A Monolithic Dual-Band HgCdTe Infrared Detector Structure

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***Abstract*—A monolithic HgCdTe photoconductive device structure is presented that is suitable for dual-band optically registered infrared photodetection in the two atmospheric transmission windows of 3–5 μm and 8–12 μm, which correspond to the mid-wave and long-wave infrared bands; MWIR and LWIR, respectively. The proposed structure employs a wider bandgap isolating layer between the two photosensitive layers such that an effective electrical barrier is formed thus prohibiting carrier transport between the two infrared absorbing layers of different cutoff wavelengths. The technology is demonstrated using a mature HgCdTe photoconductive device fabrication process. The resulting detectors have an MWIR cutoff of 5.0 μm, and LWIR cutoff of 10.5 μm.**

I. INTRODUCTION

MULTISPECTRAL infrared detectors would be highly beneficial for a variety of applications such as missile warning and guidance, overhead surveillance, target detection and tracking, thermal imaging, navigational aids, environmental monitoring, etc. [1], [2]. Dual-band detection in the mid-wave and long-wave infrared atmospheric windows has been performed using HgCdTe photodiodes [1]–[3] or photoconductive devices [4], [5]. The latter devices have used either a butting method such that the two bands are detected side by side [5], or an optically registered structure in which the two absorbing layers are sandwiched together using adhesive [4]. These techniques are mechanically demanding, are not fabricated using standard device technology, and are not suitable for on-pixel registered arrays. The structure proposed in this work presents a monolithic HgCdTe photoconductive device that is suitable for dual-band on-pixel registered infrared photodetector arrays in the atmospheric transmission windows of 3–5 μm and 8–12 μm.

II. DEVICE STRUCTURE AND FABRICATION

The device is fabricated from a starting wafer consisting of three layers of HgCdTe material grown in situ using epitaxial MOCVD, as shown in Fig. 1. The incoming radiation will pass through the IR transparent substrate, whereupon MWIR radiation is absorbed by the HgCdTe MWIR material (layer 1), whereas long-wave radiation passes through this layer. No LWIR or MWIR radiation is absorbed in the wide bandgap isolating layer (layer 2), and the LWIR radiation is then absorbed by the HgCdTe LWIR material of layer 3. Ideally, the layer 2 material acts as an electrically isolating layer between the two different absorbing layers. Using a model based on previous work [6] the middle layer is modeled as a highly resistive layer for majority carriers and a blocking layer for minority carriers. A simplified band diagram is shown in Fig. 1(b), indicating the presence of heterojunction barriers in the valence band which prohibit the flow of photogenerated minority carriers between layers 1 and 3. The barrier in the conduction band will provide a high resistance layer between the two absorbing layers. The model used in this work assumes that the valence band barriers are large enough such that photogenerated minority carriers in layers 1 and 3 are confined to their respective layers.

Experimental dual-band photoconductive detectors were fabricated on MOCVD-grown material using the device structure shown in Fig. 1. The layers were all p-type as-grown, and were subsequently n-type converted, after mesa delineation, using a Hg anneal at 200 °C for 20 days. The x value for the MWIR layer, isolating layer, and LWIR layer were 0.30, 0.60, and 0.22, respectively. The device fabrication proceeded as per standard photoconductive detector fabrication [7], except that after mesa delineation and annealing a further etch was performed through layers 3 and 2 to allow for metal contacts to the MWIR layer. A passivation layer of anodic oxide/ZnS was used and windows were then opened in the passivation layer for contact to the individual layers, with a single metal pad being used for the common contact to both detectors. The optical dimensions of the LWIR detector (length × width) were 275×300 μm^2, and 425×300 μm^2 for the MWIR detector. The thickness of each of the layers was 10 μm for the MWIR layer, 2 μm for the $x = 0.60$ middle layer, and 10 μm for the LWIR layer.

III. CROSSTALK

A relevant characteristic of monolithic dual-band detectors is the amount of signal crosstalk occurring within the device structure between the two detection bands, which should be kept to a minimum. That is, when detecting MWIR (LWIR) the amount of signal in the MWIR (LWIR) detector due to LWIR (MWIR) should be minimized. Two forms of intradevice crosstalk will be defined in this work; namely, optical crosstalk and electrical crosstalk. Optical crosstalk is detection in one layer due to impinging radiation that corresponds to the other

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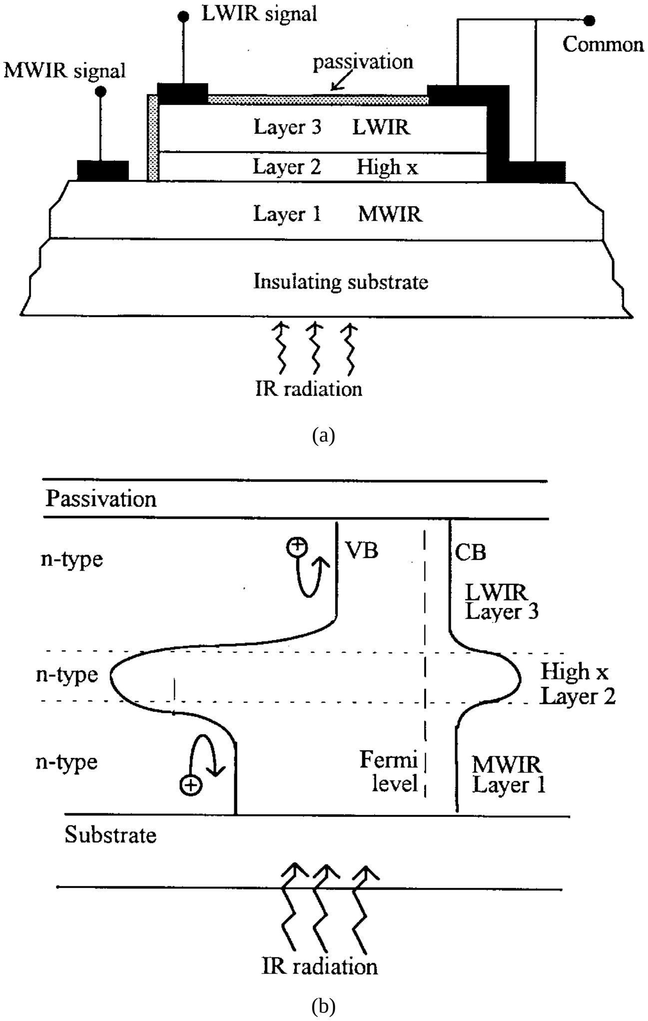

Fig. 1. (a) Cross section of monolithic dual-band photoconductive device, consisting of three HgCdTe layers and (b) schematic band diagram of three HgCdTe layers.

layer. For example if all the incident mid-wave radiation is not absorbed by the MWIR layer, some will be transmitted and eventually absorbed by the LWIR material, leading to mid-wave radiation contributing to the LWIR signal. This may be minimized by having sufficient MWIR material to absorb all of the mid-wave radiation. In effect, the MWIR layer acts as a filter of mid-wave radiation for the LWIR detector. The opposite effect, of long-wave radiation being absorbed by the MWIR material will not occur since the cutoff wavelength of the MWIR material is far shorter than the impinging LWIR radiation. For the devices considered in this work, calculations [8] show that only approximately 1.0% of incident MWIR radiation is not absorbed by the 10-μm thick MWIR layer.

Intradevice electrical crosstalk is defined as an output signal appearing at the terminals of one device-type due to absorption and modulation occurring in the other device. It must be noted that a simple representation of the three HgCdTe layers is an interconnected distributed resistor network. Hence, any modulation of the resistance due to absorption in one layer will result in a change of the overall resistance and, correspondingly, a change in resistance of the other device. For example, if the resistance of layer 1 is modulated due to impinging MWIR radiation, the resistance, and hence output signal, at the LWIR terminals will change unless the isolating layer is perfectly insulating. To increase the resistance of the middle layer the options are to decrease the doping of the middle layer, increase the bandgap of the middle layer, or decrease the area. The optimum situation occurs when the middle layer is assumed to be of infinitely high resistance and the two detectors act completely independently resulting in no intradevice electrical crosstalk.

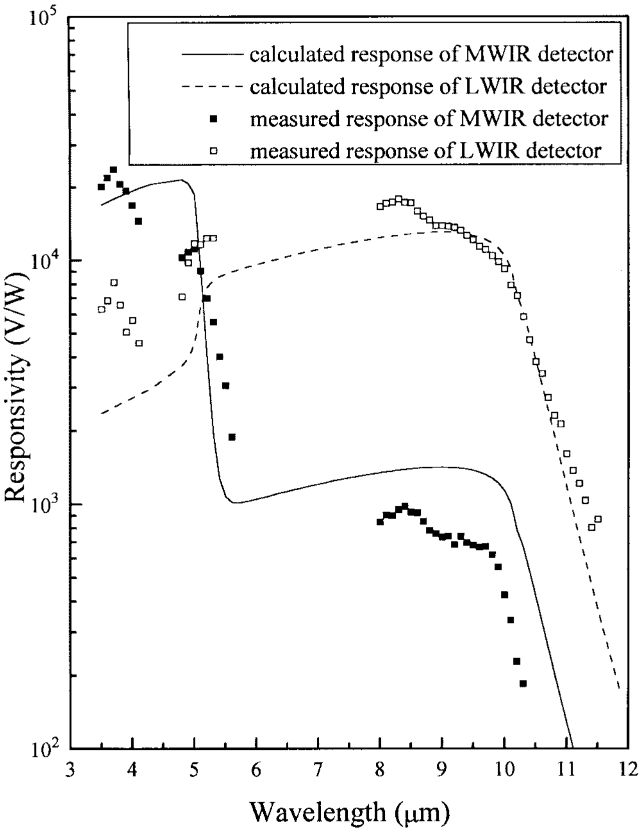

Fig. 2. Experimental spectral response of monolithic dual-band photoconductive device measured at 80 K and with an applied bias of 10 V/cm.

IV. EXPERIMENTAL RESULTS

A number of dual-band HgCdTe devices were fabricated and tested. The responsivity measurements were carried out using an Optronics Laboratories Spectral Response Measurement System, at a chopping frequency of 1 kHz. The resistance of the MWIR layer and LWIR layer obtained from *I*–*V* measurements was 885 and 270 ohms, respectively. Fig. 2 shows the measured spectral response at 80K between 3 and 12 μm for each of the two absorbing layers, indicating values of responsivity that are not optimum, primarily due to the nonoptimum structure and material used.

From the results it is seen that the amount of electrical crosstalk is excessive, especially for the LWIR detector. The crosstalk for the MWIR detector, which is the ratio of its responsivity in the LWIR region to that in the MWIR region, is 4%. The crosstalk for the LWIR detector is 45%. Note that as previously mentioned, it is assumed that the majority of crosstalk is electrical and not optical. These levels of crosstalk are considered excessive for the majority of applications, which are likely to require crosstalk levels of the order of 1%. Also shown in Fig. 2 is the calculated response using a model similar to that previously developed for multilayer photoconductors [6], and fitting parameters of mobility and doping based on the measured detector resistance. The model closely predicts the experimental results, and further simulation indicates that crosstalk can be practically eliminated (∼1%) by the use of a highly resistive and blocking middle layer ($x = 0.90$, thickness $= 2\ \mu$m, optical area $= 50 \times 50\ \mu$m^2). An interesting observation is that at wavelengths less than the cutoff of the MWIR material, the response of the LWIR layer is relatively low. However, as soon as the MWIR layer cuts off (approximately 5 μm), the response of the LWIR layer increases rapidly. This illustrates the effect of the MWIR layer acting as a filter of mid-wave radiation for the LWIR detector.

V. CONCLUSION

In this work, we have presented for the first time the concept of a monolithic dual-band HgCdTe infrared photoconductive detector structure that may be fabricated using well-established technology. Furthermore, the feasibility of the proposed structure has been verified by experimental results on fabricated dual-band devices. Simulations indicate that detector crosstalk can be eliminated using well-isolated structures resulting in individual detectors approaching the performance of equivalent single-band photoconductive detectors.

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