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Characterization of a Multilayer GaAs/AlGaAs Broadband Quantum Well Infrared Photodetectors

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Abstract: - In this study, we report on the investigation of two multilayer GaAs/AlGaAs quantum well infrared photodetectors designed for 8-12 μm spectral range detection. Fabricated devices were characterized by current-voltage and photoresponse measurements as a function of applied bias. Background-limited infrared performance (BLIP) temperatures were performed to determine the optimum bias value for photoresponse for each detector. Photoresponse measurements clearly presented that both devices have responses at the expected spectral region; 8-12 μm.

Key-Words: - QWIPs, MBE, TEM, BLIP, current-voltage, dark current, photoresponse

1 Introduction

At room temperature, an object emits most of its energy in the form of infrared radiation. Therefore, in observing object without light reflection, infrared radiation is one the most important signal. However, finding a suitable material for infrared detection is always a challenge. In order to detect radiation of a particular energy, compound semiconductors with various bandgaps are being investigated. It seems that the improvement of detector performance usually relies on the improvement of material quality rather than the detector design. There are a lot of different structures for infrared light detection like quantum well IR photodetectors (QWIPs) [2-6], HgCdTe etc. The better understanding of the correlation between the material preparation procedures and the resulting detector properties is more essential in improving the detector performance [1].

Among the different types of QWIPs, technology of the GaAs/AlGaAs multiple quantum well detectors is the most extensively studied material. QWIP is a photoconductor which has high impedance, fast response time, low power consumption and well comply requirements of large FPAs fabrication. Due to the comparably robust material properties, QWIP has potential advantages over HgCdTe in terms of the array size, uniformity, yield and cost of the systems [5,7]

2 Structures

Two multilayer GaAs/AlGaAs quantum well infrared photodetector structures were designed for 8 μm to 12 μm spectral region. The Structures were grown by molecular beam epitaxy (MBE) on (100) SI GaAs substrates. Structure 1 consists of 10 periods of the following symmetric structure (from substrate to top): 40 nm of AlGaAs (20% Al), 6 nm Si-doped GaAs, 20 nm AlGaAs (20% Al), 10 nm graded AlGaAs (from 20% to 25% Al), 10 nm AlGaAs (25% Al), 5 nm Si-doped GaAs. Structure 2 consists of 10 periods of the following asymmetric structure: 7 nm Si-doped GaAs, 10 nm AlGaAs (16% Al), 20 nm graded AlGaAs (from 16% to 20% Al), 10 nm AlGaAs (20% Al), 6 nm Si-doped GaAs, 10 nm AlGaAs (20% Al), 20 nm graded AlGaAs (from 20% to 25% Al), 10 nm AlGaAs (25% Al), 5 nm Si-doped GaAs, 10 nm AlGaAs (25% Al), 30 nm graded AlGaAs (from 25% to 16% Al), 10 nm AlGaAs (16% Al).

Those 10 repeat structures are sandwiched between two contact layers which were doped with 1×10^{18} cm^{-2} Si. The top and bottom GaAs contact layers are 400 nm and 700 nm thick, respectively. Mesas were defined by wet chemical etching and top/bottom contacts were constructed by depositing Ge/Au/Ni/Au layers followed by annealing. Defined mesas are square in shape with 400, 600, 800, 1000 and 1500 μm sides. Different mesa structures in size allow us to test the uniformity of the wafer and the quality of the fabrication.

3.Experimental

3.1. Transmission Electron Microscopy (TEM) Characterization

TEM measurement is a powerful method for determining the real thicknesses of layers. Especially the GaAs layers which are around 5 nm is very critical and it is better to verify the thickness of this layers by using TEM method. Fig. 1 shows the TEM dark field image of Structure 1. In

this figure, AlGaAs (dark) and GaAs (bright) layers can be easily identified.

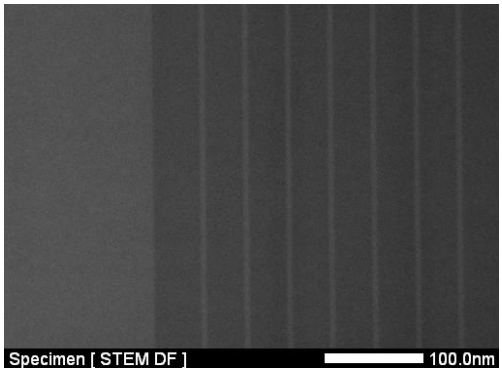


Fig. 1 TEM dark field image of structure 1

3.2. Current-Voltage Characterization

Dark current-voltage characteristics were measured in a liquid nitrogen-cooled dewar at 80 K. Square mesa devices of 400×400, 600×600, 800×800, 1000×1000 and 1500×1500 μm^2 were tested for Structure 1 and 2. The current-voltage characteristics of devices indicate excellent uniformity. Current density-voltage characteristics measured for Structure 1 at 80 K are shown in Fig. 2. The other structure showed similar behavior (not shown here).

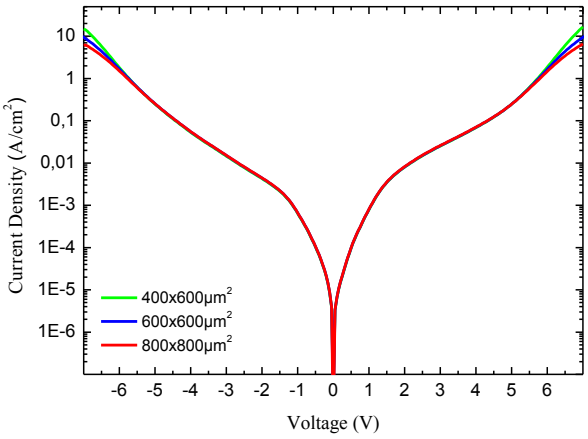


Fig. 2 Current density-voltage characteristics for the devices of different sizes for Structure 1 at 80 K.

Current-voltage spectra of the structures were recorded as a function of various temperatures before and after irradiation and the results are presented in Figs. 3 and 4 (selected temperatures are presented in order to have a clear view). Dark current measurements on structures were performed with cold shield. It is clearly seen from Figs 3 and 4 that the dark current decreases with decreasing temperature. In addition to this it is observed that the dark current values for Structure 2 is higher than that of Structure 1. This is an expected result since we have additional 7 nm quantum wells in Structure 2 which cause high dark current due to low activation energies.

By using the data in Figs. 3 and 4 it is possible to calculate the BLIP temperatures of each detector. Calculated BLIP temperatures at different bias values are presented in Fig 5.

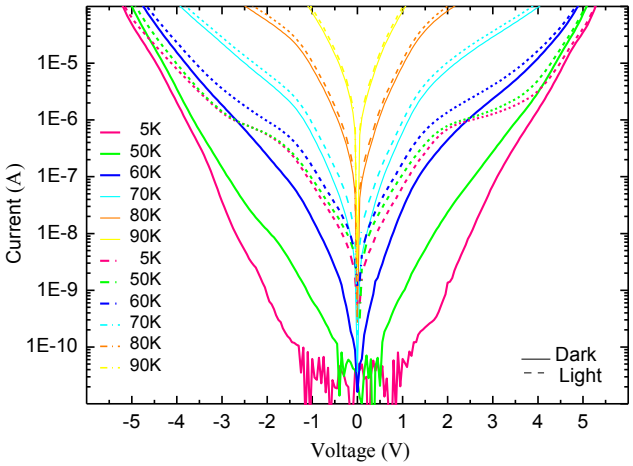


Fig. 3 Current-voltage spectra of the Structure 1 recorded as a function of various temperatures before and after irradiation.

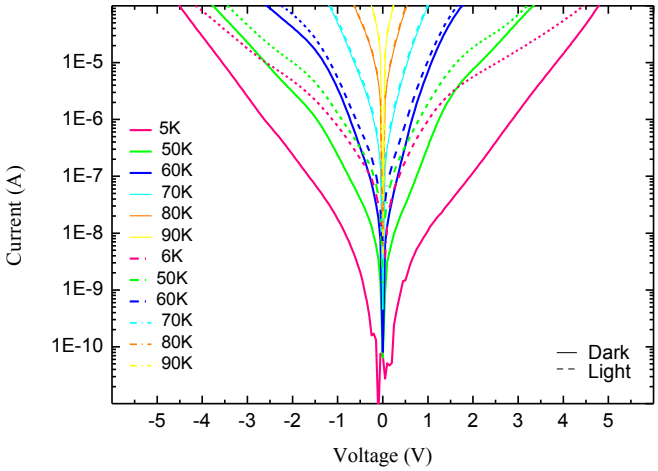


Fig. 4 Current-voltage spectra of the Structure 2 recorded as a function of various temperatures before and after irradiation.

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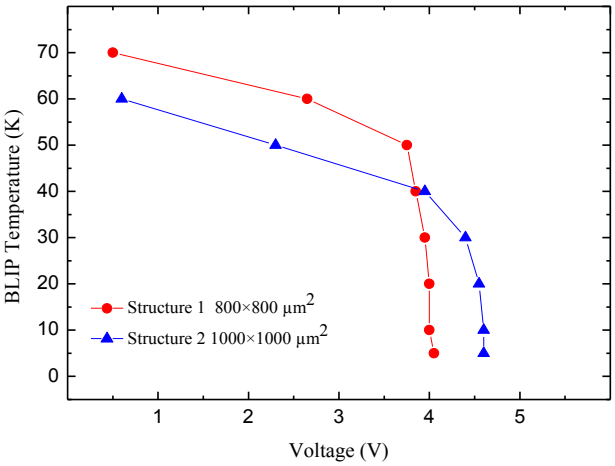


Fig. 5 BLIP temperatures for different applying voltages for Structures 1 and 2.

From Fig. 5 it is observed that the BLIP temperatures of Structure 1 is higher than that of Structure 2 at low voltages (< 3 V). This indicates that the Structure 2 needs colder temperatures to work at a given bias value compared to Structure 1.

3.3. Photoresponse

Photoresponse measurements are conducted under irradiation normal to the surface of devices. Bruker Equinox 55 FTIR is used for performing photoresponse measurements. In Fig. 6, the photoresponse spectrum of Structure 1 is presented. As it is seen from this figure Structure 1 exhibits the best performance at 1.5 V.

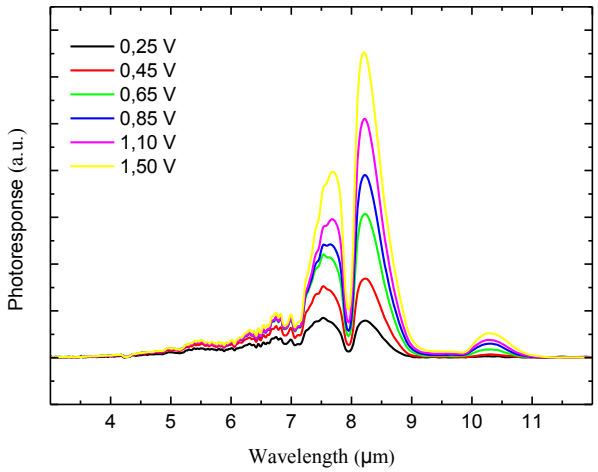


Fig. 6 Photoresponse measurement as a function of applied bias of the Structure 1.

Fig 7 shows photoresponse as a function of applied bias for Structure 2. The best performance for the region 5-10 μm was achieved at a bias value of 0.15 V. On the other hand, with increasing bias value the photoresponse of 10-11 μm region increases.

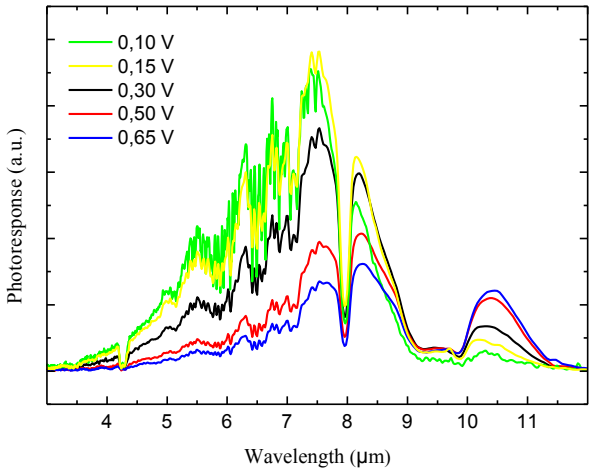


Fig. 7 Photoresponse measurement as a function of applied bias of the Structure 2.

Photoresponse of both structures are presented in Fig. 8 in order to compare the effect of different size quantum wells in the structures. As can be seen from this figure photoresponse of Structure 2 is higher at the region 10-11 μm. This is an expected result because Structure 2 contains 7 nm quantum wells in addition to 5 and 6 nm ones which indicate a better performance at longer wavelengths.

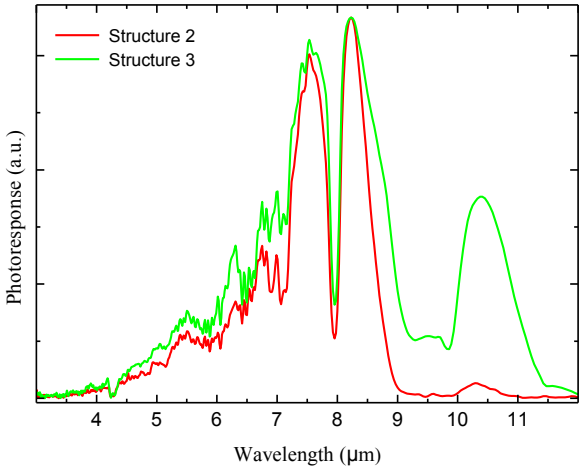


Fig. 8 Photoresponse measurements of the Structures 1 and 2. Spectra are normalized to see the difference of structures clearly.

4 Conclusion

We reported on the experimental observations of two multilayer GaAs/AlGaAs QWIPs. Our data is in consistency with literature [2, 3, 8]. From current-voltage measurements the uniformity of structures and device processing steps are verified. Photoresponse measurements have shown that the devices are working at the intended spectral region: 8-12 μm atmospheric window.

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