# Type-II InAs/GaSb superlattices for dual color infrared detection

Linda Höglund, Rickard Marcks von Würtemberg, Hithesh Gatty, Anders Gamfeldt, Carl Asplund, Eric Costard

IRnova AB, Isafjordsgatan 22 C5, SE-16440 Kista, Sweden

## ABSTRACT

Midwave-midwave dual color detection has been successfully demonstrated by using pixel filters fabricated on top of InAs/GaSb focal plane arrays (FPAs). The pixel filters used in these FPAs were designed to transmit infrared radiation in the 3.5 - 4.1 μm wavelength region and to completely block light shorter than 3.5 μm. By comparing the signals of filtered and unfiltered pixels, excellent contrast between the two bands were obtained. This design concept offers a great flexibility to tailor the transmission window to any wavelength range within the 3-5 μm wavelength region. In particular, this dual color detector concept has been used for gas detection of volatile organic compounds which have main absorption peaks at 3.3 μm.

**Keywords:** dual color, heterostructure, infrared, detector, superlattice, InAs/GaSb

## 1. INTRODUCTION

In thermal imaging, dual band infrared (IR) photodetectors offer vastly enhanced detection capabilities compared to single-band detectors. Several wavebands improve the possibility of identification and recognition of objects and gas detection is an emerging industrial application for dual color detectors. Many gases are transparent at most infrared wavelengths, but some gases absorb light in the infrared regions. In dual color detectors, one of the wavelength bands can be designed to overlap with the gas absorption peak to enable enhanced gas contrast. A number of dual color photodetectors have been realized in the InAs/InGaAsSb type-II superlattice (SL) material system, both for long wave/midwave (LW/MW) [1, 2], short wave/midwave (SW/MW) [3] and MW/MW [4, 5, 6] infrared detection. Many of these detectors utilized stacked, back-to-back photodiode designs that were connected with two terminals. In these configurations, the wave band was selected by applying the appropriate bias using dual polarity capable read-out circuits (ROICs). Other dual color detectors are three-terminal devices, where the two wave bands are operated continuously and simultaneously. These focal plane arrays (FPAs) require customized ROICs and more advanced processing, with more than one indium bump per pixel [6]. In this paper, we present results from a MW/MW dual color FPA, which was designed to enhance the sensitivity to volatile organic compounds (VOC) with absorption peaks around 3.3 μm (Figure 1.1). A broadband MWIR superlattice FPA was used and a pixel filter with transmission in the 3.5-4.1 μm wavelength band was fabricated on top of the thinned down array in a checker board pattern. As a result, VOC gases were absorbed by the unfiltered pixels only, while the filtered pixels were used as reference pixels. By combining the information from the filtered and unfiltered pixels the gas contrast was greatly enhanced. This concept allowed simultaneous operation in two distinct wave bands and no special processing or ROIC was required.

Quantum Sensing and Nano Electronics and Photonics XIV, edited by Manijeh Razeghi,
Proc. of SPIE Vol. 10111, 1011116 · © 2017 SPIE · CCC code: 0277-786X/17/$18
doi: 10.1117/12.2256514

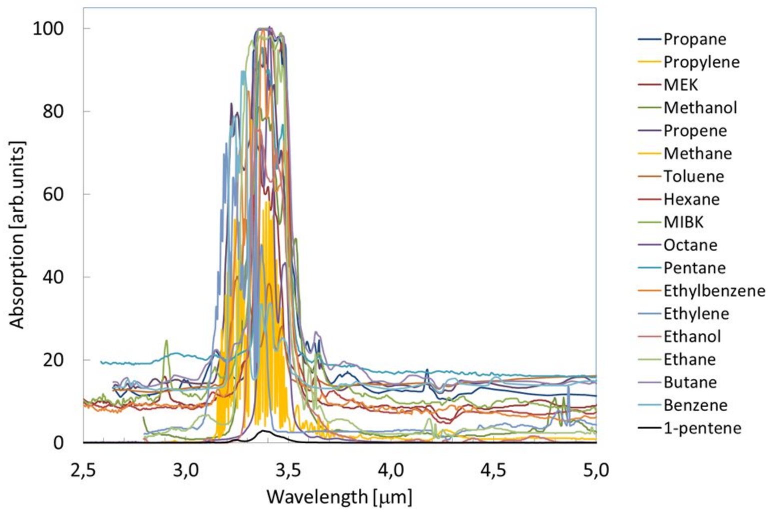

**Figure 1.1.** Absorption spectra of several volatile organic compounds showing absorption peaks around 3.3 μm.

## 2. EXPERIMENTAL DETAILS

### 2.1 Material

The dual color detector presented in this paper, is based on an InAs/GaSb SL structure with 5.1 μm cut-off wavelength at 85 K. The detector structure (schematically illustrated in **Figure 2.1**) has been described in full detail in [7] and the manufacturability of detectors based on this structure was demonstrated in [8]. After fabrication of FPAs from this material as described in section 2.2, a pixel filter with high transmission in a selected wavelength region was deposited on the arrays.

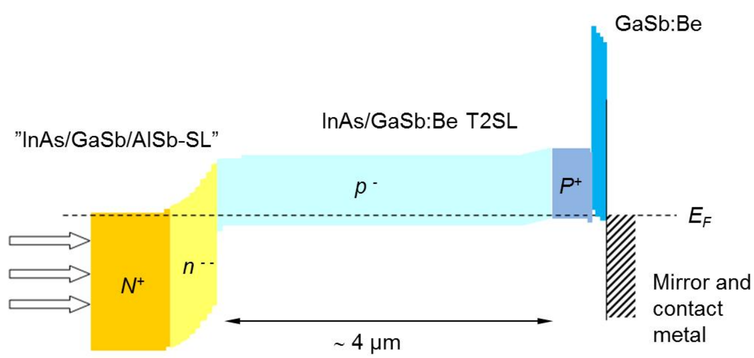


**Figure 2.1.** Double heterostructure (DH) detector design used in IRnova's detectors

### 2.2 Fabrication

320 × 256 pixels detector arrays with 30 μm pixel pitch were fabricated from the MWIR structure using standard III/V processing techniques. Stepper lithography was used to define the pixels. Pixels were formed by a combination of dry and wet etching [9] and passivated using a dielectric passivation [10]. Mirror, contact metal and indium bumps were evaporated onto the pixels before dicing. The arrays were then hybridized to the read out integrated circuit (ROIC)

ISC9705, underfill was deposited and the GaSb substrate was fully removed. Finally, the pixel filter was deposited and patterned in a checker board pattern, leaving the pixel filter on every second pixel.

# 3. RESULTS

## 3.1 Simulations and transmission measurements

Simulations of the pixel filter transmission were performed to evaluate which design would give the best gas contrast. Pixel filters with cut-off wavelengths ranging from 3.3 to 3.8 μm were compared (**Figure 3.1**). A cut-off wavelength of 3.6 um was selected, since good blocking of the gas band (3.0 - 3.5 μm) and high transmission in the reference band (3.5-4.1 μm) was obtained with this filter design.

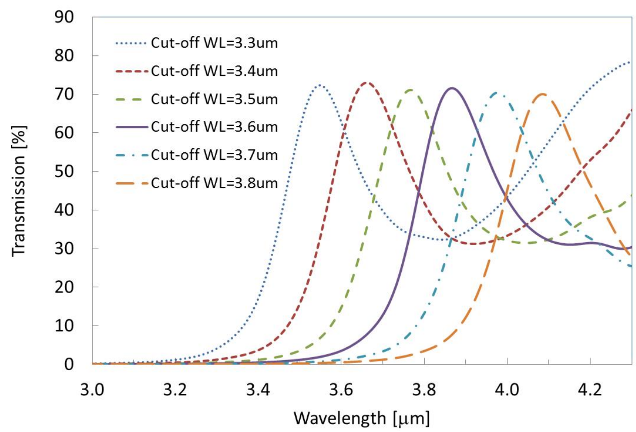


**Figure 3.1.** Simulated transmission spectra of pixel filters with different cut-off wavelengths.

Filters with the selected design were deposited on fabricated arrays as well as on plain reference wafers. The filter transmission was measured utilizing the reference wafers. In these measurements, full blocking of the gas band and high transmission in the reference band was observed (

**Figure** 3.2). Good agreement was also obtained between the measured and calculated transmission spectra.

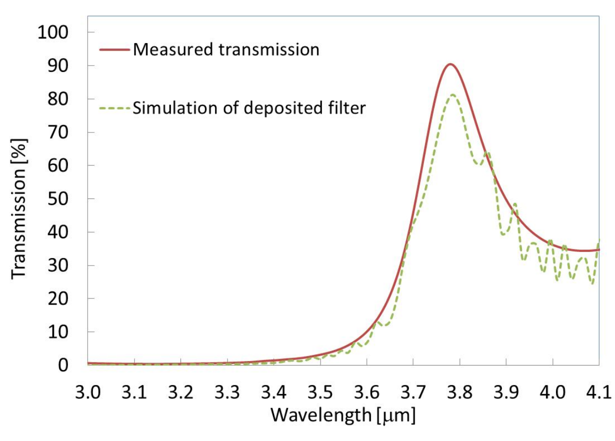


**Figure 3.2.** Measured transmission spectra of the pixel filter deposited on the array compared to the fitted calculation.

### 3.2 Demonstration of pixel filter

The pixel filter deposited on the arrays was patterned and etched in a checker board pattern (Figure 3.3a). Good alignment between pixels and pixel filters was observed (Figure 3.3b).

(a) (b)

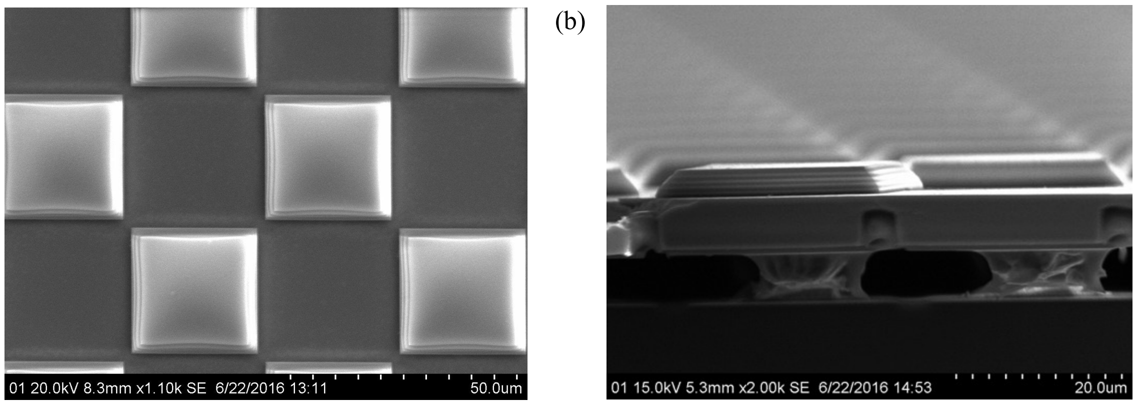


**Figure 3.3.** SEM images showing (a) the checker board patterned pixel filters (b) the alignment between the detector pixels and the filter pixels.

The FPAs with the patterned filter were mounted in a cooled test setup where images were collected from the arrays facing different extended black body targets. Also available in this setup was a gas cell, enabling the controlled introduction of gas in the path between the temperature controlled black body background and the detector. As the gas cell windows were not large enough to cover the full field of view of the detector/cold shield a simple lens setup was added to focus the image on the FPA. Standard gain and offset corrections (non-uniformity correction), were performed with a non-absorbing gas in the gas cell. Consequently, all pixels in the array are expected to have the same signal level when looking at a uniform target when no absorbing gas is present. A detail of an image taken from one of the FPAs with butane gas present in the gas cell is shown in **Figure 3.4**. Here the black body in the background was set at 40 °C and the path length of the gas was 10 mm. Clearly seen in **Figure 3.4** is the differentiation of the signal in the two different sets of pixels (with and without the pixel filter) emanating from the different gas sensitivity of the pixels.

**Figure 3.4.** Image from FPA with 40 °C blackbody and butane gas present (RT)

The distributions of pixel signals with and without butane gas present were compared (**Figure 3.5**). When the gas cell is filled with butane gas (at room temperature), two different distributions were seen, representing the filtered and non-filtered sets of pixels (**Figure 3.5a**). In contrast, when the gas cell is filled with $N_2$ (a gas with no absorption in the spectral range of the detector), all pixels were distributed around a single value **(Figure 3.5b).** These results demonstrate that the pixel filters worked as designed.

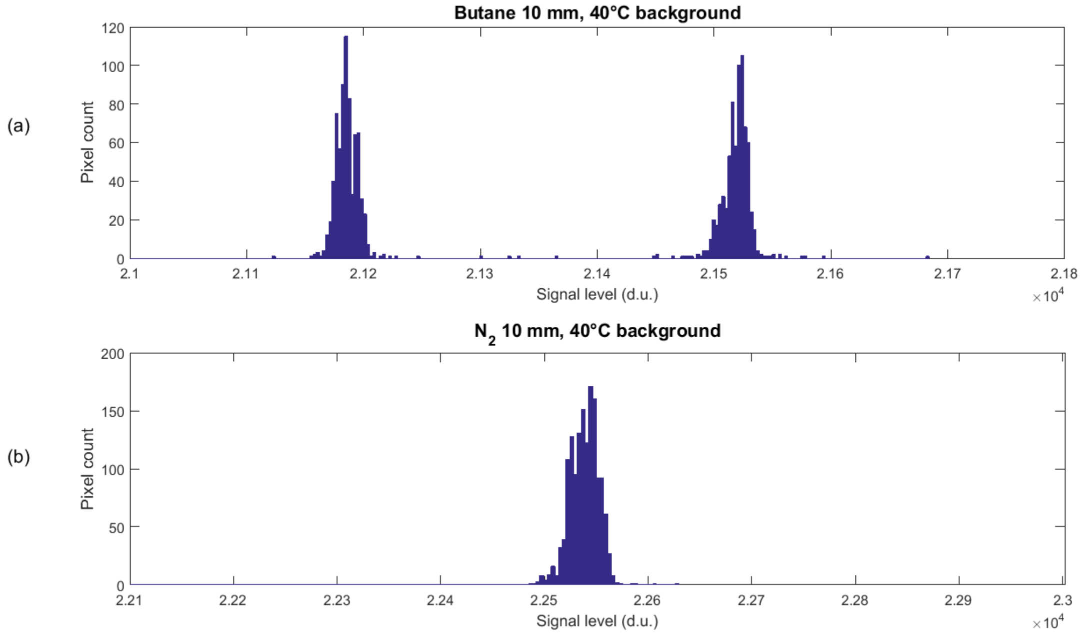


**Figure 3.5.** (a) Distribution of pixel values with butane gas present (b) Distribution of pixel values with $N_2$ gas present. In both cases a 40°C black body source was imaged.

To further demonstrate the ability to distinguish gases with this FPA, an image was taken using a basic lens setup looking at a nozzle of a gas bottle (see **figure 3.6**). Again the detector was non uniformity corrected, but no bad pixel replacement was implemented which is why some black and white pixels are still present in the image. The bottle containing pure butane gas was opened very slightly to give a small flow of gas out of the nozzle. In this image, the expected checkerboard pattern appears in the gas cloud exiting the nozzle, differentiating it from the background where no gas was present. Though not as apparent in the still image, it could be seen in the live video that most of the gas exited the nozzle with some velocity in a forward flow (in line with the nozzle direction) but a small amount had little momentum and rose slowly. Also this small gas flow can be seen as checker-board patterned in the still image above and to the left of the nozzle exit (**figure 3.6**), suggesting good sensitivity of this technique.

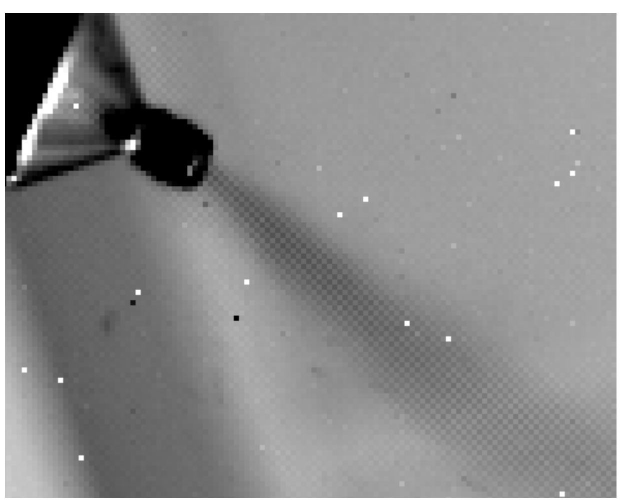

**Figure 3.6.** Image of butane gas flowing from a bottle, showing the checkered pattern in the image were the gas affects the signal of the filtered and unfiltered pixels differently.

## 4. SUMMARY

In summary, a MW/MW dual color FPA based on a broad band InAs/GaSb superlattice has been demonstrated. Different wavebands were selected by fabrication of pixel filters on top of the array in a checker-board pattern. The pixel filter in this study was specifically designed to enhance the gas contrast for volatile organic compounds (VOC), with a pixel filter blocking the 3.0-3.5 μm wavelength range, while the unfiltered pixels were sensitive in the 3.0-4.1 μm wavelength range. Excellent contrast between filtered and unfiltered pixels was demonstrated with a VOC gas present.

## REFERENCES


[1] Khoshakhlagh, A, Rodriques, J. B., Plis, E., Bishop, G. D., Sharma, Y. D., Kim, H. S., Dawson, L. R., Krishna, S., "Bias dependent dual band response from InAs/Ga(In)Sb type II strain layer superlattice detectors", Applied Physics Letters 91, 263504 (2007)

[2] Razeghi, M., Haddadi, A., Hoang, A.M., Chen, G., Ramezani-Darvish, S., Bijjam, P., "High-Performance Bias-selectable Dual-band Mid-/Long-wavelength Infrared Photodetectors and Focal Plane Arrays based on InAs/GaSb" Type-II Superlattices, Proc. of SPIE Vol. 8704, 87040S (2013)

[3] Razeghi, M., Hoang, A.M., Haddadi, A., Chen, G., Ramezani-Darvish, S., Bijjam, P., Wijewarnasuriy, P., Decuir, E., "High-performance bias-selectable dual-band Short-/Mid-wavelength infrared photodetectors and focal plane arrays based on InAs/GaSb/AlSb Type-II superlattices", Proc. SPIE 8704, 87041W (2013)

[4] Rehm, R., Walther, M., Schmitz, J., Fleißner, J., Ziegler, J., Cabanski, W., Breiter, R., "Dual-colour thermal imaging with InAs/GaSb superlattices in mid-wavelength infrared spectral range", Electron. Lett. 42, 577 (2006)

[5] Rehm, R., Walther, M., Rutz, F., Schmitz, J., Wörl, A., Masur, J., Scheibner, R., Wendler, J., Ziegler, J., "Dual-Color InAs/GaSb Superlattice Focal-Plane Array Technology", J. Electron. Mat., 40, 1738 (2011)

[6] Stadelmann, T., Wörl, A., Wauro, M., Daumer, V., Niemasz, J., Luppold, W., Simon, T., Riedel, M., Rehm, R., Walther, M., "Development of bi-spectral InAs/GaSb type II superlattice image detectors", Proc. SPIE 9070, 90700V (2014)

[7] Malm, H., Gamfeldt, A., Marcks von Würtemberg, R., Lantz, D., Asplund, C., Martijn, H., "High image quality type-II Superlattice detector for 3.3 μm detection of volatile organic compounds", Infrared Physics & Technology 70, 34–39 (2015)

[8] Höglund, L., Asplund, C., Marcks von Würtemberg, R., Gamfeldt, A., Kataria, H., Lantz, D., Smuk, S., Costard, E., Martijn, H., "Advantages of T2SL: results from production and new development at IRnova", Proceedings of SPIE, Vol. 9819, , 98190Z (2016)

[9] Chaghi, R., Cervera, C., Aït-Kaci, H., Grech, P., Rodriguez, J. B. and Christol, P., "Wet etching and chemical polishing of InAs / GaSb superlattice photodiodes", Semicond. Sci. Technol. 24, 065010 (2009).

[10] Martijn, H., Asplund, C., Marcks von Würtemberg, R. and Malm, H.,"High performance MWIR type-II superlattice detectors", Infrared Technology and Applications XXXIX, Proc. of SPIE Vol. 8704, 87040Z (2013).