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# Extended spectral response in In<sub>0.82</sub>Ga<sub>0.18</sub>As/InP photodetector using InP as a window layer grown by MOCVD

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Extended spectral response InGaAs detectors have been grown, fabricated, and characterized for near-infrared detection. The atomic structure of the  $In_{0.82}Ga_{0.18}$ As/InP interface was investigated to determine the inhibition of mismatch defects of the two-step growth by TEM. The heterogeneous interface is formed from the alternation of crystallographically abrupt and partly amorphous regions. Dark current of the detector under different temperatures was analyzed to determine the generating mechanism. Due to the presence of the InP window layer and  $In_{0.82}Ga_{0.18}$ As absorber layer in the heterostructure, the wavelength spectral response range of the detector is from 1 to 2.5  $\mu$ m.

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# Introduction

Recently the short-wavelength infrared (SWIR, 1.0-2.5 µm) region has gained interest, because it is a particularly interesting region for new and important scientific measurements: not only for planetary exploration, for the characterization of the environment of Mars but also for Earth remote sensing.<sup>1</sup> In<sub>0.20</sub>Ga<sub>0.80</sub>As p-i-n photodetectors fabricated on GaAs substrates using In<sub>x</sub>Ga<sub>1-x</sub>As metamorphic step-graded buffers have been demonstrated.<sup>2</sup> Low-darkcurrent, high response InGaAs photodetectors have fabricated with a simple mesa etch process that may be suitable for room temperature focal plane array applications.<sup>3</sup> Indium gallium arsenide arrays that sense light over a wavelength range of 0.4 to 1.7 µm have been developed.<sup>4</sup> Quasi-unipolar InGaAs/InP photodetection is discussed for enhanced optical saturation power and maximal bandwidth.<sup>5</sup> The achievement of maximum photodetector performance for many applications is dependent upon the proximity of the detector bandgap energy to the illumination energy. Nonetheless, p-i-n photodetectors, which are advantageous in their simplicity and lack of absorption geometry constraints, are typically constrained in bandgap choice by lattice matching to conventional substrates, often meaning that photodetector bandgap energy is too low or not optimum for a desired illumination wavelength. The goal of growing In<sub>0.82</sub>Ga<sub>0.18</sub>As is the

extension of the spectral response of the InGaAs infrared detectors. However, the large mismatch between epilayer and substrate results in poor material quality. In order to overcome this limitation, many schemes<sup>6-8</sup> have been developed. By introducing a buffer layer, the lattice constant could be transformed and crystalline defects will be predominantly confined to the metamorphic buffer layer. In this work we use an approach similar to the p-i-n device, but in a "p-i-n" configuration, with InP as window layer, In<sub>0.82</sub>GaAs<sub>0.18</sub> as absorber layer materials grown on an n-InP substrate to realize wavelength spectrum (1-2.5 µm) photodetectors with In<sub>0.82</sub>Ga<sub>0.18</sub>As active regions. InP-based alloys are widely used as growth template, optical cladding layers, and active layers in long wavelength optoelectronic devices for silicontransparent applications. Most importantly, InP has 1-2 orders of magnitude lower surface recombination velocity than GaAs-based materials.9,10

#### Experimental

The detector material was grown by low-pressure metalorganic chemical vapor deposition (LP-MOCVD) using trimethylindium (TMI), trimethylgallium (TMG), 10% arsine (AsH<sub>3</sub>) in H<sub>2</sub> 10% phosphine (PH<sub>3</sub>) in H<sub>2</sub> as precursors. Palladium-diffused hydrogen was used as a carrier gas.

The device process started with forming a p-region by Zn diffusion, followed by  $SiN_x$  dielectric passivation and p-metal Au/Zn/Au deposition. Afterwards, Ti/Pt/Au was deposited onto n-InP as an n-metal. Finally, the sample was diced into chips and the devices were ready for characterizations. The detector spectral response curve is measured by the Nicolet Magna IR760 Fourier transform infrared spectrometer.

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Fig. 1 illustrates the epitaxial structure of the detectors.  $In_{0.82}Ga_{0.18}As$  on InP substrates and InP on  $In_{0.82}Ga_{0.18}As$  were grown by LP-MOCVD with the two-step growth technique.<sup>11–13</sup> The growth temperature of  $In_{0.82}Ga_{0.18}As$  buffer was 450 °C, and its thickness was 80 nm. The growth temperature of  $In_{0.82}Ga_{0.18}As$  absorption layer was 550 °C, and its thickness was 3.1 µm. The growth temperature of InP buffer was 480 °C, and its thickness was 70 nm. The growth temperature of the InP window layer was 580 °C, its thickness was 0.9 µm.

Fig. 2(a)–(d) are TEM photographs of  $In_{0.82}Ga_{0.18}As$  on an InP substrate. Fig. 2(a) shows the cross-sectional views of the  $In_{0.82}Ga_{0.18}As$  can only look at the two interfaces, the interface of epitaxial layer and buffer layer of  $In_{0.82}Ga_{0.18}As$ ,  $In_{0.82}Ga_{0.18}As$  and InP interface; Fig. 2(b) shows the electron diffraction patterns of the interfaces. The electron diffraction



Fig. 1 Cross-section view of the InP/In<sub>0.82</sub>Ga<sub>0.18</sub>As/InP heterostructure



Fig. 2 TEM micrographs and electron diffraction pattern of In<sub>0.82</sub>Ga<sub>0.18</sub>As/InP.

patterns clearly reveal two sets of diffraction spots; the strong reflections of In<sub>0.82</sub>Ga<sub>0.18</sub>As material and the weak reflections of InP. Fig. 2(c) shows the buffer layer and epitaxial layer interface, the tail of the arrow points to the buffer layer, and the head to the epitaxial layer. A large lattice mismatch between In<sub>0.82</sub>Ga<sub>0.18</sub>As and InP is accommodated by the formation of a regular network of misfit dislocations. The majority of misfit dislocations (MDs) were created at the interface between the InP substrate and the In<sub>0.82</sub>Ga<sub>0.18</sub>As layer. The heterogeneous interface is formed from the alternation of crystallographically abrupt and partly amorphous regions. The goal of the InGaAs buffer is to "re-use" these dislocations at subsequent mismatched interfaces, thereby minimizing the nucleation of new dislocations.<sup>14</sup> Partial dislocation in the buffer layer has been extended to the epitaxial layer, but only in the vicinity of the buffer layer interface and not throughout the epitaxial layer material. Fig. 2(d) shows the high-angle annular dark field view of the  $In_{0.82}Ga_{0.18}As$  epilayer with clear atomic structure.

Fig. 3 shows the dark current-voltage curves of the detectors at different temperatures. The dark current of the detector increases rapidly with temperature. As the temperature decreases, the dark current of the device significantly decreased, the decline is no longer obvious after 180 K. The asymmetry of the dark I-V curves shown in Fig. 3 is caused by the asymmetrical carrier injection from the bottom and top contact layers in different current directions. With the depletion of electrons from the active layer, the electrons from the contact layer become a dominant factor to influence the dark current. Under positive bias, more electrons are introduced from the bottom contact layer to the top contact layer because of the higher sheet electron density of the bottom contact layer, thus the dark current under negative bias is lower than the positive bias condition. Fig. 4 shows the reverse current distribution of the detector. InGaAs



Fig. 3 Dark current measured as a function of bias for InP/InGaAs/InP detector at different temperatures.



detector dark current consists of diffusion current, generationrecombination current, surface recombination current and tunneling current.<sup>15</sup> In the region "I", near room temperature, under different bias, the reverse current of the detector changed little, indicating that the dark current of the detector is mainly composed of the diffusion current and generationrecombination current,16 which occurs at the heterojunction interface and produces a current leakage. This leakage is mainly caused by interface states, and the deep impurity levels formed by Zn atoms diffused into the InGaAs layer. In region II, the dark current of detector with the temperature reduces at different bias and began to separate, making the sharp decline in the diffusion current and generationrecombination current; the tunneling current caused by the defects come into play.<sup>17</sup> In the region "III", the variation of detector dark current with temperature is very small and close to constant, the diffusion current and generationrecombination current can be ignored; the dark current mechanism is the tunneling current.<sup>18</sup>

The relative spectral response of the detector is shown in Fig. 5. The curve shows the responsivity of the detector



Fig. 5 Relative spectral response of InP/In<sub>0.82</sub>Ga<sub>0.18</sub>As/InP detector at 300 K.

varying with the wavelength. The cutoff wavelength of the spectral response of the long-wavelength is decided by the absorbing layer band gap, a cutoff wavelength in the short-wavelength, and the wavelength is decided by the band gap of the window material. Fig. 5 shows the response wavelength range of the InP/In<sub>0.82</sub>Ga<sub>0.18</sub>As/InP detectors is between 1  $\mu$ m and 2.5  $\mu$ m. In<sub>0.82</sub>Ga<sub>0.18</sub>As detector spectral response fluctuated in the vicinity of 1.38  $\mu$ m and 1.9  $\mu$ m, which is mainly caused by H<sub>2</sub>O and CO<sub>2</sub> in the air on the absorption of infrared radiation of the light source. So we can find that the InP/In<sub>0.82</sub>Ga<sub>0.18</sub>As/InP detector has a wide spectral response between 1 and 2.5  $\mu$ m, which is determined by the band gap of the window and absorption layer material at room temperature.

#### Conclusion

In conclusion we have demonstrated an InP/In<sub>0.82</sub>Ga<sub>0.18</sub>As/InP on InP substrate with photoresponse in the 1–2.5  $\mu$ m range. The detector structure was grown with the two-step growth technique using LP-MOCVD. We successfully used two-step growth to realize reduction in the thickness of the buffer layer. The dark current generating mechanism differs with temperature. Removal of the lattice matching constraint permits a significant improvement in optimization. As shown here, the band gap of the detector material can be chosen to produce a desired spectral response range.

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