Multi-Band Large Format Infrared Imaging Arrays

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Summary

Large-format and multi-band focal plane arrays (FPA) based on quantum well and quantum dot infrared photodetectors have been developed for various instruments such as imaging interferometers and hyperspectral imagers. The spectral response of these detectors are tailorable within the mid- and long-wavelength infrared bands.

Introduction

The rapid development of long wavelength infrared (LWIR) Quantum Well Infrared photodetector (QWIP) cameras demonstrates the potential of GaAs/AlGaAs QWIP technology for highly sensitive, low power, low cost, and highly uniform large area focal plane array (FPA) imaging systems. These cameras utilize FPAs as large as 1024x1024 detector pixels based on optimized GaAs/AlGaAs based multi-quantum-well structures (MQWs). As a result of matured fabrication and processing technologies, these FPAs show excellent images with uniformity and pixel operability better than 99.9% [1-3]. Figure 1 shows FPA and one frame of image from a 3-4 µm, 1024x1204 format camera. GaAs/AlGaAs-based QWIP technology is an ideal candidate for the development of a multi-band FPAs due to its inherent properties such as narrow band response and wavelength tailorability [1,2]. It also permits vertical integration of multi-quantum well (MQW) stacks [1,4]. Each MQW stack absorbs photons within the specified wavelength band allowing other photons to transmit through. The $GaAs/Al_xGa_{1-x}As$ material system allows the quantum well parameters to be varied over a range wide enough to enable light detection at any wavelength range from 6 to 20 µm [1,2]. By adding a few monolayers of $In_yGa_{1-y}As$ during the GaAs quantum well growth, the short wavelength limit can be extended to 3 µm. The spectral bandwidth of these detectors can be tuned from narrow ($\Delta\lambda/\lambda \sim$ 10 %) to wide ($\Delta\lambda/\lambda \sim$ 40 %), according to application requirements [5]. Recently, we have extended this wavelength limit by monolithically integrating a near-infrared (visible – 2.1 µm) p-i-n photodiode with a mid-infrared (3-5µm) quantum well infrared photodetector (QWIP). These multi-band detector arrays are created by vertically integrating stack of detectors involving both intersubband and interband transitions in quantum structures.

Figure 1: JPL developed 1024X1024 format, 4-5 µm QWIP FPA, and one frame of the video image taken with the camera [2].

Four-band FPA

A 640x512 format spatially separated four-band QWIP FPA based on a InGaAs/GaAs/AlGaAs material system has been developed for mullti-band infrared imaging instruments [4]. Fig. 2 shows the schematic diagram of the four-band detector array consisting four QWIP stacks. The area array is divided into four sub areas each consisting 640x128 pixels, that are sensitive in 4-5.5 µm, 8.5-10 µm, 10-12 µm, and13-15.5 µm wavelength bands. Optimized two-dimensional (2-D) reflective gratings with deeper groove depths were utilized in this FPA in order to reflect light in preferred directions, allowing absorption within the active MQW layers of each IR band [6]. As shown in the Fig. 2, these gratings were created by dry etching and coated with Au. In addition to light coupling, these gratings serve as a contact to the active stack while shorting the unwanted top stacks. The unwanted bottom QWIP stacks were electrically shorted at the end of each detector pixel row and connected to a common ground. When the detector pixels are biased through the pixel top and the common ground, each pixel activates only a single QWIP stack and reads a photocurrent generated by absorbed photons within a single IR wavelength band.

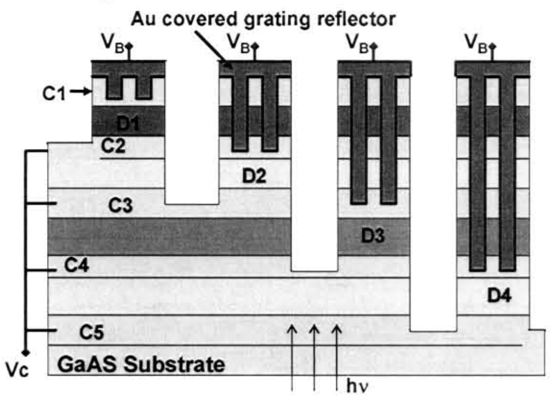

Figure 2: A schematic of the layer diagram and pixel isolation scheme of four-band detector array. D1, D2, D3, & D4 represent MQW detector layers and C1 to C5 are heavily doped contact layers. The gold coated reflective etched gratings are fabricated on each pixel allowing absorption of normal incident light. These gratings also serve as contacts to the active detector while shorting the unwanted top detectors. The unwanted bottom detectors are electrically shorted from the outside of the array.

Results and Discussion

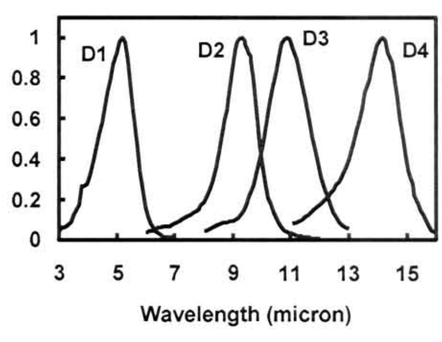

Figure 3: Normalized spectral responsivity of the detectors in the four-band QWIP FPA.

Fig. 3 shows the measured normalized spectral responsivity curves at V_B = - 1.5V bias voltage for each detector. Spectral band widths for all four detectors D1, D2, D3, and D4 are $\Delta\lambda/\lambda_p$ ~ 26%, 15%, 17%, and 11% respectively. As expected, the narrower band width and the flat responsivity near zero bias voltage indicate the bound-to-bound nature transitions in detector D4 [1,2]. Detectors D3 and D2 show a slightly broader spectral bandwidth, with increasing responsivity right at the beginning of the bias voltage, confirming the bound-to-continuum design [1,2]. Detector D1 is specifically designed to cover a 4-5.5 µm wavelength range with $\Delta\lambda/\lambda_p$ ~ 26% broader responsivity by utilizing a three well superlattice within the each period of the MQW [5]. Also, the shorter wavelength response in this detector is achieved by using deeper $In_{0.33}Ga_{0.67}As$ quantum wells with lattice mismatched $Al_{0.3}Ga_{0.7}$ As barriers.

During the fabrication of detector arrays, individual pixels were defined by photolithographic processing techniques [1,2,4]. Four separate detector bands were defined by a deep trench etch process, and a detector short-circuiting process eliminated the unwanted spectral bands. As shown in the Figure 2, the unwanted top detectors were electrically shorted by a gold coated reflective 2-D etch gratings. The unwanted bottom detectors were electrically shorted through the column from the outside of the array. After fabrication, a few detector arrays were hybridized to 640x512 CMOS multiplexers [4]. A four-band QWIP FPA hybrid was mounted onto a 84-pin lead-less chip carrier and installed into a laboratory dewar for characterization. In order to demonstrate 4-band simultaneous imaging, detectors are biased at V_B = -1.5 V and back-illuminated through the flat thinned substrate [3,4]. For imaging, the detector array is operated at temperature T = 45K, where the photocurrents are higher than the dark currents, and each detector shows a very high $D^* > 5 \times 10^{10}$ cm$\sqrt{Hz}$/W for 300 K background with f/2 optics. This initial array gave excellent images in all four IR bands with pixel operability more than 99.9%, demonstrating the high yield of III-V material based QWIP technology. Figure 4 shows one frame of a video image taken with a four-band 640x512 pixel QWIP camera.

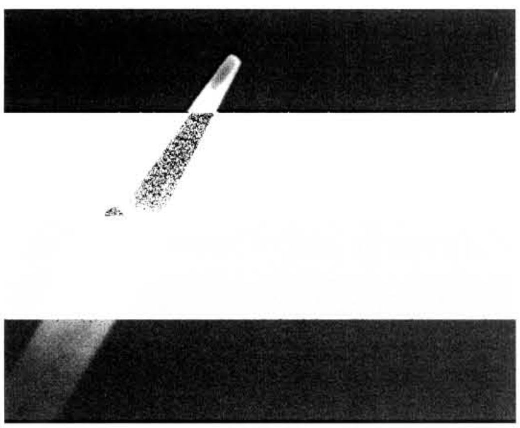

Figure 4: One frame of video image of a soldering iron taken with the four-band 640x512 pixel QWIP camera. Different portions of the same object are imaged, from top to bottom, in 3-5 μm, 8.5-10 μm, 10.5-12 μm, and 13-15 μm.

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