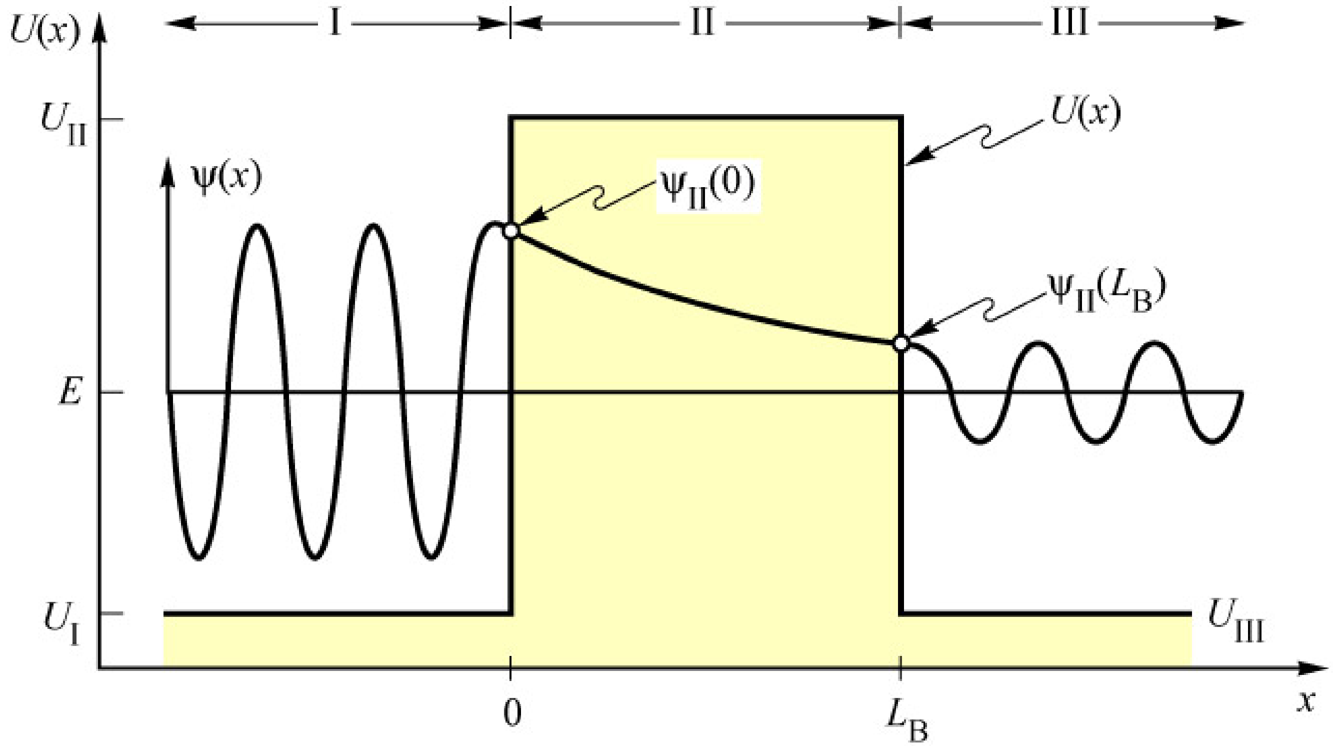
Resonant tunneling diode (RTD) structures

Tunneling probability through one barrier can be calculated using the WKB approximation. This approximation allows us to obtain the tunneling probability through an arbitrary shaped barrier.



Wave function of a particle with energy E tunneling through a quantum barrier.

The wave function in the WKB approximation is given by:

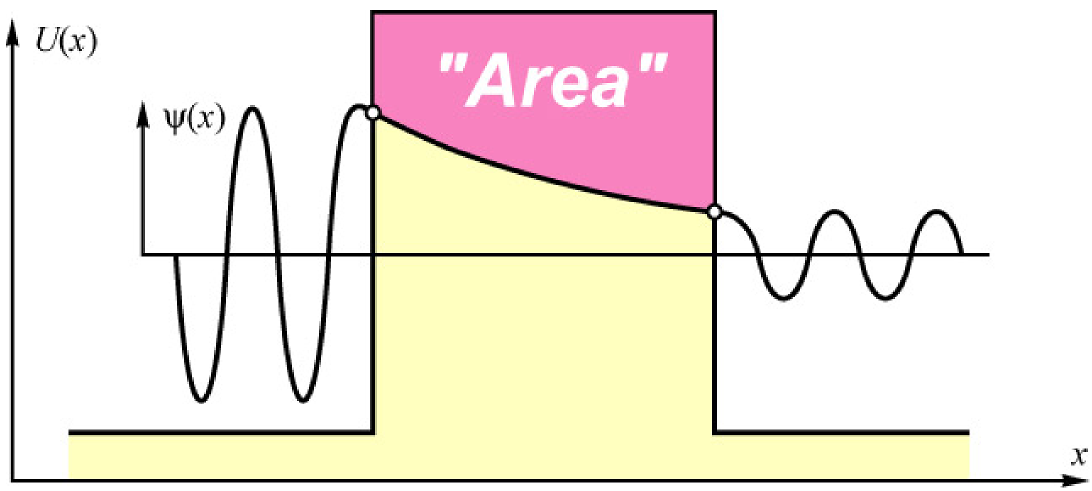
$$\psi_{\mathrm{II}}(x) = \psi_{\mathrm{II}}(0)\, \mathrm{e}^{-\int_0^x \kappa(x)\,\mathrm{d}x}$$

$$= \psi_{\mathrm{II}}(0)\, \mathrm{e}^{-\int_0^x \hbar^{-1} \sqrt{2m^*[U(x)-E]}\,\mathrm{d}x}$$

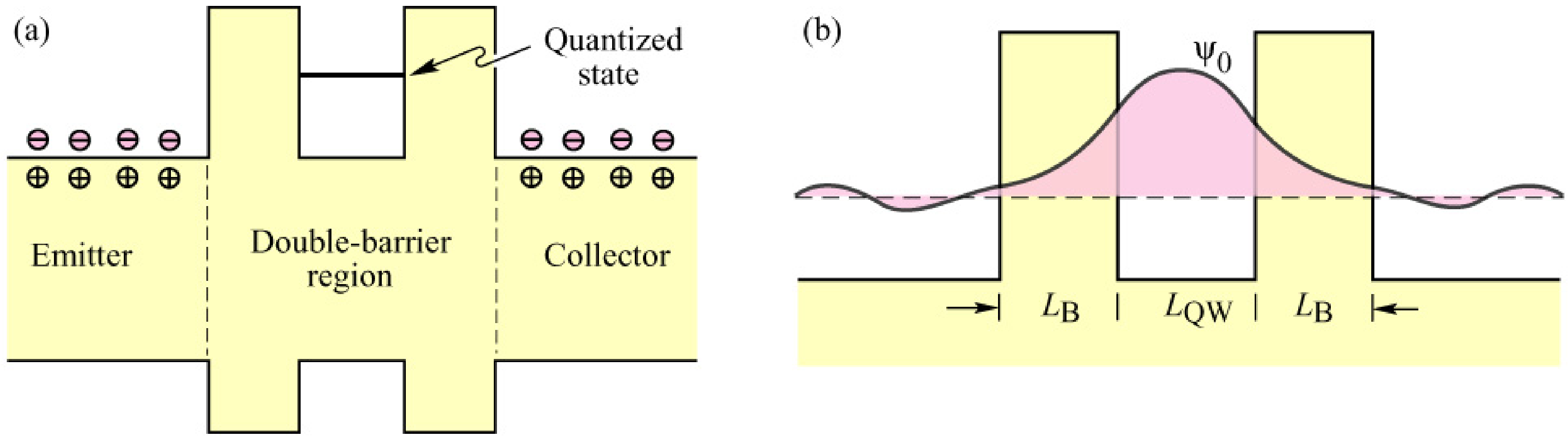
The tunneling probability in the WKB approximation is given by:

$$T = e^{-\int_{x=0}^{L_\mathrm{B}} 2\hbar^{-1} \sqrt{2m^*[U(x)-E]}\,\mathrm{d}x}$$

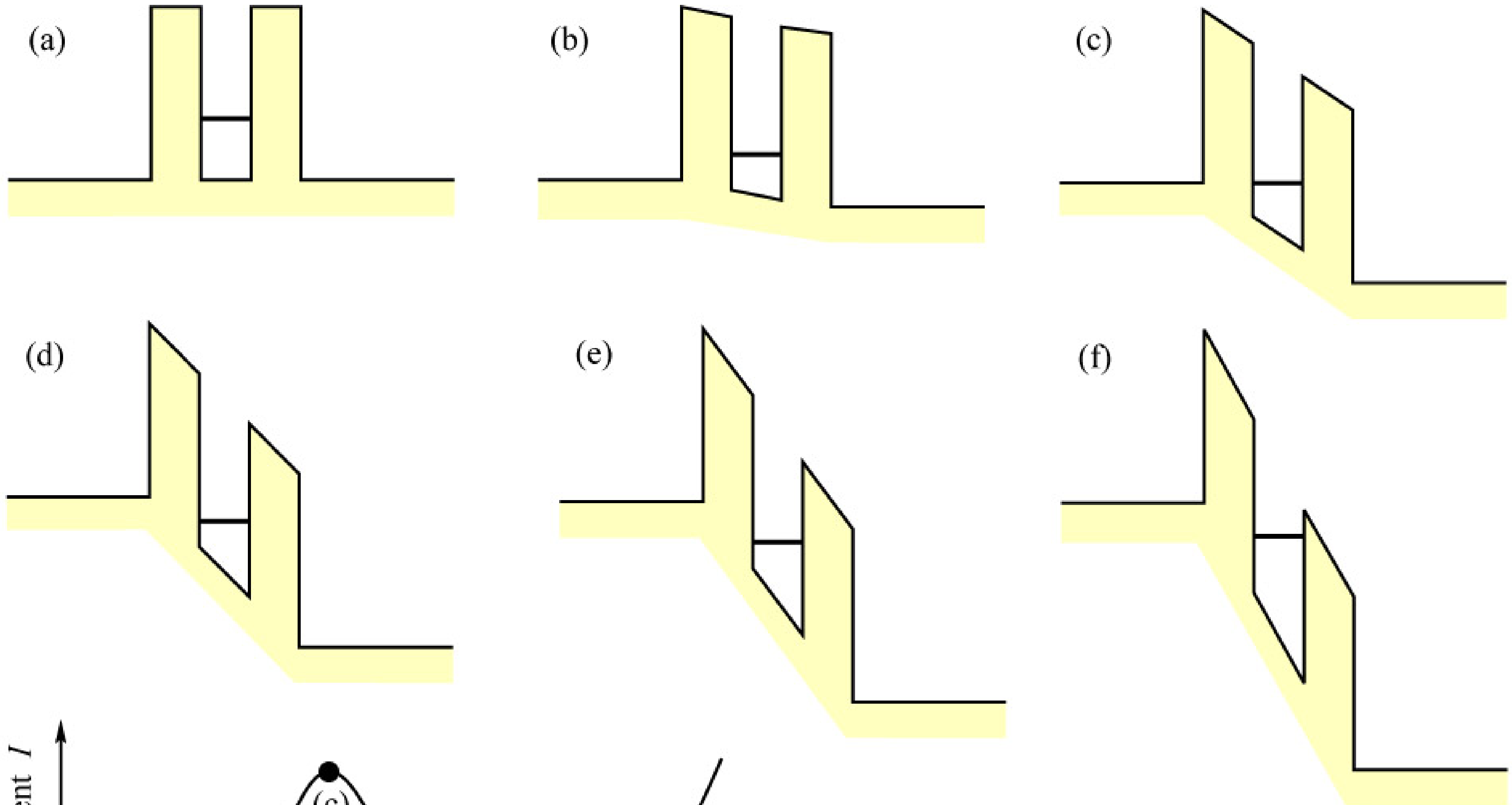
Sometimes it is said that the tunneling probability is proportional to the "area" that is tunneled through. Strictly speaking, this is not correct (Why?). However it may be helpful to think that way.

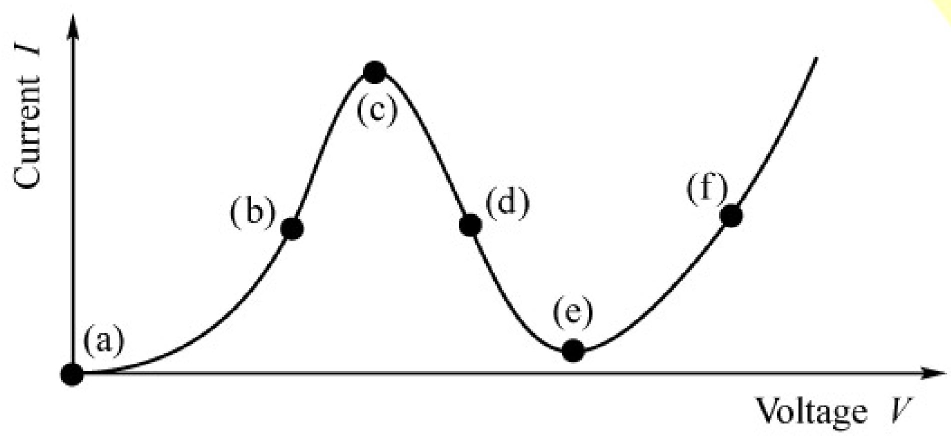


Band diagram of RTD:



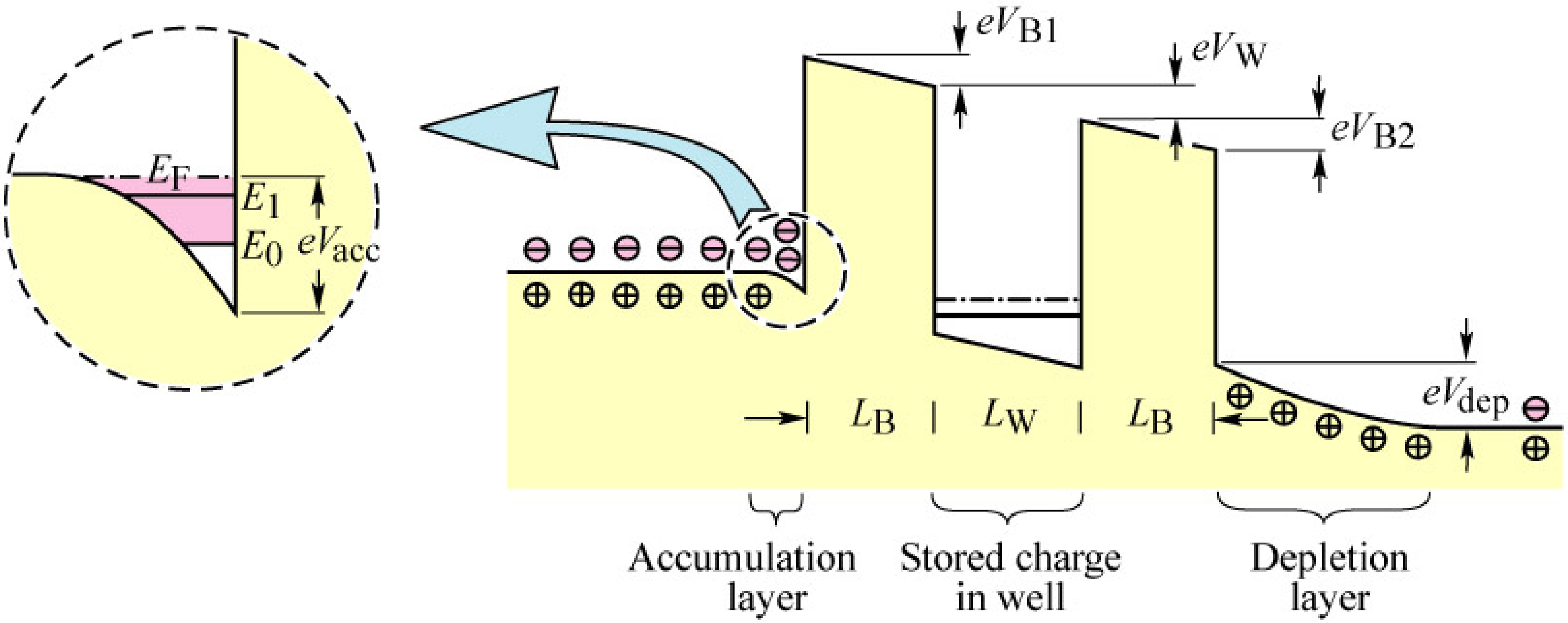
(a) Band diagram of an n-type resonant-tuneling structure and (b) ground-state wave function in the well.





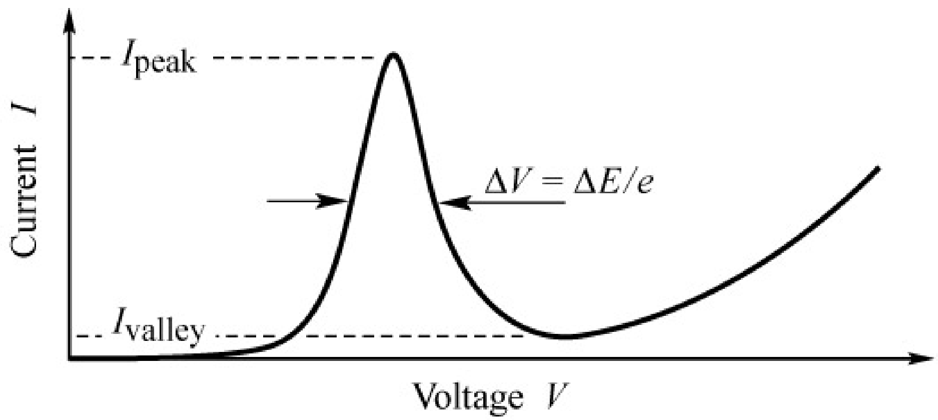
Band diagram and current-voltage characteristic of a resonant-tunelling structure under different bias conditions.

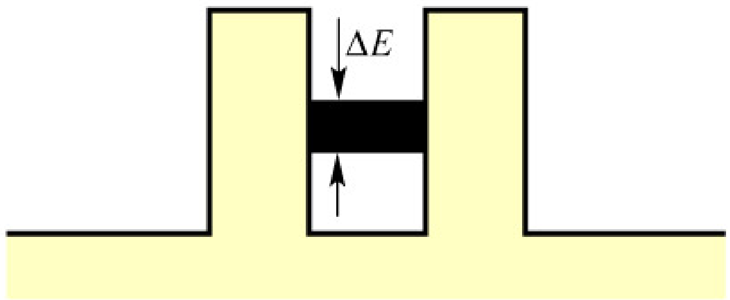
Charges in RTD:



Potential drops in a resonant tunelling structure including the potential drop in the accumulation layer (V_{acc}), in the first barrier, well, second barrier, and the depletion region (V_{dep}).

The width of the resonance:





Linewidth of current resonance peak. Also shown are the peak and valley current.

What are the broadening mechanisms?

Inhomogeneous broadening mechanisms are caused by inhomogeneities of the structure. What are possible inhomogeneities?

- Quantum well thickness fluctuations
- Alloy fluctuations in well and barrier

Homogeneous broadening mechanisms are caused by lifetime-broadening. What is lifetime broadening?

The uncertainty principle states:

$$\Delta E \, \Delta t \quad \geq \quad \hbar \qquad (1)$$

This is the ***energy – time form of the Heisenberg uncertainty relation***. This relation states that the energy of a quantum mechanical state can be obtained with highest precision (small ΔE), if the uncertainty in time is large, *i. e*. for transitions with a long lifetimes. The energetic width of transitions given by the uncertainty principle is called the ***natural linewidth***.

We interpret the time Δt as the time that the electron dwells in the quantum well (dwell time).

Calculation of the dwell time using the “attempt-to-escape model”

RTDs with a parabolically shaped well:

- Energy levels are equidistant
- Harmonic oscillator
- Resonance peaks should occur at equal voltage intervals

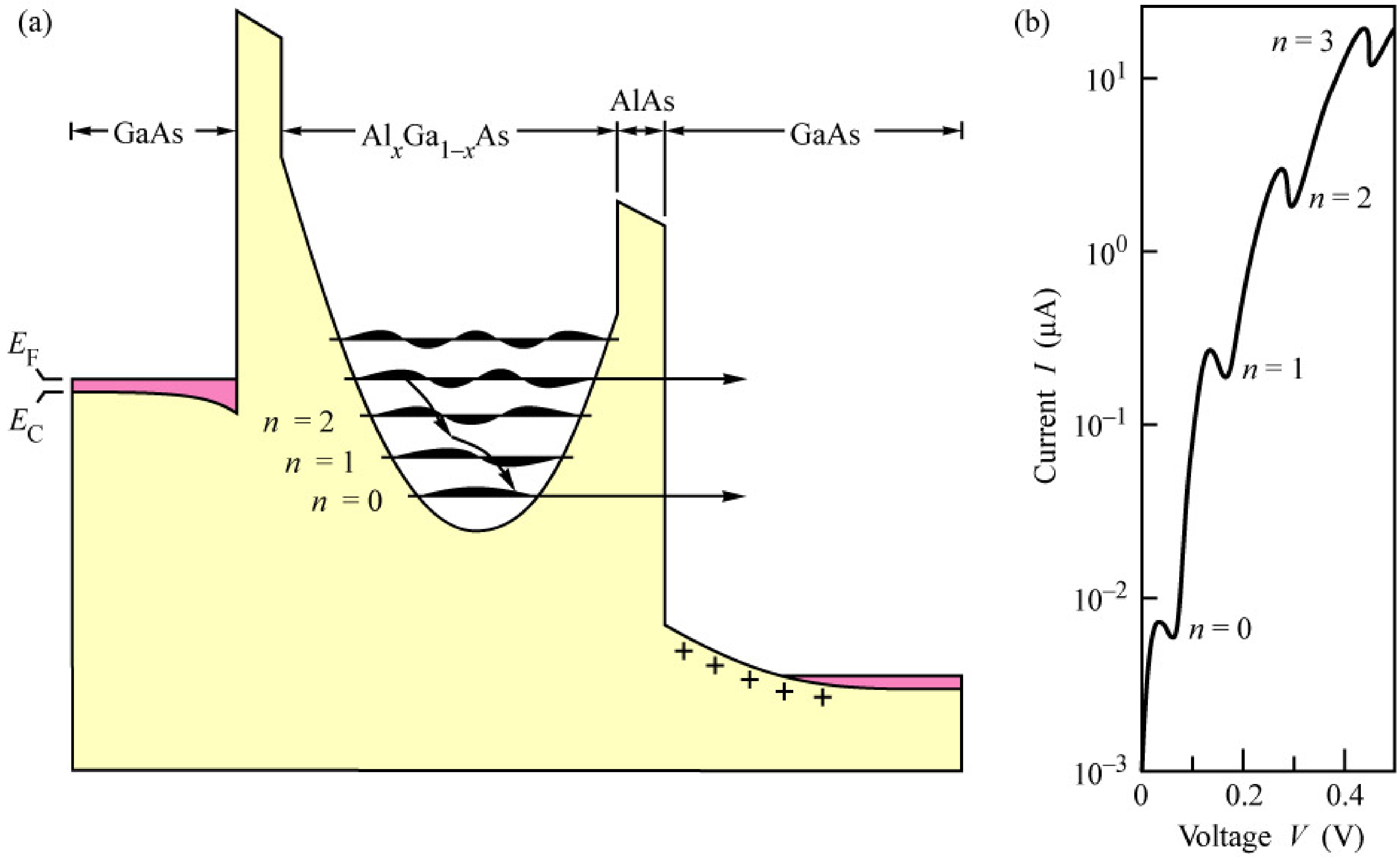
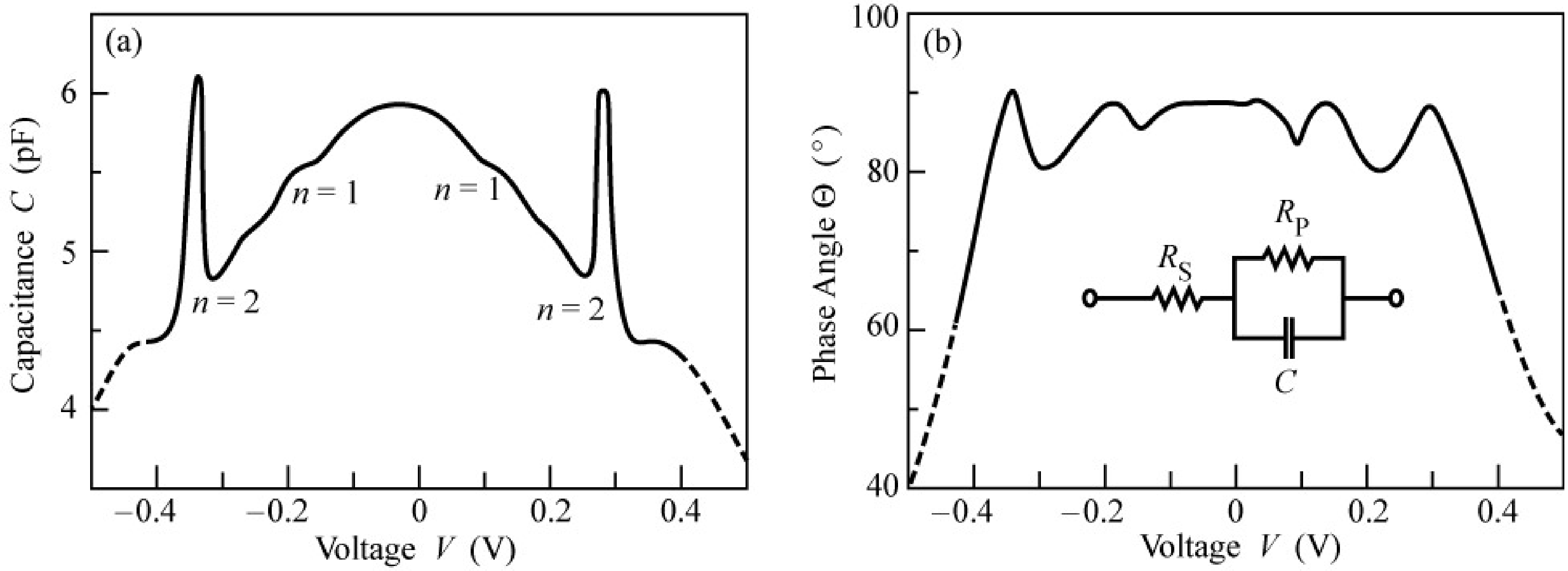


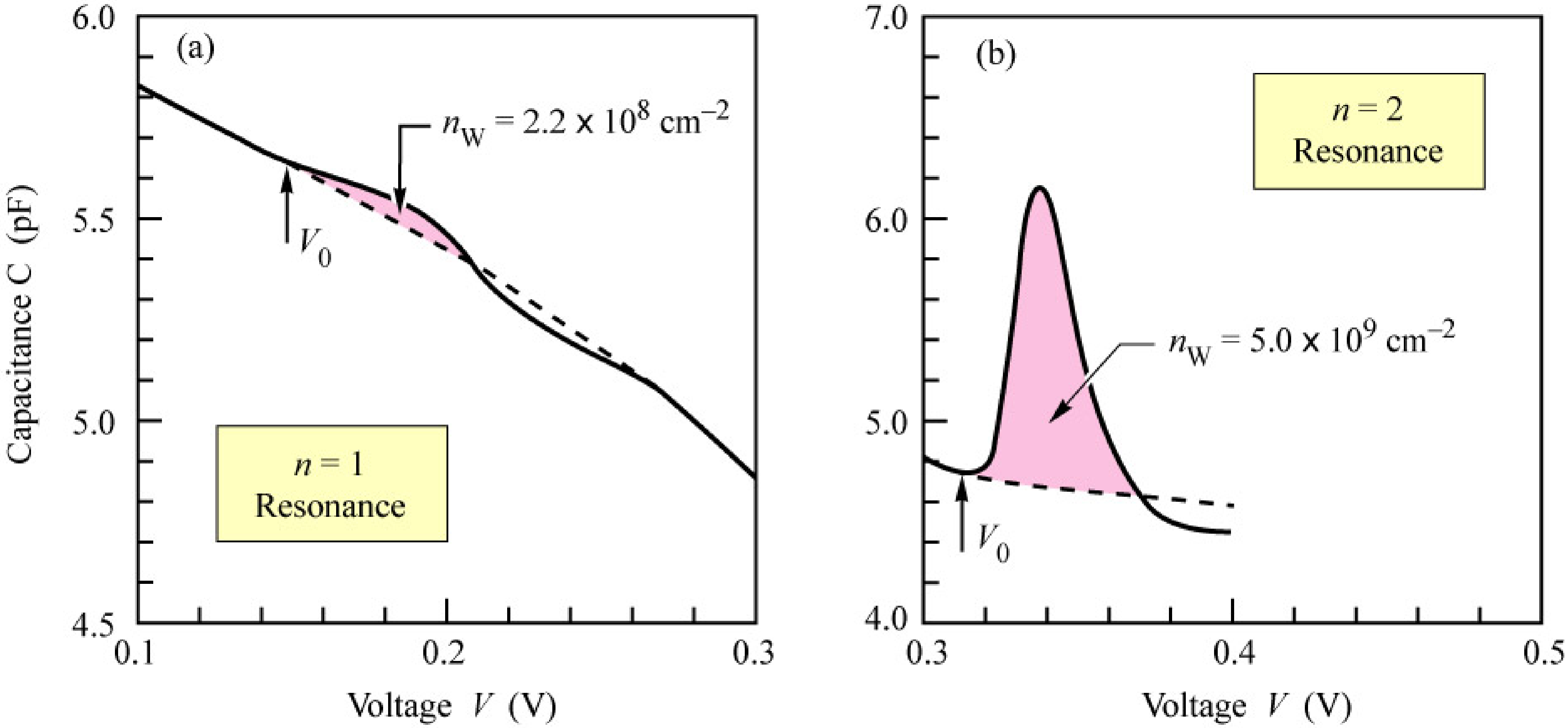
Illustration of the conduction band diagram of a resonant-tunneling structure with a parabolic well. The two tunneling processes, elastic (energy conserved) and inelastic (electron undergoes energy relaxation in the well), are indicated by arrows. (b) Current-voltage characteristic of an $Al_xGa_{1-x}As$ / GaAs parabolic well resonant tunneling structure at T = 4.2 K. Four resonances, n = 0 to n = 3, are observed.

C-V measurements allow for the determination of charge in the well:



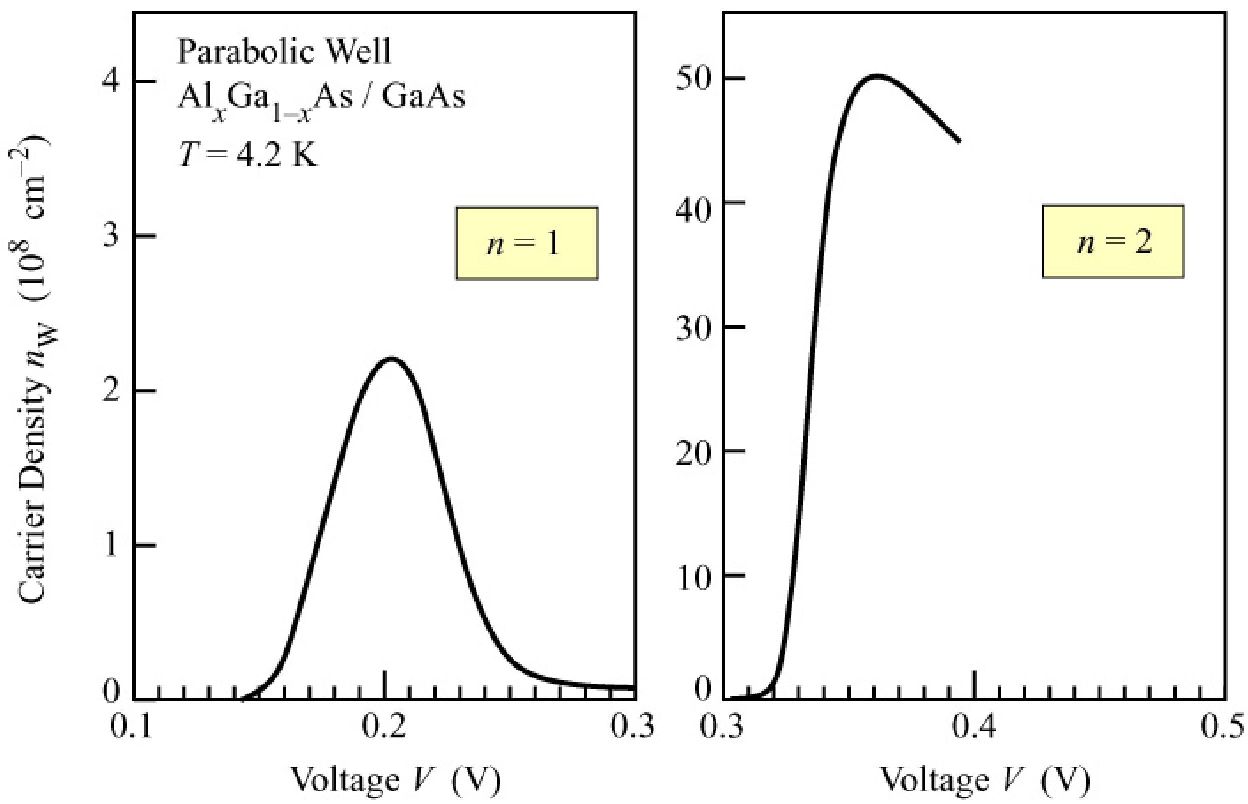
(a) Capacitance-voltage characteristic of a resonant tunneling structure with parabolic well at $T = 4.2$ K. A shoulder and a peak are observed at the $n = 1$ and $n = 2$ resonances, respectively. (b) Phase angle between current and voltage measured at a frequency of 10 MHz.

Extraction of the charge in the well from the C-V data:



Capacitance-voltage curve at 4.2 K in the vicinity of the (a) n = 1 and (b) n = 2 resonance. The maximum charge densities are 2.2×10^8 cm^{-2} and 5.0×10^9 cm^{-2} for the n = 1 and n = 2 resonance, respectively.

Extraction of the charge in the well for the n = 1 and n = 2 resonances from the C-V data:



Evolution of the charge density in the well with voltage for the n = 1 and n = 2 resonance.

RTD applications

- Oscillator circuits consisting of R, L, C, and RTD. The NDR (negative differential resistance) exhibited by RTDs can be used to compensate for unavoidable ohmic losses in oscillator circuits.
- Logic applications. Circuits consisting of power supply, resistance, and RTD have two stable and one unstable operating point. This can be used for memory devices and logic devices.