important outputs [14–16]. In this work, we have selected those sensitive parameters for analyzing their effect on *R–V* characteristics. Fig. 2 shows a set of $\mathrm{Log}_{10}R$–*V* characteristics corresponding to random variations in the values of different parameters within 10% range of their typical values. It may be seen that the four different parts of the characteristics show significant changes in response to the design parameter variation and therefore qualitatively signify dependence on these parameters. We would like to emphasize here that the sensitivities depend on the typical values of design parameters and therefore, need to be investigated each time when the typical device design changes. Based on the sensitivities for our typical case, we have identified a number of signature parameters, described in following sub sections.

3.1. Zero-bias dynamic resistance, R_0

Zero bias dynamic resistance-area product (R_0A) is the most important and well studied performance parameter of HgCdTe photodiode as it signifies the technological capability of the dark current control [1–4]. Majority of the design and processing efforts are usually targeted towards making R_0A as high as possible. Since area is kept constant for all the photodiodes over the whole array, the parameter R_0 shows the same variations as R_0A has. Furthermore, the photodiodes are usually operated at near zero bias. Therefore, impedance matching with ROIC also makes R_0 an important parameter from imager performance point of view.

Although R_0 contains information about all the conduction mechanisms, it is mainly governed by the diffusion, *G–R* and the shunt current mechanisms as apparent from Fig. 1b. Combined with the other signatures, such as peak dynamic resistance and

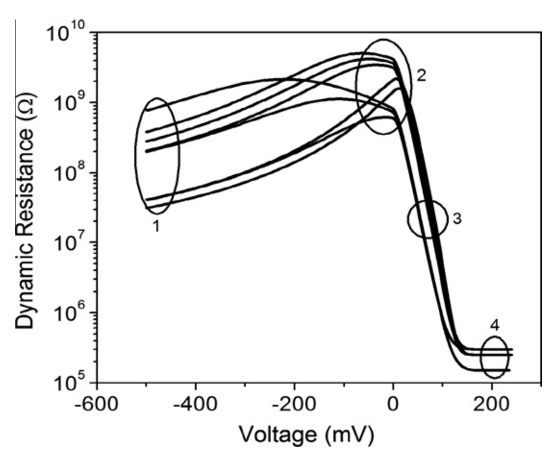

Fig. 2. Variations in *R–V* characteristics of a MWIR HgCdTe photodiode due to change in various physical parameters within process variation limit.