Tunnel Diodes

A variation on the tunneling problem is to consider two such barriers separated by some distance L, i.e., a square well with walls of finite height V_0 and finite thickness a as illustrated by the potential barriers in Figure 6-32. A particle originally in the well moves back and forth, striking the walls periodically. Each time it strikes a barrier, it has a small but finite probability of tunneling through it and escaping. Such quantum mechanical tunneling is at the heart of a number of physical phenomena or devices such as the tunnel diode and the superconducting Josephson junction.

As we might expect, electrons approaching the twin barriers from outside have a probability, albeit small, of tunneling through both of them, as shown by the wave packet approaching the pair of barriers in Figure 6-32. The region between the barriers is a finite well, with walls of thickness a rather than infinity as in Section 6-3, and solution of the Schrödinger equation leads to quantization of the energy, just as in our earlier discussion. This leads to the very interesting result that, if the velocity v of the electrons approaching from outside the well is such that their kinetic energy E_k

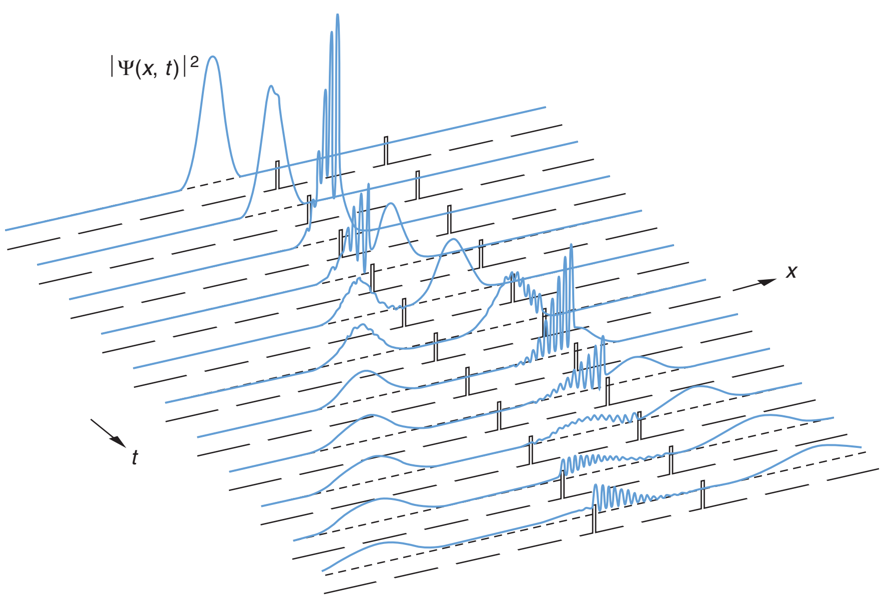
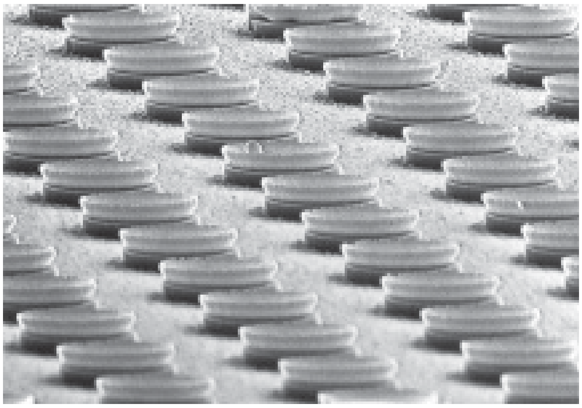


FIGURE 6-32 Probability density for a wave packet incident on two barriers. The barriers are both V_0 high and the energy of the particles is $E < V_0$. At each encounter, part of the packet is transmitted and part reflected, resulting in part of the packet being trapped between the barriers. The sharp spikes are unphysical artifacts of the discontinuities in the slope of the potential.



Electron micrograph of an array of resonant tunneling diodes made by Gerhard Sollner and coworkers at MIT Lincoln Laboratory. Each diode is 8 microns across. Semiconductor layers of nanometer thickness form a quantum well in each diode. The group has achieved 720 GHz oscillation, a record for solid-state oscillators, with a similar diode mounted in a waveguide resonant circuit. *[Micrograph courtesy of T.C.L.Gerhard Sollner, MIT Lincoln Laboratory.]*

matches the energy of one of the quantized levels in the well E_n, then the width of the well is equal to a half-integer number of electron de Broglie wavelengths λ.

$$L = \frac{n}{2}\lambda = \frac{nh}{2p} = \frac{nh}{2\sqrt{2mE_k}} = \frac{nh}{2\sqrt{2mE_n}} \qquad \textbf{6-80}$$

This means that the multiply reflected waves inside the well interfere constructively and as a result the transmission of electrons through *both* barriers can be as large as 100 percent, even though the transmission through one barrier may be less than 1 percent! (This is analogous to a similar resonant effect in the Fabry-Perot interferometer.) This *resonant transmission* at certain energies led to the development of the *resonant tunneling diode* by Esaki, Chang, and Tsu.[18] Such devices, with both equal and unequal height barriers have a number of useful properties. For example, the resonant tunneling diodes illustrated in the accompanying photograph have operated as an oscillator at 720 GHz, a record for solid state devices.