A LWIR Multispectral / Polarimetric Imager

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Abstract

Following the successful development of the UK's megapixel 3rd gen LWIR camera based on Thales LWIR QWIP Technology, and the subsequent development of a polarisation sensitive camera variant, the diffraction grating coupling mechanism for the detectors is been exploited again to develop a 2nd camera variant with LWIR wavelength and polarisation discrimination. Two detector architecture options have been explored and detectors based on the less complex option have been manufactured and tested. A 3 band LWIR polarisation-sensitive camera is being built.

Keywords: LWIR; Polarimeter; QWIP; IR Camera, multispectral

Introduction

This programme was made possible by the previous successful development of a Megapixel (1280x1024 pixels) LWIR camera based on Thales QWIP technology.

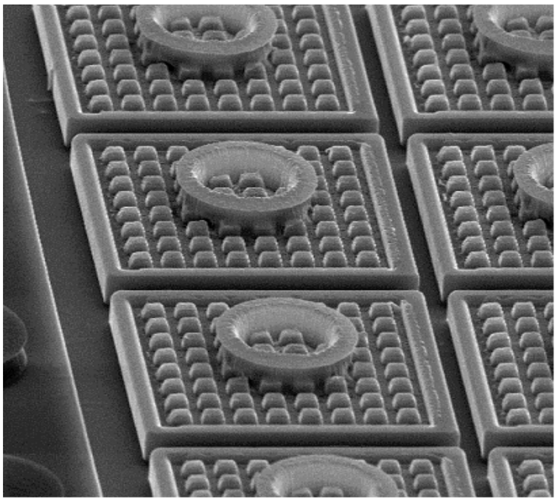

Figure 1 - Electron micrograph of a conventional QWIP array

A conventional QWIP detector has a diffraction grating on the surface (the quantum wells are not sensitive to radiation at normal incidence, and the diffraction deviates the radiation into angles where the quantum wells are sensitive). Usually, a 2-dimensional, fixed-pitch grating is used, as shown in Figure 1, as this eliminates polarisation sensitivity, and also limits wavelength sensitivity to one band within the LWIR.

As previously reported (1), linear instead of 2-D gratings were used for the first camera variant produced, and this provided polarisation sensitivity. For the camera variant reported here, introducing variations in the grating pitch provides wavelength sensitivity in addition to polarisation sensitivity. The use of a microscanner in the camera combined with the grating coupling method used on the QWIPs enables the design of camera that will resolve both multispectral and polarimetric components of a scene, while retaining all the benefits of a high resolution megapixel imager. A study undertaken at Thales indicated that such a discriminating imager might be beneficial in locating difficult targets, including disturbed earth. The benefit of QWIP technology is that this discrimination can be added without significant loss of sensitivity or increased cost.

The Detectors

The design, development, and manufacture of the processed multispectral/polarimetric GaAs focal plane arrays (FPA) were undertaken by Alcatel-Thales III-V Lab in France, to a specification defined by Thales Optronics Limited (2). Sofradir has manufactured the integrated detector cooler assembly (IDCA) incorporating the multispectral/polarimetric detector.

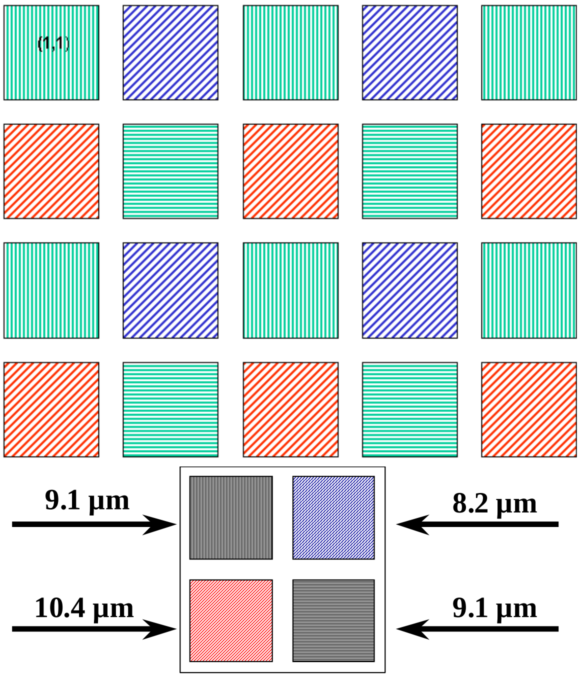

Figure 2 – Multispectral / polarimetric detector layout

To provide the multispectral and polarisation sensitivity, linear gratings are formed on a set of four (2x2) detector elements, as shown in Figure 2. Three different grating pitches are implemented in each group of 4 pixels. The vertical and horizontal gratings are both tuned to 9.1µm, and the 45° gratings are tuned one each to 8.2µm and 10.4µm. The choice of wavelengths for the 3 bands is to maximise discrimination of disturbed earth. The 2x2 pattern is replicated across the whole array. The standard 1280x1024 megapixel microscan pattern is modified to allow the scene to be viewed by each of the 4 pixels in a 2x2 cell in turn. This produces 4 sequential 640x512 frames with polarimetric and spectral characteristics for subsequent extraction, processing and display.

Multispectral FPA Architecture Options

Two detector architecture options were originally proposed for implementation of the multispectral / polarimetric detector.

- **Single stack architecture**. 1 broadband active layer, 3 different quantum well types (λ_1, λ_2, λ_3, where $\lambda_1<\lambda_2<\lambda_3$). Relies on the grating pitch on any given pixel to select the appropriate waveband from the broadband structure. Simpler architecture for processing and fabrication.

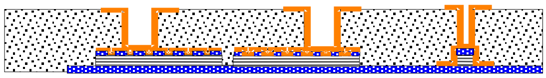

Figure 3 – Single stack architecture

- **Double stack architecture.** 2 active layers, 1 narrowband layer (λ_2 quantum well), 1 broadband active layer (λ_1 & λ_3 quantum wells). With reference to Figure 4, each group of 2x2 pixels includes two S_1 and two S_2 pixels. Horizontal or vertical gratings are created on the S_2 pixels with appropriate pitch to maximise coupling into the λ_2 (9.1µm) QWIP structure. In the S_1 pixels the narrowband layer is shorted out, leaving only the two spectrally well separated QWIP structures active. Gratings at 45deg orientation and with appropriate pitch to maximise coupling into the λ_1 (8.2µm) or λ_3 (10.4µm) structures are created on each S_1 pixel to achieve the final wavelength and polarisation discrimination. Fabrication of this structure is clearly more complex.

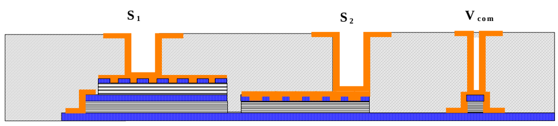

Figure 4 – Double stack architecture

Based on the lower fabrication complexity, the single stack option was chosen as the architecture to be implemented in the first batch of multispectral FPAs.

Single Stack Active Layer Design

Two different active layers types were assessed for the single stack design. Both designs had broadband absorption based on three different quantum wells. The band structures for the two designs are shown in Figures 5 & 6. In each case the 3-well structure was repeated 13 times in the active layer.

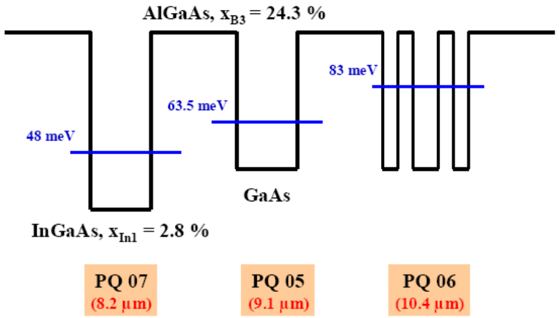

Figure 5 - Active layer band structure option 1

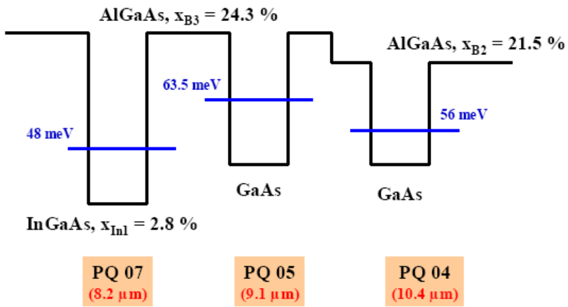

Figure 6 - Active layer band structure option 2

Epitaxial Layer Growth

After calibration of the growth system, three runs were performed to grow the active layers for FPA fabrication. After one unsuccessful run, two further successful runs were completed, one for each active layer design option. In each run two wafers were grown for FPA processing and one for optical coupling calibration.

Characterisation Of The Active Layers

With reference to Figure 6, it can be seen that both runs ART584 and ART585 exhibited the required broadband absorption peak, from 8.3 µm to 10.5 µm. ART579 was the unsuccessful run, with a narrow absorption peak.

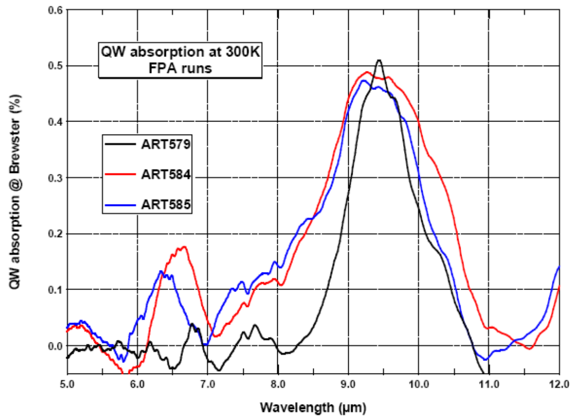

Figure 6 - Active Layer Absorption Measurements

Characterisation Of Fabricated FPAs

Test gratings were implemented on wafers from both ART584 and 585 – subsequently referenced by processing codes T475 and T476 respectively. Checks were made on dark current density, and I(V) characteristic that confirmed that non-spectral detector characteristics did not alter with the orientation of the optical coupling on each pixel. The dark current was thermally activated, and the activation energy was close to 130 meV at –1 Volt for T475 and T476. This compared favourably with regular QWIPs used for the standard Catherine-MP thermal imager and showed that the dark current performance was not degraded by the broadband structure. It further demonstrated that as far as ROIC saturation capacity was concerned, an operating temperature close to 70K was achievable.

Figure 7 & 8 show the spectral responsivity for 3 optimised gratings for T475 and T476 at a number of operating temperatures. In both cases the spectral crosstalk was found to be significant and the peak wavelength responses did not line up with the design specification. However, crosstalk did show some reduction with operating temperature.

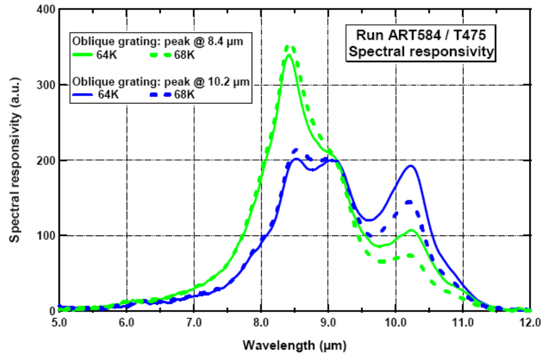

Figure 7 - Spectral responses for T475, showing the influence of operating temperature

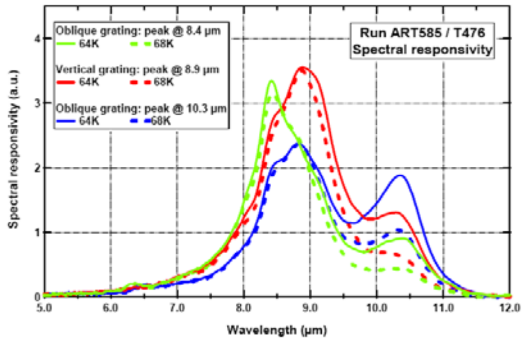

Figure 8 - Spectral responses for T476, showing the influence of operating temperature

Reasons For Poor Multispectral Performance

The poor spectral performance exhibited in Figures 7 & 8 prompted further investigation of possible causes. Three main causes were identified, as follows:

- **The overall spectral shape was too narrow**
  Calibration steps during layer growth should be lengthened; the designed bandwidth should be larger than the required bandwidth (e.g 8.2µm, 9.1µm and 10.4µm requires 8.1µm, 9.1µm and 10.5µm).

- **Temperature dependence of spectral shape**
  The spectral shape varied with operating temperature, a broadband response becoming narrower as the temperature rose above 70K. This is attributed to the evolution of the electric field distribution within the structure, and the use of a super-quantum well, or use of carefully equilibrated, uncoupled quantum wells may compensate for this behaviour.
- **Crosstalk between the 3 bands was very high**
  Although modifications to the operating temperature could reduce the effect in some instances, high spectral crosstalk is probably intrinsic to the single stack architecture, and could only be avoided by resorting to a double stack design.

Conclusion And Follow-on Work

The investigation of the spectral performance issues seen with the single stack design for a 3-band multispectral LWIR imager have shown that even when optimised, the performance specified in (1) is unlikely to be achieved. The recommended route forward (4) is to re-design the 3-band detector based on a double stack QWIP architecture defined earlier in this paper, with careful attention also given to the design of the optical coupling scheme. Modelling shows that 3-band spectral performance as shown in Figure 9 is achievable. Spectral crosstalk will not be zero, but should be minimised.

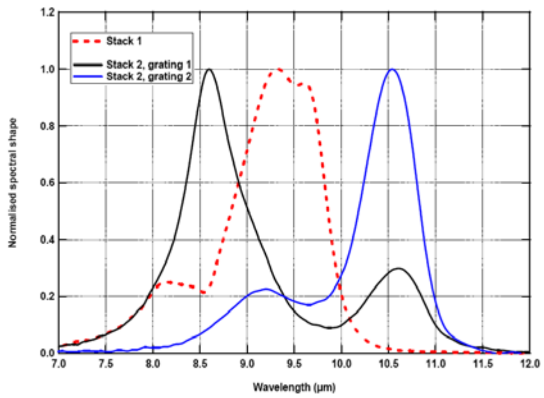

Figure 9 - Modelled performance for a double stack architecture 3-band detector

As an interim measure, Thales and III-V Lab have fully characterised all available single stack detectors (5), and identified one with the spectral characteristics shown in Figure 10 as having at least some useful spectral discrimination when operated at a lower than normal temperature such as 68K. Measurement has also confirmed that this detector has good polarimetric discrimination. This detector will be integrated into an IDCA and installed in a Catherine MP camera very shortly. It is anticipated that supplementary results from camera lab and field-testing will be available for presentation at the EMRS DTC Technical Conference in June 2009.

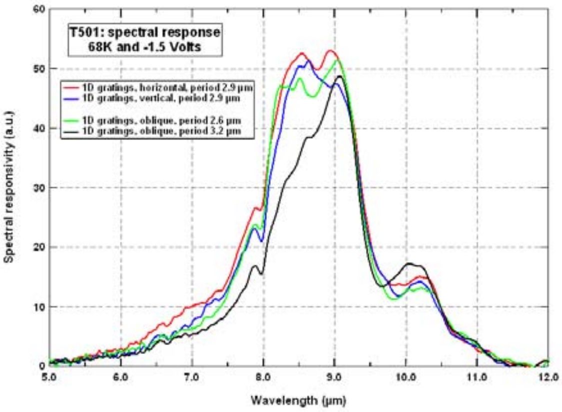

Figure 10 – Spectral characterisation of Wafer T501

Acknowledgements

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References

1. JF Parsons, R Craig, "A LWIR Polarimetric Imager", EMRS DTC Technical Conference, Edinburgh 2008
2. R Craig, "Multispectral QWIP die", Thales Optronics technical specification, TOL07/TS/U/SEG037, June 2007
3. A Nedelcu, "Multispectral Polarimetric QWIP die for Catherine MP", Thales Alcatel III-V lab technical note, AT35/T/2008/06/0085, June 2008
4. A Nedelcu, "Development of a Multispectral Polarimetric QWIP die for Catherine MP", Thales III-V Lab technical proposal, AT35/T/2009/01/0183, January 2009
5. A Nedelcu, A Christie, "Multispectral Polarimetric QWIP die for Catherine mp – Characterisation of Wafer T501", Thales Optronics technical report, TOL09/TR/P/SEG0030, February 2009.