Multi-Colour MOVPE MCT Diodes

L. G. Hipwood*, C. L. Jones, C. D. Maxey, H. W. Lau, P. Abbot, R. A. Catchpole, and M. Ordish,
SELEX-Sensors and Airborne Systems,
Southampton SO15 0EG, United Kingdom.

Abstract

The drive towards improved target recognition has led to an increasing interest in detection in more than one infrared band. Many groups have demonstrated two-colour detection, typically by employing two back-to-back junctions, one for each colour. In this paper we describe a method for introducing a third colour via an absorber of intermediate wavelength placed between the two junctions. Electronic barriers are used to isolate this intermediate region. The design and location of the barriers in the structure are such that the barrier height is readily controlled by the applied bias, enabling the intermediate colour to be turned on by applied bias.

To provide the positional and doping control needed in the materials structure, MOVPE growth of MCT is used. Both FPA's hybridised to a read-out chips with switchable inputs, and test diodes for direct assessment, have been produced. This paper concentrates on the test diode assessment, as this provides the greater insight into the operation of the device. It is envisaged that such a device will be used with sequential framing of the different colours to provide quasi-temporal imaging.

The successful demonstration of the 3-colour concept is described.

Keywords: *MCT, multi-colour infrared, FPA, MOVPE, mercury cadmium telluride.*

1. Introduction

The requirement for improved target recognition and temperature estimation has led to an increasing interest in IR detection in more than one band. Current systems employ separate FPAs for each colour, or alternatively a filter is used (dichroic, mechanical wheel, striped with dithering) with a single FPA[1]. These approaches require subsequent processing to align images spatially or temporally. There is a clear advantage in terms of system design, weight, and power dissipation in having a single multicolour FPA achieving spatial and/or temporal coherence.

HgCdTe (MCT) is an ideal choice as a material for multi-colour applications due to the ability to tune the bandgap by varying the Cd mole fraction, x. Recently several groups have reported 2-colour MCT IR FPA's.[2-7] Two colour detection is achieved by having back-to-back pn junctions with either individual contacts to each junction, (two contacts per pixel allowing both temporal and spatial coherence) or a single pixel contact whereby the colour is selectable by the bias direction. In the latter case only spatial coherence is usual, though switching the bias between frames can generate a quasi-temporally coincident image. The requirement for only one contact per pixel allows a smaller pitch to be achieved for this approach and simplifies the array manufacture. (It is possible to

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* les.hipwood@selex-sas.com
http://www.selex-sas.com/

have true temporal coherence by biasing alternate rows of the FPA in different directions, loosing true spatial coincidence and effectively doubling the pixel pitch in one direction).

In the bias selectable 2-colour detector, the reverse biassed junction determines the response, A barrier layer of high Cd mole fraction is required between the two junctions to isolate the longer-wave (LW) response by preventing photo-generated carriers from the shorter wave (SW) side reaching the LW junction. Note that the terms LW and SW as used here are relative, and do not necessarily coincide with the LWIR and SWIR bands. The spectral response for the LW junction thus has a cut-on determined by the SW band-gap, i.e. the LW cut-on coincides with the SW cut-off. The introduction of a third colour by having an intermediate absorber between the two junctions is the subject of this paper, allowing the diode to exhibit one of three cut-offs depending on bias direction and magnitude.

2. 3-COLOUR CONCEPT

The bias dependent cut-off is achieved by employing three absorbers in an n-p-n structure with low p-doped electronic barriers at the junctions, see figure 1. The first n-region (in direction of radiation) defines the shorter wave (SW) side; the p-region, the intermediate wave (IW) response; and the top n-layer the longer wave (LW) response. At low biases either the SW or LW response would dominate, depending on which junction is reverse biased, in a similar way to a 2-colour detector. In this bias range, the barriers prevent electron flow from the IW region from both the photogenerated carriers from IW absorption, and by direct injection from the forward biased junction. As the barrier region is low doped, any applied bias will predominately fall on this side of the junction. Increasing reverse bias will, therefore, reduce the barrier until eventually energetic electrons generated by IW photons can cross the junction. For example, with the SW junction reverse biased, the cut-off wavelength should change from the SW cut-off to the IW as the bias is increased, figure 2 (this bias direction is defined as negative). Changing the bias direction (positive bias) would move the cut-off out to the LW. Similarly increasing positive bias would, in the ideal case, move the cut-on from being coincident with the IW cut-off to the SW cut-off. This is schematically shown in figure 3. Note that this ideal LW response may not be achievable in reality due to the IW absorber being insufficiently thick in a practical device to absorb all the IW radiation. In this case the LW cut-on will be determined to a certain extent by the SW cut-off regardless of the positive bias magnitude.

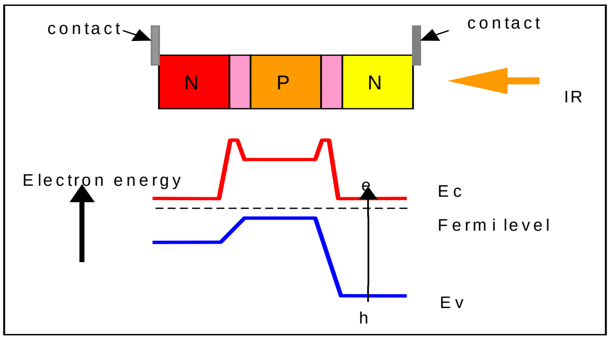

Figure 1. 3-color concept and associated zero-bias energy band diagram

3. MATERIALS AND DEVICE STRUCTURE

3.1 Layer growth

MCT was grown by MOVPE on GaAs substrates as described in reference 8. The substrates had an orientation just off the (100) direction to reduce the size of pyramidal hillock growth defects. The large lattice mismatch between MCT and GaAs (14%) is taken up by a CdTe buffer layer grown at low temperature (≈300°C) using methyl, allyl tellurium (MATe) as the Te source, conditions chosen to suppress hillock densities to less than 5 cm^{-2}. The MCT layers were grown by the interdiffused multilayer process (IMP) [9] using di-iso propyl tellurium (DiPTe) and di-methyl cadmium (DMCd) precursors, and elemental Hg. Growth proceeds by growing multiple layers of HgTe and CdTe which inter-diffuse, the relative thicknesses of the layers determining the Cd mole fraction. Donor and acceptor doping was by iodine and arsenic respectively, using iso-butyl iodide (IBI) and *tris*-di-methyl amino arsine (DMAAs) as the sources. Excellent uniformity and reproducibility has been achieved using this growth recipe.[8]

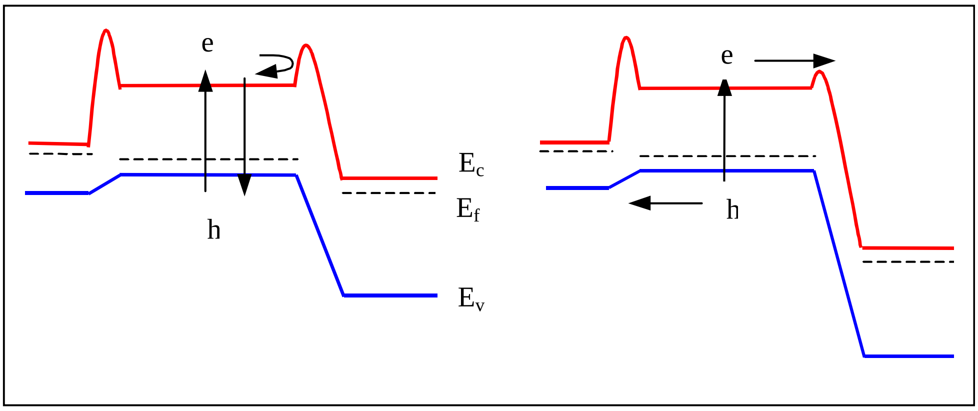

Figure 2. Effect of negative bias on IW response; left: low bias; right: high bias.

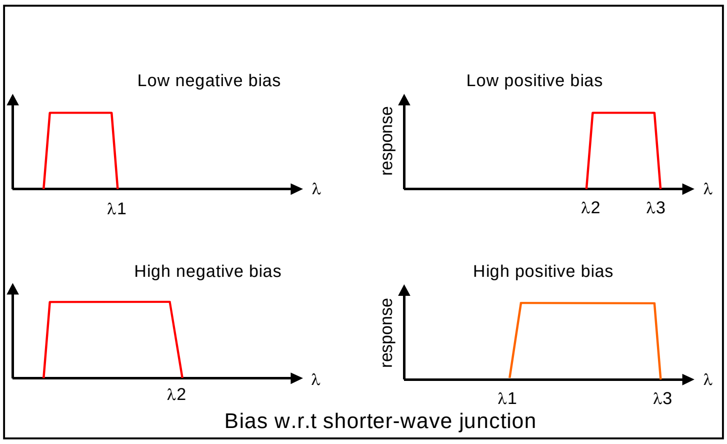

Figure 3. Idealised spectral responses. λ1, λ2 and λ3 are determined by the SW, IW and LW band gaps respectively

The structure investigated for this work was (in order of growth) $n_1P^-p_2P^-n_3$ where lower case letters refer to the absorber regions, with subscripts 1, 2 and 3 representing increasing cut-off wavelengths, while P^- refers to low doped high Cd mole fraction barrier layers. The absorbers were chosen to have cut-offs in the SWIR/MWIR range, nominally aimed at 3, 4 and 6 µm. Figure 4 shows a simulation of the growth profile based on the measured growth parameters, and includes the modelled effects of interdiffusion. Note that the p-type doping is kept low in the vicinity of the SW barrier to ensure that the barrier is within the depletion layer of the junction to enable barrier lowering. For this structure the LW barrier is used solely as a diffusion barrier for the reasons outlined in the preceding section, so the doping here need not be reduced.

3.2 Energy band modelling

The band diagram at zero bias for the structure of figure 4 is shown in figure 5. The SW conduction band spike is shown in figure 6 as a function of applied negative bias, where it can be seen that –1 V is sufficient to effectively remove the barrier.

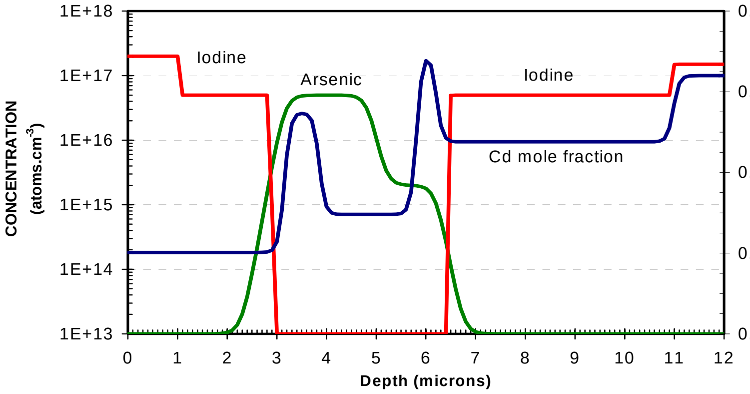

Figure 4. Simulated growth profile for 3-colour structure.

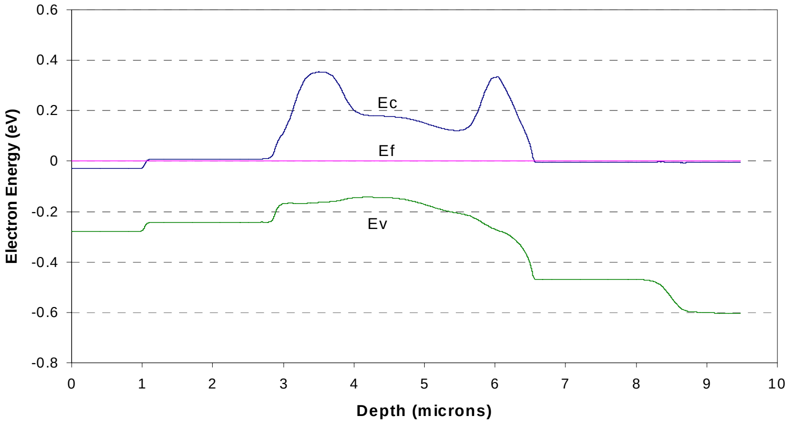

Figure 5. Energy bands at zero bias for the structure of figure 4.

3.3 Fabrication

Focal plane arrays (FPA) of size 320×256 on a 30 μm pitch were fabricated using mesa etching for pixel isolation. The mesas were etched to a depth of 8 μm, through both junctions, using a mixture of Br and HBr with bubble agitation. The diodes were passivated by electron beam evaporated CdTe followed by annealing to aid inter-diffusion into the MCT. Hybridization to the CMOS read-out chip (ROIC) was achieved by flip chip bonding using evaporated indium bumps on both components. The pixel input is switchable between an NMOS and PMOS input to allow both diode polarities in alternate frames. After hybridisation the GaAs growth substrate can be removed to reduce thermal stresses. Removal of the growth substrate also eliminates optical cross-talk which would otherwise occur from internal reflections.

In addition to the 320x256 arrays, test-arrays are produced for hybridization to lead-out discs. Variable mesa sizes within these arrays enables bulk and surface leakage currents and noise sources to be isolated. These test arrays are used for I-R-V, and spectral response assessment. This paper concentrates on the results from these test diodes as opposed to the ROIC hybrids, as this gives greater insight into the operation of the detectors.

4. CHARACTERISATION

4.1 R-V

Diodes are characterised by I-R-V assessment at a number of temperatures down to 77K. Bulk cooling in a Dewar is used, liquid nitrogen at 77K, and freons at higher temperatures of 145 and 192K. An HP parameter analyser is connected to the Dewar via a switch box to allow the sequential testing of up to 64 diodes. The R-V measurements at 192K are shown in figure 7 confirming that good back-to-back diodes are produced. The diodes were viewing a room temperature scene in F/1.5. The negative bias resistance of around 1GΩ is near the measurable limit of the kit.

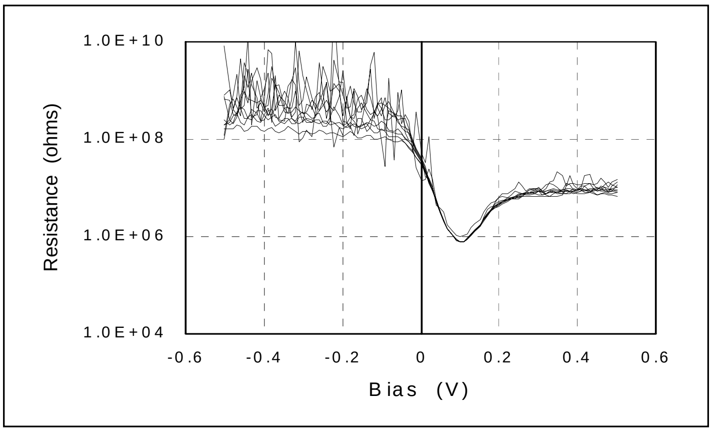

Figure 7. R-V characteristics at 192K for 30μm sq diodes

4.2 Spectral

The spectral response as a function of bias is measured using a Bio-Rad FTIR instrument with a transimpedance amplifier. Apart from a coated Ge window, no filters were used and the reference spectrum was measured immediately before starting the device measurements. Figure 8 shows the obtained spectral response, the cut-on at ~4300 cm^{-1} is given by the window. In this figure, λ1, λ2, and λ3 represent the cut-off wavelengths of the SW, IW and LW absorbers respectively. In positive bias the LW/IW junction is in reverse bias and a bias independent LW spectrum is obtained above 0.2V. The doping levels chosen result in no barrier lowering at the LW/IW junction at these applied biases. The response below λ2 is due to incomplete absorption in the IW absorber resulting in carrier generation in the LW absorber at these wavelengths. Carriers generated in the IW absorber have insufficient energy to surmount the LW barrier.

As the positive bias is reduced to below 0.2 V, the LW signal collapses and a signal from the SW side begins to appear with the current flowing in the opposite direction. In this regime the built-in fields dominate the behaviour, and the largest field is at the SW/IW junction due to the larger band-gaps. Further reduction in the bias to 0 V causes the SW response to grow.

Changing the bias polarity to negative puts the SW/IW junction into reverse bias, giving the SW response with cut-off λ1. Increasing the bias magnitude lowers the electron barrier at this junction and allows a response from the IW absorber, moving the cut-off out to λ2 as shown at –0.6 V in figure 8. The increase in the SW signal with increasing negative bias is due to incomplete SW absorption in the SW absorber. A further iteration of the design will include thickening the SW absorber to reduce the effect.

From figure 8, it is seen that the cut-off wavelength has been changed from λ1 to λ2 to λ3 by varying the bias magnitude and direction.

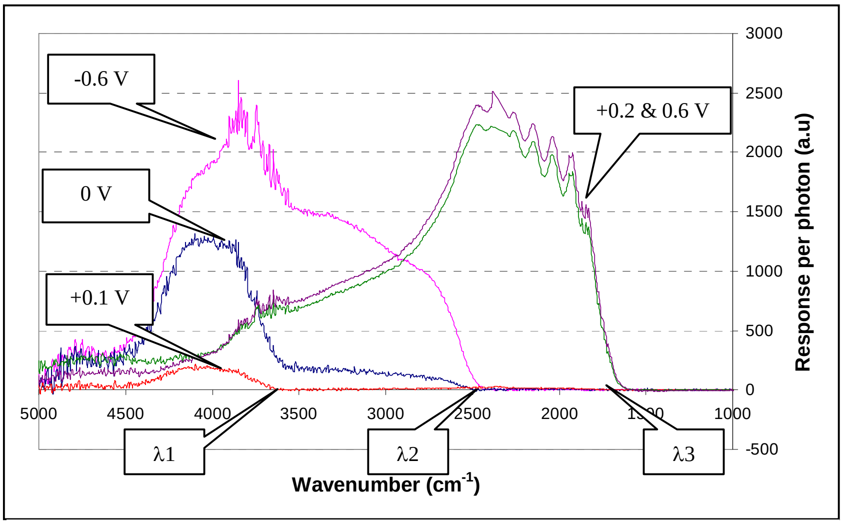

Figure 8. Spectral response of a 3-color detector at various biases.

5. CONCLUSION

A concept for achieving three colour detection from a two terminal device has been successfully demonstrated. Arrays have been produced where the cut-off can be switched between three values by varying the bias magnitude and direction. The longest and shortest cut-off are obtained as a conventional 2-colour device, i.e. reverse biasing one or other junction. An intermediate cut-off is introduced at higher biases with the SW junction reverse biased. The mechanism is the lowering of an electronic barrier by the applied bias to allow the photo-generated electron injection from the intermediate absorber to the junction.

The performance of the detector is critically dependent on the barrier's doping level and position in relation to the junction. To ensure adequate barrier lowering, the barrier must be low doped and of the same polarity as the intermediate absorber, and be located adjacent to the junction. The MOVPE growth process is shown to readily achieve such control.

It is envisaged that such a structure can be utilised in an FPA hybridised to a ROIC with a switchable input, allowing sequential framing of the different colours.

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