Room-Temperature QWIP Detection at 10 Microns

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Abstract

Liquid-nitrogen cooled quantum-well infrared photodetectors (QWIP) provide high response and high-speed detection of 10-micron radiation. When processed with high doping, QWIP's have been found to provide sensitive detection for long-wavelength infrared radiation at elevated temperatures. Experimental measurements using both direct and heterodyne detection show excellent performance at 10 microns and at temperatures up to 300 degrees-Kelvin. This high temperature operation allows applications in small or power limited platforms and significantly reduces the cost of the infrared detection system. Although only single element detectors have been evaluated, linear and 2-D arrays are expected to have similar performance characteristics. Experimental results for both video and heterodyne detection will be presented.

1. Introduction

Most applications for quantum well infrared photodetectors (QWIP) have required array devices used in thermal imaging[1]. Because of the weak signals found in thermal imaging, the QWIP development has been driven to produce low noise devices. However, QWIPs are inherently fast detectors with speeds far exceeding standard HgCdTe devices[2]. For some applications such as heterodyne detection, a higher detector noise may be tolerated. Our interest has been in developing a very high-speed heterodyne detector for measurements of CO_2 laser scattering where a higher detector noise would not be a problem due to the large shot noise from the local oscillator. The high absorption efficiency of these detectors has also been explored and previously reported[3]. Because the development of the lower noise QWIPs has required reducing the operating temperature to below the standard liquid nitrogen temperature, these new detectors, with higher noise, are expected to provide an opportunity for operation above liquid nitrogen temperatures.

2. Detector Description

The detectors investigated in this program were produced by Dr. H. C. Liu at the National Research Council of Canada. They consist of 100 sets of GaAs wells and Al_xGa_{1-x} As barriers. The GaAs well center region is doped with Si to produce an equivalent two-dimensional density of 1.0×10^{12} /cm^2 for one sample and 1.5×10^{12} /cm^2 for the other. Each well is 6.6 nm wide and each barrier is 25 nm wide. The devices have top and bottom GaAs contact layers with a 45-degree edge facet for optical coupling. The Al fraction is 0.200 for the detector with a doping level of 1.0×10^{12} /cm^2 and 0.192 for the detector with 1.5×10^{12} /cm^2 . The thickness of the layers is selected to optimize the detector's performance for the dominant CO_2 laser line around 10.6 microns. Although only single element detectors were evaluated, such a configuration would easily produce linear arrays and with some modification 2-D arrays.

3. Heterodyne Operation

The heterodyne response has been examined using a test facility developed at Oak Ridge National Laboratory[4]. Fig 1 shows the noise-equivalent-power (NEP) of the detector plotted as a function of the difference frequency from the local oscillator laser set at 10.6 microns. The heterodyne NEP is related to the heterodyne quantum efficiency η by :

$$NEP = \frac{2h\nu}{\eta}$$

Where h is Plank's constant and ν is the frequency of the radiation (approximately 28,300 GHz.) The factor of 2 in this relation enters because the QWIP is a photoconductive device. The data were taken with the local oscillator power set at 50 mW. Normally this is much higher than the power levels in other heterodyne 10-micron receivers. Most heterodyne receivers operate with the local oscillator power operating around 1 mW. At higher powers, the heating of the detector will usually degrade the detector's performance. For the receiver using the detector with the higher doping level, it appeares that the elevated temperatures did not degrade the heterodyne performance. For local oscillator power levels between 1 and 100 mW, the receiver's quantum efficiency remained flat. For these tests, the detector consists of a 40 micron 100 well pair QWIP, biased to approximately 10 mA. The detector is followed by a pair of low noise amplifiers (flat from 0.1 to 8 GHz), with the signal processed in a 0 to 18 GHz spectrum analyzer. The radiation source for this measurement was a 212^{o} C blackbody. The spectral response was limited by the bandwidth of the amplifiers and the bias tee that is flat to 6 GHz. The application was the measurement of high velocity ions in a magnetically confined fusion device with an expected maximum Doppler shift of 5 GHz. Therefore the electronic limitation of approximately 8 GHz was well suited for the measurements. The noise is fairly flat over the frequencies of interest, but the level is still quite high. At a value of $1x10^{-18}$ W/Hz, the quantum efficiency of the detector is only about 4%. This showed very little improvement over the previous measurements using detectors with lower doping levels[5].

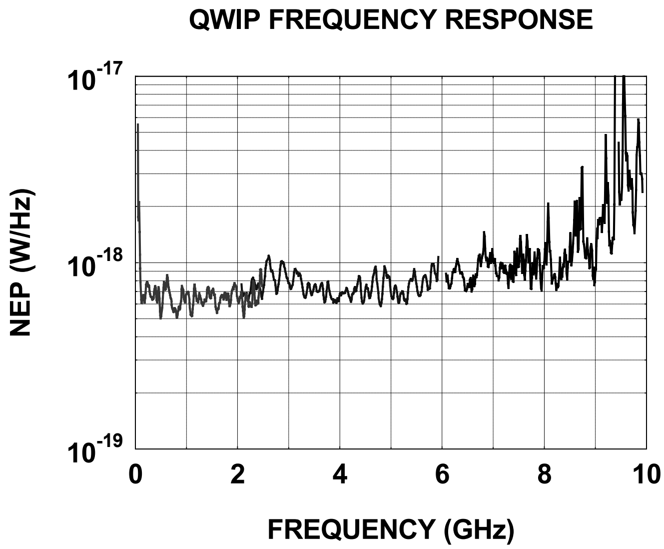

Figure 1 QWIP heterodyne response. The detector consists of 100 pairs of wells with a square cross section of 40 microns and the doping level is at 1x 10^{12} /cm^3 .This data was taken at liquid nitrogen temperatures with 50 mW of local oscillator power at 10.6 microns.

4. Direct Detection

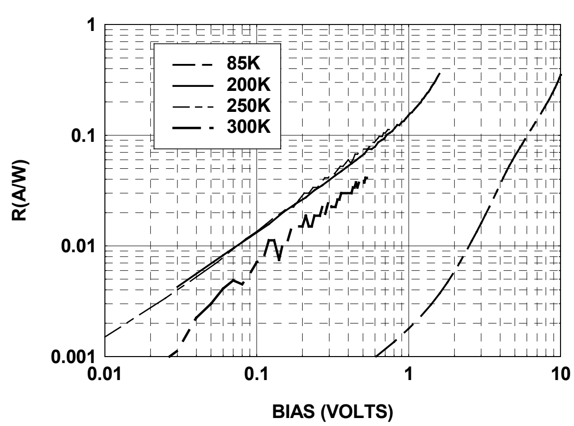

Figure 2 Responsivity for the QWIP with 1.0x 10^{12} /cm^2 doping as a function of bias voltage and temperature.

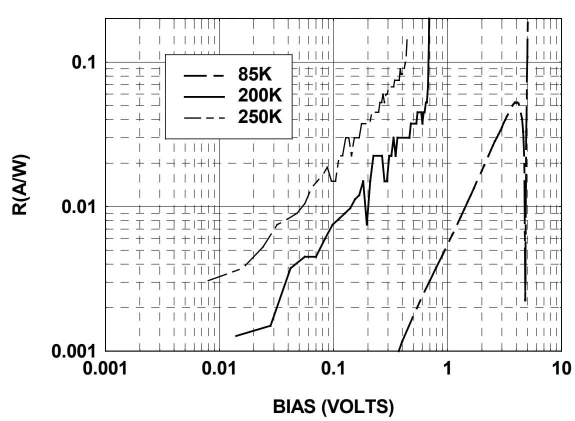

Figure 3 Responsivity for the QWIP with 1.5 x 10^{12} /cm^2 doping as a function of bias voltage and temperature.

To examine the temperature response for these detectors with high doping levels, tests were performed on both. Both detectors were 100 microns square. The radiation source for these measurements was a CO_2 laser with its power attenuated to 1 mW. This level was found to supply sufficient signals for relatively low noise measurements without heating the detector. The response curves for these detectors are given in Figs 2 and 3. The bias was increased until the detector became unstable, usually around 100 mA. The detector was mounted in a Lakeshore Dewar on loan from the National Research Council of Canada for performing these tests. This Dewar is liquid nitrogen cooled but also includes a heater to control the detector temperature. The sample shown in Fig 2 has a doping of 1x 10^{12} /cm^2 . Note that for a fixed bias, the detector responsivity showed an increase with increasing temperature at low temperatures and only a small decrease in responsivity with a temperature change from 250 to 300 K. Fig 3 shows a similar response for a detector with a doping level of 1.5 x 10^{12} /cm^2; however, the higher doping appeared to have a lower responsivity. Also with the higher noise level, the response at room temperature (300K) did not have a sufficient range in bias voltage to produce a measurement. The maximum responsivity was found at the maximum bias voltage where the operation became unstable. Changing the bias to a constant current source could improve the consistent operation near this threshold. The voltage bias was likely heating the detector, decreasing the resistance and causing thermal runaway.

The detectivity was determined from the responsivity measurements and an additional measurement of noise using the relationship:

$$D* = \frac{R}{\sqrt{S_i / A}}$$

Where D* is the detectivity, R is the responsivity, *Si* is the current noise power spectral density, and A is the detector area. With the doping being around an order of magnitude higher than previous QWIP detectors, the dark current is also about an order of magnitude larger and the resulting detectivities are smaller than those found in other infrared detectors. Fig 4 shows the detectivity for the doping level of 1.0 x 10^{12} /cm^2 and Fig 5 shows it for 1.5 x 10^{12} /cm^2. Note that the detectivity remains relatively constant for changes in bias but does show a decrease with increasing temperature.

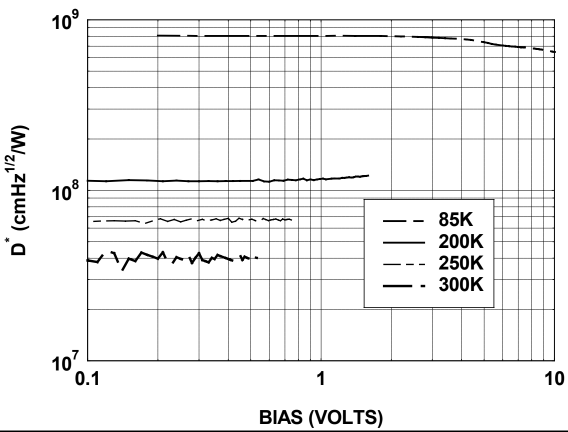

Figure 4 Detectivity for the QWIP with a 1.0 x 10^{12} /cm^2 doping as a function of bias voltage and temperature.

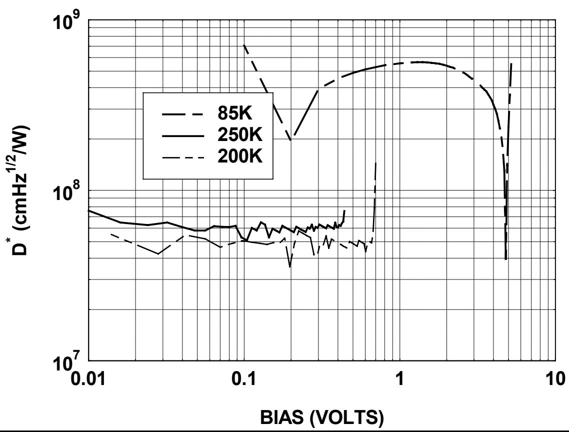

Figure 5 Detectivity for the QWIP with a 1.5 x 10^{12} /cm^2 doping as a function of bias voltage and temperature.

5. Conclusions

High doping levels of QWIPs allow high temperature operation, up to and including room temperature. Cooling could improve the performance of the QWIP detectors; however, depending on the operating temperature, an appropriate doping level may be found for optimal performance.

6. Acknowledgements

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