Crosstalk of HgCdTe LWIR n-on-p diode arrays*

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Abstract: Crosstalk of HgCdTe long-wavelength infrared (LWIR) n-on-p diode arrays was measured using scanning laser microscopy. During the measurement, HgCdTe diode arrays with different diode pitches were frontside illuminated by a He–Ne laser at liquid nitrogen temperature and room temperature. The experimental results show that crosstalk between the nearest neighboring diodes decreases exponentially as the diode pitch increases, and the factors that affect the obtained crosstalk are presented and analyzed. Crosstalk out of the nominal diode area (optically sensitive area) is also measured and discussed.

Key words: crosstalk; HgCdTe; n-on-p diode arrays; scanning laser microscope
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1. Introduction

In recent years, HgCdTe infrared focal plane arrays (FPAs) have been widely used in infrared imaging applications[1]. In order to improve the spatial resolution, diode dimension and diode pitch in FPAs are reduced. An unwanted effect of the size reduction increases crosstalk between neighboring detectors. Meanwhile, increase of minority carrier diffusion length tends to raise crosstalk among diodes in FPAs despite improvements in detector response. Crosstalk in detectors stems from two sources: optical crosstalk and electrical crosstalk. The former is related to the optical reflection and refraction of incident radiation on detectors, and the latter results from the motions of photo-generated carriers. Both sources affect the electrical output of devices. Therefore, the geometric structures of detectors, material parameters, and device technologies are important factors affecting crosstalk behavior. As a result, analysis of crosstalk is a complicated issue.

An infrared micron-sized spot would be ideal as an irradiating source in testing the crosstalk of HgCdTe FPAs. It is, however, difficult to focus an infrared light beam down to a micron-sized spot that is much smaller than the diode size and diode pitch. In particular, for infrared light with wavelength from 8 to 14 μm, the focused light spot diameter is usually 40 μm or more[2,3]. Thus, focused low power lasers in the visible or near-infrared range are often used as the irradiating source for the measurement of crosstalk in HgCdTe diode arrays[4,5]. Musca *et al.* performed crosstalk measurements on mid-wavelength HgCdTe infrared planar devices (MWIR) and LWIR mesa-isolated devices[4]. Karp *et al.* investigated crosstalk of MWIR HgCdTe diode arrays[5]. In the above works[4,5], the HgCdTe diode arrays were backside illuminated by a 1.047 μm laser beam at liquid nitrogen temperature.

Although crosstalk properties of infrared detectors are usually studied in the backside illuminated configuration, some detectors work in a frontside illumination geometry. In this paper, we measure the crosstalk of HgCdTe LWIR n-on-p planar diodes using a scanning laser microscope in frontside illumination geometry, which is instructive for devices working in the frontside illumination case. The photo-generated current (crosstalk) on a diode is measured when its neighboring diode is under illumination by the laser beam of a 632.8 nm He–Ne laser. HgCdTe diode arrays with different diode pitches were designed for the study.

2. Experiment

HgCdTe LWIR n-on-p diodes were fabricated by a planar process. A Hg vacancy-doped p-HgCdTe epilayers with a 5 μm CdTe buffer layer was grown on semi-insulating GaAs (211) B substrates by a Riber-32P molecular beam epitaxy system. The thickness of the epilayer is about 11 μm and the Cd concentration is about 23%. Hall measurement shows that the Hall mobility of the epilayer is about 786 cm^2/(V·s) and the hole concentration is about 5×10^{15} cm^{-3} at 77 K. The n regions were formed by boron ion-implantation. The diode sizes are 150×150 μm^2 and 100×100 μm^2. For the 150×150 μm^2 diodes, the diode pitches vary from 35 to 65 μm. The diode pitch refers to the shortest distance between two nearest neighboring diodes, as depicted in Fig. 1. A 250-nm-thick ZnS passivation layer was grown prior to the deposition of the p-type and the n-type contacts. All diode rows of different pitches and diode sizes were fabricated on the same wafer in order to eliminate systematic errors.

Figure 1 shows the device configuration of the designed HgCdTe LWIR n-on-p diode array for crosstalk measurement. During the measurements, a 632.8 nm wavelength of He–Ne

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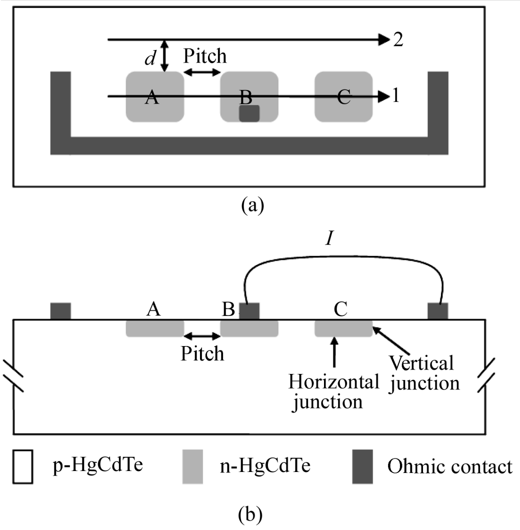

Fig. 1. Schematic configuration of one HgCdTe LWIR n-on-p diode array for crosstalk testing: (a) Top view; (b) Cross-section view.

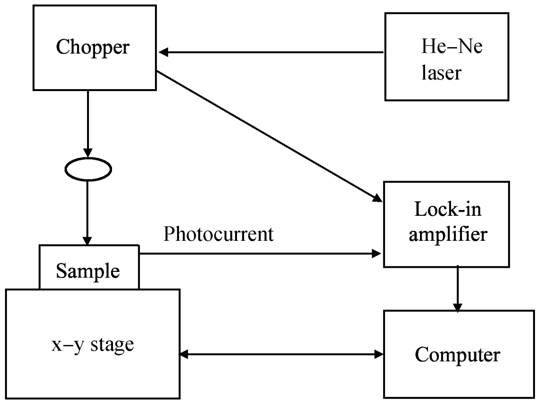

Fig. 2. Schematic diagram of the crosstalk testing setup based on scanning laser microscopy.

laser with a focused spot size of about 2 μm was used to frontside illuminate the diode arrays. The measurements were performed at both liquid nitrogen temperature and room temperature. The size of diodes A, B, and C is 150 × 150 μm^2 and the diode pitch is 40 μm. When the focused laser beam scans linearly across the three diodes, only diode B is connected to the leads of an ammeter to record the photocurrent. Figure 2 presents the experimental setup for the laser beam induced current (LBIC)[6, 7] measurement in this work.

3. Results and discussion

Figure 3(a) shows the photocurrent obtained by a line scan across the centers of diodes A, B, and C, respectively, at 85 K. The scan route is denoted by arrow 1 in Fig. 1(a). To better illustrate the photo-responses, Figure 3(b) shows the zoom-in view of the flat parts (a, b, and c) in Fig. 3(a). When the focused He–Ne laser spot scans on the surface of HgCdTe diode A away from the vertical pn junction, most photo-generated electron–hole pairs are created roughly 200 nm (light penetration depth) below the surface, which is smaller than 1 μm depth of the n region in the sample, as shown in Fig. 1(b). A small portion of the photo-generated electrons and holes are created in the junction region 1 μm below the surface and the holes are sweep out of the junction region by the built-in electric field into the p region. The increase in hole density in the p region breaks the delicate balance between diffusion and drift in the pn junction of the diode B, leading to the measured photocurrent in diode B that is short-circuited, as shown by a in Fig. 3. When diode B is excited, some of the photo-generated holes in the n region are swept out of the pn junction into the p region, forming a measured current in short-circuited diode B, as shown by b in Fig. 3. Note that diode A is open-circuited, therefore there is no current passing through diode A except an induced photovoltage cross the diode.

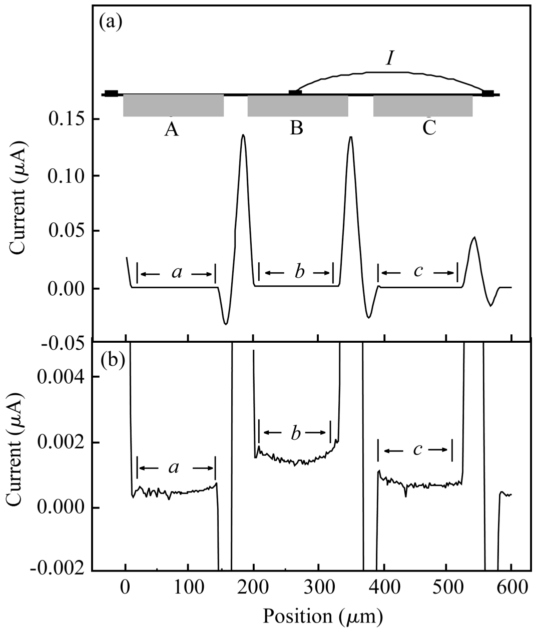

Fig. 3. Photocurrent after a line-scan across the centers of diodes A, B, and C at 85 K. The scan route is denoted by the arrow 1 in Fig. 1(a). (a) Overall photocurrent, and the top inset is a cross-section view of the corresponding device configuration. (b) Enlarged view of the flat parts in Fig. 3(a) in order to better illustrate the different photo-responses for three flat parts (a, b, and c).

The situation in which the laser beam scans on the vertical junction of diode A and diode B is rather complicated. Photo-generated holes and electrons are created in the n region, junction region, and p region, since the laser beam spot size (~ 2 μm) is much bigger than the junction size (~ 50 nm). Those electrons and holes are very hot since the photon energy of the laser is much higher than that of the band gap. The observed current peaks and valleys are due to the vertical pn junctions in the diodes, indicating that, for frontside illumination, crosstalk could be a serious problem if no other measure (mesa structure, for instance) is adopted. A detailed analysis of the current response in this case is rather challenging and beyond the scope of this paper.

In the case of backside illumination, the value of crosstalk between diodes A (or C) and B is calculated by crosstalk = I_A/I_B (or crosstalk = I_C/I_B), where I is the area under the photocurrent curve for one diode[4]. The calculation, however, needs to be modified for the frontside illumination, since the measured photocurrent is also contributed by the current peaks due to the vertical junctions of each diode. Owing

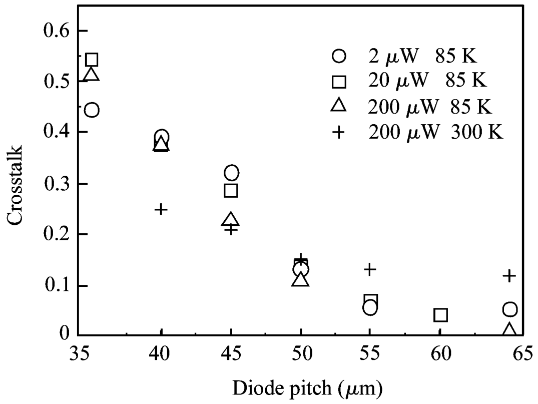

Fig. 4. Measured crosstalk of HgCdTe LWIR n-on-p diode arrays with different diode pitches, laser powers, and temperatures.

to the fact that the measured photocurrent in the flat parts is dominated by current across the horizontal junctions, the average photocurrent in each flat part in Fig. 3 is taken to be the photo-response (I_A, I_B, or I_C) due solely to each diode. Thus, the photo-response I_A—the average current measured on diode B when the laser beam scan on diode A—represents the diffusion of photo-generated carriers generated in diode A into diode B. I_A normalized by the photo-response I_B—the current measured on diode B when the laser beam scans on diode B—is thus defined as the crosstalk calculated by I_A/I_B, or I_C/I_B if the crosstalk between diode C and diode B is calculated. The reason we choose the frontside illumination is that it is much easier in this case for the laser beam to focus on the desired regions on the surfaces of the diodes.

Our measured crosstalk of about 50% for the 35-μm-pitch diodes is much larger than the crosstalk of less than 10% reported in earlier work[4, 8]. In addition to the differences in material parameters, device structures, illumination conditions, short-circuit and open-circuit connection strategies, and crosstalk definition, two important points should be made to account for the values of our obtained crosstalk. One is that the diodes are not isolated, i.e., no mesa structures or other isolation methods are used for eliminating the crosstalk in our case[9]. The other is that the laser used here has a much shorter wavelength than the band gap of the HgCdTe material. The hot photo-electrons could become energetic enough to leap into the neighboring diode. Our measured crosstalk indicates that, with increasing diode pitch, crosstalk decreases exponentially, as shown in Fig. 4. At pitch = 60 μm, the crosstalk decreases to 5%. Thus, our obtained results are actually close to the data reported in Refs. [4, 8], implying the effectiveness of the frontside illumination geometry for crosstalk study. The crosstalk decreases to below 5% at pitch > 60 μm, indicating that a wide pitch is favorable for the elimination of crosstalk. The exponential decrease of crosstalk with the increase of diode pitch also suggests that the crosstalk is dominated by electrical type, since the optical contribution is not strongly pitch-size dependent.

In Fig. 4, measured crosstalk of HgCdTe LWIR n-on-p diode arrays are presented at three different laser powers. No significant laser power dependence of crosstalk was observed in our work. Moreover, the temperature dependence of crosstalk is not significant, as shown by the 200 μW data at 85 K and 300 K in Fig. 4.

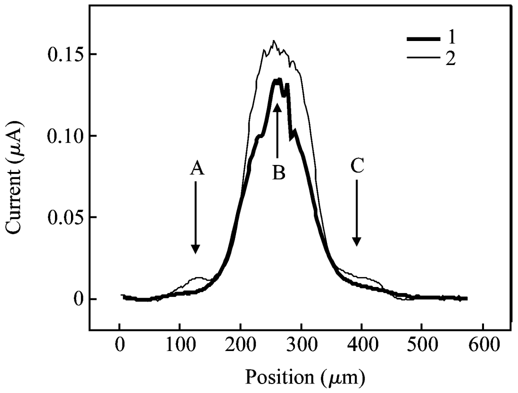

Fig. 5. Photocurrent after line-scans out of the diodes A, B and C were performed at 85 K. The scan route is denoted by arrow 2 in Fig. 1(a). Arrows A, B and C point to positions of the diode centers.

Crosstalk measurement is also performed when the scanning laser beam is out of the diode area (optically sensitive area). Figure 5 illustrates the photocurrent measured at 85 K for 100 × 100 μm^2 HgCdTe LWIR diodes with a diode pitch of 30 μm and the laser scan route along arrow 2 shown in Fig. 1(a). Curve 1 in Fig. 5 is the photocurrent measured when the distance between the scan route and diodes is 50 μm, i.e. d = 50 μm in Fig. 1, showing that there is a maximum photocurrent when the laser beam scans close to diode B (note that only diode B is connected to an ammeter). The photocurrent decays exponentially when the laser scans away from diode B. Curve 2 in Fig. 5 is the photocurrent obtained when d is about 20 μm, showing an increase in photocurrent in the vicinity of each diode since this scan route is closer to the diodes. The measured photocurrent results from diffusion of the carriers generated outside the diodes into the nominal diode area. Figure 5 implies that photo-generated electrons and holes in the vicinities of the diode areas would affect the diode signal strongly—the surface region other than diode area might also be optically sensitive. Thus, to use the devices properly, some measures must be taken to block optical signal incidence on the optical “non-sensitive” area.

4. Conclusions

In summary, we have investigated experimentally the crosstalk of HgCdTe LWIR n-on-p diode arrays with different diode pitches using a scanning He–Ne laser microscope. Crosstalk between the nearest neighboring diodes was calculated for the frontside illumination case. The obtained crosstalk decreases exponentially as the diode pitch increases. We also present some factors that affect the magnitude of the measured crosstalk. No significant laser power and temperature dependences of crosstalk were observed in our work. It is also suggested that crosstalk may arise from the region in the vicinities of the diode areas since some of the photo-electrons and holes generated out of the nominal diode area can diffuse into the nominal diode area and contribute to the crosstalk between the nearest neighboring diodes.

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