

# Characterization of Nanoscale Quantum Dots-in-a-Well Infrared Sensors

Jennifer Hou

Molecular and Cellular Biology, Johns Hopkins University

**NNIN REU Site: Nanoscience @ UNM, University of New Mexico, Albuquerque, NM**

NNIN REU Principal Investigator(s): Professor Sanjay Krishna, Electrical and Computer Engr., University of New Mexico

NNIN REU Mentor(s): Rajeev Shenoj, Electrical and Computer Engineering Department, University of New Mexico

Contact: jhou4@jhu.edu, skrishna@chtm.unm.edu, rshenoj@ece.unm.edu

## Abstract/Introduction:

Infrared detectors have many military, medical, and industrial applications due to their ability to detect radiation in the form of heat. Research groups are striving towards third-generation infrared detectors that have large-area focal plane arrays, improved functionality, and increased operating temperatures [1]. In order to operate at higher temperatures, the dark current (thermally generated electrons) needs to be lowered; then these devices can become more cost-effective by reducing their reliance on expensive cooling equipment.

The innovative quantum dots-in-a-well (DWELL) infrared detector has indium arsenide (InAs) dots, three-dimensionally quantum confined, “embedded in” an  $\text{In}_{0.15}\text{Ga}_{0.85}\text{As}$  well [1]. Electrons in InAs dots can become photoexcited and make intersubband transitions (dot to dot, to well, and to continuum) in the conduction band (Figure 1). DWELL detectors decrease dark current and offer greater “control over the operating wavelength,” where the width of the quantum well can be altered to change energy transitions [1].

The DWELL structure was developed from a single  $\text{In}_{0.15}\text{Ga}_{0.85}\text{As}$  well to a dots-in-a-double well (DDWELL) structure with  $\text{In}_{0.15}\text{Ga}_{0.85}\text{As}/\text{GaAs}$  wells [1] as shown in Figure 1. Less use of indium for the  $\text{In}_{0.15}\text{Ga}_{0.85}\text{As}$  well reduces the strain that was caused by the lattice mismatch between  $\text{In}_{0.15}\text{Ga}_{0.85}\text{As}$  and GaAs, allowing the growth of more stacks and thus more photocurrent absorption. The  $\text{Al}_{0.10}\text{Ga}_{0.90}\text{As}$  barriers located between the asymmetric wells lowered the dark current by blocking the passage of some thermally generated electrons and prohibited electron coupling between active regions. The focus of this project was to optimize the  $\text{Al}_{0.10}\text{Ga}_{0.90}\text{As}$  barriers by characterizing and comparing devices that have 30, 50, and 65 nm  $\text{Al}_{0.10}\text{Ga}_{0.90}\text{As}$  barriers.

## Experimental Procedure:

The characterization parameters investigated were: current-voltage characteristics, spectral response, responsivity, and specific detectivity. Each device—single well with 50 nm barrier, double well with 30, 50, or 65 nm barrier—was individually placed into a cryostat, in which the air was vacuumed from the cavity to avoid condensation and then cooled to a low temperature (i.e. 30, 77K) to reduce the signal from thermally generated electrons.

First, a semiconductor parameter analyzer was used to obtain current-voltage characteristics for the current from both

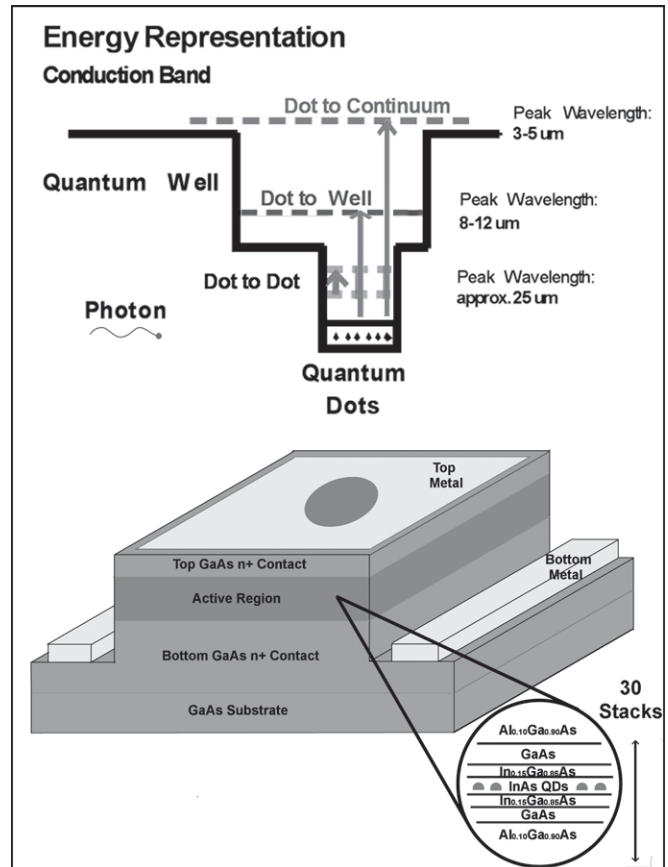


Figure 1: Schematic DWELL energy (at 0V bias) and DDWELL physical representation.

photoexcited and thermally generated electrons. For dark current measurements, a cold shield was used to block any incident light from reaching the device. The temperature of each device was raised from 30°K up to 100°K (150°K for the double well with 65 nm barrier, Sample D) to determine which barrier width was optimal at reducing dark current. Second, the devices’ spectral response at various bias voltages was obtained using a Fourier transform infrared spectrometer (FTIR). Third, responsivity, the signal output per IR power input [2], was used to measure the amount of light absorbed by the detector. For the setup, a blackbody set to a specific temperature (i.e. 527°C) cast an infrared beam which was modulated by a chopper. This frequency was used to trigger

the spectrum analyzer. Also, the current amplifier produced a bias voltage across the top and bottom metal contacts to capture the signal current. Last, specific detectivity or the “normalization of the signal to noise ratio” was calculated to find out the device’s ability with regards to others of various aperture areas or materials [3].

## Results and Conclusions:

At 30K, the dark current for the single well with 50 nm barrier (Sample A) was greater than that of any of the double well structures (Figure 2). As the barrier width increased for the double well, the dark current decreased; the 65 nm barrier had the lowest of these values. At 77K, the dark current increased with temperature for all devices. The single well with 50 nm barrier still had the highest dark current. Also, the dark current values were similar for the double wells with 50 and 65 nm barriers.

Spectral response was measured to determine the highest operation temperatures and to observe the spectral properties of the devices. At 30°K, there was already a greater presence of noise for the single well with 50 nm barrier and double well with 30 nm barrier than for the other devices. Sample D had spectral response peaks of 8.7  $\mu\text{m}$  for -5V and of 6.5  $\mu\text{m}$  for 5V, showing bias-tunability (Figure 3). The device’s spectral response was obtained up to 140°K. The double well with 65 nm barrier was optimal with a peak responsivity of 66 mA/W and a peak detectivity of  $3.1 \times 10^9 \text{ cmHz}^{1/2}/\text{W}$ , taken at a -5V bias and at 77K for an 8.7  $\mu\text{m}$  wavelength (Figure 4).

In conclusion, DDWELL photon detectors retain many qualities (“bias-tunability and multi-color operation”) [4] of the DWELL structure; but they additionally lower strain to permit more stacks and decrease dark current to achieve both higher operating temperatures and detectivity.

## Future Work:

For the advancement of DDWELL photon detectors, the next steps are to reduce strain even more, which will allow for greater photocurrent absorption and to include these devices in focal plane arrays.

## Acknowledgements:

I would like to thank my advisor, Prof. Sanjay Krishna for this profound experience and for his guidance and support. I would like to thank my mentor, Rajeev Shenoj for his encouragement and helpful advice. I would like to thank Prof. Poland. Special thanks to the QDIP group members, to the staff at CHTM, to Stefi Weisburd, and to my family. Last, I deeply thank the National Nanotechnology Infrastructure Network Research Experience for Undergraduates Program and the National Science Foundation for their generous funding.

## References:

- [1] S. Krishna et al, “Quantum Dot Based Infrared Focal Plane Arrays,” Proc. IEEE 95, 1-2, 4, 13 (2007).
- [2] J.D. Vincent, “Fundamentals of Infrared Detector Operation and Testing,” A Wiley-Interscience Publication, 9, 17 (1990).
- [3] Ibid., 9, O.W. P. Wroclawskiej, Materials Science, 133.
- [4] S. Krishna et al, “Quantum Dot Based Infrared Focal Plane Arrays,” Proc. IEEE 95, 1 (2007).

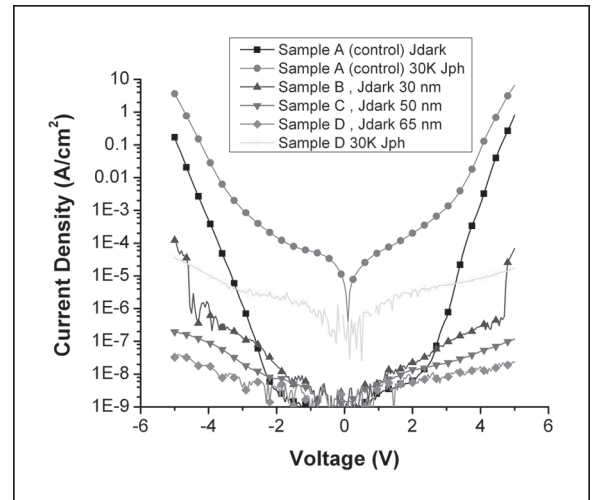


Figure 2: Current density comparison at 30K.

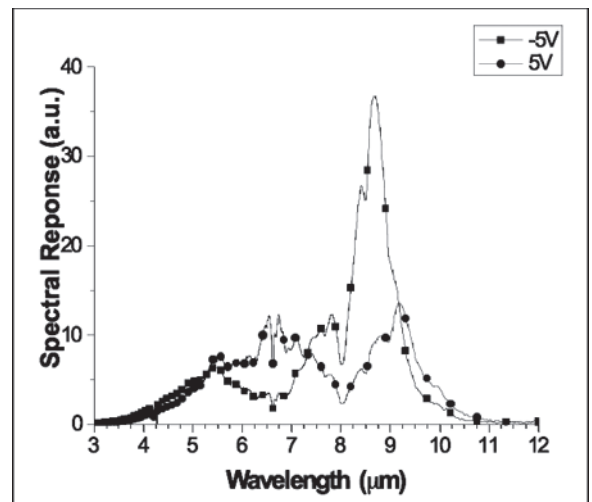


Figure 3: Spectral response for Sample D at 77K.

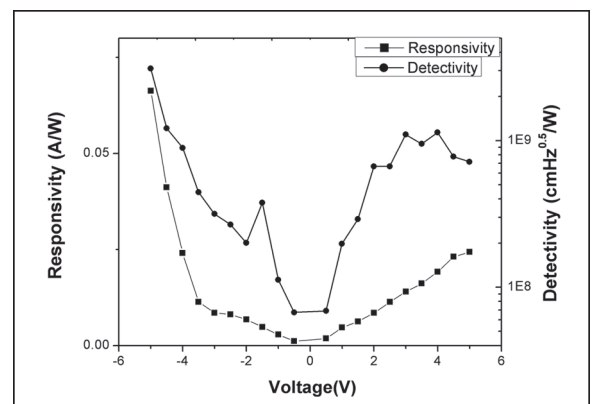


Figure 4: Responsivity and detectivity for Sample D at 77K.