Suppression of extension of the photo-sensitive area for a planar-type front-illuminated InGaAs detector by the LBIC technique*

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Abstract: To suppress the extension of the photo-sensitive area of a planar-type InGaAs detector, the structure of the detector was modified, and the small-diffusion-area diffusion method, circle-type covering contact and guard-ring were introduced. The laser-beam-induced-current (LBIC) technique was used to study the photo responsive characteristics of the photo-sensitive area of different detector structures. It was indicated that, by modifying the size of the diffusion area, the width of the circle-type covering contact, the distance between the guard-ring and the photo-sensitive area and the working status of the guard-ring, extension of the photo-sensitive area could be effectively suppressed, and the detector photo-sensitive area could be exactly defined.

Key words: InGaAs photodiode; LBIC; planar type device; photo-sensitive area
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1. Introduction

InGaAs detectors for near-infrared (1–3 μm) spectra have the distinct advantages of low leakage current, high quantum efficiency, high reliability and room temperature operation. After decades of development, InGaAs detectors, especially linear InGaAs detector arrays, have found wide applications in many fields such as near-infrared spectroscopy, spectral characterization, agricultural monitoring, industrial process control, moisture measurement, biomedical analysis, and space remote sensing[1−4]. A large-scale InGaAs detector array has been successfully used in space remote sensing[5−7].

The planar-type InGaAs detector is quite suitable for remote sensing due to its small dark current, high detectivity, high reliability etc, and the planar structure is the most commonly used one. However, for the planar-type InGaAs detector, it is difficult to define the photo-sensitive area due to its extension, and there is large crosstalk between neighboring pixels. In large-scale planar-type detector arrays especially, the photo-sensitive area of the detector pixel is greatly reduced, and the problem of the extension of the photo-sensitive area will become even more acute. Generally speaking, there are three sources for the extension of the photo-sensitive area in planar-type InGaAs detectors, i.e. increase of the diffusion hole area during device fabrication, side diffusion in the ion doping process and the side-collecting effect of the photon-generated carriers around the PN junction area. Extension of the photo-sensitive area would introduce big problems in detector-structure design, and the side-collecting effect of the photo-generated carriers around the PN junction area would bring down the modulation transfer function (MTF) of the detector arrays and thus reduce the precision of the image. It is meaningful to study the suppression of the extension of the photo-sensitive area in planar-type InGaAs detector arrays. In this paper the structure of the planar-type front-illuminated InGaAs detector is re-modified, and the laser-beam-induced-current (LBIC) technique is used to study the suppression of the extension of the photo-sensitive area in the new structured planar-type InGaAs detector arrays.

2. Structure design and fabrication of the detectors

There are already many reports on the principles of LBIC[8,9], and they will not be listed in detail here. The paper begins with the structure design and fabrication of the detectors.

2.1. Detector structure design

Considering the three sources for the extension of the photo-sensitive area in planar-type front-illuminated InGaAs detectors, the detector structure was modified as follows: the diffusion area was reduced to give enough space for the side-etching of the diffusion mask, side diffusion in the ion doping process and the side-collecting effect of the photon-generated carriers around the PN junction area, a guard-ring was fabricated around the photo-sensitive area, and the circle covering contact was used to define the photo-sensitive area as that the size of the inner circle of the contact is equal to the designed

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Table 1. Detector structures.

No.	Diffusion-hole size (μm^2)	Attachment structure		
		Circle covering contact size (μm)	Guard-ring (μm)	
			Width	Distance between photo-sensitive area
A	80 × 90	×	×	×
B	80 × 90	10	×	×
C	80 × 90	×	10	55
D	80 × 90	10	10	55
E	40 × 45	×	×	×
F	40 × 45	×	5	27.5
G	30 × 40	×	×	×
H	30 × 40	×	10	30
I	10 × 500	×	10	10

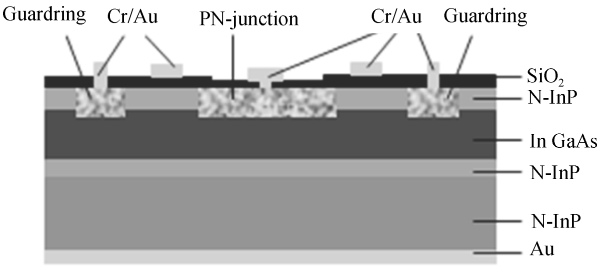

Fig. 1. Planar InGaAs detector structure.

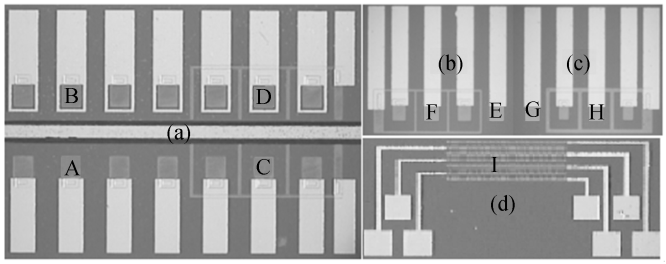

Fig. 2. Plan form of the detectors.

size of the photo-sensitive area.

2.2. Detector fabrication

The planar-type front-illuminated photo-detectors were fabricated on n-InP/i-InGaAs/n-InP epitaxial materials from the EpiWorks Company. The epitaxial structure consisted of a 1 μm n-InP top layer with a carrier concentration of 3×10^{16} cm^{-3}, a 2.5 μm i-$In_{0.53}Ga_{0.47}As$ absorbing layer with a carrier concentration of 5×10^{16} cm^{-3}, a 0.5 μm n-InP buffer layer with a carrier concentration of 2×10^{18} cm^{-3} and a 600 μm n-InP substrate with a carrier concentration of 2×10^{18} cm^{-3}. After rinsing, a SiO_2 layer was sputtered on the epitaxial wafer to act as a diffusion mask. Then the diffusion hole of the photo-sensitive area and guard-ring was fabricated using the wet-etching method, and the sealed-ampoule diffusion method was used to form the P-InP photo-sensitive area and guard-ring area. After that the front P-contact of the detector and guard-ring was fabricated. A SiO_2 layer was used as the passivation layer. The Cr/Au layer was sputtered around the photo-sensitive area to act as the circle covering contact. Finally an Au layer was evaporated on the polished backside of the detector as the back N-contact. A cross section of the detector is shown in Fig. 1.

The fabricated detectors were divided into four groups as shown in Table 1 and Fig. 2. Group 1 with a designed photo-sensitive area size of 100×100 μm^2 and actual diffusion-hole size of 80×90 μm^2 was designed into four detector structures, A without any attachment, B with a 10 μm wide circle covering contact, C with a 10 μm wide guard-ring which was 55 μm away from the photo-sensitive area, D with a 10 μm wide circle covering contact and a 10 μm wide guard-ring which was 55 μm away from the photo-sensitive area, as shown in Fig. 2(a). Group 2 with a diffusion-hole size of 40×45 μm^2 was designed into two detector structures, E without any attachments, F with a 5 μm wide guard-ring which was 27.5 μm away from the photo-sensitive area, as shown in Fig. 2(b). Group 3 with a diffusion-hole size of 30×40 μm^2 was designed into two detector structures, G without any attachments, H with a 10 μm wide guard-ring which was 30 μm away from the photo-sensitive area, as shown in Fig. 2(c). The photo-sensitive area size of group 4 was 100×100 μm^2 with a neighboring photo-sensitive area distance of 10 μm and was named I, as shown in Fig. 2(d).

3. Experimental results and discussions

The experiments were carried out on the Micro LBIC system from SEMILAB. The pulsed laser had a wavelength of 980 nm, a pulse frequency of 1 kHz and a laser beam radius of 5 μm. The 980 nm light was not the peak responsive wavelength of the InGaAs detector, but was still in the 0.9–1.7 μm wavelength region, and the experimental result is credible. All the measured LBIC signals were normalized to form a clear comparison.

3.1. Suppression of theextension of the photo-sensitive area by using the circle covering contact

Normalized LBIC signal gray isoline maps of device A and B are shown in Fig. 3(a); for the detector without any attachments, the region around the photo-sensitive area also contributes to the detector signal, and the photo-sensitive area evidently extends. After the circle covering contact is brought in, the extension of the photo-sensitive area is greatly suppressed because part of the incident light is reflected by the covering contact. If we choose the full width at half maximum in Fig. 3(b) as the actual photo-sensitive area size, it is 95 μm for detector B, rather smaller than the 107 μm for detector A, and this is quite near the designed 100 μm. It is shown that the combination of small diffusion-hole and circle covering contact is

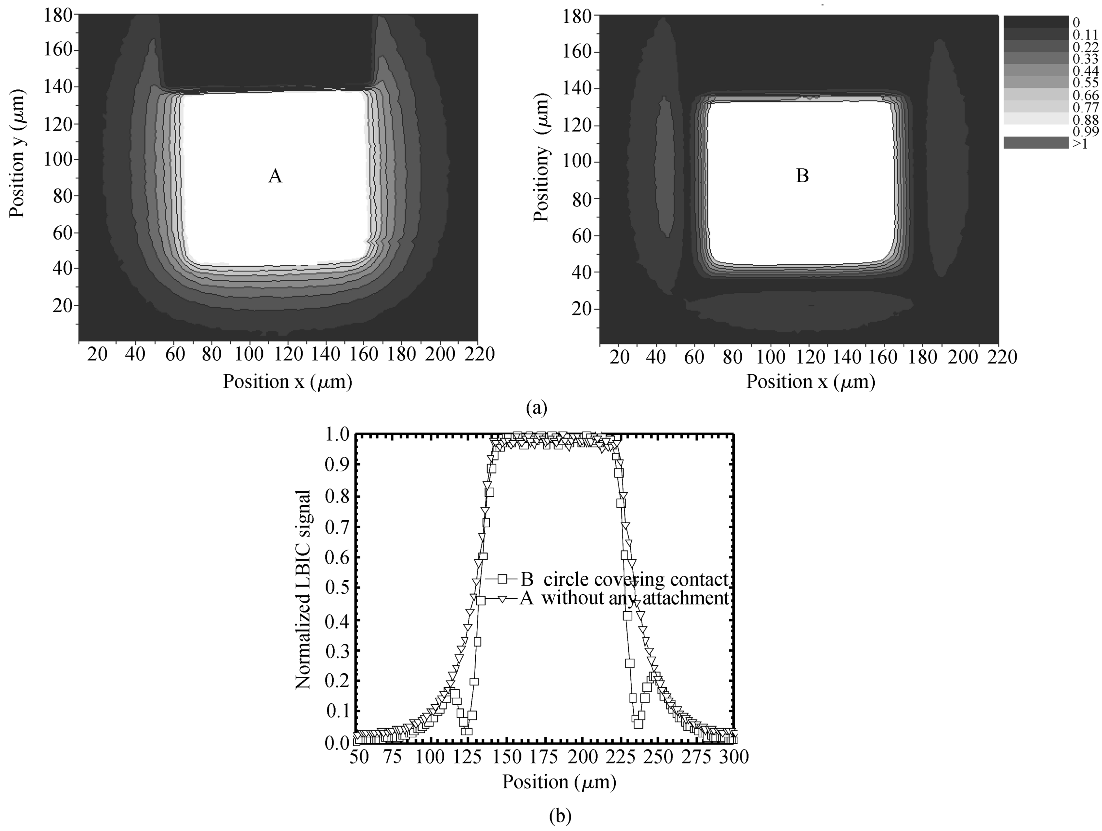

Fig. 3. Suppression of the extension of the photoactive area by using a circle covering contact.

helpful to suppress the extension of the photo-sensitive area. There is still an LBIC signal in the region without covering contact, and this could be optimized by widening the covering contact. However, in large-scale detector arrays with quite small pixel pitch, the circle covering contact cannot be widened as one likes, and also the stray light arising from the light reflected by the covering contact would cause big problems in detector encapsulation; this limits the applications of the circle covering contact. Some other methods are desired to suppress the extension of the photo-sensitive area.

3.2. Suppression of the photo-sensitive area by using guard-rings at different distances

Normalized LBIC signal gray isoline maps of devices C, F and H with the guard-ring short connected are shown in Fig. 4(a); extension of the photo-sensitive area could be suppressed to a certain extent. A guard-ring at a distance 55 μm away from the photo-sensitive area has a small suppression effect because it lies too far away and cannot collect the photo-carriers around the photo-sensitive area effectively. When the distance is reduced to 30 μm and 27.5 μm, the LBIC signals of the detectors are obviously suppressed in a rectangular region because a short connected guard-ring at a smaller distance can effectively collect the photo-carriers around the photo-sensitive area.

For the detector I, as shown in Fig. 2(d), if the neighboring pixel of detector I is short connected and acts as the guard-ring, the guard-ring to photo-sensitive area distance is reduced to 10 μm, most of the photo-generated carriers near the guard-ring are collected and cannot contribute to the signal of detector I. The extension of the photo-sensitive area for I in this direction is greatly suppressed, and 10 μm is a suitable value.

If we choose the full width at half maximum in Fig. 4(a) as the actual photo-sensitive area size, when the guard-ring to distance is reduced from 55 to 30, 27.5 and 10 μm, the extension of the photo-sensitive area is also reduced from 11.6, 9.2, 9, 6.2 μm, as shown in Fig. 4(b). However, the beam radius of the system is 5 μm, which is the main limitation for the precision of the measurement system. There is no evident relationship between the guard-ring to photo-sensitive area distance and extension of the photo-sensitive area. Based on the experimental data to date, it is hard to give a quantitative analysis of this. A future study should study this.

3.3. Suppression of the extension of the photo-sensitive area by using guard-rings with different working statuses

For detector F with a guard-ring to photo-sensitive area distance of 27.5 μm, as shown in Fig. 5(a), there is a tiny difference for the guard-ring under different working statuses. It is indicated that the guard-ring to photo-sensitive area distance of 27.5 μm is still too large to effectively suppress the extension of the photo-sensitive area. To improve the effect of the guard-ring, a smaller guard-ring to photo-sensitive area distance and a short connected guard-ring should be introduced.

When the guard-ring to photo-sensitive area distance is reduced to 10 μm, if the two neighboring pixels of detector I are floating, parts of the photo-carriers generated near these two pixels would be collected by detector I due to the photo-generated carrier lateral diffusion effect, as shown in Fig. 6(a). Also, as one of the neighboring pixels is short connected, al-

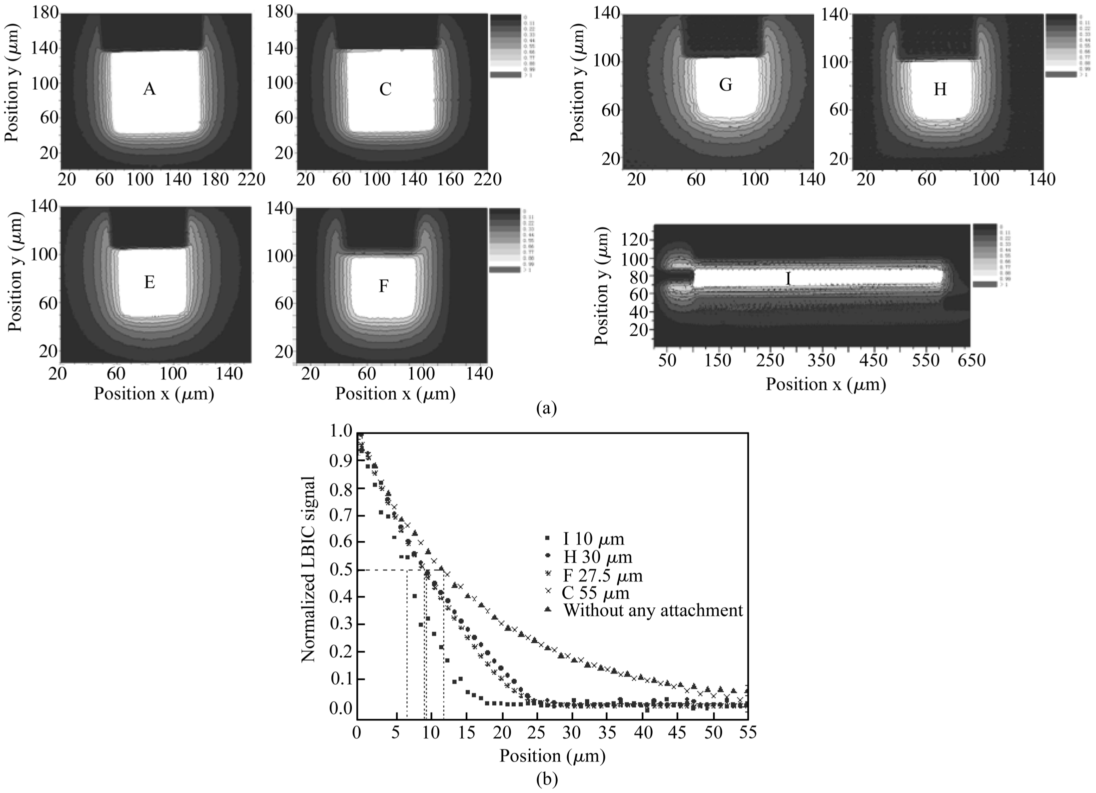

Fig. 4. Suppression of extension of the photoactive area by using guard-rings at different distances from it.

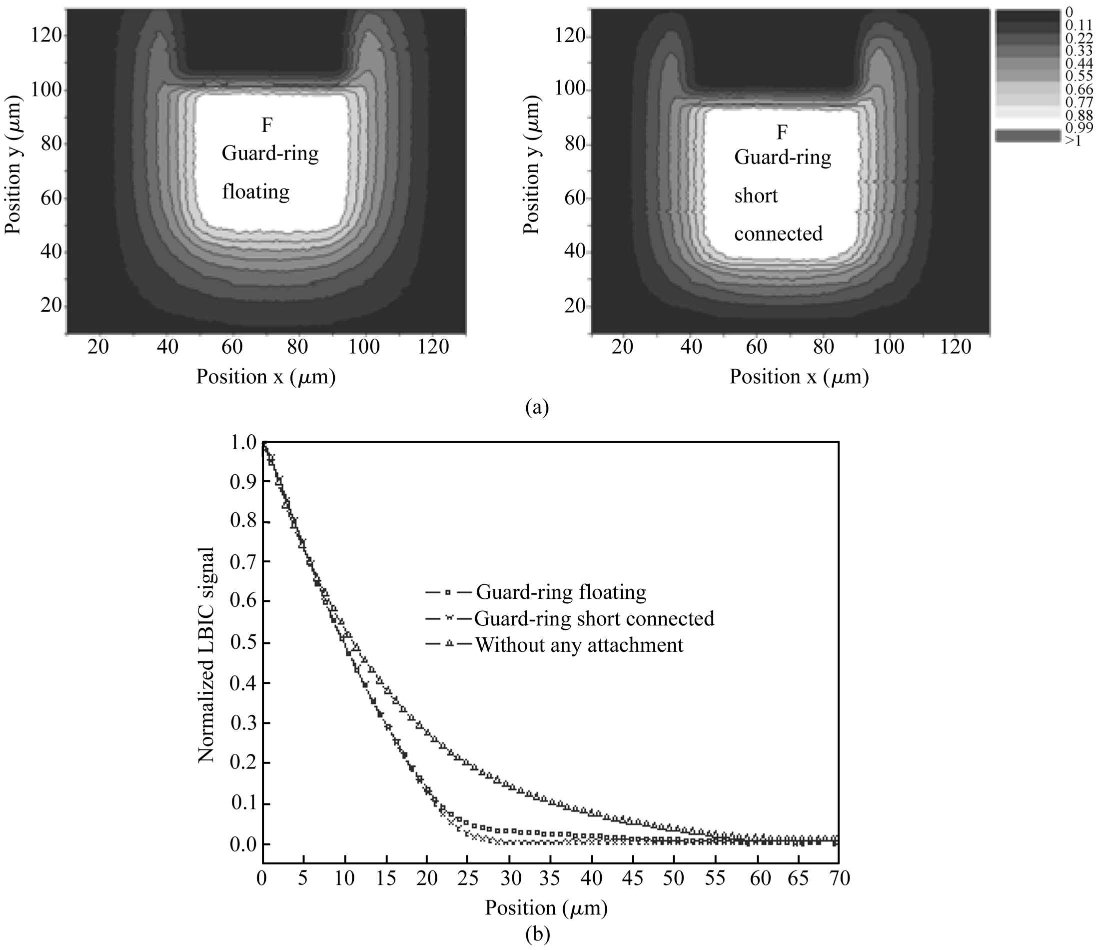

Fig. 5. Suppression of extension of the photo-sensitive area by using guard-rings under different working statuses for detector F.

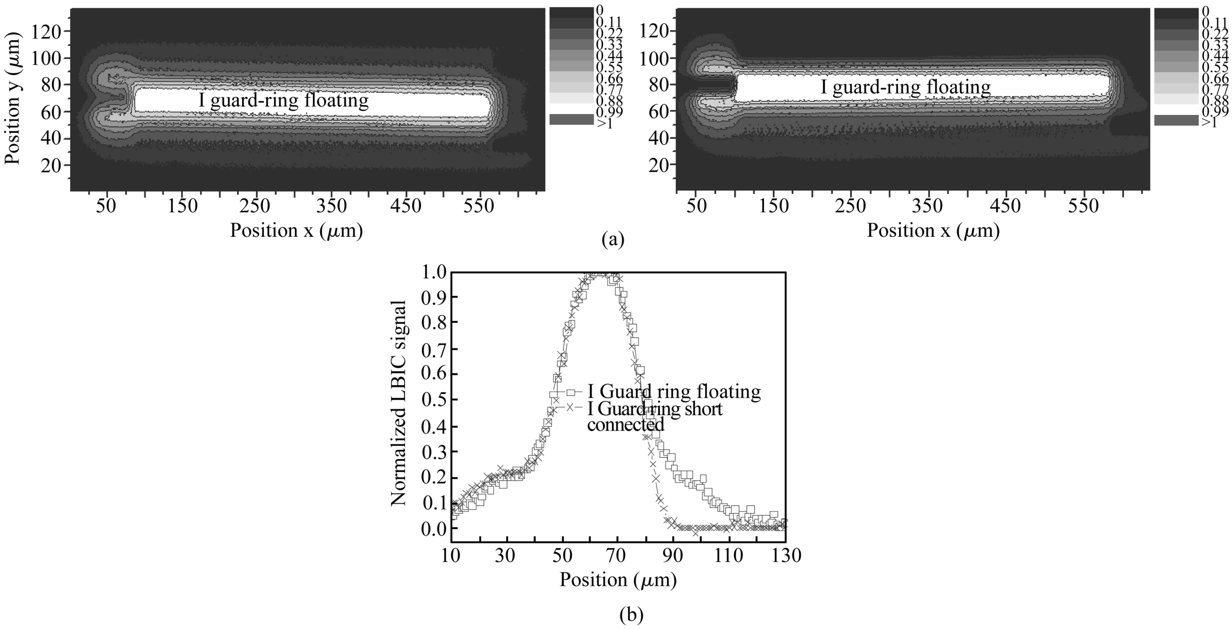

Fig. 6. Suppression of extension of the photoactive area by using guard-rings under different statuses for detector I.

most all of the photo-carriers generated near this pixel would be collected by its own contact, and the photo-carrier lateral diffusion effect in this direction is greatly suppressed; the extension of the photo-sensitive area is thus suppressed, as shown in Fig. 6(b).

4. Conclusions

The structure of a planar-type front-illuminated InGaAs detector has been re-modified, and the small-diffusion-area diffusion method, circle-type covering contact and guard-ring have been introduced. The LBIC technique was used to study the photo responsive characteristics of the photo-sensitive area of different detector structures. It was indicated that a combination of small diffusion-hole and circle covering contact was helpful in suppressing the extension of the photo-sensitive area. However, in large-scale detector arrays with quite small pixel pitch, the circle covering contact could not be widened as one likes, and the stray light arising from the light reflected by the covering contact would cause big problems in detector encapsulation, thus limiting the applications of the circle covering contact. Fortunately, a guard-ring with a proper guard-ring to photo-sensitive area distance, and especially a short connected guard-ring, was helpful in suppressing the extension of the photo-sensitive area. The combination of small diffusion-hole, circle covering contact, guard-ring could effectively suppress the extension of the effective photoactive area and exactly define the detector photo-sensitive area. Limited by the experimental precision, all the above conclusions were arrived at qualitatively; a future study should go on to obtain quantitative results.

References

[1] Olsen G H, Joshi A M, Ban V S. Current status of InGaAs detector arrays for 1–3 μm. Proc SPIE, 1991, 1540: 596

[2] Joshi A M, Ban V S, Mason S, et al. 512 and 1024 element linear InGaAs detector arrays for near infrared (1–3 μm) environmental sensing. Proc SPIE, 1992, 1735: 287

[3] Olsen G H, Joshi A M, Ban V S, et al. Multiplexed 256 element InGaAs detector arrays for 0.8–1.7 μm room-temperature operation. Proc SPIE, 1988, 972: 279

[4] Kozlowski L J, Tennant W E, Zandian M, et al. SWIR staring FPA performance at room temperature. Proc SPIE, 1996, 2746: 93

[5] Moy J P, Chabbal J J, Chaussat S, et al. Buttable arrays of 300 multiplexed InGaAs photodiodes for SWIR imaging. Proc SPIE, 1986, 686: 93

[6] Moy J P, Hugon X, Chabbal J, et al. 3000 InGaAs photodiode multiplexed linear array for SPOT4 SWIR channel. Proc SPIE, 1989, 1107: 137

[7] Hoogeveen R W M, van der Ronald J A, Goede A P H. Extended wavelength InGaAs infrared (1.0–2.4 μm) detector arrays on SCIAMACHY for space-based spectrometry of the Earth atmosphere. Infrared Physics & Technology, 2001, 42: 1

[8] Zhang Kefeng, Wu Xiaoli, Tang Hengjing, et al. Crosstalk and photoactive area of InGaAs linear detector by LBIC technique. Infrared and Laser Engineering, 2007, 36: 23 (in Chinese)

[9] Zhang Kefeng, Wu Xiaoli, Tang Hengjing, et al. Study on photoactive area of planar InGaAs linear detector by LBIC technique. Laser and Infrared, 2007, 37: 947 (in Chinese)