AGILE AND VERSATILE INFRARED TECHNOLOGY BASED ON QWIPs

K. K. Choi*, G. Dang, and J. W. Little
Electro-optics and Photonics Division, US Army Research Laboratory, Adelphi MD 20783

A. Majumdar and D. C. Tsui
Dept. of Electrical Engineering, Princeton University, Princeton, NJ 08544

ABSTRACT

We have taken two different approaches to achieve wavelength tunable infrared detection based on quantum well infrared detectors (QWIPs). In the first approach, we designed a detector material structure whose detection peak wavelength is switchable by applying opposite bias. In the second approach, we designed a detector unit cell, which consists of a number of detector elements, each sensitive in one specific wavelength. By addressing the corresponding detector element in each unit cell, an electronic configurable focal plane array can be obtained.

1. INTRODUCTION

The Objective Force of the US Army demands an infrared technology for situation awareness that can be fast adapted to different mission environments and objectives. An infrared focal plane array (FPA) which is capable of changing its detection wavelength electronically will be useful in improving the signal to clutter ratio, overcoming specific obscurants and identifying certain chemical agents.

2. Voltage tunable QWIPs

We have investigated different QWIP architectures that allow wavelength tunable infrared detection. In the first approach, we designed a detector material structure whose detection peak wavelength is switchable by applying opposite bias. It can be used for two-color detection with a time-multiplexed readout circuit. The wavelength tuning mechanism is based on electron transfer between coupled quantum wells (QWs) under bias. In this design, two QWs of unequal sizes are separated by a thin barrier thickness to form a unit cell. The entire structure consists of a number of unit cells separated by a larger barrier thickness. The thermal equilibrium within each unit cell leads to electron transfer between the unequal wells under bias. Fig. 1 shows the direction of electron transfer from QW #1 to QW #2 under positive bias. Since QW #2 has a larger energy separation, the material is sensitive at a shorter wavelength of 7 µm as shown in Fig. 2. On the other hand, when the bias is switched to negative bias, the electrons are transferred from QW #2 to QW #1 as shown in Fig. 3. Because of the smaller energy spacing in QW # 1, the infrared absorption shown in Fig. 2 is at the longer wavelength regime. The absorption width is also much wider.

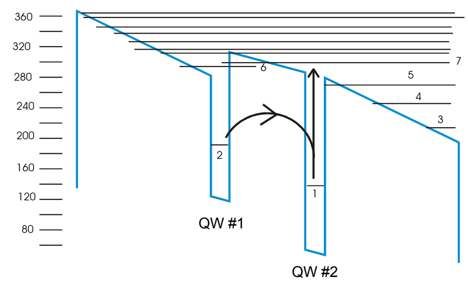

Fig. 1 Energy band diagram of a coupled QW structure under +3V bias. The curved arrow shows the direction of electron transfer. The straight arrow shows infrared absorption. The horizontal lines are discrete energy levels.

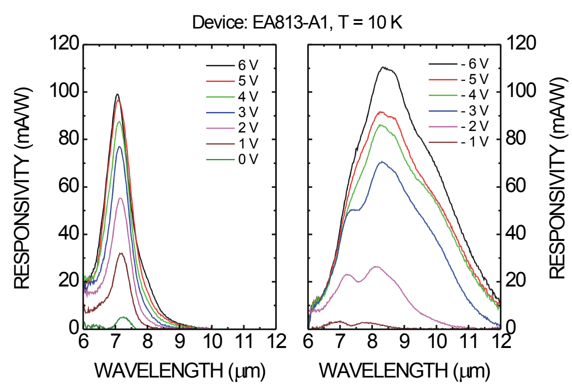

Fig. 2 The detector spectral responsivity under positive bias and negative bias.

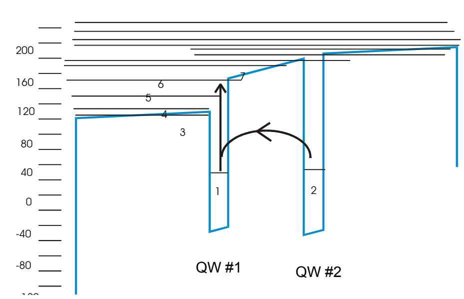

Fig. 3 Energy band diagram of a coupled QW structure under –3V bias.

3. Quantum Grid Infrared Photodetectors

A unique characteristic of QWIPs is its lack of normal incident absorption. A light coupling mechanism is needed to convert the electric polarization from horizontal to vertical for absorption. By tailoring the characteristics of a light-coupling scheme, one can create new detector functionality, which is not possible with the usual infrared materials. Our second approach of achieving electronically adaptive FPAs is based on narrow band coupling. The ideas is that one can divide a FPA with N × N pixels into n × n detector unit cells, each cell contains m × m detector pixels, where m = N/n and N ~1000. Each pixel is a QWIP with a specific detection wavelength defined by the light-coupling geometry. The adaptable nature of the array comes from the readout scheme. If one displays the corresponding pixel in each cell separately, one can detect m^2 individual wavelengths simultaneously, each with n × n spatial resolution. In another extreme, if one adds all the signals in a unit cell together, one will have a single display of an extremely broadband detection with n × n resolution. Likewise, if one adds the signals from different detector pixels together, one can make many combinations of detection wavelengths and bandwidths. Thus, one will have a very versatile adaptive array.

In the present design, the detector pixel is made of a quantum grid infrared photodetector (QGIP). Each QGIP shares the same QWIP material but has different grid geometry. The QWIP is made of binary superlattices to provide extreme broadband (~10 μm) absorption. The structure of the grid, on the other hand, determines the specific wavelength to detect at each detector element in the array. The grid structure consists of narrow strips of QWIP materials with metal cover on top. The metal cover acts as a dipole antenna, which strongly scatters light when the width of the antenna equals an odd number of half-wavelengths of the incident light in the material. The wavelength selectivity is further enhanced by adjusting the height of the grid line, which acts as a slab dielectric resonator for the scattered light. With the optimum height, the fundamental waveguide mode of the resonator can be excited by the metal antenna with a large quality factor, resulting in large and sharp infrared absorption. In a QGIP adaptive array, detectors with different line widths will detect different wavelengths simultaneously. The display of the corresponding detector elements in different unit cells will yield the picture of a scene at different wavelengths. Alternatively, displaying the signal from different pixels within a cell yields the emission or absorption spectrum of an object without using dispersing optics. Combining these spatial and spectral capabilities will greatly enhance the battlefield target search and identification and the defeat of camouflage.

Fig. 4 shows the 3-dimensional perspective of a QGIP within the unit cell. Fig. 5 shows the calculated quantum efficiency of ten QGIPs with different strip widths. The range of the widths is from 0.74 to 2.59 μm. The height of the grid lines is 3 μm, and the imaginary part of the dielectric constant ε_i is 1. With this set of structural parameters, each QGIP detects at an integral value of wavelength, with $\Delta\lambda/\lambda = 9.4\%$. The absorption width can be tailored by changing the doping density of the material to suit an application.

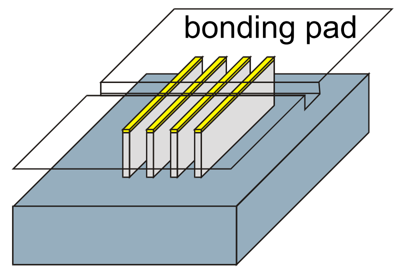

Fig. 4 A QGIP pixel structure.

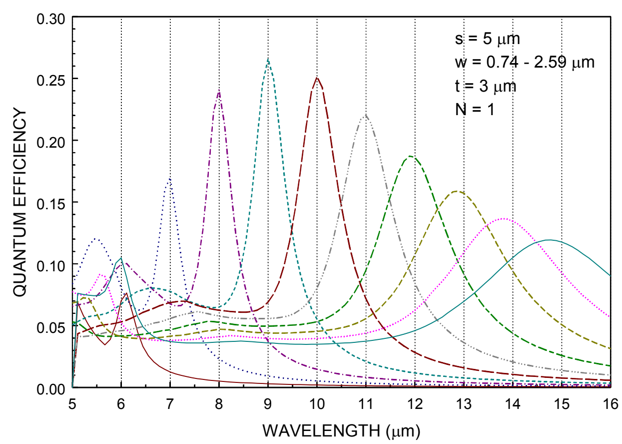

Fig. 5. Calculated (unpolarized) absorption spectra of 10 QGIPs with different w ranging from 0.736 (first curve on the left) to 2.59 μm (last curve). The reflection loss of the thick GaAs substrate has been included.

4. Conclusion

Using the first approach, we have demonstrated a QWIP with detection wavelength at 7 μm under +3 V and 9 μm under –5 V. At the same time, the detection changes from narrow band (bandwidth = 0.6 μm) to broadband (bandwidth = 3.2 μm). These changes enable the same target being viewed under different wavelengths and bandwidths, and are useful in applications such as landmine detection. In the second approach, we employed a wavelength specific light coupling scheme to achieve simultaneous multi-color detection in a single FPA. The number of wavelength bands and their bandwidth can be adjusted by design.