# GaAs/AlGaAs quantum well infrared photodetector with low noise*

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(Received 6 April 2005)

A novel kind of multi-quantum well infrared photodetector (QWIP) is presented. In the new structure device, a p-type contact layer has been grown on the top of the conventional structure of QWIP, then a small tunneling current is instead of the large compensatory current, which made the device low dark current and low noise characteristics. The measured result of dark current is consistent with the calculated result, and the noise of the new structure QWIP is decreased to one third of the conventional QWIP.

**CLC number**: TN362 **Document code**: A **Article ID**: 1673-1905(2005)01-0037-03

GaAs/AlGaAs multi-quantum wells infrared photodetector (QWIPs) relating to the single device and the focal plane arrays were developed very fast in last ten years, even then the performance of QWIPs for 8～12 μm are not as good as MCT's[1-3]. To improve the performance of QWIPs, a novel kind of structure of QWIPs is reported in the paper. In the new structure device, a p-type contact layer has been grown on the top of the conventional structure of QWIP, then a small tunneling current is instead of the large compensatory current, which makes the device low dark current and low noise characteristics.

QWIPs are operated by photoexcitation of electrons between ground and first excited or continuing state subbands of multi-quantum wells (MQWs) which are artificially fabricated by placing thin layers of two different high-bandgap semiconductor materials alternately, such as n-type GaAs and i-type AlGaAs. The bandgap discontinuity of two materials creates quantized subbands in the potential wells associated with conduction bands or valence bands. The structure parameters are designed so that the photo-excited carriers can escape from the potential wells and be collected as photocurrent $J_p$ shown in Fig. 1. When the electrons are excited from the ground states, the same number of empty quantum states are generated, which should be refilled to keep the photo absorption. Therefore, there is a large compensation recombination current $J$, which is offered by electrode, through the device structure. The dark current in conventional GaAs/AlGaAs QWIPs is combination of sequential tunneling, thermally assisted tunneling and thermionic emission[4]. The sequential tunneling that happened between the ground state could be ignored under the low temperature, such as 77 K. It means that the dark current of the conventional GaAs/AlGaAs QWIPs is combination of thermally assisted tunneling and thermionic emission basically. Based on the theories of quantum mechanics[5-7], the dark current of conventional GaAs/AlGaAs QWIPs depended on the thickness and potential of the barrier layer, the higher potential and larger thickness would decrease the dark current of the device. It is the main problem in the conventional GaAs/AlGaAs QWIPs that the thickness and potential of the barrier layer could not be large enough, which induced the large dark current, due to the limitation of the detection wavelength and sensitivity of the device.

In Fig. 1, a p-type contact layer has been grown on the top of the conventional structure of QWIPs, then the injected current should be limited, which made the device low dark current and low noise characteristics[8].

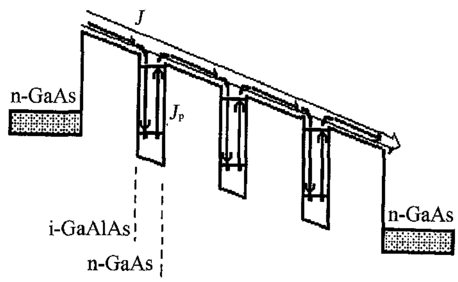


**Fig. 1 A p-type contact layer grown on the top of the conventional structure of QWIPs**

There is a difference of the first absorption region between the new structure and the conventional one. In the new structure the n-type GaAs layer as an electron potential well is sandwiched between the p-type GaAs layer and i-type $Al_xGa_{1-x}As$ layer. As the conventional

* Supported by National "973" program (TG2000068302)

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QWIPs, change of the component of Al in $Al_xGa_{1-x}As$ layer or change of the thickness of n-type GaAs layer can modify the distribution of electron in quantum well.

Because of the different transportation mechanism in the new structure device, the new type detector works at reverse bias, that is to say, p-type layer is biased on negative, that means the electron could not be injected from p-type layer. There is a little current leakage from the structure without infrared radiation if ignoring the thermal excitation, so the dark current of new structure detector is lower than that of the conventional QWIPs.

When the electron escapes from quantum well under infrared radiation, the empty quantum states generate due to carriers excitation is refilled by interband tunneling process from p-type layer.

We calculated the dark current with the different structure based on the theory model in reference[4]. The results shown in Fig. 2. The new type detectors with a p-type layer have less dark current compared with conventional structure under low temperature (77 K). It implied that the new type detector should have less noise and higher detectivity.

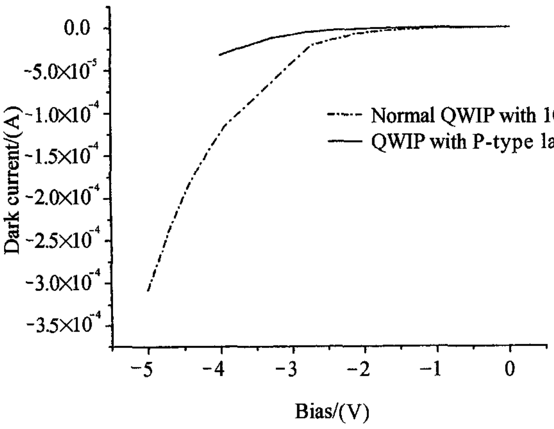


**Fig. 2 Dark current vs. bias at 77 K**

Two samples are grown by MOCVD system. The sample one is grown on (100) isolated GaAs substrate, which consisted of 50 periods of $Al_{0.3}Ga_{0.7}As$/GaAs MQWs along z direction. Each $Al_{0.3}Ga_{0.7}As$ barrier is 40 nm thick and GaAs well is 4 nm thick. The GaAs well is Si doping at level of $1\times10^{18}$ $cm^{-3}$. Doping level in the cap and bottom layer is $1\times10^{18}$ $cm^{-3}$ and the thickness is 0.6 $\mu m$. The sample two is based on the sample one where the tunneling junction is grown on. Therein the doping level of n-type GaAs layer is $4\times10^{18}$ $cm^{-3}$ and the p-type layer is $1\times10^{19}$ $cm^{-3}$. The cap layer is p-type GaAs as the contact layer. All samples are grown on the VEECO D125 MOCVD system, and C and Si have been used as impurity. The growth temperature is 720 ℃, the press of the chamber is 8 000 $P_a$, and rotated speed is 1 000 rpm.

To characterize the device, a 200 × 200 $\mu m^2$ mesa structure is formed by standard GaAs processing, and is packaged in low temperature dewar.

The characteristics of dark current at low temperature (77 K) of the two samples are shown in Fig. 3. It is obvious that the dark current with p-type layer structure is lower than that of the conventional, which is consistent with our analysis. The characteristics of noise and photocurrent of the two samples are shown in Fig. 4. There is not obvious difference on the photocurrent between

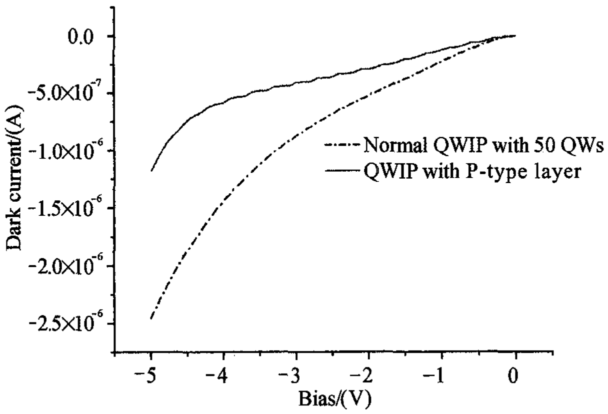


**Fig. 3 Dark current vs. bias at 77 K**

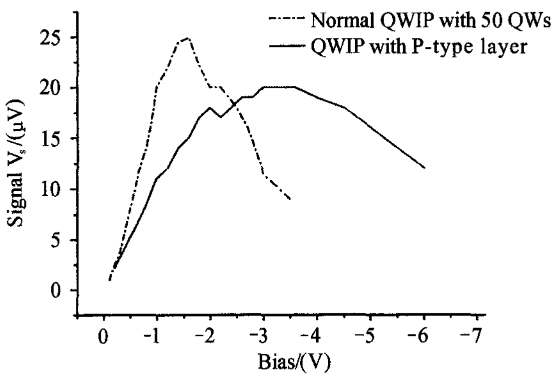


**Fig. 4(a) Photocurrent vs. bias**

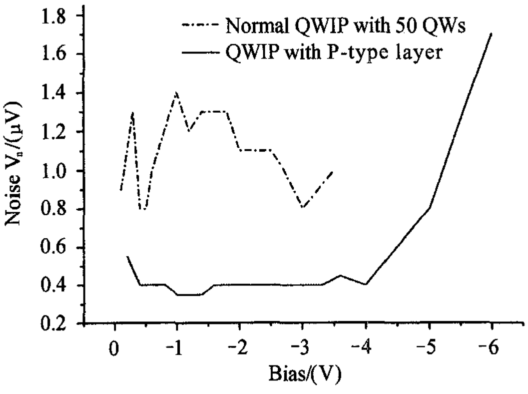


**Fig. 4(b) Noise vs. bias**

two samples, but the characteristic of noise for QWIPs with p-type layer is much better than normal one.

The characteristic of dark current has been analyzed carefully, and a p-type contact layer has been suggested that brings about a tunneling current instead of the large compensatory current which decreases the dark current, accordingly the low noise of the QWIPs device, and improves the detectivity of the detector.

## References

[1] Antoni Rogalski. *Infrared Physics & Technology*, **43**(2002), 187.

[2] A. C. Goldberg, S. W. Kennerly, and J. W. Little, *Proc. SPIE*, **4369**(2001), 532.

[3] A. Rogaiski, *Proc. SPIE*, **4650**(2002), 117.

[4] SHI Yan-li, DENG Jun, and DU Jin-yu. *J. of Semiconductor*, **22** (2001), 503.

[5] Fu Y., Willander M., Li Ning, and Lu W., *J. Infrared Mllim Waves*, **21**(2002), 400.

[6] Robert Rehm, Harald Schneider, Martin Walther, and Peter Koidl, *Appl. Phys. Lett.*, **180**(2002), 862.

[7] David M. T. Kuo, Angbo Fang, and Y. C. Chang. *Infrared Physics & Technology*, **42**(2001), 433.

[8] SHI Yan-li, DENG Jun, and DU Jin-yu. *Appl. Phys. Lett*, **19** (2000), 269.