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***Abstract*—Three-dimensional, realistic full-wave electromagnetic and electrical simulations were done considering a planar HgCdTe 5×5 pixel miniarray with $5\,\mu$m-wide square pixels, illuminated by narrow Gaussian beams. The results suggest that, by avoiding quasi-neutral regions in the detector's absorber through majority carriers depletion, the inter-pixel crosstalk due to the diffusion of photogenerated carriers is significantly reduced.**

I. Introduction

The II-VI alloy HgCdTe is one of the most versatile materials for the realization of large format infrared (IR) focal plane arrays (FPAs) [1]. Majority carrier depletion of the absorber was indicated as a method to suppress the dark current originating from quasi-neutral regions, reducing the need of expensive cryogenic cooling systems [2], [3]. We show that carrier depletion is also effective to cut down the diffusive inter-pixel crosstalk [4], [5], a deleterious effect due to lateral carrier diffusion in planar FPAs, particularly relevant when the pixel pitch (often 3 – 15 μm) is much smaller than minority carriers diffusion length (in the orders of tens of micrometers).

II. Photodetector structure

Fig. 1 shows the photodetector structure: it is a planar 5×5 pixels miniarray with $5\,\mu$m-wide square pixels with p-on-n doping scheme, consisting in a small modification of a literature example [6], more extensively described in [7]. A narrow-bandgap, low donor-doped and compositionally graded $Hg_{1-x}Cd_xTe$ absorber is connected by two transition layers to two wide-bandgap HgCdTe regions (buffer and cap, Fig. 1(c)) with appropriately chosen doping profile. The absorber's compositional grading makes the detector suitable for both mid wavelength (MWIR, $\lambda \in [3,5]\,\mu$m) and long wavelength (LWIR, $\lambda \in [8,14]\,\mu$m) operation. The HgCdTe properties were described through the models reported in [4], taking into account the composition, doping, and temperature dependence of the HgCdTe alloy. The Shockley-Read-Hall (SRH) recombination processes were modeled as in [8] considering a lifetime around $100\,\mu$s. Fermi-Dirac statistics and incomplete dopant ionization were taken into account.

III. Modeling method

The geometry, doping and composition profiles were defined employing the Sentaurus three-dimensional (3D) numerical simulator by Synopsys [9], also used to perform the electrical simulations in the drift-diffusion approximation. With reference to Fig. 1(a,b), in the present work we defined the inter-pixel crosstalk as the photoresponse of a neighboring pixel (NNs or CNs) to a beam illuminating the central pixel (CP).

In order to obtain the solution of the electromagnetic problem, we sampled the absorber's and the transition regions' composition profiles [7], converting them to staircases of $N = 30$ sublayers, each with uniform value for the complex refractive index $n_r + i\kappa$ according to the sublayer's HgCdTe composition ([4], Table I), as shown in Fig. 1(b,d). With this approach, the EMW commercial simulator [9] was able to solve the electromagnetic problem by a full-wave approach, according to the Finite Differences Time Domain (FDTD) method [10]. The optical generation rate distribution G_{opt} into the pixel due to interband optical absorption was inserted as

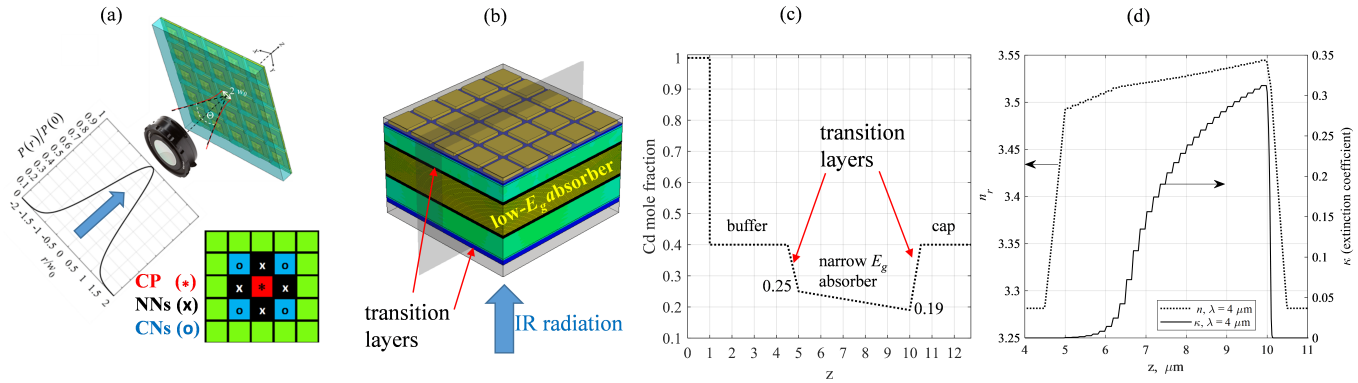
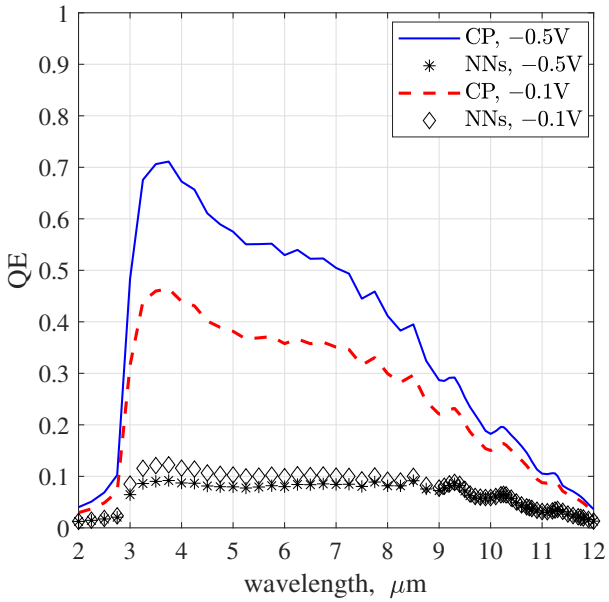


Fig. 1. (a) The 3D miniarray and (b) its Cd mole fraction x of $Hg_{1-x}Cd_xTe$ profile along z (E_g is the bandgap). (c) The discretization of the real n_r and imaginary κ parts of the absorber's refractive index profile along z.



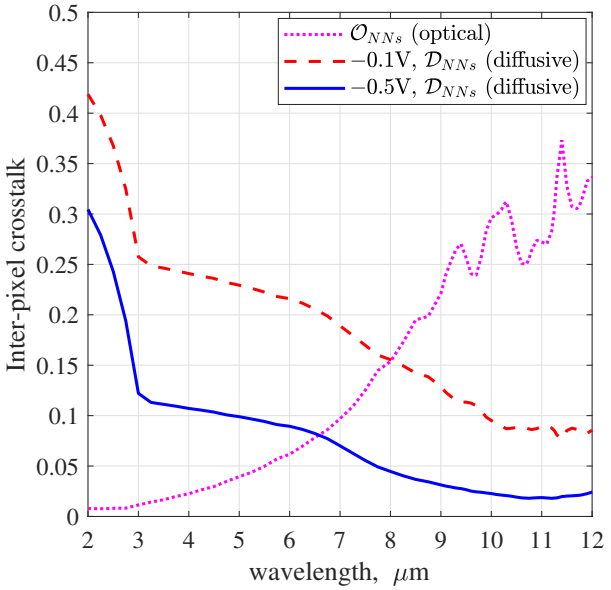


Fig. 2. (a) The CP and NNs spectral QE for the described Gaussian beam illumination centered on the CP, for $T = 140\,\mathrm{K}$ and $V_{\mathrm{bias}} = -0.1\,\mathrm{V}$ and $-0.5\,\mathrm{V}$. (b) For the same temperature, the "optical" and "diffusive" inter-pixel crosstalk (adimensional ratios) are shown for $V_{\mathrm{bias}} = -0.1\,\mathrm{V}$ and $-0.5\,\mathrm{V}$ (the optical crosstals is bias-independent).

a source term in the drift-diffusion continuity equations after having applied the same reverse bias V_{bias} to all the pixels.

IV. Results, comments and conclusions

Fig. 2 shows the spectral quantum efficiency QE and the inter-pixel crosstalk at $T = 140\,\mathrm{K}$ for $V_{\mathrm{bias}} = -0.1\,\mathrm{V}$ and $-0.5\,\mathrm{V}$ for the described illumination, where the definitions for the "optical" $\mathcal{O}_{NNs}$, "total" $\mathcal{C}_{NNs}$, and "diffusive" $\mathcal{D}_{NNs}$ contributions to the crosstalk

$$\mathcal{O}_{NNs} = \frac{\int_{V_{NNs}} G_{\mathrm{opt}}(x,y,z)\,dx\,dy\,dz}{\int_{V_{CP}} G_{\mathrm{opt}}(x,y,z)\,dx\,dy\,dz} \tag{1}$$

$$\mathcal{C}_{NNs} = \frac{I_{ph,\,NNs}}{I_{ph,\,CP}}, \quad \mathcal{D}_{NNs} \approx \mathcal{C}_{NNs} - \mathcal{O}_{NNs} \tag{2}$$

have been introduced (I_{ph} is the photocurrent, V_{CP} and V_{NNs} are the CP and NNs pixel volumes). By increasing the reverse bias from $-0.1\,\mathrm{V}$ to $-0.5\,\mathrm{V}$, the carrier depletion in the absorber increases significantly, allowing a larger fraction of photogenerated carriers to drift towards the CP contact, before they diffuse laterally: this is pretty apparent comparing the dashed and solid lines in Fig. 2(a,b), referred to $-0.1\,\mathrm{V}$ and $-0.5\,\mathrm{V}$ respectively. The moderate electrical field in the absorber that originates from the depletion of the majority carriers is enough to curtail the inter-pixel "diffusive" crosstalk even at moderate reverse bias. Beside the ensuing Auger suppression [3], this is an additional advantage of carrier-depleted detectors. Futher investigations will cover the response to non-monochromatic illumination [11], [12], considering different and higher values of temperature, and characterizing the effect of the absorber's background doping.

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