Crosstalk Suppressing Design of GaAs Microlenses Integrated on HgCdTe Infrared Focal Plane Arrays

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Abstract— **Crosstalk suppressing design of dielectric GaAs microlenses integrated on traditional HgCdTe infrared focal plane arrays (IRFPAs) is presented in this paper, by exploiting the finite difference time domain (FDTD) technique. Responsive photocurrent and crosstalk between most adjacent IR detector pixels have been numerically simulated using Crosslight TCAD commercial software. An optimal curvature of GaAs microlenses has been achieved by maximizing its ability to focus the incoming infrared plane wave at a specific point near the interface of GaAs substrate and HgCdTe absorber layer.**

I. INTRODUCTION

The scale of infrared focal plane arrays (IRFPAs) is being enlarged by shrinking the pixel size. Ideally, the reduction in IRFPA pixel dimension can achieve improvements in image resolution without significant decrease of sensitivity. However, as the pixel size is continuously decreased, IRFPA detectors encounter a degraded optical efficiency, as well as an increase in the crosstalk between adjacent detector pixels. These issues can be resolved through suitable pixel design and placement of microlenses in front of each photodiode, to redirect and focus light into corresponding active detector regions.

Infrared detectors based on HgCdTe material have been widely used and largely investigated [1–5]. Many studies on design of microlenses have also been numerically carried out in terms of traditional geometrical optics for devices of different materials including HgCdTe [6–7]. When the pixel size is approaching to or less than the Airy spot of an IR system, it becomes necessary to investigate the optical energy distribution inside the device considering wave characteristics of incoming radiation, i.e., according to the Maxwell equations. Therefore, the finite difference time domain (FDTD) technique is used to simulate photo response and pixel crosstalk of microlensed HgCdTe IRFPAs, and then an optimized radius of dielectric GaAs microlenses is introduced in this paper.

II. MODEL AND METHOD

The cross-sectional structure of the microlensed HgCdTe planar array investigated in this work is schematically shown in Fig. 1. Three adjacent pixels are modeled in two-dimensional mode with a pitch of 20μm, and each of them consists of an ion-implanted vertical n^+-on-p $Hg_{1-x}Cd_xTe$ homojunction ($x = 0.27$) and a spherical microlens formed on the back of GaAs substrate. Thickness of Hg vacancy doped p-type absorption layer is 9μm, and total thickness of GaAs substrate is 20μm including microlenses with radius of curvature adjustable. The width and depth of the n-type region are 18μm and 1μm, and the maximum donor and acceptor densities are $2\times10^{17}\text{cm}^{-3}$ and $8\times10^{15}\text{cm}^{-3}$, respectively. The HgCdTe IRFPA detectors are modeled to operate at 77K, and the microlens corresponding to the central pixel is illuminated independently from backside by 5μm monochromatic infrared plane wave, to evaluate crosstalk of most adjacent photodiode as a ratio of photocurrents.

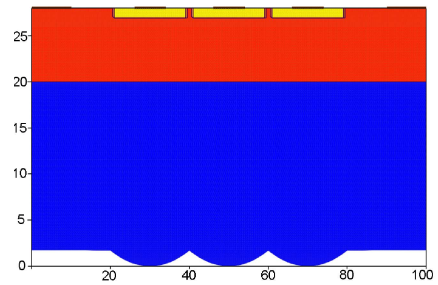

Figure 1. Cross-sectional structure of HgCdTe IRFPAs integrating GaAs microlens arrays against the corresponding ion-implanted p-n photodiodes.

Firstly, optical energy distribution inside the entire device is obtained using the FDTD algorithm where boundary conditions of perfectly matched layer (PML) is utilized. Thereafter, the photoelectrical characteristics of IRFPA detectors are derived by solving the coupled system of continuity equations, Poisson equation and the drift-diffusion current equations. Structure setup and numerical calculations are conducted by applying computer aided design (TCAD) commercial software package of Crosslight Csuprem and Apsys. Then the optimal microlens radius can be determined in a reasonable way, even when the pixel size is shrunk near or even less than the Airy spot of infrared optical systems.

III. RESULTS AND DISCCUSION

A. Simulation Results

A series of simulations are carried out with the radius of microlens changed from 10μm to infinite. Three typical optical energy distributions of HgCdTe IRFPA detectors are depicted respectively in Fig. 2. In fact, focusing spots of the microlenses with radii of 11μm, 15μm and 30μm are located within GaAs substrate, at the interface of GaAs substrate and HgCdTe absorption layer and within HgCdTe layer, respectively.

Fig. 3 and 4 display the responsive photocurrent of central pixel and crosstalk between most adjacent infrared detectors

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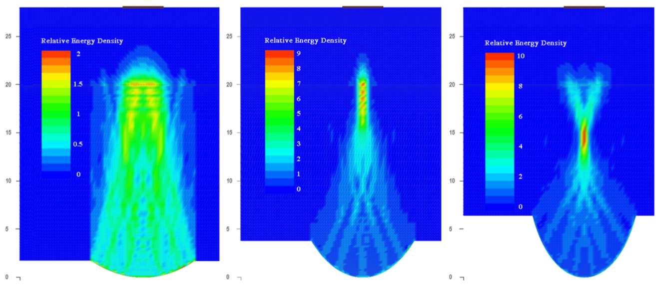

(a) (b) (c)

Figure 2. Optical energy distributions inside HgCdTe IRFPA intigrating GaAs microlens arrays with infrared plane wave back-side illuminated on single microlens with radius of (a) 30μm, (b) 15μm, (c) 11μm, respectively.

respectively with various electron lifetime values. As shown in Fig. 3, characteristics of responsive photocurrent versus radius of microlens are relatively complicated. As microlens radius increases, responsive photocurrent decreases a little firstly, and begins to increase to a maximum value when microlens radius equals 17μm, and then continues to decrease monotonically. As illustrated in Fig. 4, the minimum crosstalk value appears at microlens radius of 13μm, independent from the minority carrier lifetime. For minority carrier lifetime of 20ns, optimized crosstalk between most adjacent detector pixels is suppressed to only about 7.2%, less than half of that without integrating microlenses. Meanwhile, responsive photocurrent is enhanced by a factor of about 1.3. The optimal value of microlens radius can be adjusted from 13μm to 17μm, since the responsive photocurrent and crosstalk are insensitive to radius variation in this range.

B. *Disccusion*

As shown in Fig. 2, the maximum optical intensity does not appear at microlens focusing spot that should be located deeply into HgCdTe absorption layer. This is thought to be caused by the high absorption coefficient of HgCdTe material, since most incoming infrared radiation will be absorbed within a thin layer near the interface. For this reason, the key to suppressing the crosstalk is to constrain carrier generation in a focusing spot as small as possible at the interface, which has been verified by our simulations.

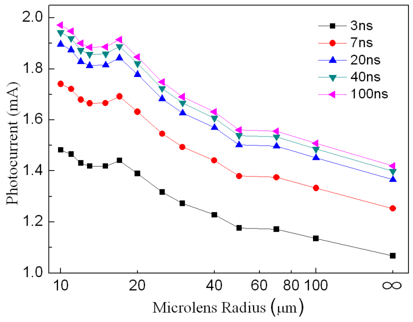

Figure 3. Responsive photocurrent of photodiode versus microlens radius with minority carrier lifetime of 3ns, 7ns, 20ns, 40ns and 100ns.

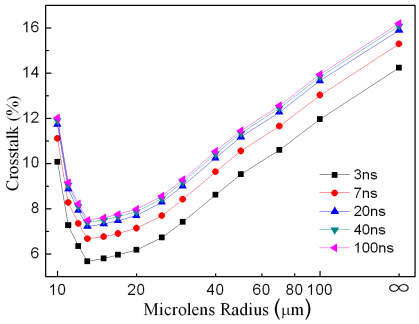

Figure 4. Crosstalk versus microlens radius with minority carrier lifetime of 3ns, 7ns, 20ns, 40ns and 100ns.

In this paper, the photoresponse and crosstalk are simulated without taking account of recombination at the interface of HgCdTe absorption layer and GaAs substrate. Actually, the minority carrier recombination cannot be ignored because of large mismatch of crystal lattice between HgCdTe epitaxial layer and GaAs substrate. However, the effect of interface recombination is probably fairly similar to that of lifetime reduction of minority carrier, as they both mainly affect the number of electrons that can reach the *n*-region but make little difference in the distribution of light absorption.

I. CONCLUSION

The responsive photocurrent and crosstalk between most adjacent pixels of HgCdTe IRFPA integrating microlenses in front of their corresponding photodiodes have been simulated numerically in two dimensions by exploiting FDTD method of Crosslight TCAD software. An optimal radius of spherical GaAs microlens is achieved by maximizing its ability to focus the incoming infrared plane wave at a specific point near the interface of GaAs substrate and HgCdTe absorber layer. For the configuration in this paper, i.e., a pixel size of 20μm, radiation wavelength of 5μm and GaAs substrate thickness of 20μm, microlenses with radius around 15μm is very beneficial to increase responsive photocurrent and simultaneously reduce crosstalk.

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