# Bias-Dependent Tunable Response of Normal Incidence Long Wave Infrared Quantum Dot Detectors

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Intersubband quantum dot detectors have shown steady progress in their performance ever since their first demonstration in 1997. In the past five years, QD detectors have demonstrated (a) normal incidence operation in the mid-wave infrared (MWIR, 3-5 μm)[1], long-wave infrared (LWIR, 8-12μm)[2] and very long-wave infrared (VLWIR, >14 μm)[3] (b) high temperature operation (up to 150K at ~4 μm)[4] (c) large responsivity (3 A/W, $V_b$=-1V) and detectivity (2x10$^9$ cmHz$^{1/2}$/W, $V_b$= -0.3V) with a cut-off at 8.2 μm at T=78K[5] (d) large gain (~25) and conversion efficiency (57%)[5]. However, most of the QD detectors reported in literature exhibit a broad spectral response (Δλ/λ~35%), possibly due to the large size/shape fluctuations. For certain forward-looking infrared (FLIR) applications, a broadband response is desirable. However, for multispectral imaging/hyperspectral imaging (MSI/HSI) applications, narrower spectral bands are needed. *In this paper, we report development of array compatible individual high-performance quantum dot pixel structures that allow for spectral tuning by the application of an external bias. Custom-made post-processing algorithms have been used to further enhance and optimize their tuning and spectral-separation capability far beyond the device limit.*

The dots-in-a-well (DWELL) detector consists of 10 layers of InAs dots placed in a thin $In_{0.15}Ga_{0.85}As$ well, which in turn is placed in a GaAs matrix. The DWELL structure provides better confinement for the carriers trapped in the quantum dots by lowering the ground state of the QD relative to the GaAs bandedge. This leads to lower thermionic emission and higher detectivity. We recently reported a DWELL detector operating at $\lambda_{cut\text{-}off}$= 8.2 μm (Δλ/λ ~35%) with a large responsivity ($R_{peak}$=3.58 A/W at T=78K) and a large detectivity ( $D^*_{peak}$ = 2.7x10$^9$cmHz$^{1/2}$/W, T=78K). In the QD detectors that we have tested so far, we have observed a bias dependent red-shift in the peak wavelength of the QD detectors. The bias dependent spectra and the wavelength Theoretical modeling of this large Stark-shift (Δλ~1 μm for Δ$V_b$=1V) is presently being undertaken to better understand the effect of bias on the QD band structure and the results of this study will be discussed in the presentation.

The experimentally observed large shift could be exploited to realize a bias-dependent tunable detector. Although QD detectors provide a wide spectral coverage, the large full width at half maximum (FWHM) is inadequate for spectral sensing applications. We report an innovative post-processing algorithm to increase the available spectral resolution while maintaining the broad spectral coverage of the QD detectors. This approach involves performing simple algebraic operations using a predefined algorithm on the spectral curves for different bias voltages as shown in Fig 2. In particular, for a desired spectral response, i.e., a certain peak wavelength and spectral width, the algorithm seeks the optimal linear combination of a limited number of bias-controlled spectra that best approximates the desired spectral response. Preliminary results using this algorithm indicate that a unimodal response that can be *continuously tuned between 5-8 μm* with a spectral FWHM down to 0.5 μm (a decrease by a factor of 4!) can be obtained using between five and twenty spectra, corresponding to equally-spaced bias voltages between –1 and 1 V as shown in Fig.3. Besides its benefit as an enabling technique in virtually controlling the spectral response of detectors, another advantage of this technique is that these "smart" sensors can be operated in the FLIR mode (possibly without the use of the post-processing algorithm) or in the HSI/MSI mode with the use of the post-processing algorithm or anywhere in between. These results will be discussed in detail in the presentation.

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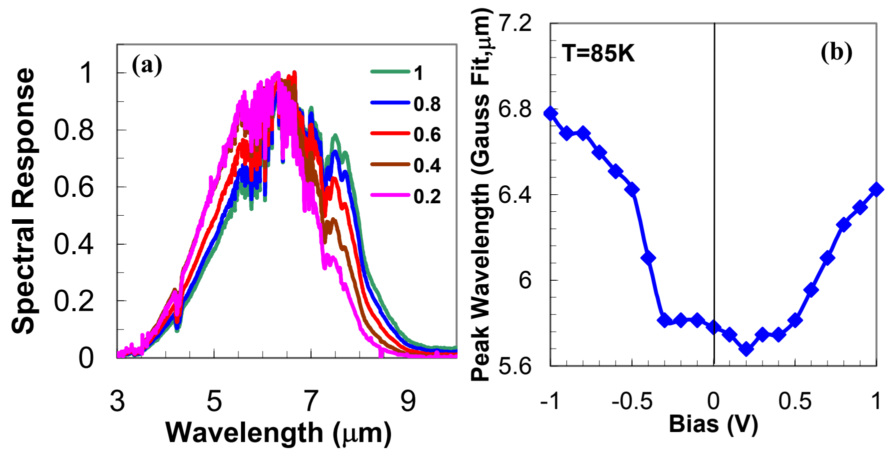


**Fig. 1:** Bias dependent (a) spectra and (b) peak wavelength (from a Gaussian fit) of a 10 layer $InAs/In_{0.15}Ga_{0.85}As$ DWELL detector. The structure on the spectra are not fluctuations but rather reflect the atmospheric absorption over this wavelength range

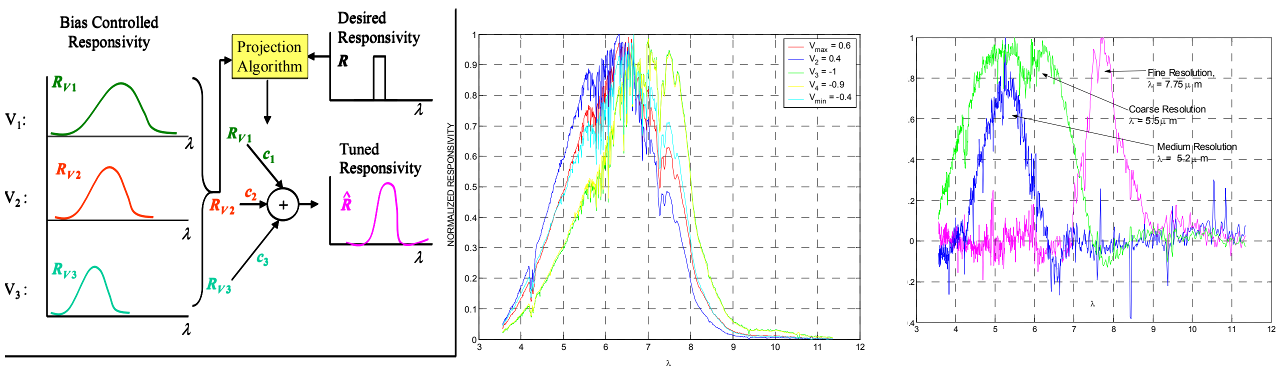


**Fig.2**. (a) A schematic of the proposed bias-controlled and post-processing-based tuning technique, (b) a sampling of several responses at different bias voltages. (c) three characteristic derived responses. These responses show independent resolution and center wavelength tuning

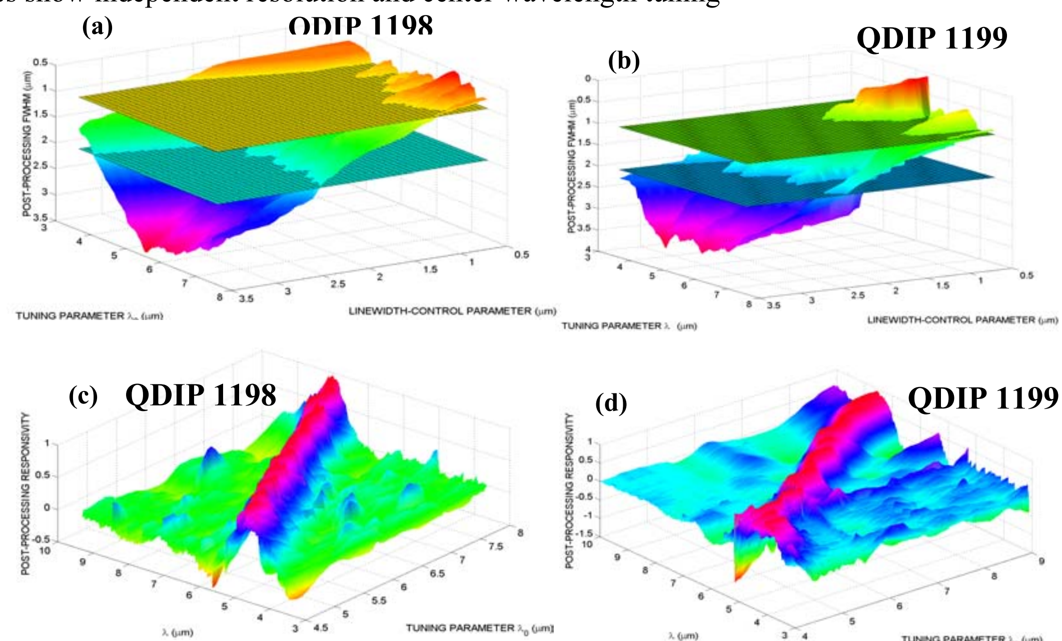


**Fig. 3**: Tunable response between 5-8 μm with narrow FWHM obtained from two QD detectors with slightly different heterostructures. Panels (a) and (b) present the spectral resolution (FWHM) as a function of center wavelength (tuning) and linewidth control parameter. Resolution better than 1 μm can be achieved across the tuning range (5-8 μm). Panels (b) and (c) present a surface plot of the spectral response at the highest resolution setting as a function of tuning wavelength.