**Figure captions**

**Figure 1**. Ballistic motion of electrons (a) accelerated by electric field; (b) thermionically injected from a wide-gap material; (c) injected by tunneling into a state of kinetic energy.

**Figure 2**. Conduction band profile of a heterostructure for ballistic electron spectroscopy (after Heiblum et al. 1985).

**Figure 3**. Electron energy distributions $(EE)^{1/2} f_{\rm m}$ (solid lines) corresponding to the mesoscopic functions $f_{\rm m}(EE)$ that evolve from the non-equilibrium Maxwellian ensembles characterized by an initial temperature $T_{\rm i}$ (after Grinberg et al. 1991). The illustrated case corresponds to the lattice temperature $T = 300\,{\rm K}$. The equilibrium distributions are indicated by stippled lines and the initial distributions by dashed lines.
(a) $T_{\rm i} = 75\,{\rm K}$; (b) $T_{\rm i} = 1000\,{\rm K}$.

**Figure 4**. Illustration of the Hess diode, its energy band diagram and current-voltage characteristics. Labels 1 and 2 indicate a low-current, high-resistance state and a high-current, low-resistance state, respectively.

**Figure 5**. Calculated current-voltage characteristics of a multilayer real-space-transfer diode. Solid line displays $v(F)$ for parameters as in the legend. The dashed line corresponds to the same set of parameters, but a different effective mass ratio: $m_1/m_2 = 0.3$

**Figure 6**. Band diagram of a modulation-doped real-space transfer diode (after Hess et al., 1979). At equilibrium electrons reside in narrow-gap layers 1; heated by an electric field they transfer into wide-gap layers 2 of lower mobility.

**Figure 7**. Schematic diagram of a charge injection transistor. Emitter electrons heated up by the field applied between electrodes $S$ and and $D$ undergo real-space transfer, as indicated by

the arrow. By symmetry, the output current $I_C$ at a fixed collector bias $V_C$ is an exclusive-OR function of the input voltages: $I_C = \mathbf{xor}(VS, V_D)$.

**Figure 8**. Room temperature characteristics of a CHINT/NERFET device with $W = 25\,\mu\text{m}$ and $Lch = 1\,\mu\text{m}$ (after Mensz et al. 1990b). The drain current ($I_D$) and collector current ($I_C$) are plotted versus the heating drain voltage $V_D$ at a fixed collector bias $V_C = 3.9\,\text{V}$. Insert shows the collector-bias dependence of the peak-to-valley ratio and the leakage current, defined as the magnitude of $I_D$ at $V_D = 0$.

**Figure 9**. Principle of the multi-terminal logic device ORNAND. Three input terminals arranged with a 3-fold cyclic symmetry (top figure) define three channels 1-2, 2-3, and 3-1. The RST current $I_C$ as a function of the voltages $\mathbf{V}_1$, $\mathbf{V}_2$, and $\mathbf{V}_3$, regarded as logic signals, obeys the truth table shown below. The value of $I_C$ is low (logic-0) in two states when $\mathbf{V}_1 = \mathbf{V}_2 = \mathbf{V}_3$ and is high (logic-1) in the other six states. By the symmetry, all the logic-1 states give the same $I_C$.

**Figure 10**. The ORNAND gate (after Mastrapasqua et al. 1993).

(a) Optical and electrical logic operation obtained in a quasi-stationary measurement at room temperature for $V_C = 2.4\,\text{V}$. Electrodes 3 and $\tilde{3}$ are tied together. The binary values "logic-0" and "logic-1" of the input signals $\mathbf{V}_1$, $\mathbf{V}_2$, and $\mathbf{V}_3$ correspond to $0$ and $3\,\text{V}$, respectively. The particular grouping of the states into OR and NAND reflects the choice of $\mathbf{V}_3$ as the "control" electrode.

(b) Cross-section of the device structure. Cyclic symmetry of an ORNAND gate results from the periodic boundary condition obtained by tying together electrodes 3 and $\tilde{3}$.

**Figure 11**. Metal Base Transistors: a) MOMOM; b) MOMS; c) SMS. Each of the M (metal) or S (doped-semiconductor) electrodes is contacted independently and can be biased with

respect to the other electrodes. The figure shows the energy-band diagrams of metal-base transistors under operating bias conditions.

**Figure 12**. Unipolar ballistic transistors with a monolithic all-semiconductor structure.

a) tunneling hot-electron transfer amplifier (THETA), a tunnel-emitter transistor (after Heiblum, 1981);

b) planar-doped barrier (PDB) transistor (after Malik et al. 1981);

c) induced-base (IBT) transistor (after Luryi, 1985).

**Figure 13**. Schematic band diagram of an abrupt-junction heterostructure bipolar transistor (after Kroemer, 1981). Minority carriers are injected into the base "over a cliff" of energy $\Delta$.

**Figure 14**. Intrinsic frequency characteristics of a coherent transistor (after Grinberg and Luryi, 1993).

(a) The common-emitter current gain. Solid line shows the calculated $\beta^2(\omega) \equiv |h_{21}^{e}|^2$, and the dashed lines indicate the gain roll-off in the conventional frequency range ($f < f_T$) and the extended range ($f > f_T$);

(b) Frequency dependences of the unilateral gain $|U|$, the output resistance $r_{22} \equiv \mathcal{R}e(z_{22}^{e})$, and the common-emitter current gain $\beta \equiv |h_{21}^{e}|$, assuming $\Delta = 10kT$, the collector transit time $\tau_C = 1\,\text{ps}$, and base transit time $\tau_B = 2\,\text{ps}$.

**Figure 15**. Common-emitter current gain $|h_{21}|$ and the unilateral power gain $|U|$ of a model coherent transistor with a special graded-gap base design, optimized for stable oscillation at 94 GHz. Base total width $W = 1\,\mu\text{m}$. Transistor is assumed loaded with the parasitics with state-of-the art equivalent circuit parameters, e.g. $C_{Cx} = 2C_C$. Conventional current-gain cutoff is $f_T \approx 32\,\text{GHz}$, however the transistor also exhibits a range of current gain $|h_{21}| > 1$ at $f \approx 2\pi f_T$ (near the second peak in $U$). The fundamental peak in $U$ occurs near $\pi f_T$.

**Figure 16**. Schematic diagram of a double-heterostructure laser. Electron injection into the narrow-gap active layer is partly by tunneling; holes which are heavier are mostly injected by thermionic emission.

**Figure 17**. Schematic diagram of the quantum cascade laser structure and the kinetics of carrier transport. To ensure identical conditions, each cascade period must be neutral. The mobile charge in the undoped quantum well is compensated by the positive donor charge in the reservoir. The rates of (nonradiative) transitions between the subbands and the escape rate from the lower subband into the reservoir are characterized by time constants $\tau_{21}$ and $\tau_{1\,\mathrm{out}}$, respectively.

**Figure 18**. Graphical solution of the threshold equation (29) for a parabolic model of the quantum subbands. Assuming a concave upward curve $\hbar\gamma_0(T_e)$ and $T < T_{\max}$, the lasing range is defined by $T_{\mathrm{th}}^{(1)} < T_e(J) < T_{\mathrm{th}}^{(2)}$. In view of Eq. (26), the two thresholds [$T_{\mathrm{th}}^{(1)}$ and $T_{\mathrm{th}}^{(2)}$] in the effective temperature $T_e$ determine both the lower and the upper thresholds for the pump current.

**Figure 19**. Frequency dependence of the optical response $\delta S(f)/\delta S(0)$ to the variation of different parameters in a stripe multiple quantum well laser (after Gorfinkel and Luryi, 1993). Curve 1: modulation by the pumping current, curve 2: modulation by the electron temperature, curve 3: dual modulation as in Eq. (37).