High-Field Transport Modeling for Compact Power Sources

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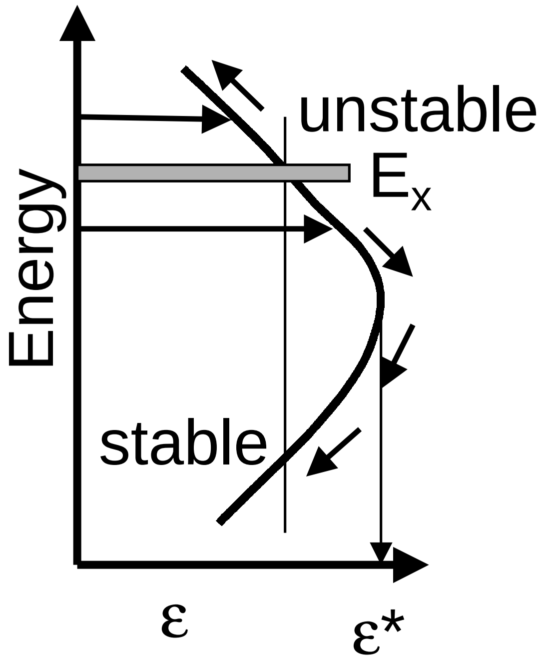
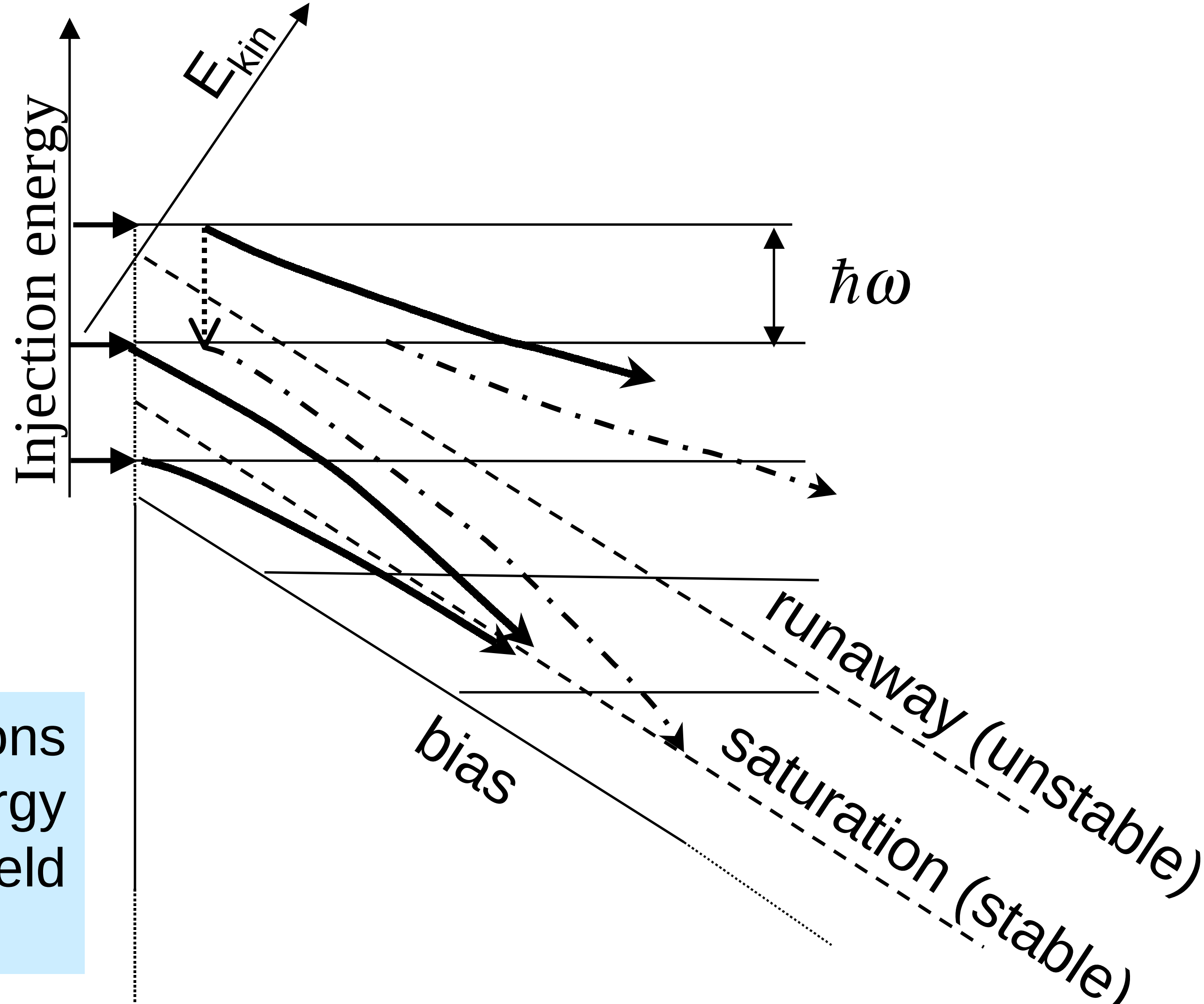
Current objectives

- Implement the feature of arbitrary momentum of the injected carrier into the runaway effect (RAE) simulator.
- Improve the RAE simulator by accounting for the non-parabolicity effects.
- Obtain the distribution function for the low-field runaway regime and investigate its features.
- Start optimization of the HET parameters.

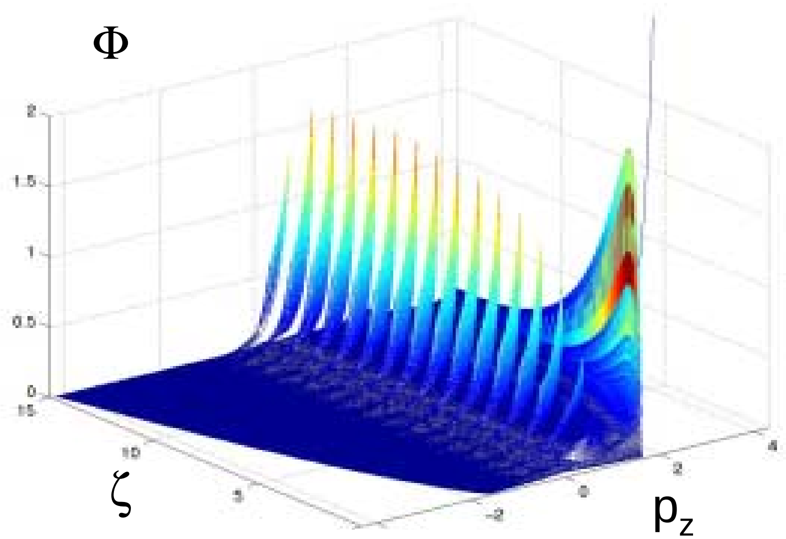
Low-field runaway: possible scenarios

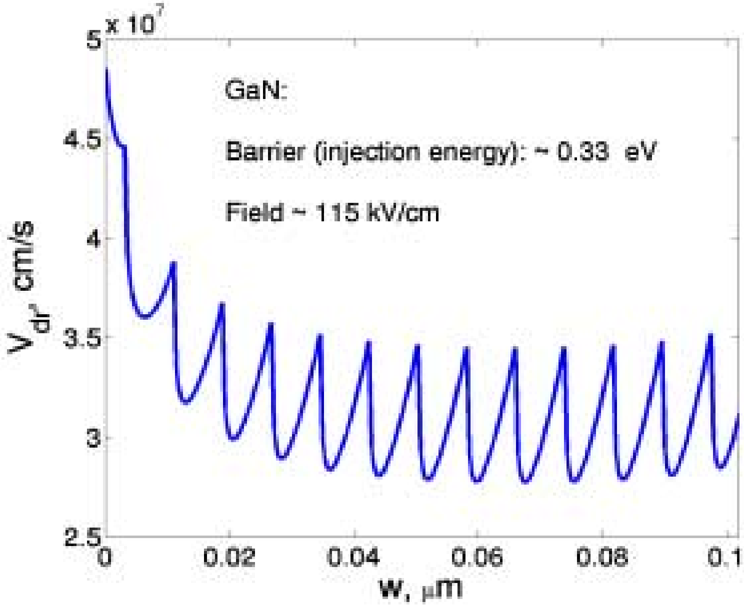


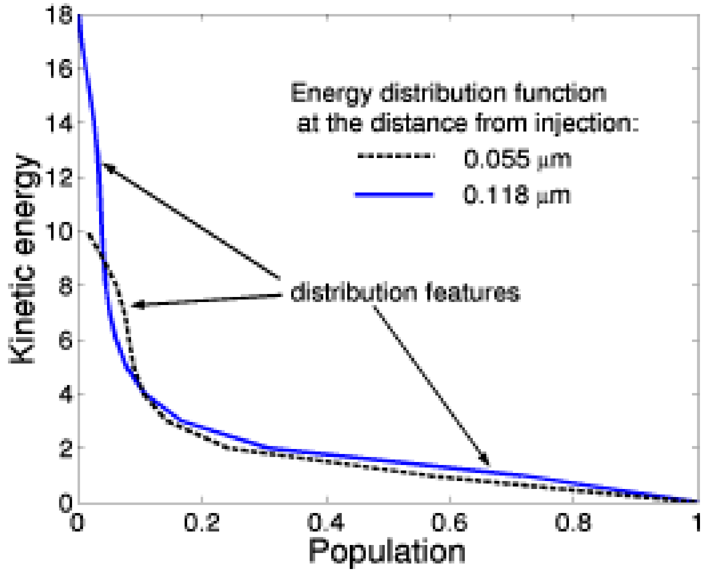


At field ε > ε*, electrons injected with any energy will runaway (high-field RAE).

$E_{inj} < E_x$

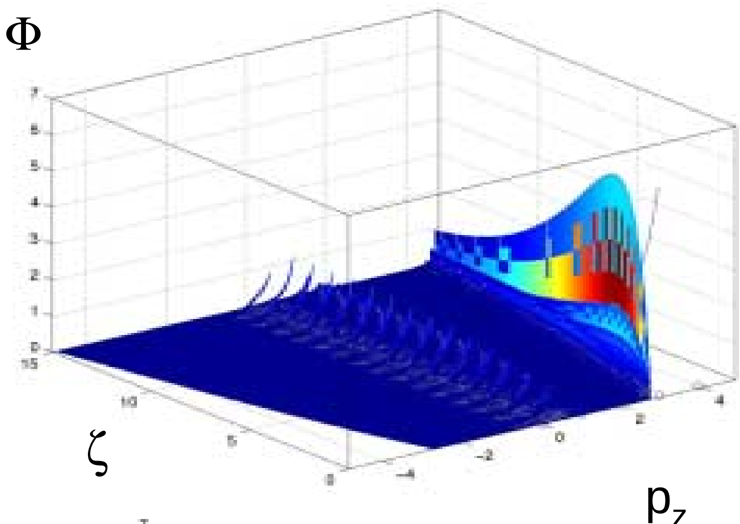




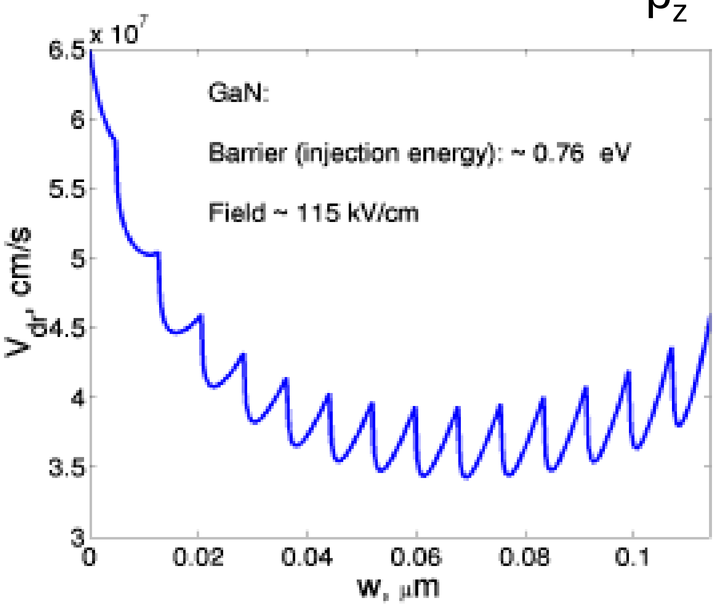


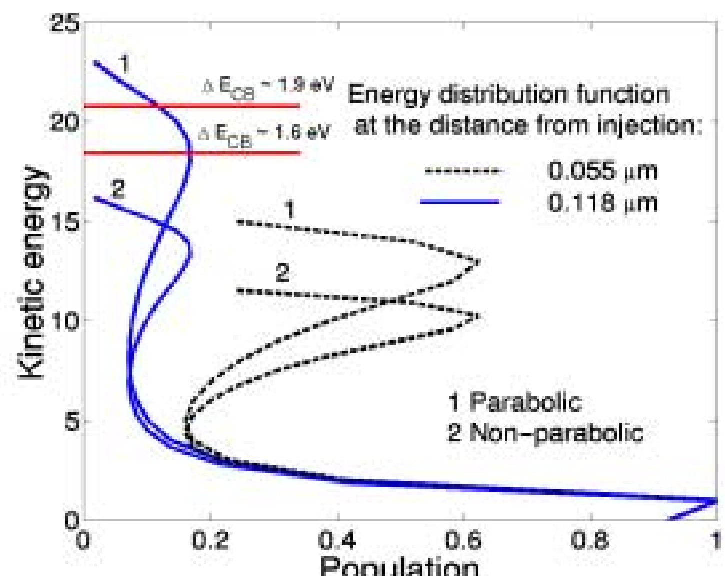
- V_{dr} is 14 % higher than that for the carriers accelerated from the bottom of CB for 0<w<0.05 µm;
- Due to LFRAE, the distribution function is broader => the velocity is, in general, higher until the distance required for hot carrier acceleration to the upper valley.

$E_{inj} > E_x$

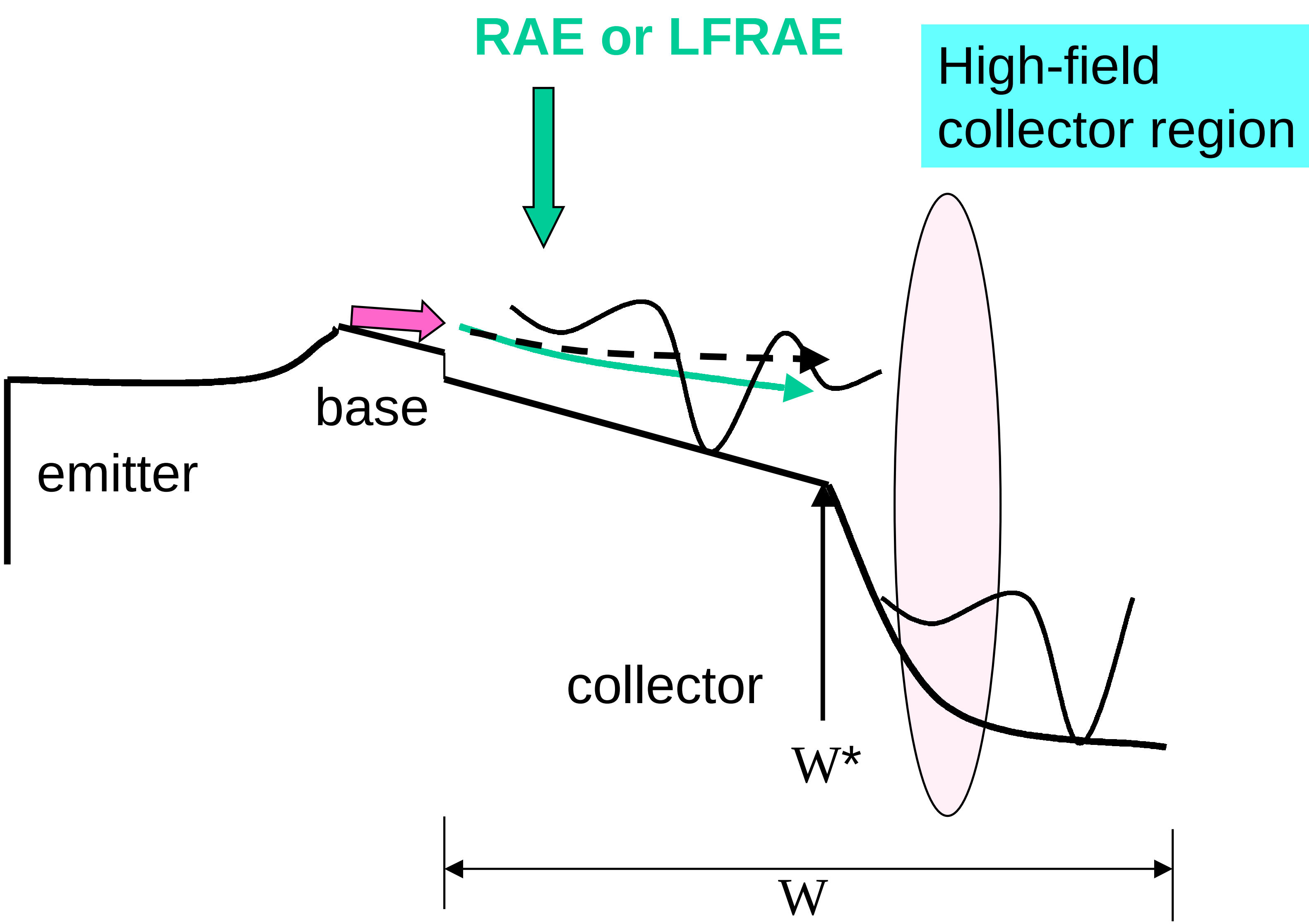


- V_{dr} is larger and has a minimum. The velocity RAE at low field is detected.
- Due to LFRAE, the distribution function has **two** maxima, i.e., there are **two** distinct groups of carriers with *different* velocities.
- Non-parabolicity helps keeping hot carriers in the Γ valley for more than 100 nm.





HET modeling



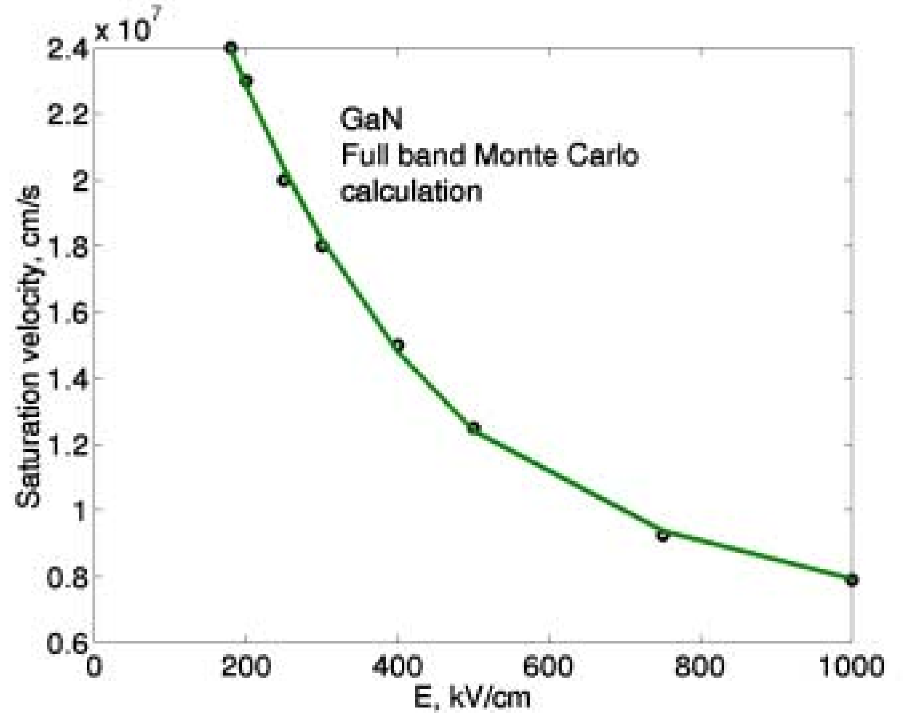
Parameter definition

$$f_t = (2\pi\, T_{ef})^{-1};$$

$$f_{\max} = \sqrt{\frac{f_t w}{8\pi\, A\kappa\, R_b}}$$

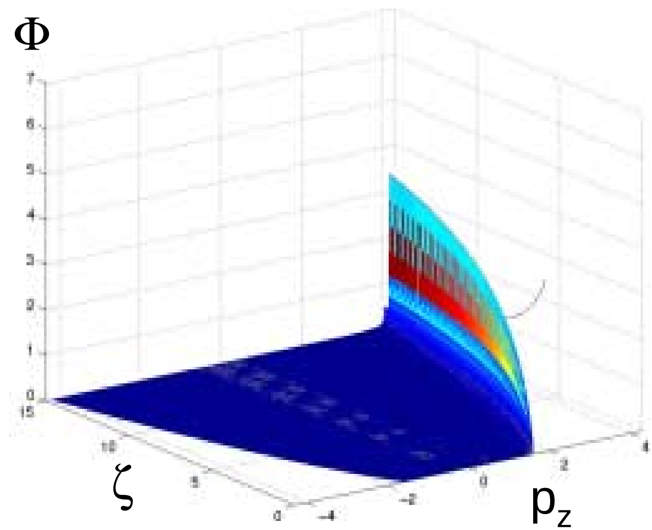
$$T_{ef} = T_v + \left(C_{be} + A\kappa / w\right)\frac{kT}{qI_c};$$

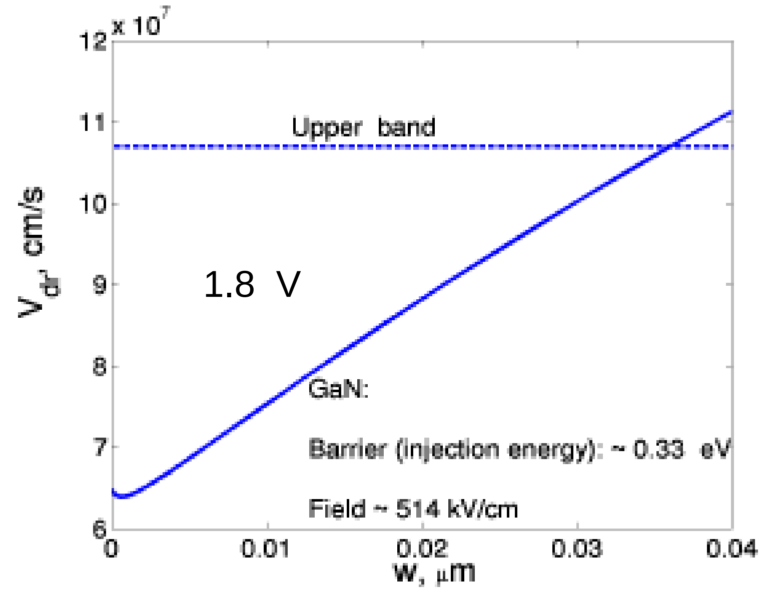
$$T_v = \int_0^{w^*} \frac{1 - \frac{x}{w}}{V(x)}\, dx + \Theta(w - w^*)\frac{(w - w^*)^2}{V_{sat}(E)w};$$

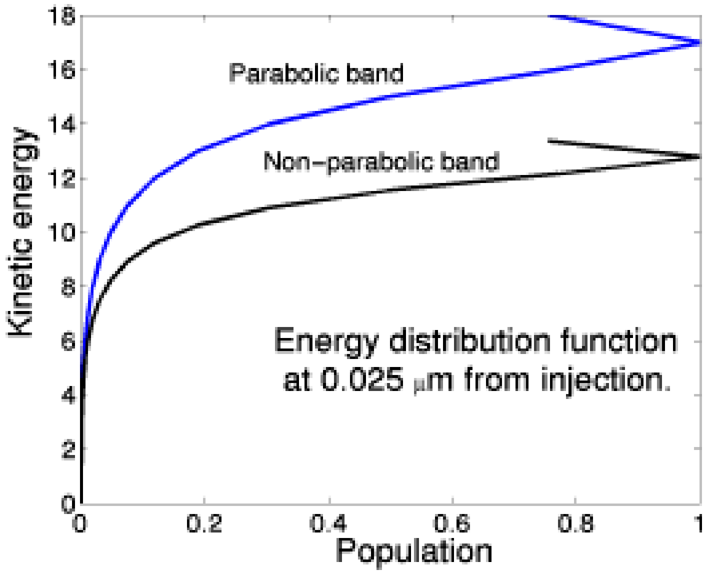


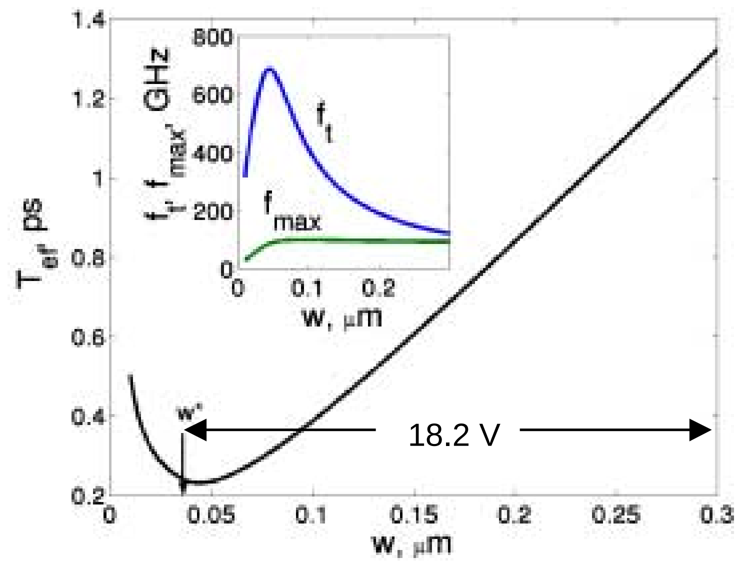
$V_{sat}(E) = -0.036\, E^3 + 93.4422\, E^2 - 86106\, E + 3.6586 \times 10^7;$ (E in kV/cm)

RAE with injection from the barrier

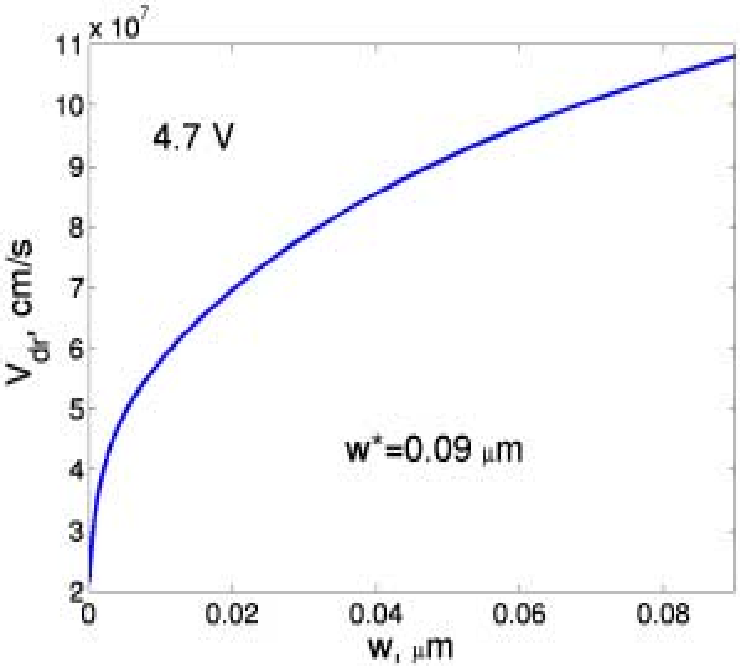


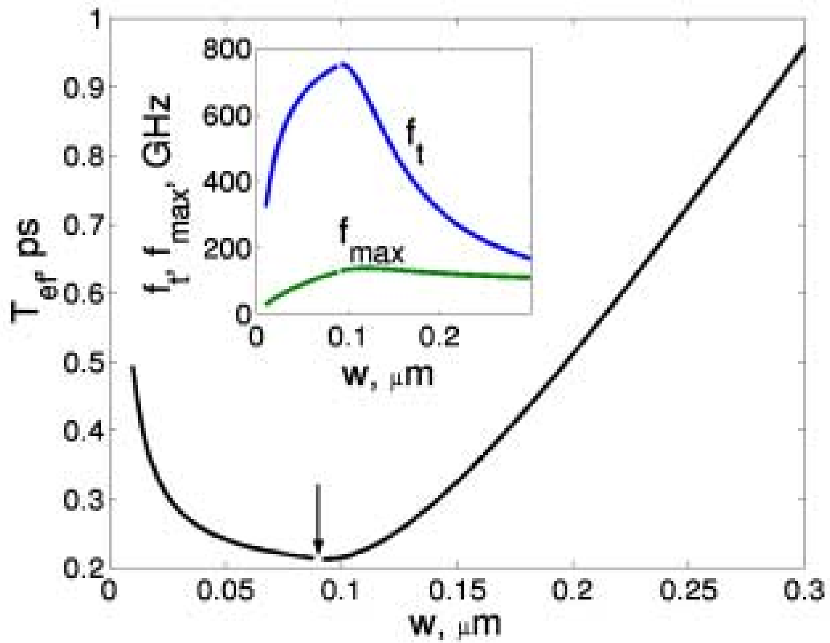






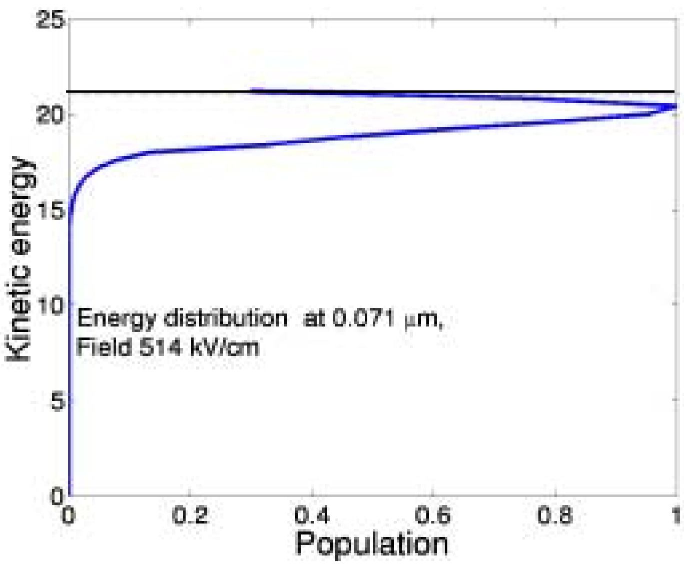
RAE of thermalized electrons

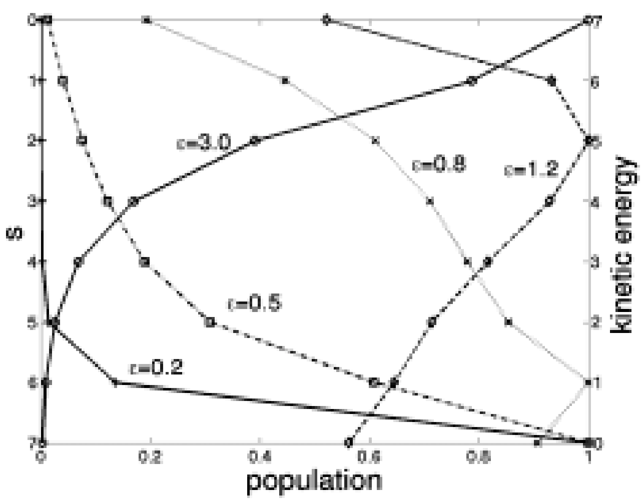


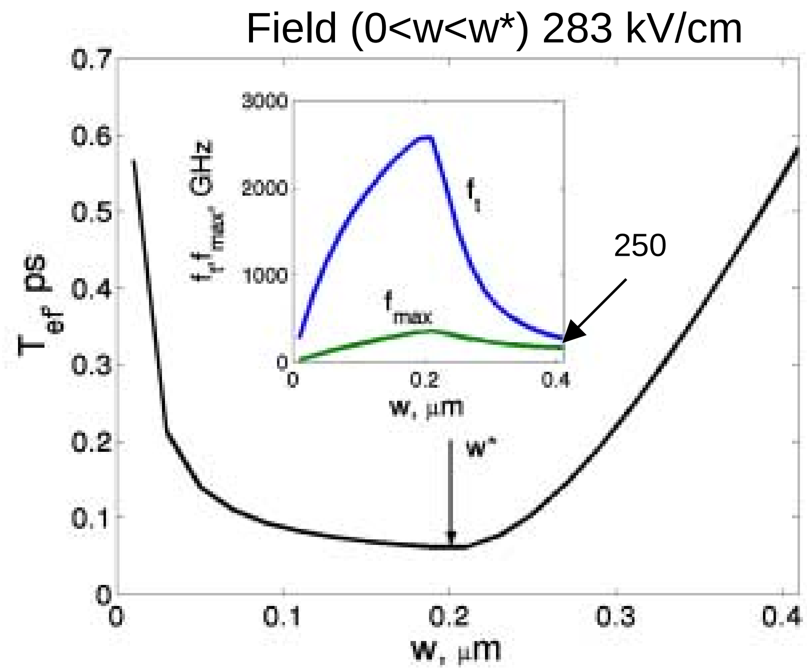


- Carriers stay ***longer*** in the Γ valley => voltage distribution, w*, f_t, and f_{max} are improved;
- A 100 kV/cm field increase in the high-field collector has a weaker impact on the performance due to the weak dependence $V_{sat}(E)$.

Impact of upper valleys







Capture to the upper valley in a RAE regime and the current reduction should be taken into account, especially for the fields about 300 kV/cm.

Conclusions

- Using collector design parameters provided recently by the UCSD group (Prof. Asbeck), a preliminary estimate suggests that the cut-off frequency in a sub-THz frequency range can be achieved in a nanoscale-range collector. However, keeping V_c=20V, Ic=4mA, R_b~210Ω, and C_{be}~5fF, $f_t \sim f_{max}$ can be satisfied only for a sub-micron scale collector with a relatively long high-field region. V(x,E) **and** RC-delay need to be optimized.
- Since T_v in the low-field region is weighted, the LFRAE can be utilized for improvement of this parameter for 0<w<w*.
- Since large non-parabolicity is a favorable condition for an increase of w*, it is reasonable to investigate the potential of In-contained multinary compounds for the collector fabrication.
- *The unique 2-beam character of LFRAE transport should be considered for novel nanoscale device applications*:
  - tunable high-frequency generation?
  - utilization of threshold character of high-velocity beam for signaling?

Accomplishments

- The RAE simulator was expanded to consider the arbitrary momentum of the injected carriers.

- The non-parabolicity of the conduction band was taken into account.

- The carrier distribution in the LFRAE regime was obtained for the first time. The LFRAE manifests (a) two-beam behavior with a different carrier velocity in each beam, (b) non-thermalized asymptotics, and (c) a minimum on the dependence of average velocity on the distance.

- Optimization of the HET collector parameters was initiated. Computations suggest that improvement of f_t/f_{max} ratio requires reduction of RC-delay (proper I_c management) in the HET collector.