A Self-consistent Model of Quantum Well Infrared Photodetectors (QWIP)

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Contents

- Theory
- Single well consideration
- Simulation of full device
- Conclusions

Quantum Capture/Escape

- **Bound and unbound states in a quantum well are from solution of quantum mechanical wave equation.**
- **Population of carriers within a quantum well is based on a rate equation approach with electron capture/escape.**
- **Capture/escape rates are calculated from LO phonon-electron scattering rates [1][2].**

[1] Smet, Fonstad, and Hu, J. Appl. Phys., Vol. 79, No. 12, p. 9305, 15 June 1996

[2] Savić *et al.* J. Appl. Phys. **98**, p. 084509, 2005

Quantum Drift-Diffusion Model

- **Poisson's equation is solved to determine the local electrical field distribution based on doping and free carrier distribution in 2/3 dimensions.**
- **Transport in QWIP is based on drift-diffusion theory with quantum corrections when treating heterojunctions and quantum wells [1].**
- **Depending on computation resources, intersubband optical absorption spectrum may be imported from a single well model or self-consistently obtained from full device simulation for each well.**

[1] "Quantum drift-diffusion model", presentation file available: http://www.crosslight.com/downloads/quantum_dd.pdf

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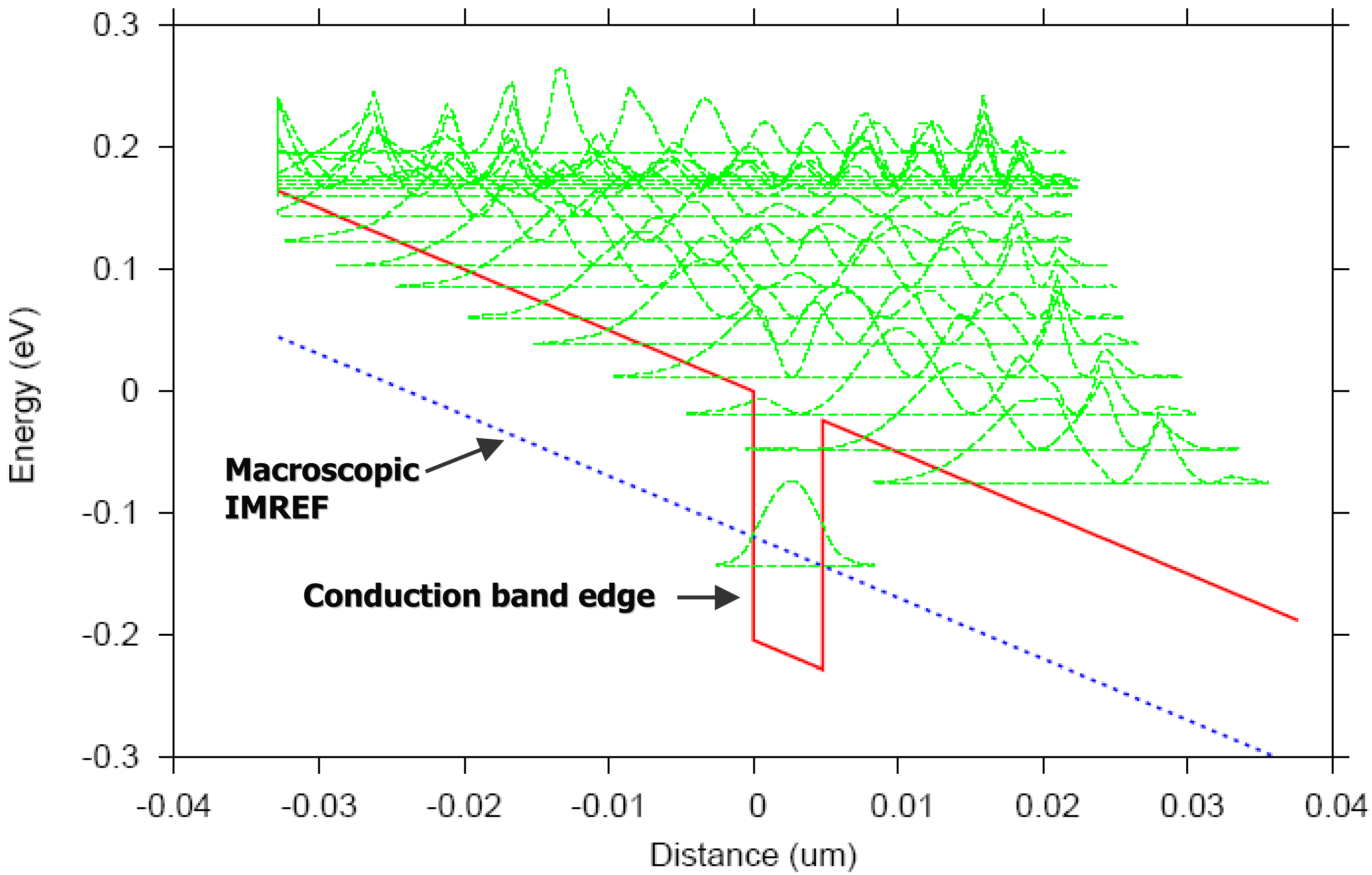
Bound and Unbound States



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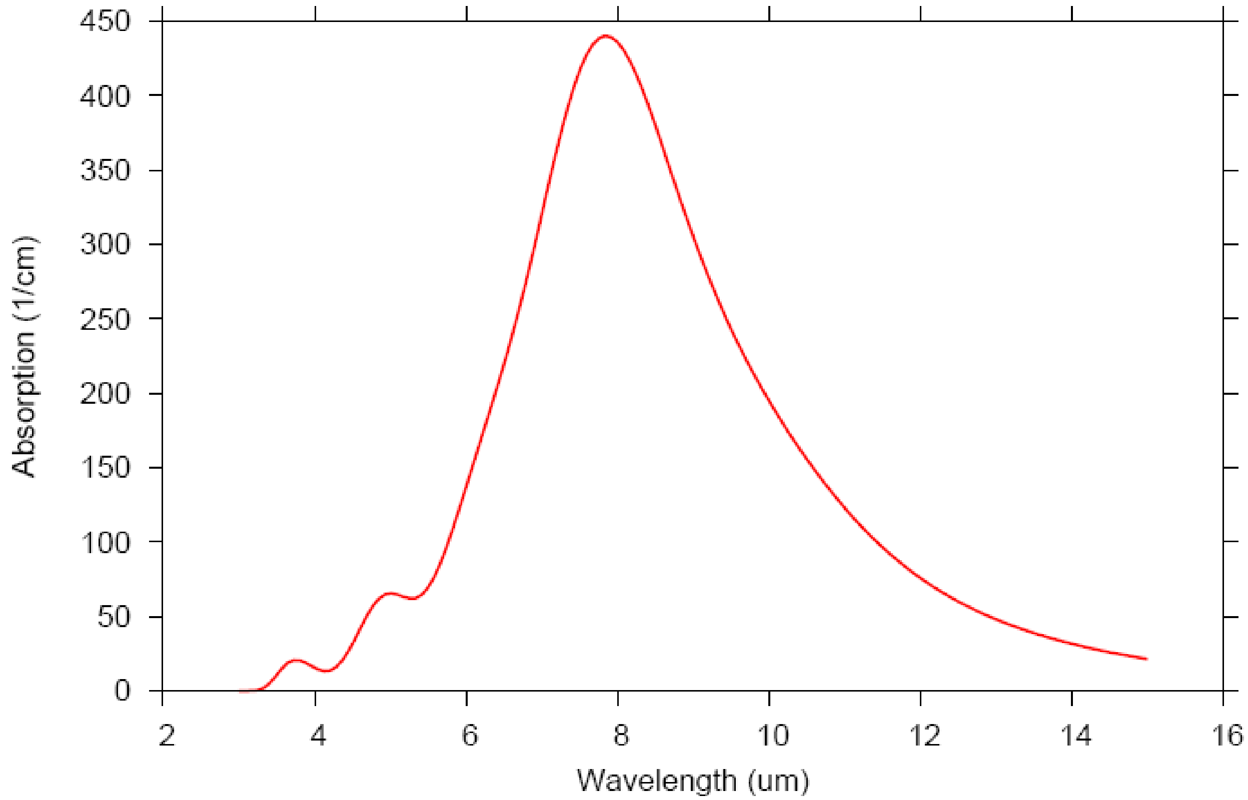
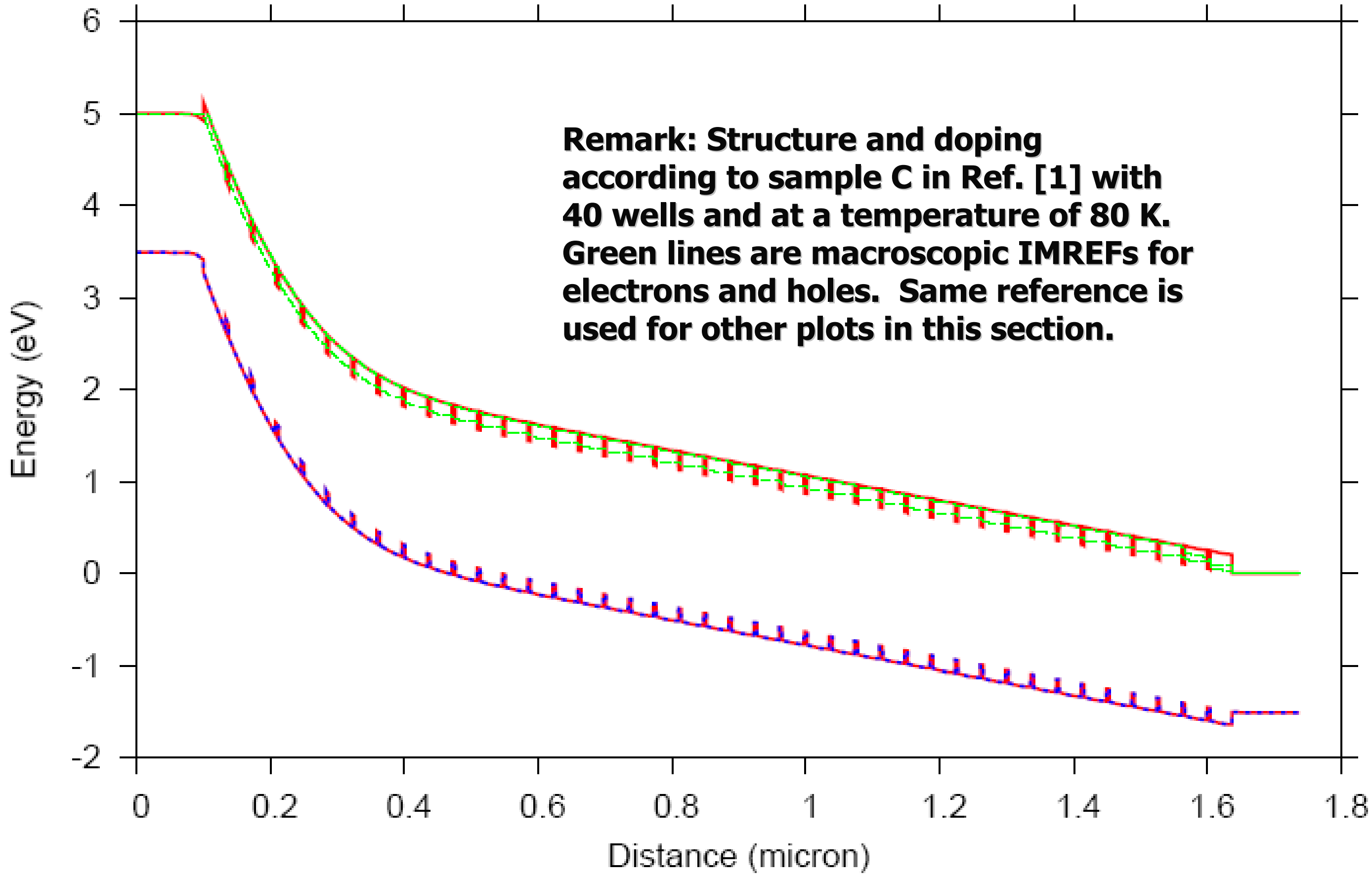
Intersubband transition model



Remark: all possible intersubband transitions between energy levels are evaluated to compute the absorption spectrum. Gaussian line broadening is assumed in this calculation.

Contents

Simulated band diagram

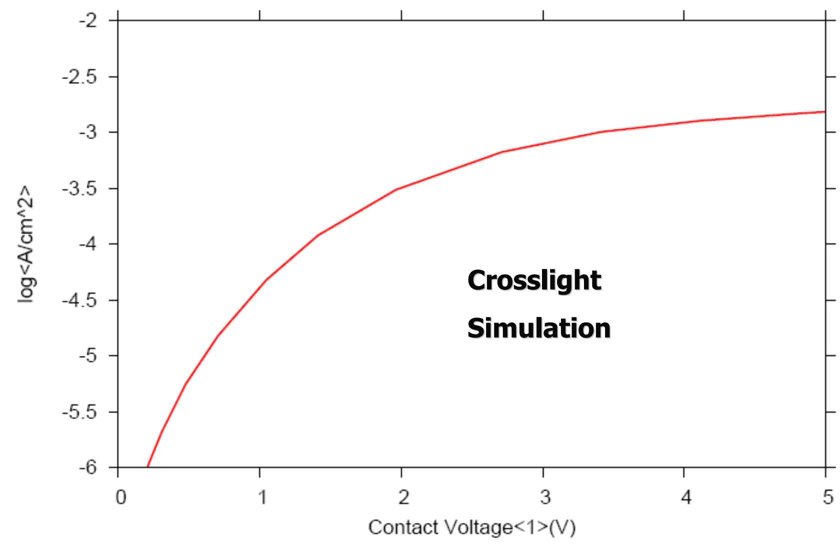


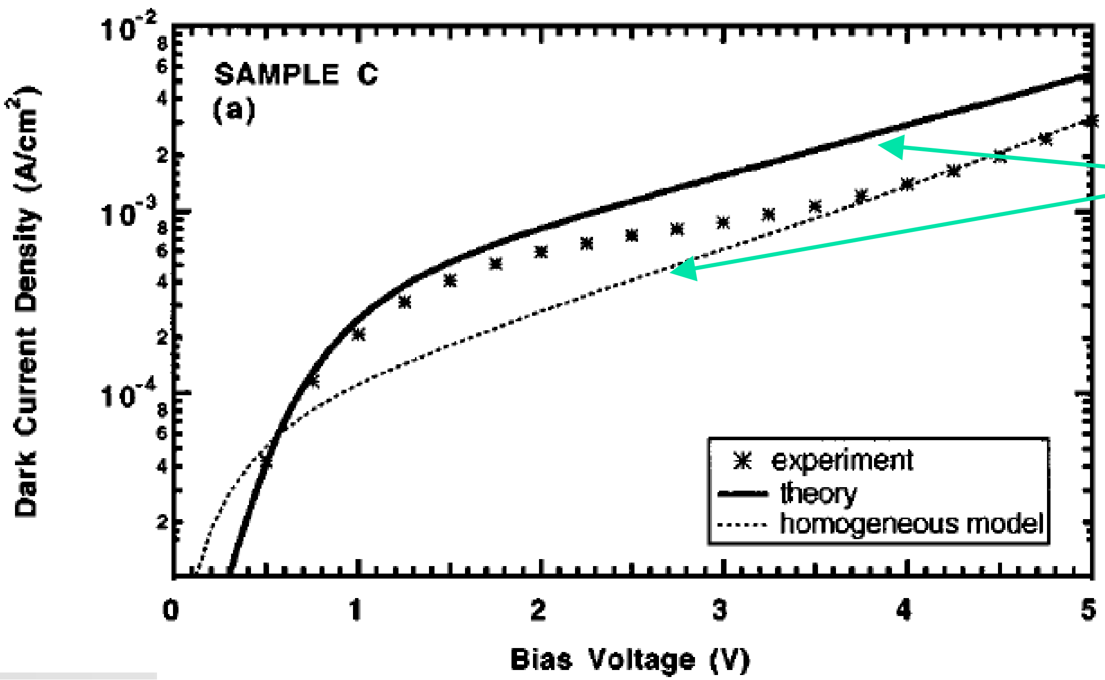
[1] Thibaudeau, Bois, and Duboz,

J. Appl. Phys., Vol. 79, No. 1, p. 446, 1 January 1996

Dark current model

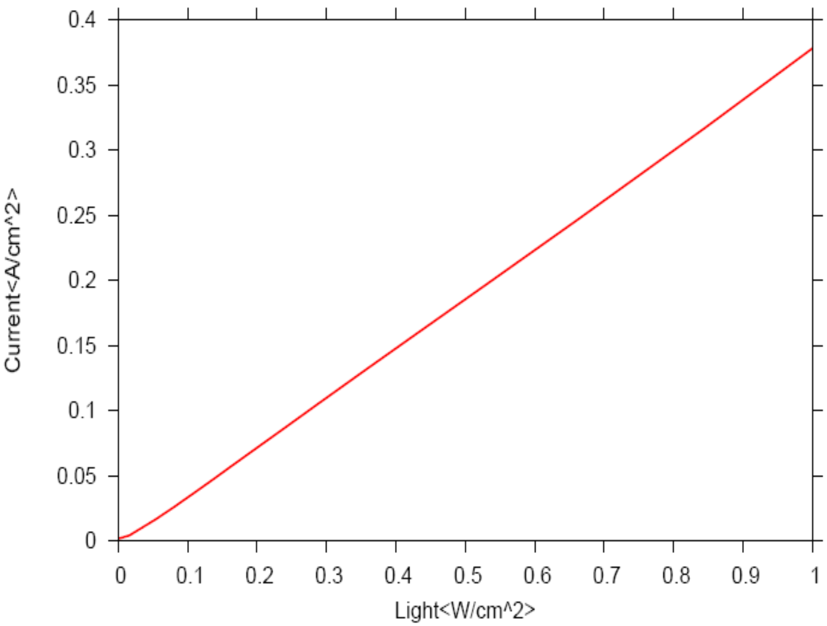
- Thermionic emission according to local field appears to account for the dark current behavior correctly.
- Optionally quantum tunneling and hot-carriers models may be activated which may result in better in fit.





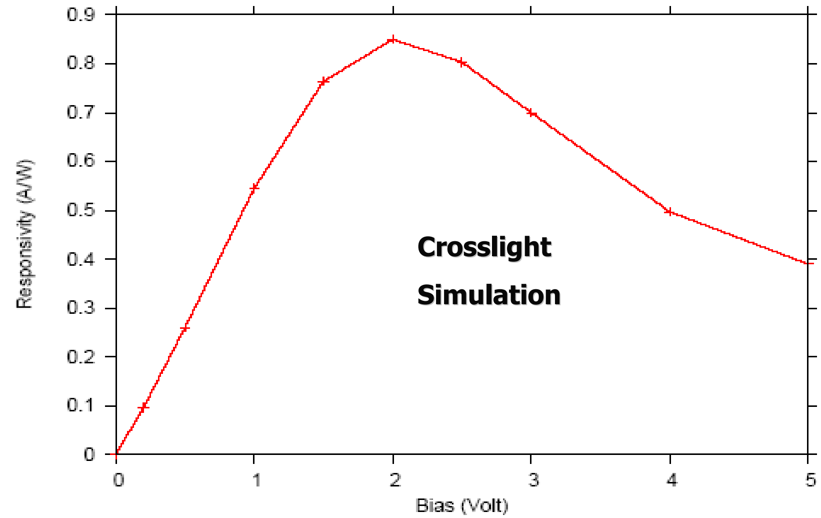
Current versus light

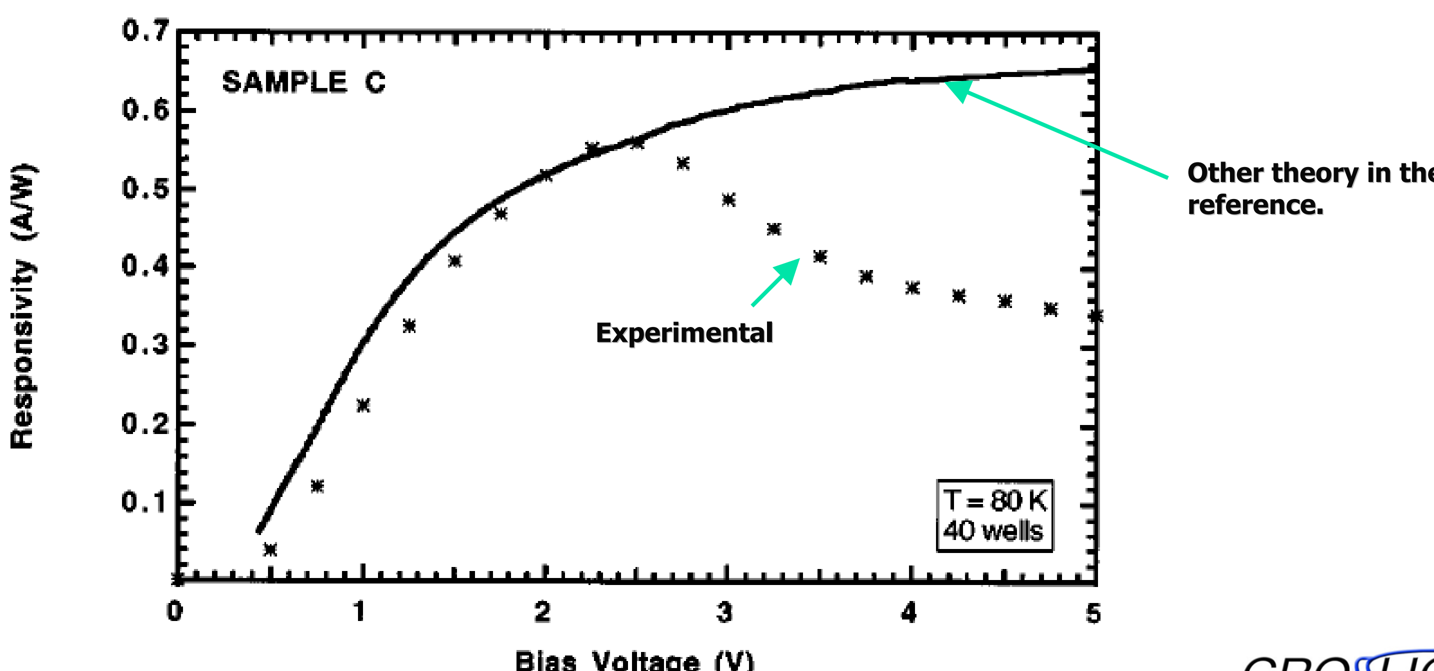
- Carrier excitation from bound state in well to unbound state in barrier is based on quantum correction to drift-diffusion theory so that a macroscopic 2/3 dimensional model for the full device may be simulated at a reasonable time scale.
- Extraction of photo-carriers to the electrode may be based on local field profile or on an average global field intensity, depending on how localized the photo-carriers are.



Bias dependent responsivity

- Simulation of responsivity at low bias indicates that for this particular device, photo-carrier extraction is insensitive to details of local field distribution.
- The photo-carrier extraction behavior is better explained by an averaged global field dependence.
- Possible explanation : energetic photo-carriers in the unbound states are not well localized and tend to experience an average field at a larger length scale.





Conclusions

- Crosslight's APSYS has been adapted to provide a comprehensive physical model of QWIP.
- Reasonable agreement with experiment verifies the adequacy of the model.
- Non-local quantum correction to the drift-diffusion theory is needed to explain photo-carrier extraction in QWIP properly.