Georgia State University

Quantum mechanical effects in internal photoemission THz detectors

M. B. Rinzan, S. G. Matsik, and A. G. U. Perera

Department of Physics and Astronomy

Georgia State University

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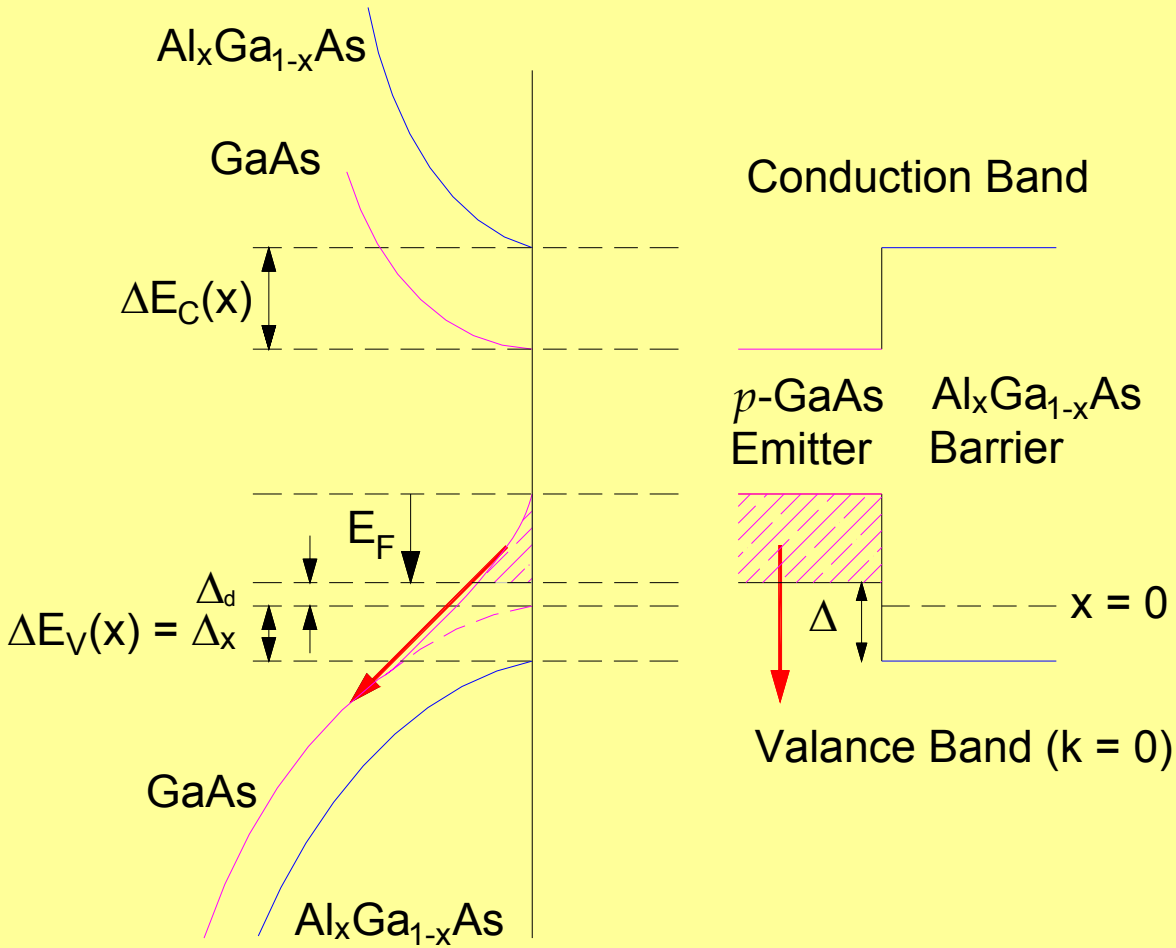
Outline

- Heterojunction Terahertz detectors based on Internal photoemission
- Photoemission models- Existing vs. Proposed
- Photoemission loss from quantum mechanical reflection
- Effect of reflection on detector response
- Conclusion

Interfacial Workfunction in HEIWIPs

Band diagram for *p*-type



$$\Delta = \Delta_x + \Delta_d$$

Δ_x : **GaAs/$Al_xGa_{1-x}As$ valance band offset**

Δ_d : **Offset due to emitter doping**

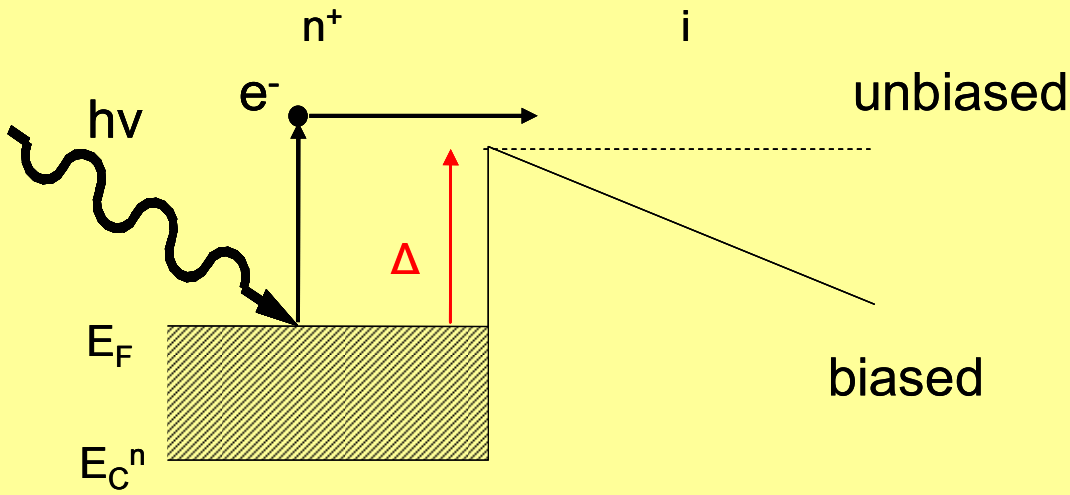
Assumptions for calculating Photoemission

Carriers are in 3-D distribution

Carrier momentum (k) change is due to free carrier absorption

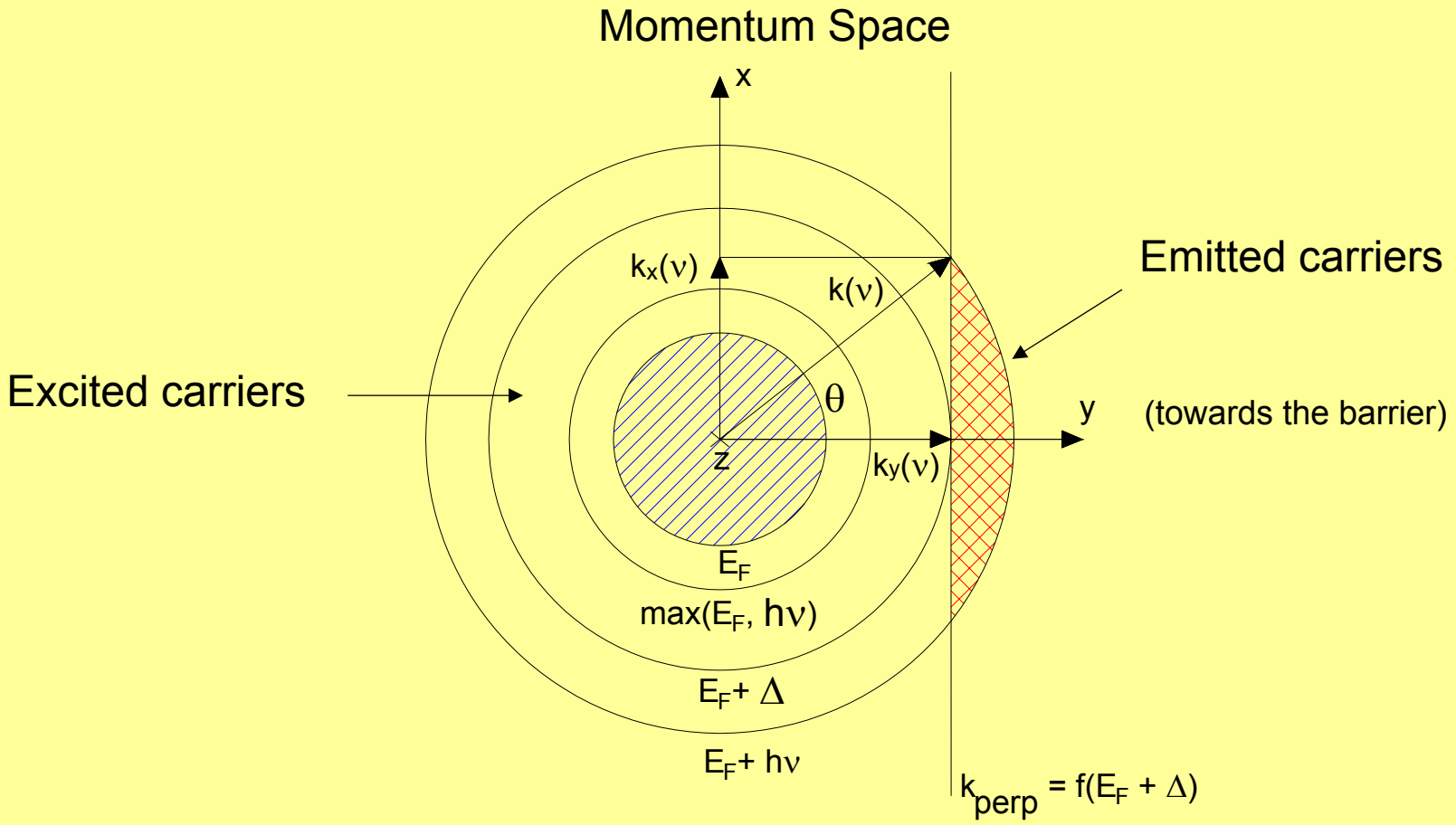
Emitter material is isotropic for carrier transport

Threshold Wavelength (λ_0)



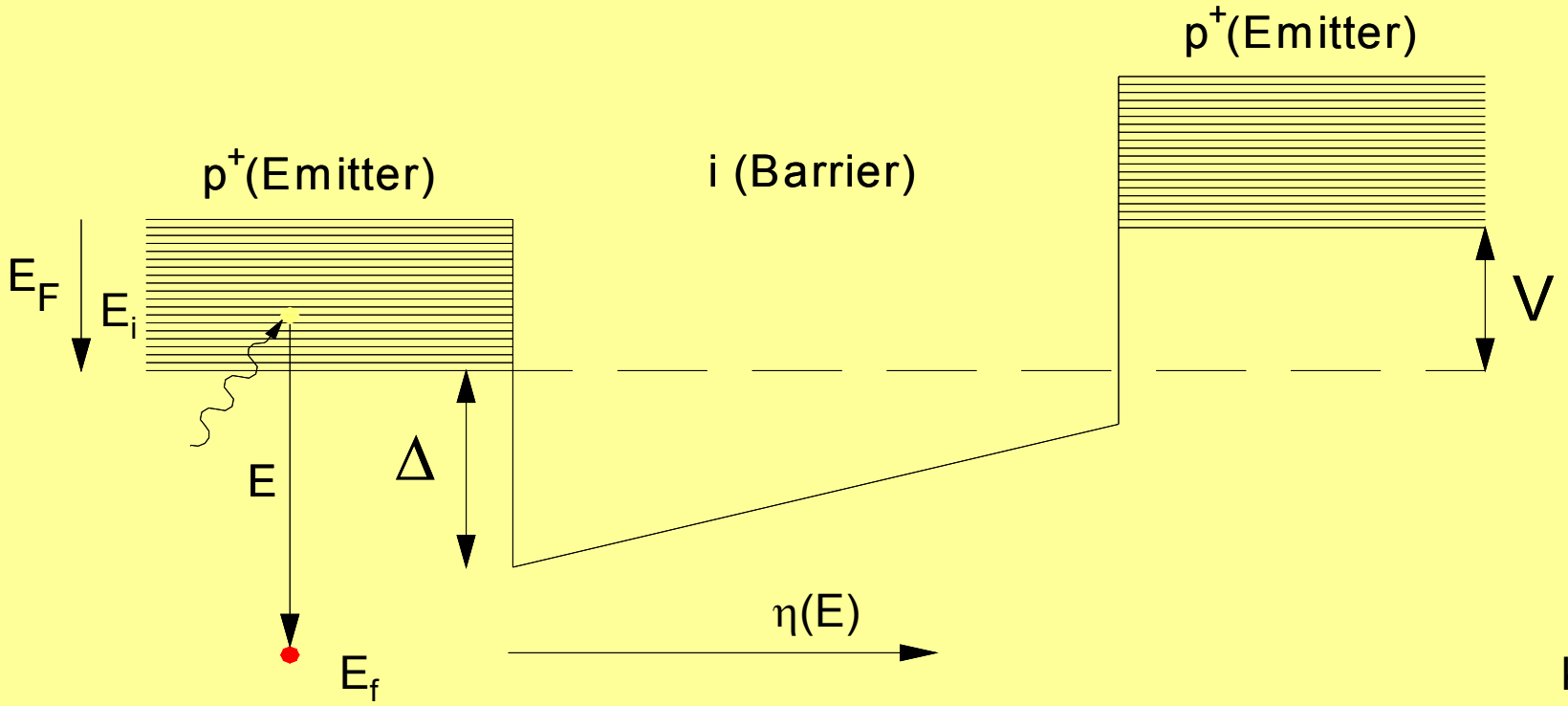
Threshold Wavelength, λ_0 (μm)= 1240 / Δ (meV)

Current Model for Photoemission



- No photoemission of carriers with final momentum k, where $k_y < k_{perp}$
- Threshold wavelength is well defined by $\lambda_0 = 1/ k_{perp}$

Transmission Probability T(E)

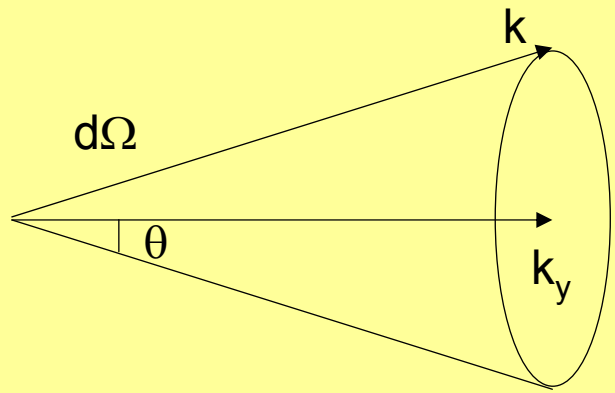


$\eta(E)$ should be modified to $\eta(E) \times T(E_y)$

$$N_{Emitted} = \int f(k_y)\, T(k_y)\, d\Omega$$

Where $T(k_y) = T(E \cos^2 \theta)$

$$f(k_y) = f(E - h\nu)$$

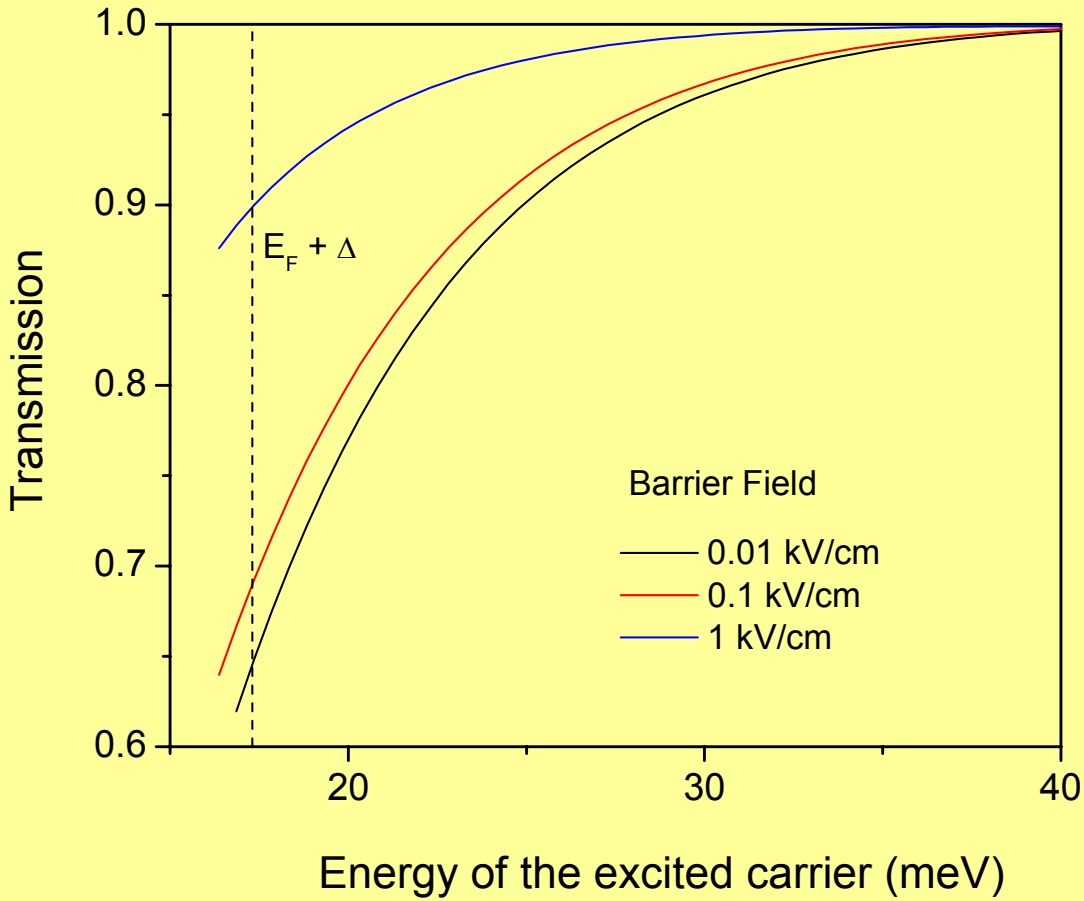


Solid State Electronics (**9**) **949** (1966)

Reflection loss for THz Detectors

E_F = 11 meV Δ = 7 meV

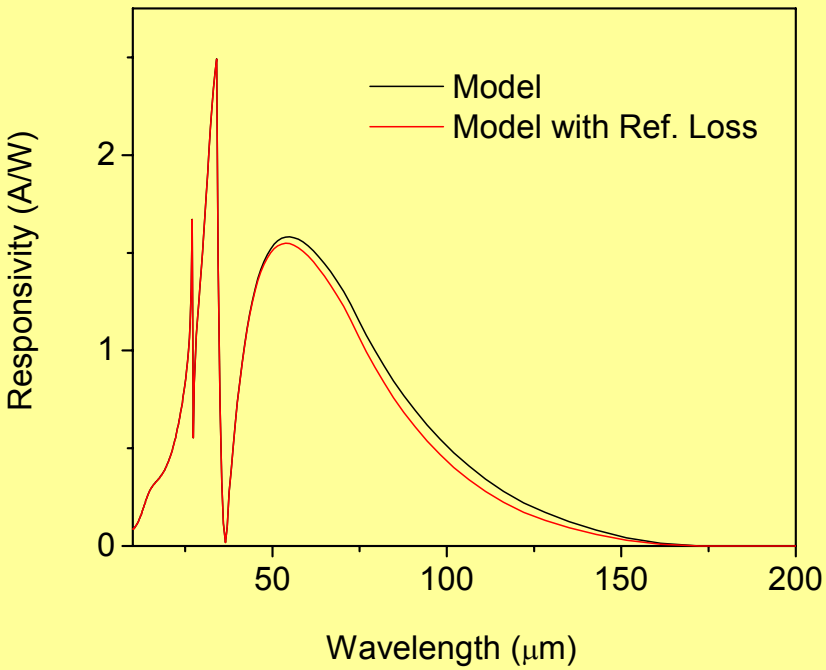
λ_0 = 174 μm

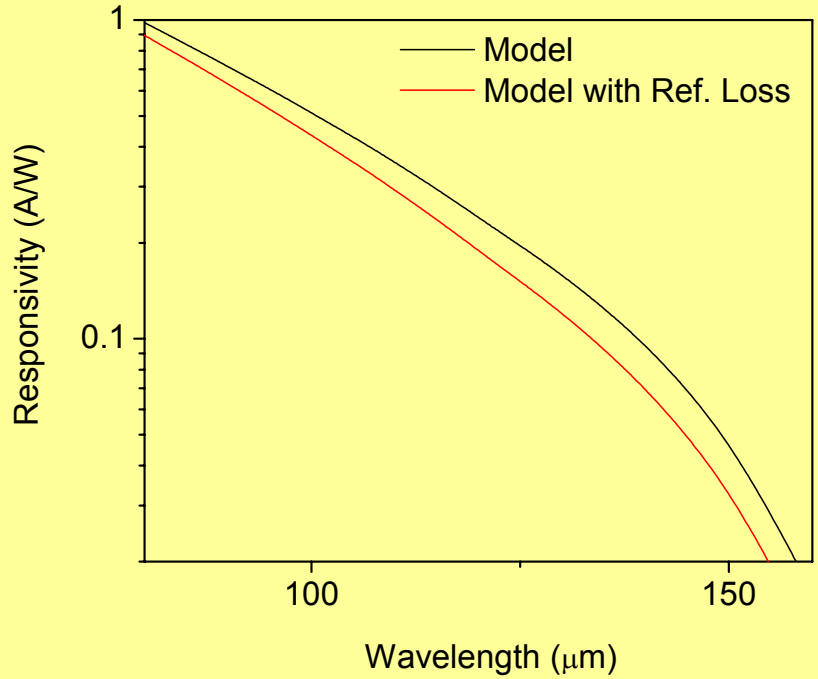


Reflection loss for Long wavelength

Threshold Wavelength = 174 μm

Field = 1 kV/cm

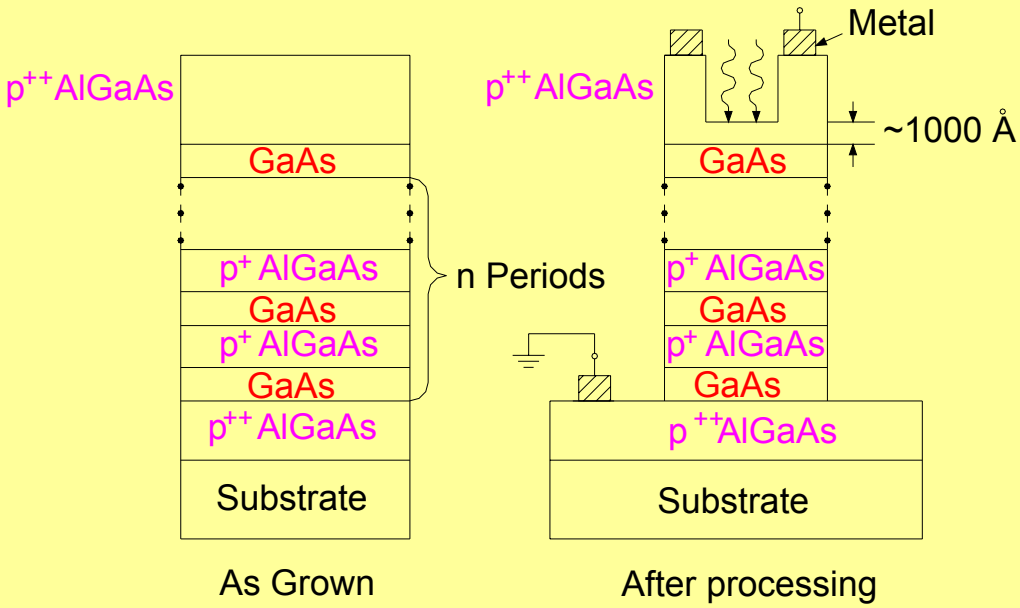




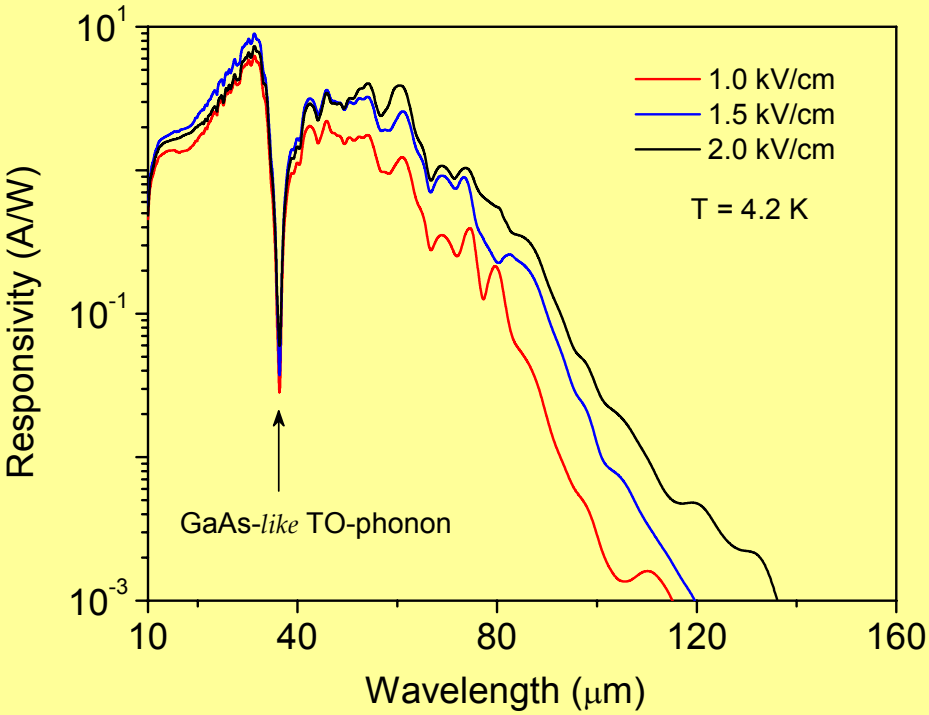
V0207 THz Detector

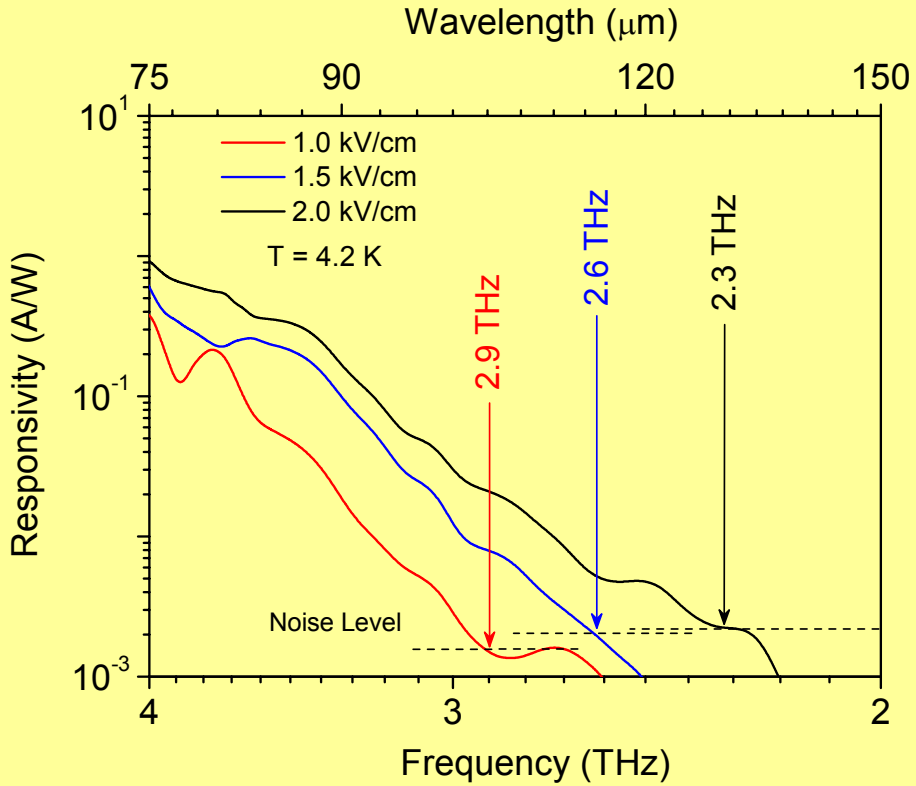
Al Fraction 0.005

Measured $(f_0)_{min}$ = 2.3 THz [$(\lambda_0)_{max}$ = 128 μm]



Responsivity: V0207





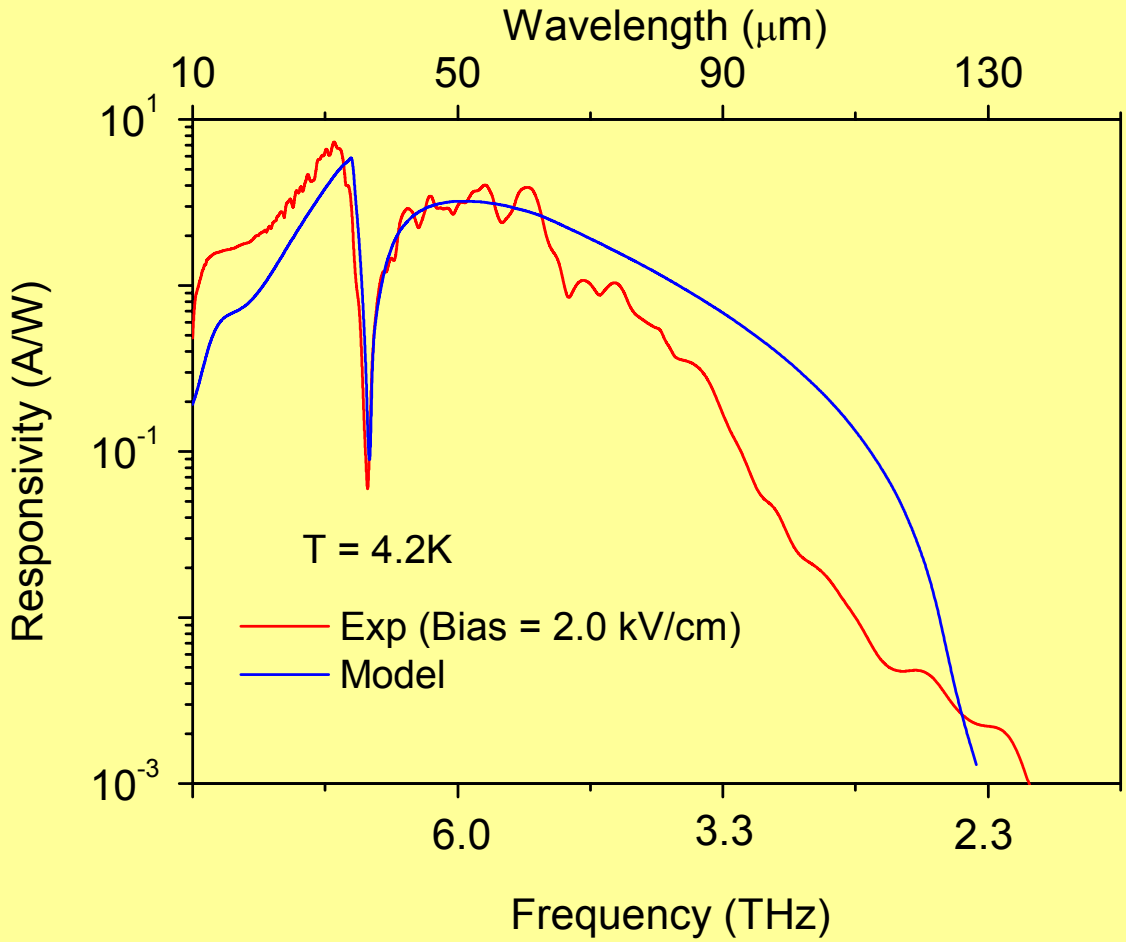
For Bias = 2 kV/cm

$D^* = 3\times10^{11}$ cm$\sqrt{\text{Hz}}$/W

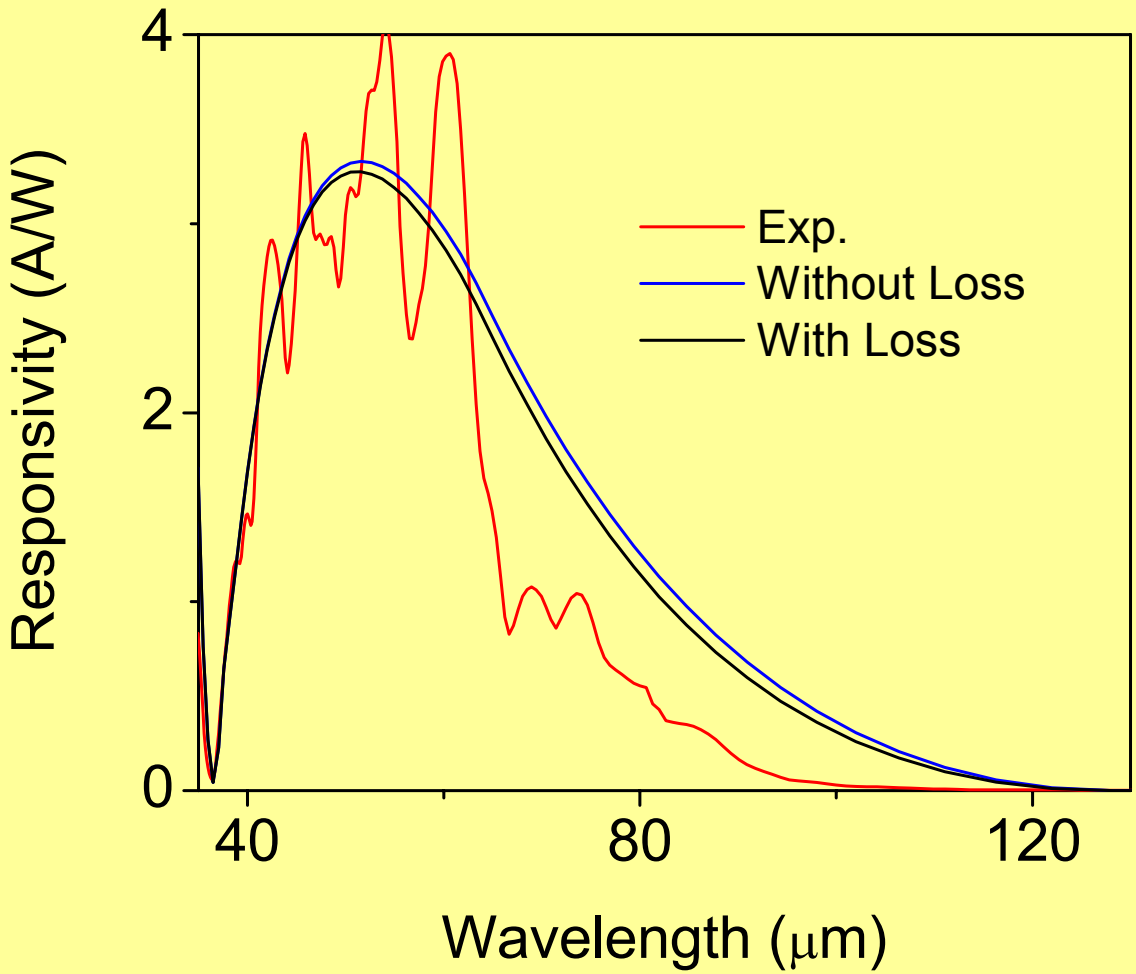
$\eta = 9$ % at 6 THz

APL(**86**) 071112 (2005)

Response model: V0207



Response model: V0207



Short wavelength HEIWIP (1332)

W_{Top} = 200 nm

$W_{Emitter}$ = 18.8 nm

W_{Barrer} = 125 nm

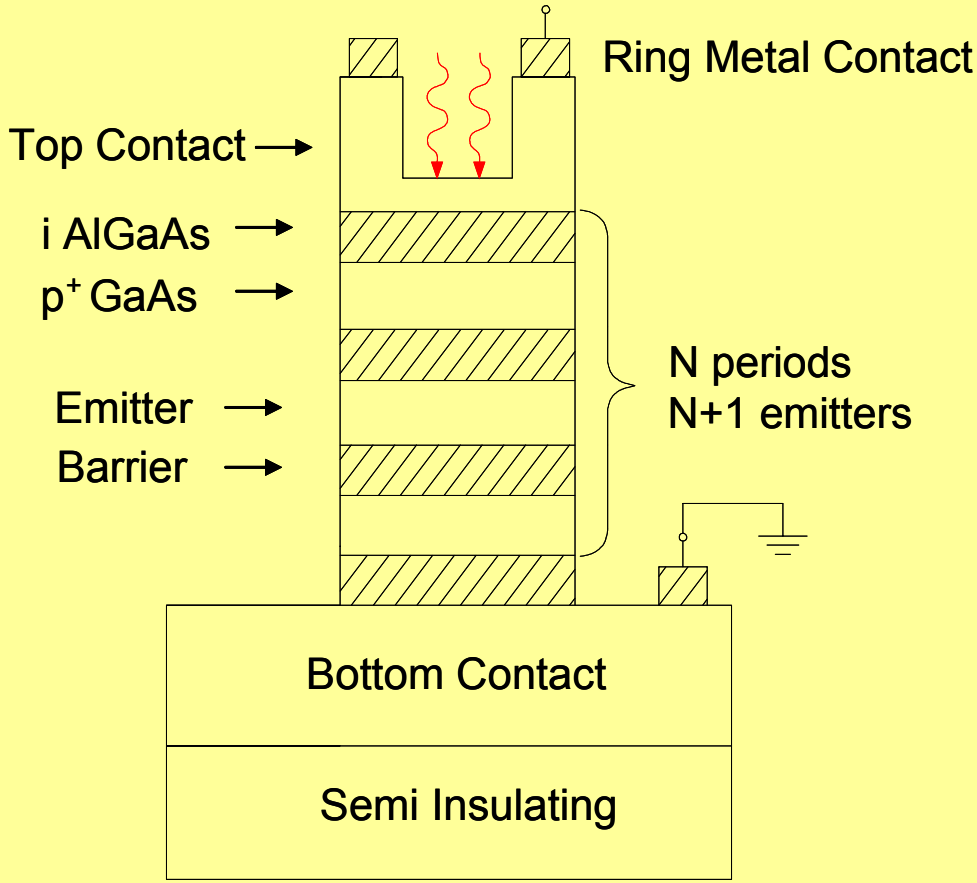
W_{Barrer} = 700 nm

N_{Top} = 2 ×10^{19} cm^{-3}

$N_{Emitter}$ = 3 ×10^{18} cm^{-3}

N_{Bottom} = 1.5 ×10^{19} cm^{-3}

12 periods

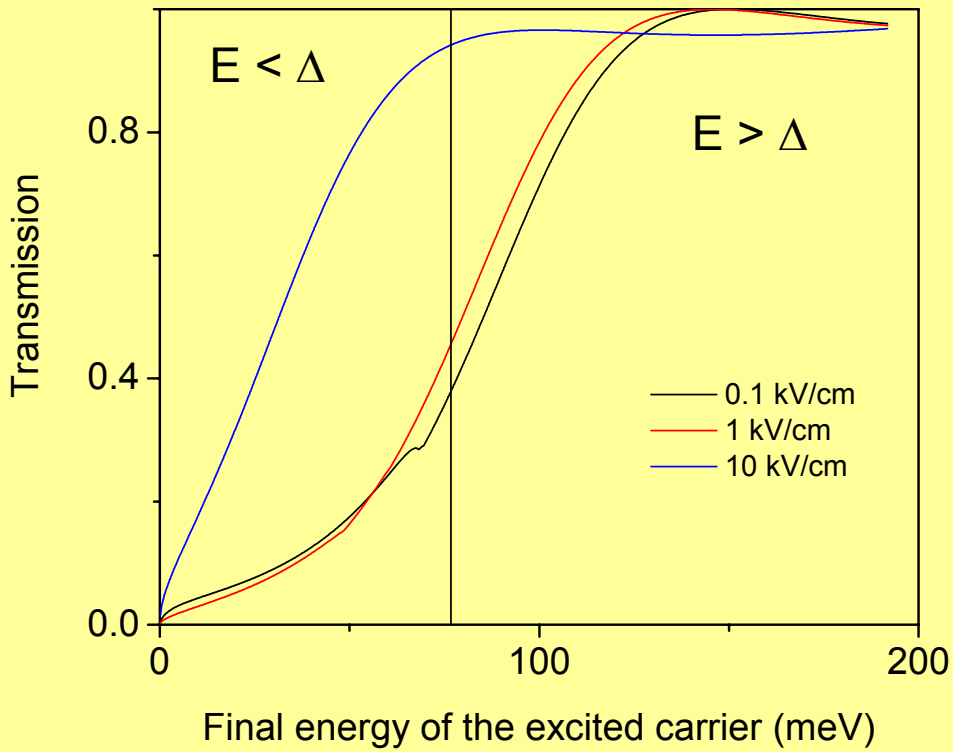


After Processing

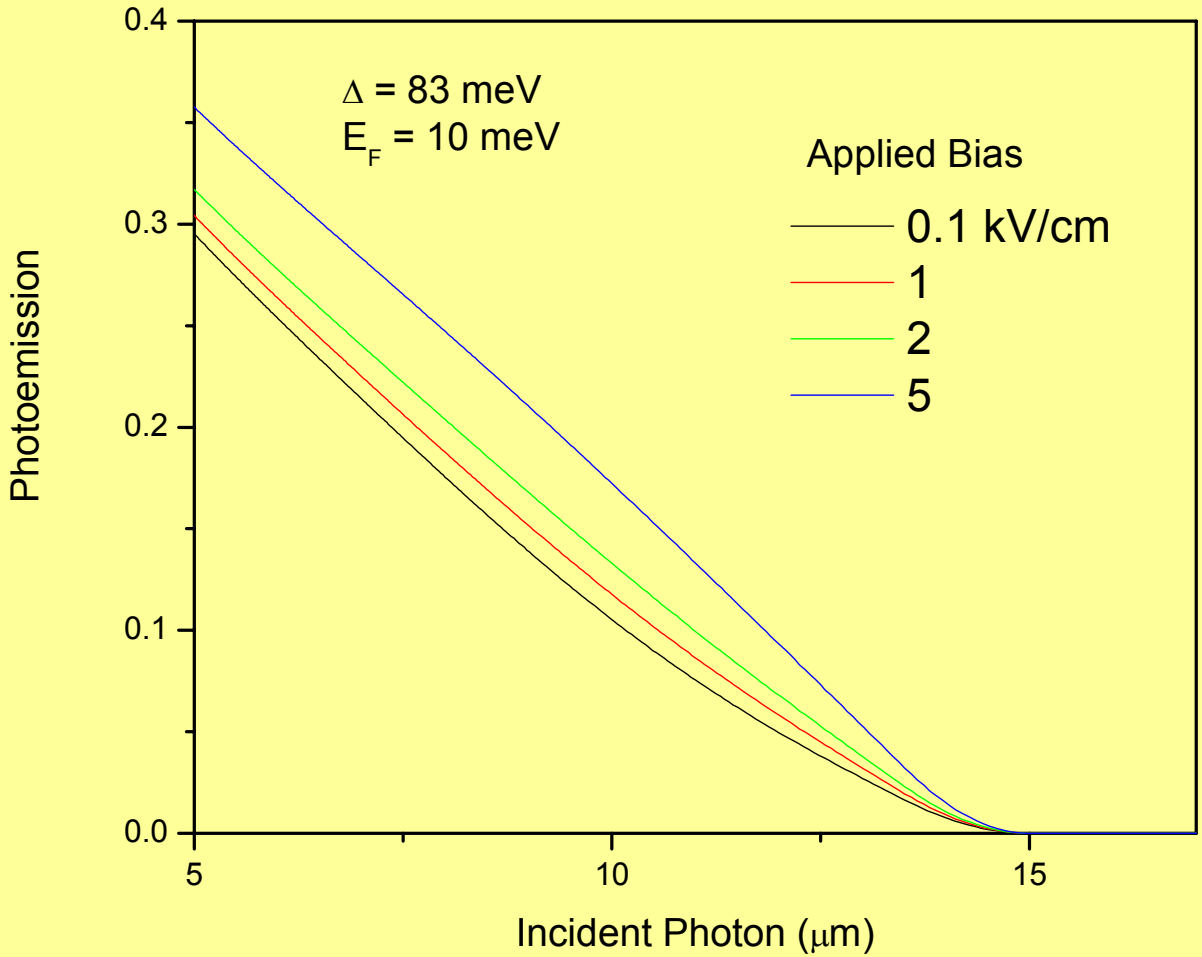
Reflection loss for Short Wavelength

E_F = 4 meV, Δ = 74 meV

λ_0 = 16.7 μm



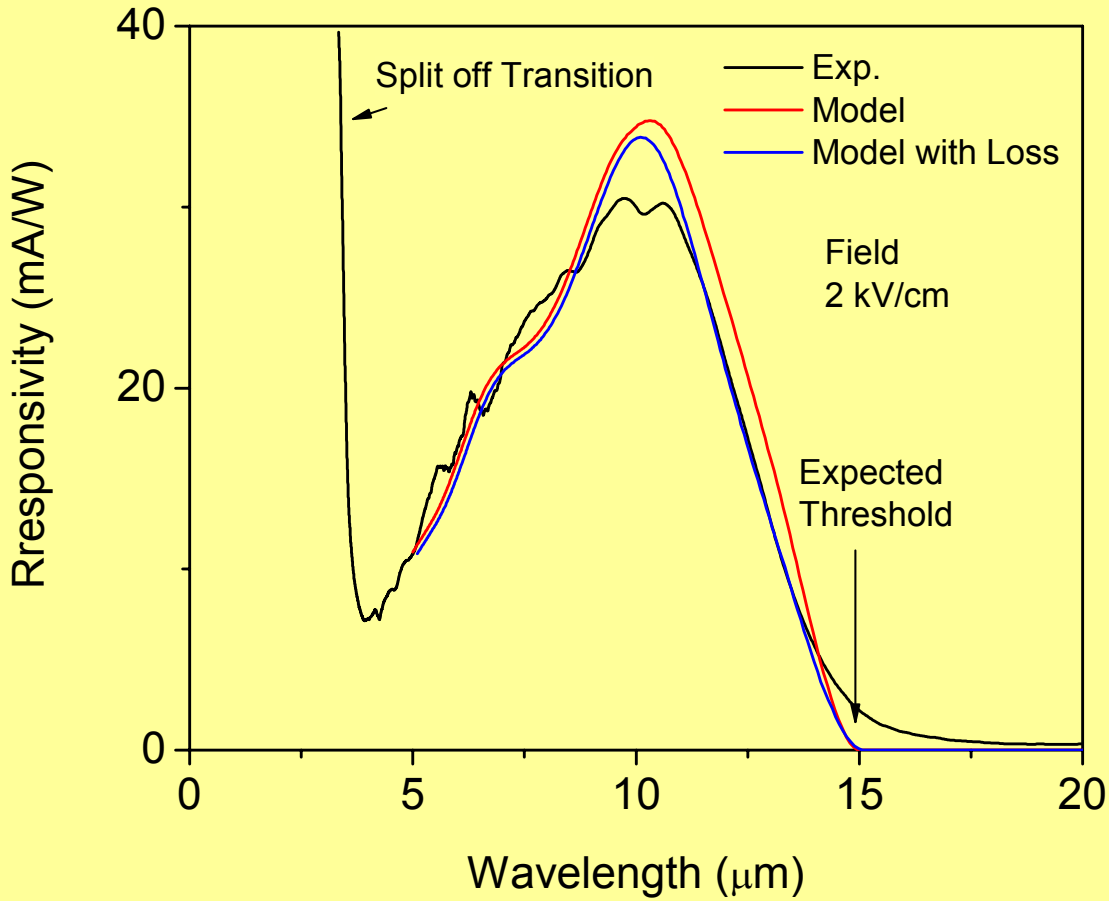
Photoemission vs. Bias Field



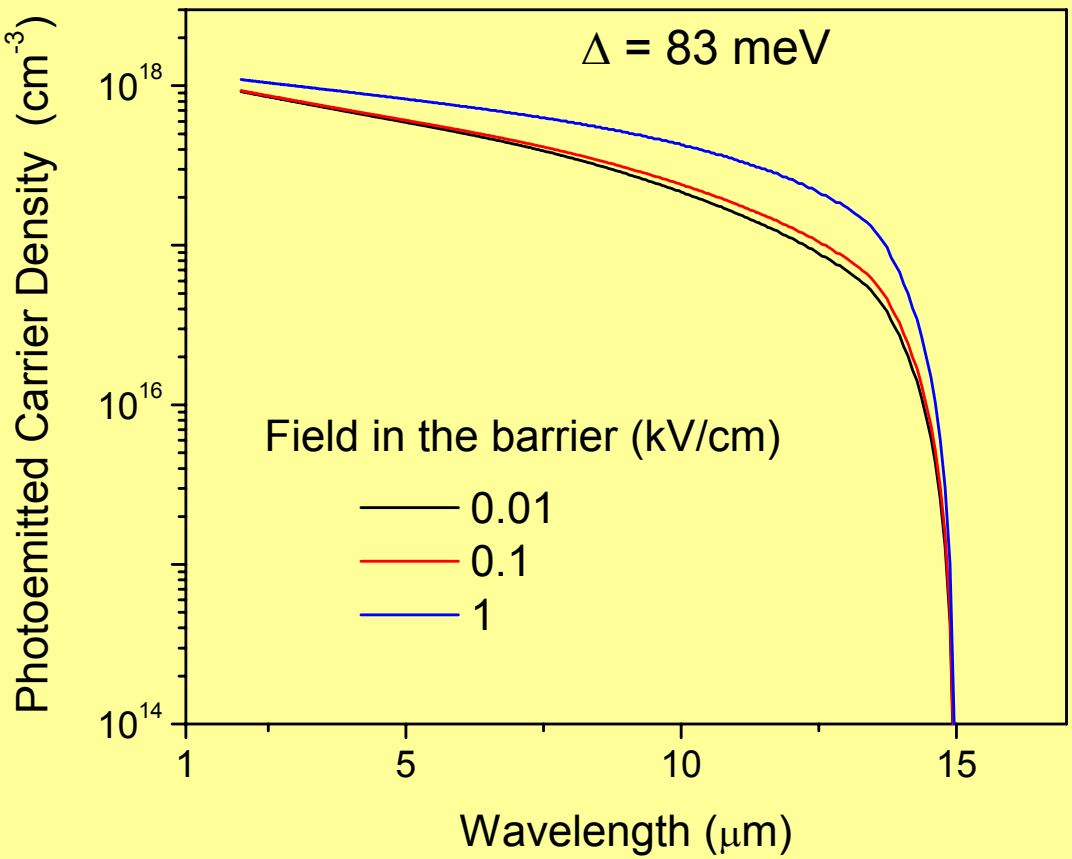
Reflection loss for Short Wavelength

E_F = 4 meV, Δ = 74 meV

Experimental λ_0 = 16.7 μm

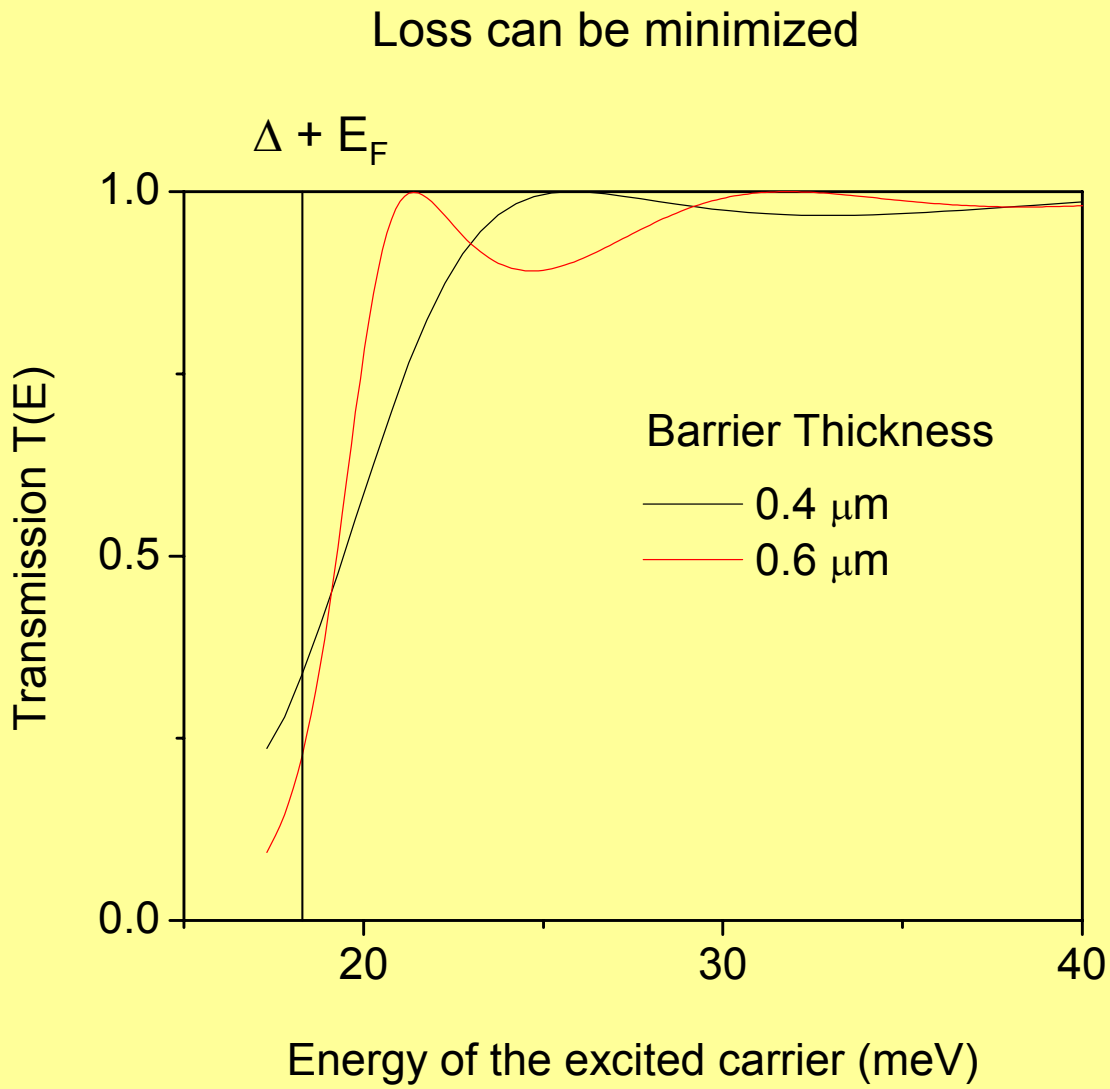


Photoemitted carrier density vs. Bias



Emission Increases with Bias

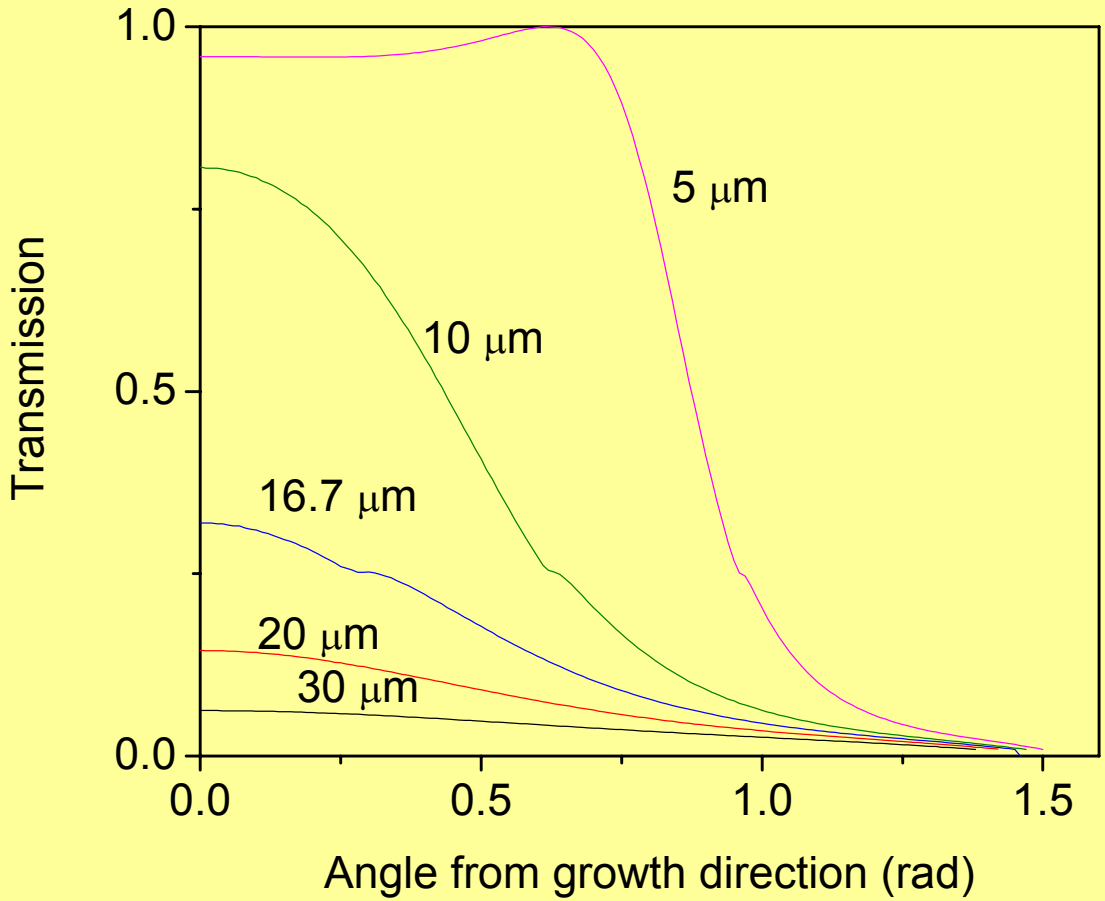
Reflection loss vs. Barrier thickness



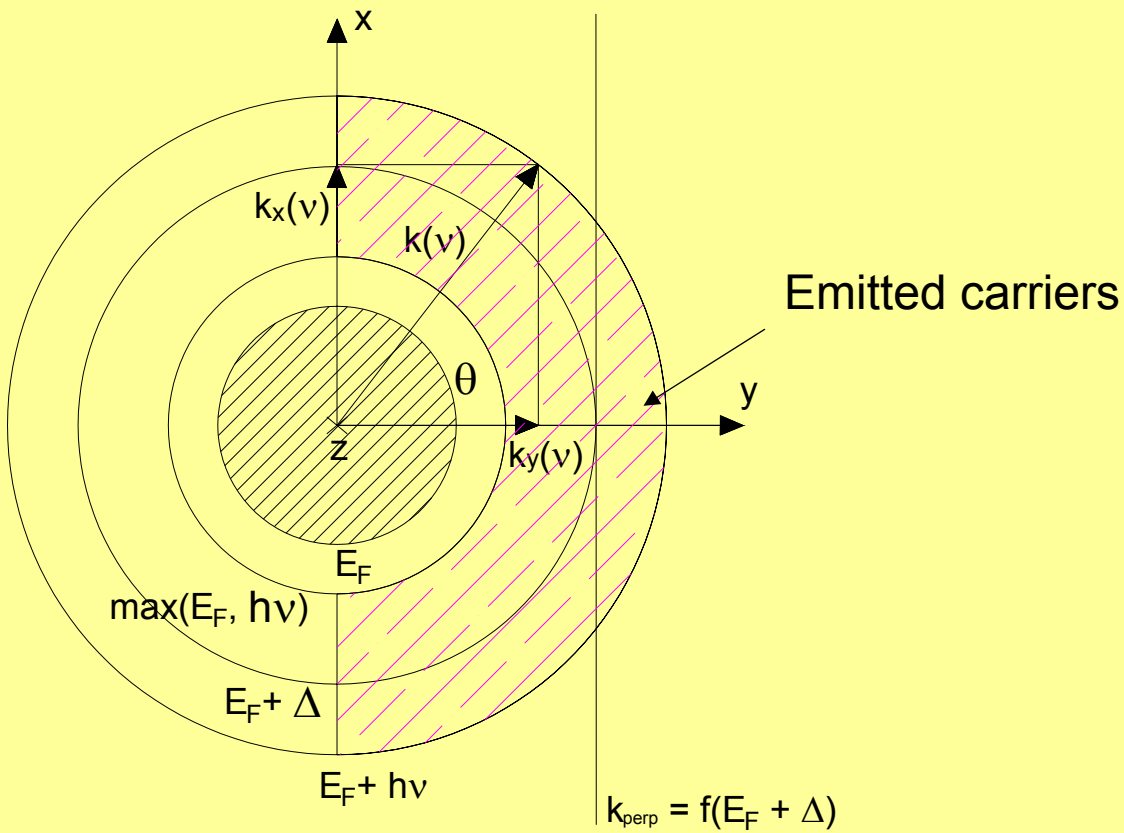
Is Photoemission Possible for hν < Δ ?

E_F = 4 meV, Δ = 74 meV

λ_0 = 16.7 μm

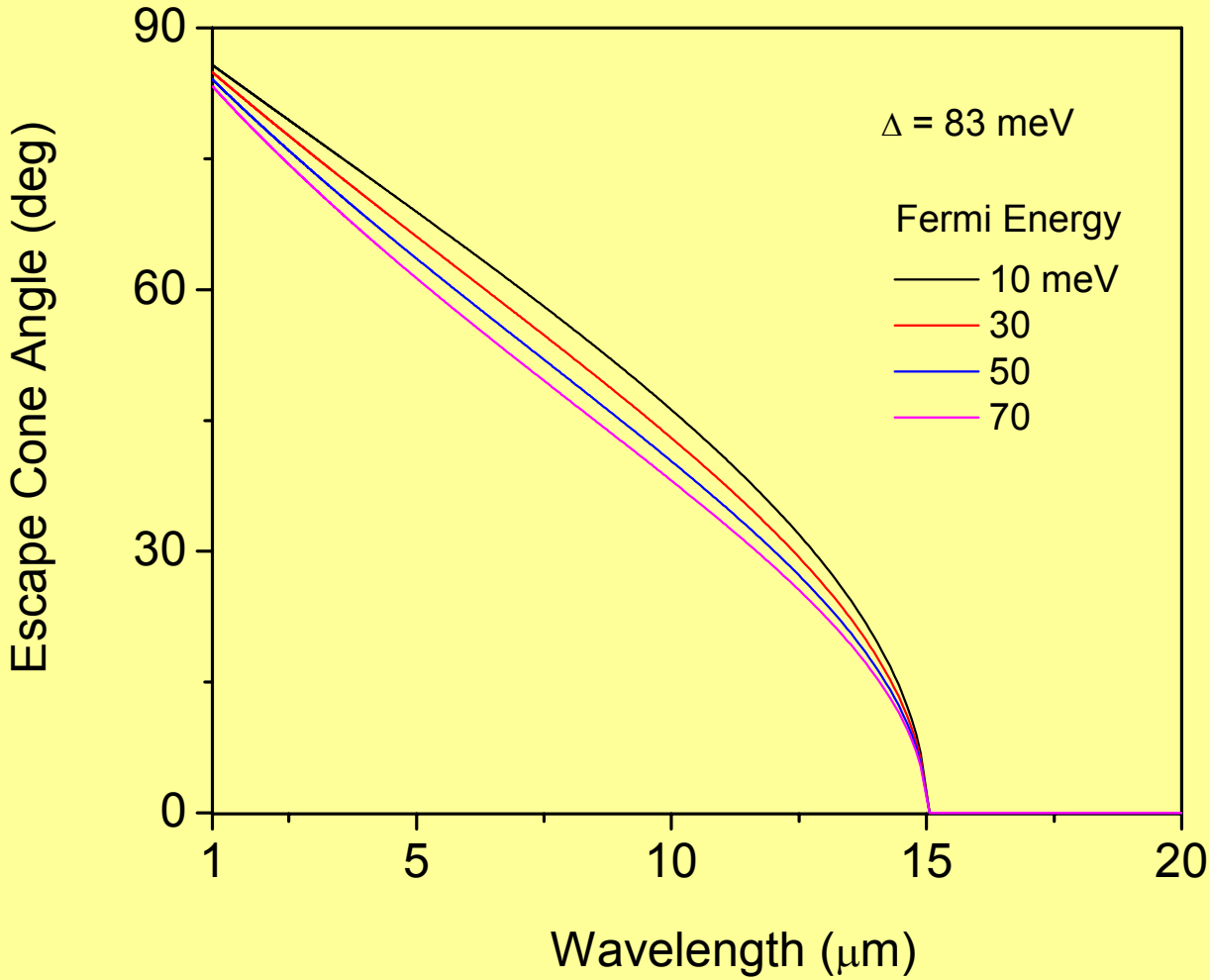


Proposed Model for Photoemission



- Photoemission prob. is non-zero even for carriers with $k_{perp} < k_{\Delta}$
- Threshold wavelength is not well defined
- Instrument noise level determines the threshold

Escape Cone vs. Incident Energy



Conclusion

- Reflection loss is significant in short wavelength detectors
- Reflection loss decreases detector signal around the threshold wavelength
- Needs quantum mechanical treatment for hot carrier scattering events