III-V Based Room Temperature THz Detectors

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Abstract—**Results are reported on a GaAs/AlGas based THz detector operating up to room temperature. The detector gave a response of 4 A/W at 330 K and 0.015 A/W at 309 K indicating the response is due to effects of thermally generated carriers. By optimizing the material it should be possible to improve the detector response.**

I. Introduction And Background

The THz region is of considerable interest with research on both single element detectors and imagers. There are many new applications being developed, particularly for security and quality control. The development of new detectors operating at high temperatures will aid these applications. The use of p-type intraband detectors offers the possibility to cover a wide frequency range in a single detector. Transitions to the split-off band have shown[1] response for frequencies of 100-150 THz (3-2 μm) at operating temperatures up to 330 K. Free-carrier absorption leads to response in the same detectors down to 75 THz (4 μm). The extension of the response in these detectors into the THz range would be of wide potential application. In this paper, results are presented on a p-type GaAs/AlGaAs detector responding in the THz at room temperature. Use of other III-V material combinations to optimize the 5-75 THz range response will be considered.

II. Results

The THz response was observed in detectors designed to optimize the split-off response in the near IR and hence not optimized for THz response. The structure consisted of 30 periods of p-doped GaAs emitters and $Al_{0.57}Ga_{0.43}As$ barriers. This gives a free carrier threshold of 75 THz (4 μm) close to the split-off transition threshold of 85 THz (3.5 μm). The spectral response of the detector was measured using an FTIR with a Si composite bolometer used to calibrate the response. In addition to the expected response at higher frequencies, THz response was also observed for these detectors. The response in the 12-150 THz range for various bias voltages at a temperature of 330 K is shown Fig. 1. This response extends to much lower frequencies than the free carrier response threshold of 75 THz. When the light was blocked, no signal was observed. The THz response increases slowly with temperature as seen from Fig. 2 where the response at 250 K is shown. The strong response observed above 75 THz is due to photoabsorption producing transitions from the light-heavy hole band to the split-off band. The response is nearly flat below 75 THz, with small oscillations superimposed on in it. The source of these oscillations is unknown at this time, but could be due to the absorption features in the structure. The response in the frequency range of 5-15 THz is shown in Fig. 3

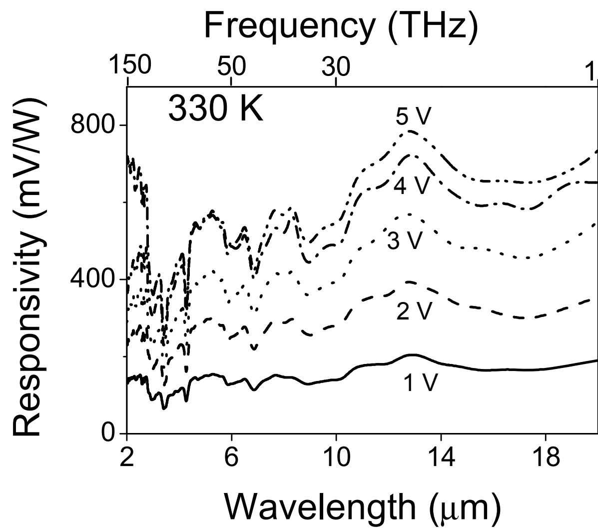

Figure 1: The response of the GaAs/AlGaAs THz detector in the 12-150 THz range for 5 different biases at a temperature of 330 K. The maximum response was ~800 mV/W for a bias of 5 V. The response was nearly constant over most of the range.

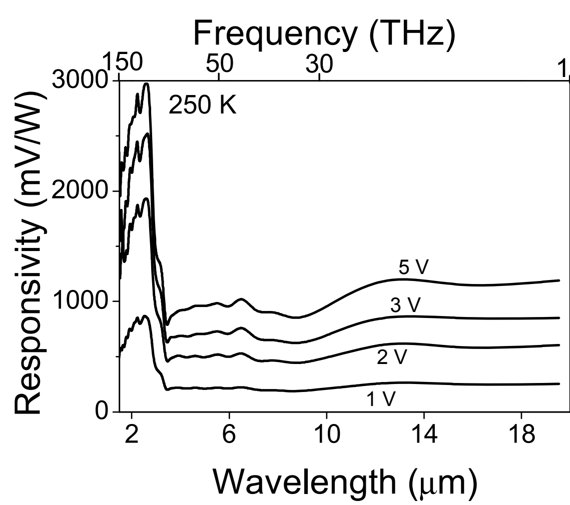

Figure 2: The response for the same sample at a temperature of 250 K. The lower temperature has led to a small increase in the response. The strong response above 75 THz (4 μm) is due to direct transition to the split-off band.

The fact that the increase in voltage response is small when the temperature is changed indicates the response is probably

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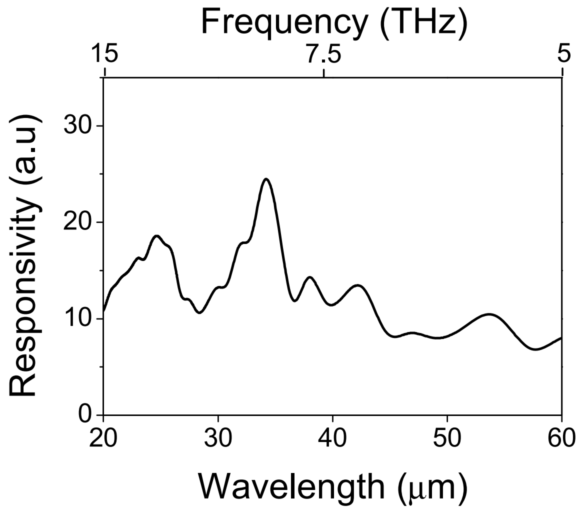

Figure 3: The response for the same detector in the 5-15 THz range at a temperature of 309 K. The lower temperature has led to a large reduction of the response.

associated with changes in the thermal population of the carriers at higher temperatures. A possible explanation based on the excited carriers being in the split-off band which is 340 meV above the light/heavy hole bands. Unlike the standard semiconductor bolometric response in which the signal is due to increases in the number of electrons and holes produced through thermal generation, the signal in this detector comes from an increase in the number of carrier in the split-off band with temperature. The carriers in the split-off band could then scatter into the light/heavy hole bands above the barrier and escape. The escaped carriers would then be collected by an applied electric field, contributing to the current. In this approach, the observed photocurrent would be due to heating of the sample with the corresponding increase in the current as in a bolometer, but with a different mechanism (using the split-off band) for the change in the resistance which produces the signal.

The detector was not optimized for thermal response, hence the efficiency could be increased. The detector sample consisted of a 400 μm × 400 μm square mesa on a ~3 mm 5 mm substrate ~500 μm thick. This had a large thermal mass reducing the temperature change and hence the response signal. It should also reduce the response speed of the detector. In addition, only a ~1 mm diameter area was illuminated and the device was not in an integrating cavity reducing the absorbed radiation. By optimizing the sample size and placing it in an integrating cavity, it should be possible to improve the detector response. For a small bolometer, the response is given by[2]

$$R = \frac{IR_d \alpha}{G(R_d + R_l)},$$

where I is the current, R_d and R_l are the detector and load resistor, G is the heat flow rate, and $\alpha = (dR_d/dt)/R_d$ is the fractional rate of change in the detector resistance. For the split-off bolometer $\alpha = \Delta/k_bT^2$ where Δ is the split-off energy , T is the temperature, and k_b is Boltzmann's constant. The response observed for the detector corresponds to a heat flow rate of ~20 mW/K. For a small sample size, specifically mounted for use as a themal detector, the heat flow rate can be reduced to ~15 μW/K. Using this value, if the size of the sample is assumed to be reduced so that it does not limit the response, and the sample is assumed to be in an integrating cavity so that all the radiation is absorbed, the response of the detector should be increased to ~2000 V/W.

One possibility for improving the Thz response is using alternate materials to increase the response. As the splitoff band energy varies with material it should be possible to use different materials to allow the split-off energy to be controlled. As the carrier density in the split-off band and hence the resistance at a given temperature, depends on the split-off energy, optimizing the energy should lead to higher response. For example, the splitoff energy of the antimonide materials ~800 meV. A THz detector based on a p-type GaSb/AlGaSb heterostructure would have a fractional increase in carriers in the split-off band about twice that of an GaAs/AlGaAs detector. This would lead to corresponding increases in the response for the GaSb/AlGaSb detector.

III. Conclusions

In conclusion, room temperature THz detection has been demonstrated using a p-type GaAs/AlGaAs detector. This detector responded using a thermal mechanism. The mechanism involves a new type of bolometric response, based on the increase in carriers in the split-off band for p-type material. These carriers are free to be transported through the detector, producing the photosignal. This is a new approach to bolometer development, and could lead to improved detectors. By using other materials, the operating temperature can be optimized for the desired range. These detectors offer an interesting new approach to THz detection at high temperature, and could lead to many new THz applications.

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2. The Infrared Handbook, W. L. Wolfe and G. J. Zissis, editors, Office of Naval Research, Washington, DC (1985)