Introduction to RTDs: Relaxation Scattering in the Emitter

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• Width of E1 varies exponentially with bias! => truly bound state!
• Electron sheet density in the emitter is $10^{10}-10^{12}/\text{cm}^2$
  => strong electron-electron and electron-phonon scattering
  => state is broadened

\[
\tau = 0.1\ \text{ps}
\]
\[
\Gamma = \frac{\hbar}{2\tau} = 6.6\text{meV}
\]
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Relaxation in the Emitter - $\eta = 6.6 \text{meV}$

- NEMO [APL94] introduced the relaxation in the reservoirs $\eta = \frac{\hbar}{2\tau} = 6.6 \text{meV}$
- Mimics the broadening through scattering
- Critical item in the understanding of RTD transport
• Emitter and collector ASSUMED to be in equilibrium
  => Reservoirs => STRONG scattering
• $\eta = 6.6\text{meV}$ is added to Hamiltonian in reservoirs
  => non-Hermitian
  => current not conserved AND NOT computed
  => only compute equilibrium charge
• Central device region treated with NEGF
  => non-equilibrium charge and current
- Central resonance C1 almost unaffected
- Emitter resonances E1 significantly broadened >6.6meV
- The relatively narrow central resonance is probing the states in the emitter
- Overall current increases
Conduction band edge, transmission, and current density

(a) 0.32V
Top Emitter (TE)
Bottom Emitter (BE)

(b) \(\eta=0\)
0.32V

(c) \(\eta=6.6\text{meV}\)
0.32V

(d) 0.42V
Top Emitter (TE)
Bottom Emitter (BE)

(e) \(\eta=0\)
0.42V

(f) \(\eta=6.6\text{meV}\)
0.42V

\(E_F\)
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Conduction band edge, transmission, and current density

(d) 0.42V
Top Emitter (TE)
Bottom Emitter (BE)

E_F

(g) 0.76V
Top Emitter (TE)
Bottom Emitter (BE)

E_F

(e) η=0
0.42V

C2

C2

E2

C1-E1

(f) η=6.6meV
0.42V

C2

E2

C1-E1

(h) η=0
0.76V

E2

E1

C1

(i) η=6.6meV
0.76V

E2

E1

C1
Conclusions

• Realistic doping profiles
  => triangular quantum wells in the emitter.
  => confined states in the emitter
  very long lifetime / very narrow states in the
  mathematically ideal case
• High electron density in the emitter, Equilibrium conditions!
  => strong equilibrating scattering
  => states are broadened
• NEMO introduced an empirical broadening model
  » Partition the device into reservoirs and NEGF region
  » Reservoirs are non-Hermitian – compute charge only
  » Central NEGF region sees effects of thermalized states
• For typical high performance InGaAs/InAlAs RTDs:
  set the relaxation to $\eta=6.6\text{meV}$
  => scattering time of about $t=0.1\text{ps}$.
• The relaxation rate should not be used to match experimental data on a one-time basis.
• Central resonance C1 almost unaffected