OPTODET: Modeling of HgCdTe Photodetectors in the LWIR and MWIR region

Pradyumna Muralidharan[1], Dragica Vasileska[1], and Priyalal S. Wijewarnasuriya[2]
[1]School of Electrical, Computer and Energy Engineering, Arizona State University, Tempe, AZ 85281, USA
[2]Sensors and Electron Devices Directorate, U.S Army Research Laboratory, Adelphi, MD 20783 - 1197
E-mail: pmuralid@asu.edu, vasileska@asu.edu, priyalal.wijewarnasuriya@us.army.mil

Abstract – The tool OPTODET is developed to investigate and explain the device behavior of HgCdTe Photodetectors with variation in temperature, composition and doping. Our theoretical model employs complete Fermi – Dirac statistics and all major recombination mechanisms. Special consideration is given to non – ideal characteristics, such as band to band tunneling, trap assisted tunneling and impact ionization.

I. INTRODUCTION

HgCdTe's properties can be utilized in a wide range of applications, such as: optical gas sensing, environmental monitoring, free-space optical communication, clean energy generation, biomedical and thermal imaging. Its narrow bandgap properties make it an imperative material for infrared detection. Its tuneable bandgap (0.2eV to 1.5eV) also leads to the possibility of forming novel heterostructure devices. A tuneable bandgap allows HgCdTe to access both the LWIR (8-14 µm) and MWIR (2-6 µm) regions.

II. NUMERICAL MODEL

A 1-D drift diffusion based simulator has been designed to calculate various parameters of a HgCdTe photodetector. All simulations assume parabolic conduction bands. We simulate an abruptly doped p-n junction considering complete Fermi – Dirac statistics. The analysis of device behaviour requires the solution of a set of transport equations that are comprised of the continuity equations for electrons and holes, Poisson's equation and careful treatment of all the recombination mechanisms. For simulation of dark current characterization, traditional recombination mechanisms have been considered such as SRH, Radiative and Auger mechanisms [1]. At low temperatures many non – ideal characteristics define the I-V characteristics. Band to band tunnelling, Trap assisted tunnelling and impact ionization models have been added to describe non – ideal behaviour [2, 3]. Absorption Co-efficient of $Hg_{1-x}Cd_xTe$ was modelled by implementing the Kane model for energies above the conduction band edge and the Urbach model for energies below the conduction band edge [4].

III. RESULTS AND DISCUSSION

Fig 1 describes the p^+-n structure which has been simulated. Optical analysis of the device has been performed by simulating characteristics such as Detectivity (Fig 2), Responsivity (Fig 3) and all components of Quantum Efficiency (Fig 4) [5]. Electrical analysis was conducted by simulating dark current (Fig 5) and Dynamic Resistance (Fig 6). A model to calculate transit times of photo generated carriers has also been developed which helps in understanding the response of the photodetector. As we operate at low temperatures the effect of carrier freezeout has also been addressed.

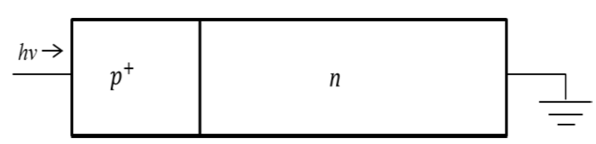

Fig 1: p^+-n device, with p-side illumination.

For a cadmium composition (x) of 0.22 we obtain a Detectivity of 2.2 x 10^{11} Jones at 77K. A high QE ~ 0.8 is obtained assuming R (Fresnel Co – efficient) = 0.22. We obtain a high dynamic resistance ~ $10^{11}\Omega$ at 77K and $10^{12}\Omega$ at 70K. Fig 5 shows the diffusion and tunneling dominated regimes of the dark current.

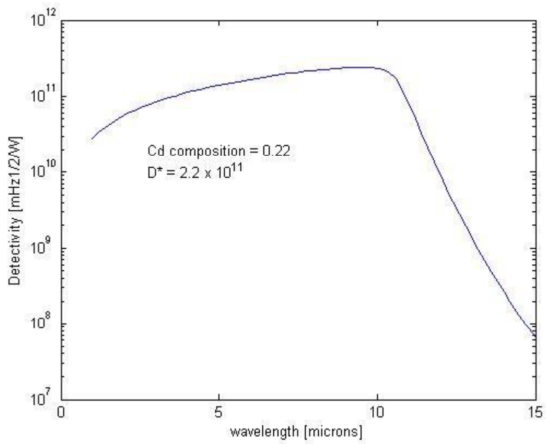

Fig 2: Detectivity vs. Wavelength for Cd composition *x*=0.22 at 77K.

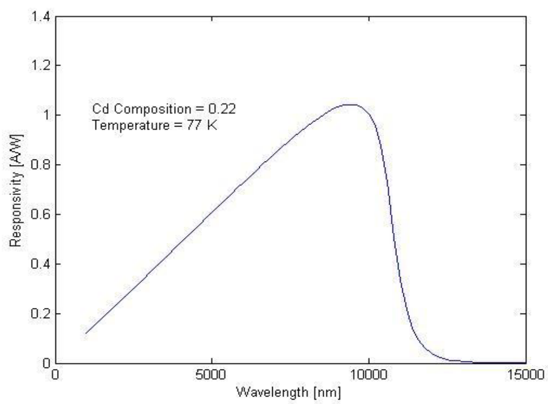

Fig 3: Current Responsivity vs. Wavelength at 77K.

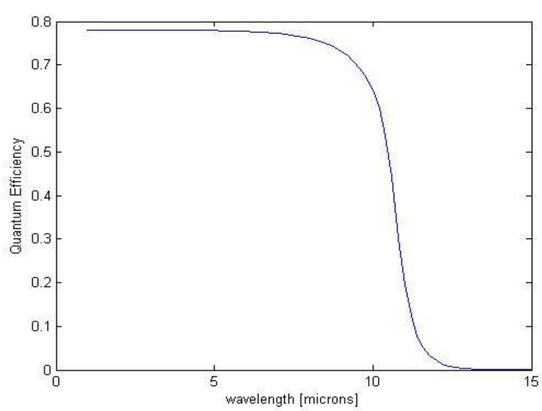

Fig 4: Quantum Efficiency vs. Wavelength.

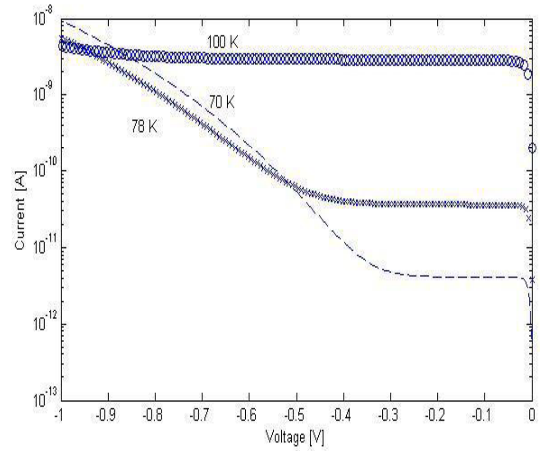

Fig 5: I-V characteristics of $Hg_{0.8}Cd_{0.2}Te$ at different temperatures.

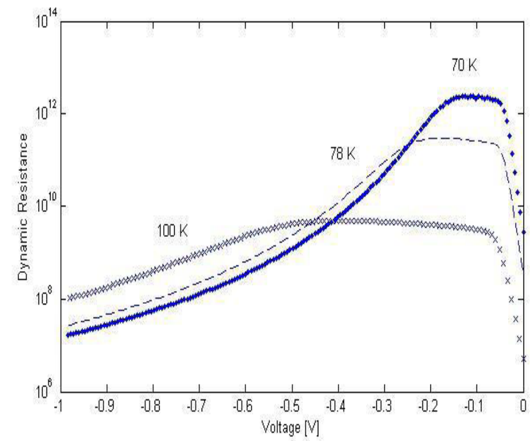

Fig 6: Dynamic Resistance of $Hg_{0.8}Cd_{0.2}Te$ at different temperatures.

REFERENCES

[1] V.Srivastav, R. Pal, and V. Venkataraman, "Performance study of high operating temperature HgCdTe mid wave infrared detector through numerical modelling", ***J.Appl.Phys***, (2010).

[2] K.Jozwikowski, M. Kopytko, A.Jozwikowska,"Enhanced Numerical analysis of current voltage characteristics of long wavelength infrared n-on-p HgCdTe photodiodes", ***Journal of Applied*** Physics, (2010).

[3] G.A.M Hurkx, D.B.M Klassen, M.P.G Knuvers, "A New Recombination Model for Device Simulation Including Tunneling", ***IEEE Trans. Elec. Devices***, (1992).

[4] B. Li, J.H. Chu, Y. Chang, Y.S. Gui, and D.Y. Tang, "Optical absorption above the energy band gap in $Hg_{1-x}Cd_xTe$", ***Infrared Phys.*** 32 (1991)

[5] Y.Tian, B.Zhang, T.Zhou, H.Jiang and Y.Jin, "Theoretical Analysis of the Detectivity in N-p and P-n GaSb/GaInAsSb Infrared Photodetectors", ***IEEE Trans. Elec. Devices***, (2000).