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A

HW 9 ECE 65600 by Peide Ye

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Answer the multiple choice questions below by choosing the one, best answer. Then ask a question about the lecture.

d) 1) For high-field transport in a bulk semiconductor, we write the Einstein relation as $D_n/\mu_n = 2u_{xx}/q$. What is u_{xx} for a non-degenerate semiconductor with parabolic energy bands? (Assume that the drift energy is negligible).

a) $u_{xx} = nk_BT_e/2$, where T_e is the electron temperature.

b) $u_{xx} = nk_BT_e$, where T_e is the electron temperature.

c) $u_{xx} = 3nk_BT_e/2$, where T_e is the electron temperature

(d) $u_{xx} = k_BT_e/2$, where T_e is the electron temperature.

e) $u_{xx} = 3k_BT_e/2$, where T_e is the electron temperature.

For a 3D parabolic band, the average kinetic energy per particle is $\langle E\rangle = \frac{3}{2} k_B T_e$

$u_{xx} = \frac{1}{3}\langle E\rangle = \frac{1}{2} k_B T_e$

e) 2) In practice, one commonly extends the near-equilibrium drift-diffusion equation to high-fields by replacing the mobility and diffusion coefficients by electric field dependent quantities, as in $J_{nx} = nq\mu_n(\mathcal{E})\mathcal{E}_x + qD_n(\mathcal{E})dn/dx$. What assumption is necessary to write the DD equation in this form?

a) Parabolic energy bands.

b) Non-degenerate carrier statistics.

c) The microscopic relaxation time approximation.

d) That the energy relaxation time is shorter than the momentum relaxation time.

(e) That the shape of the distribution, whatever it is, does not vary with position.

c) 3) Assume that there is a dominant optical (or intervalley) phonon scattering process that dominates under high electric fields. How does the saturated velocity depend on the optical phonon energy, $\hbar\omega_0$?

a) $\upsilon_{SAT} \propto \hbar\omega_0$.

b) $\upsilon_{SAT} \propto (\hbar\omega_0)^2$.

(c) $\upsilon_{SAT} \propto \sqrt{\hbar\omega_0}$.

d) $\upsilon_{SAT} \propto 1/\hbar\omega_0$.

e) $\upsilon_{SAT} \propto 1/\sqrt{\hbar\omega_0}$.

$\frac{1}{2} m^* v_{max}^2 \approx \hbar\omega_0$

$v_{SAT} \propto \sqrt{\hbar\omega_0}$

c) 4) Which of the following statements is true when the drift energy is small compared to the thermal energy?

a) $\langle \tau_m \rangle \approx \langle \tau_E \rangle$.
b) $\langle \tau_m \rangle >> \langle \tau_E \rangle$.
c) $\langle \tau_m \rangle << \langle \tau_E \rangle$.
d) $\langle \tau_m \rangle$ and $\langle \tau_E \rangle$ both increase with increasing energy.
e) $\langle \tau_m \rangle$ and $\langle \tau_E \rangle$ are independent of energy.

τ_m can happen via elastic scattering
τ_E can happen via inelastic scattering
elastic collisions are much more frequent than inelastic

c) 5) In the classic description of the velocity vs. electric field characteristic in bulk Si, $v_d = \mu_{n0} \mathcal{E} \Big/ \sqrt{1+\left(\mathcal{E}/\mathcal{E}_C\right)^2}$, approximately what is the magnitude of the critical electric field, $\mathcal{E}_C$?

a) ≈ 0.1 kV/cm.
b) ≈ 1 kV/cm.
c) ≈ 10 kV/cm.
d) ≈ 100 kV/cm.
e) ≈ 1000 kV/cm.

$V_{SAT} \approx 1 \times 10^7$ cm/s , $\mu_{n0} \approx 1400$ cm^2/V·s

$\mathcal{E}_c = \frac{V_{SAT}}{\mu_{n0}} \approx 7.1$ kV/cm ≈ 10 kV/cm

d) 6) What is meant by the term, "non-local" semiclassical transport.

a) Transport that cannot be described by a DD equation with a field-dependent mobility and diffusion coefficient.
b) Transport in an electric field that varies more rapidly in space than the energy relaxation length, where T_e is the electron temperature.
c) Transport in an electric field that varies more rapidly in time than the energy relaxation time.
d) All of the above.
e) None of the above.

c) 7) Under what conditions does velocity overshoot occur for a rapidly varying electric field?

a) When transport is ballistic.
b) When transport is quasi-ballistic.
c) When the momentum relaxation time is much shorter than the energy relaxation time.
d) When the momentum relaxation time is much longer than the energy relaxation time.
e) When the momentum relaxation time is nearly equal to the energy relaxation time.

$\tau_m < t < \tau_E$

a) 8) Assume that a strong electric field is switched on at $t = 0$. Which of the following statements is true about the velocity vs. time transient?

a) The drift velocity overshoots its steady-state value.
b) The carrier energy overshoots its steady-state value.
c) The drift velocity and carrier energy overshoot their steady-state values.
d) The drift velocity overshoots its steady-state value and the carrier energy undershoots its steady-state value.
e) The drift velocity undershoots its steady-state value and the carrier energy overshoots its steady-state value.

Carriers initially accelerate almost ballistically, so velocity rises faster than in steady state

a) 9) Which of the following statements is true about the drift and thermal energies during a velocity vs. time transient like that in questions 3)?

a) The drift energy overshoots its steady-state value.
b) The thermal energy overshoots its steady-state value.
c) The drift energy and thermal energy overshoot their steady-state values.
d) The drift energy overshoots its steady-state value and the thermal energy undershoots its steady-state value.
e) The drift energy undershoots its steady-state value and the thermal energy overshoots its steady-state value.

Drift energy is the direct kinetic energy $\frac{1}{2} m v_d^2$

During the velocity-overshoot phase, v_d is temporarily larger than its final steady-state value

d) 10) When comparing velocity vs. time transient to a steady-state velocity vs. position transient, which of the following is true?

a) Temporal velocity overshoot is stronger than s.s. spatial velocity overshoot.
b) Diffusion effects are much stronger in steady-state than in transient situations.
c) Ensemble effects are much stronger in steady-state than in transient situations.
d) All of the above.
e) None of the above.

If we try to design a faster possible transistor, do we want the length of the transistor channel to be longer or shorter than the distance it takes for an electron to heat up?