3D Electromagnetic and Electrical Simulation of HgCdTe Pixel Arrays

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***Abstract*—We have investigated the combined electromagnetic and electrical response of HgCdTe based pixel detector arrays with different geometries. We have computed the propagation of the optical signal in the detector structure by solving Maxwell's curl equations using a finite-difference time-domain approach. From the field distribution inside the device, we have evaluated the optical carrier generation rate. Using this information in a 3D numerical model based on drift-diffusion, we have computed the quantum efficiency and photo-response of a number of pixel geometries. Specifically, we have analyzed the response of both mesa type and planar detector arrays with and without CdZnTe substrate. Furthermore, the electromagnetic response has also been evaluated for different metal contact dimensions and configurations. It is found that for mesa type arrays without the substrate, significant reflection effects take place in the device that lead to resonance peaks in the photo-response.**

I. INTRODUCTION

The new generation of infrared (IR) focal plane arrays (FPAs) will need to meet aggressive performance benchmarks such multi-color detection, low dark current, and high resolution. It is necessary to scale the pixel pitch much below what is currently employed in order to successfuly design and fabricate large format, high resolutoin FPAs. Current generation FPA pixel pitches are on the order of 30–40 μm. As a results of the shrinking of pixel dimensions, detectors in the long-wave IR spectral region will approach the size of the wavelengths of interest. In addition to diffraction effects from the size of the pixel, reflections from material interfaces and the mesa sidewalls are expected to play a prominant role in the performance of wavelength scale devices. It is already seen that current generation planar devices and mesa devices have different spatial characteristics.[1] In fact, simulations and experiments have indicated reflections from mesa sidewalls and material interfaces can lead to increased cross talk between neighboring pixels in an FPA.[2] Accurate predictions of FPA performance with small pixel pitches will require the evaluation of the electromagnetic response of the pixel structure coupled with the physical simulation model.

In this work we first intend to study the electromagnetic response of HgCdTe-based pixel arrays of varying geometry. Secondly, we will integrate this electromagnetic model with our 3D physical device model[3] to study the combined electromagnetic and electrical response of the pixel array under different illumination conditions.

II. RESULTS

For this work, we examined both the electromagnetic response of a single pixel with various geometries as well as the electrical response of 3×3 pixel array. An example geometry is shown in figure 1 with both the grid for the finite-difference time-domain (FDTD)[4] simulation and the array used in the physical device simulation. The geometry can be easily varied to look at the effect of pixel size and shape on the photo-generated carrier distribution and quantum efficiency (QE).

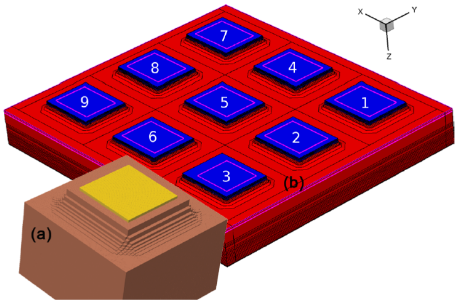

Fig. 1. (a) The pixel model used in the FDTD simulation showing the staircase approximation of the mesa sidewalls. (b) 3×3 pixel array used in the physical device simulation.

With a geometrical model created, we use an FDTD solver to calculated the electric and magnetic fields everywhere in our device. With this knowledge, we can easily relate the absorbed power to the optical generation rate. A plot of the generation rate is shown in figure 2 for two different illumination wavelengths in a 15 μm cutoff material. For the shorter wavelength illumination, the optical generation rate does not significantly deviate from an exponential decay in the material. However, for longer wavelengths, there is a significant spatial non-uniformity in the optical generation rate due to reflections from the mesa sidewalls and material interfaces.

The optical generation rate can be interpolated onto the mesh used for the physical device simulation and used as a generation rate during a drift-diffusion simulation. This technique allows the calculation of device performance in an FPA. Figure 3 shows the QE for several different simulation cases. The solid line with squares shows the results for a simple exponential decay model which ignores all reflections and the

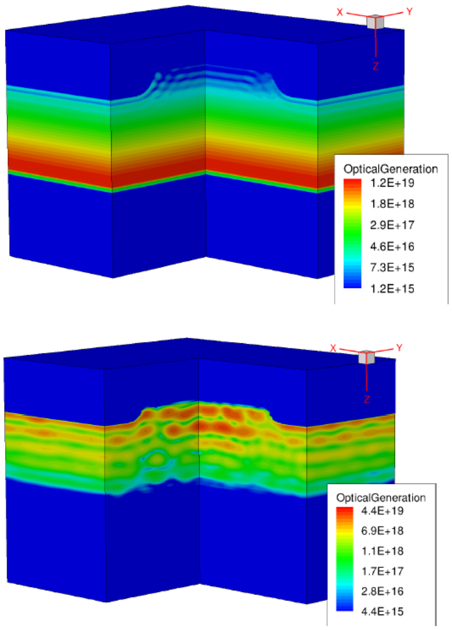

Fig. 2. The spatial distribution of the optical generation rate for a mesa pixel detector backside illuminated with two wavelengths: $\lambda = 8\,\mu$m for the upper panel and $\lambda = 15\,\mu$m for the lower panel. The material cutoff is $15\,\mu$m.

wave nature of light. The dashed line with triangles shows the results for an FDTD simulation run with no reflection from the contact on the top surface of the mesa or the mesa sidewalls. The dash-dotted line with circles shows the full FDTD results incorporating reflections from the mesa contact and sidewalls. We notice an increase in the cutoff wavelength stemming from increased reflections making the effective optical length larger.

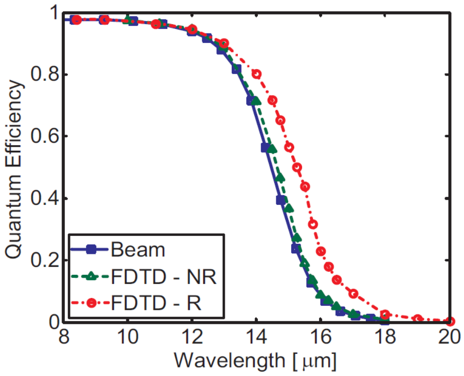

Fig. 3. Computed quantum efficiency for the central pixel (pixel number 5) in Fig. 1(b) when the 3×3 array is uniformly illuminated under the following conditions: (solid line with square symbols, blue in color) beam illumination with exponential decay of the photon flux; (dashed line with triangle symbols, green in color) FDTD solution with no reflection from the contact or the mesa profile; (dashed-dot line with circle symbols, red in color) full FDTD solution. All simulations performed with a CdZnTe substrate and $19 \times 14\,\mu$m anode.

If we remove the CdZnTe substrate from the device, interesting changes in the QE occur. Figure 4 presents the normalized QE of three different devices with substrate removed. The pixel dimensions are $24\,\mu$m for all three cases with various contact sizes. A peak occurs in the cutoff region of the QE. The height of the peak depends on the size of the contact, with a larger peak corresponding to a larger contact. With no contact present, the peak turns into a shoulder in the QE plot. This peak is only present when there is reflection from the mesa top and sidewalls as well as the backside of the detector.

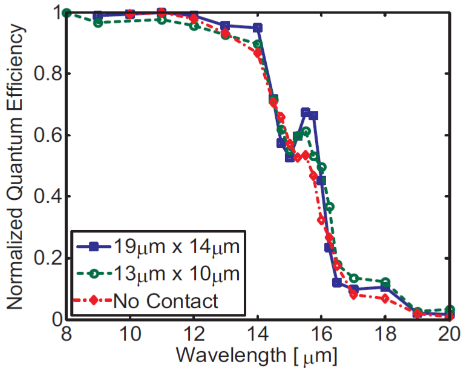

Fig. 4. Computed normalized quantum efficiency for the central pixel (pixel number 5) in Fig. 1(b) for the substrate-less array under uniform illumination and in the following conditions: (solid line with square symbols, blue in color) full FDTD solutions with contacts of dimension $19 \times 14\,\mu$m on a $24 \times 19\,\mu$m mesa; (dashed line with triangle symbols, green in color) full FDTD solution with contacts with dimension $13 \times 10\,\mu$m; (dashed-dot line with circle symbols, red in color) full FDTD solution with no contacts.

III. CONCLUSION

We have presented the results of combined electromagnetic and electrical 3D simulations of HgCdTe based pixel detector arrays with varying geometries. It is apparent that the geometry of the detector can substantially alter the spatial distribution of the optical generation rate. With the substrate removed, the increased reflection from the backside surface can combine with the reflections from the mesa contact and sidewalls to create a peak in the cutoff region of the QE plot. Further studies are needed to examine the effect of pixel geometry on crosstalk in an array.

REFERENCES

[1] O. Gravrand, J. Desplanches, C. Delbègue, G. Mathieu, and J. Rothman, “Study of the spatial response of reduced pitch $Hg_{1x}Cd_xTe$ dual-band detector arrays,” *Journal of Electronic Materials*, vol. 35, no. 6, pp. 1159–1165, June 2006. [Online]. Available: http://dx.doi.org/10.1007/s11664-006-0236-4

[2] O. Gravrand and S. Gidon, “Electromagnetic modeling of n-on-p HgCdTe back-illuminated infrared photodiode response,” *Journal of Electronic Materials*, vol. 37, no. 9, pp. 1205–1211, September 2008. [Online]. Available: http://dx.doi.org/10.1007/s11664-008-0478-4

[3] D. D’orsogna, S. Tobin, and E. Bellotti, “Numerical analysis of a very long-wavelength HgCdTe pixel array for infrared detection,” *Journal of Electronic Materials*, vol. 37, no. 9, pp. 1349–1355, September 2008. [Online]. Available: http://dx.doi.org/10.1007/s11664-008-0438-z

[4] A. Taflove and S. C. Hagness, *Computational Electrodynamics: The Finite-Difference Time-Domain Method, Third Edition*, 3rd ed. Artech House Publishers, June 2005. [Online]. Available: http://www.worldcat.org/isbn/1580538320