P-N Diodes & Applications

Outline

- Major junction diode applications are
  - Electronics circuit control
  - Rectifying (forward mode)
  - Special break-down diodes: Zener and avalanche
  - Switching
  - Circuit tuning (varactor)
  - Tunneling diodes (negative resistance)
- Optoelectronics (intro only – more in chapter 8)
  - Photodiodes, photodetectors
  - Solar cells
  - Lasers, LEDs

Examples: a company product line

	BUTTON DIODES (Molded Products and Dish Diodes)
	TRANSIENT VOLTAGE SUPPRESSORS (35 and 50 Amp)
	FULL WAVE BRIDGE RECTIFIERS (1 to 50 Amp)
	FAST RECOVERY BRIDGE RECTIFIERS (1 to 35 Amp)
	POWER RECTIFIER MODULES (Single and Three Phase)
	ULTRAFAST RECOVERY DIODES
	SUPER EFFICIENT RECTIFIERS
	SCHOTTKY BARRIER RECTIFIERS
	FAST RECOVERY DIODES
	GENERAL PURPOSE RECTIFIERS
	HIGH VOLTAGE DIODES

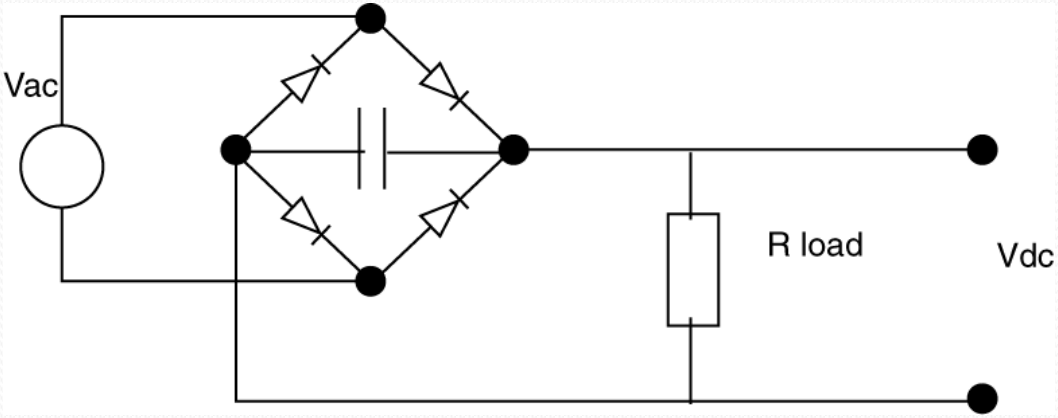
Operational modes of diodes

Voltage/Current	Small signal current	Large injection current	Photoinjection /emission
Forward	switching, mixing, rectifying (small signal processing)	switching, mixing, rectifying (power devices)	Optoelectronics: lasers, LEDs
Reverse	varactor, rectifying		Pin photodiode, Solar cell
Reverse breakdown	switching	voltage clamp (TVS)	Avalanche PD

- Design features/parameters: materials, dopants and doping concentration, device configuration and geometry, metallization/contact.
- In the market, people make discrete component diodes or simple diode IC's tailored for specific applications

Rectifiers

- **Utilizes the forward bias property**



•Prefer low series resistance, low differential impedance: *why? how?*
•Prefer low turn-on voltage *why? how?*
•On reverse: prefer high break down voltage, low leakage current *why? how?*
•Design issues:
- •How to make high current?
- •How to prevent unwanted breakdown (punch through)
- •How to trade-off between the Vbr and low series resistance?
- •How to make the most of diode geometry?

Large reverse bias

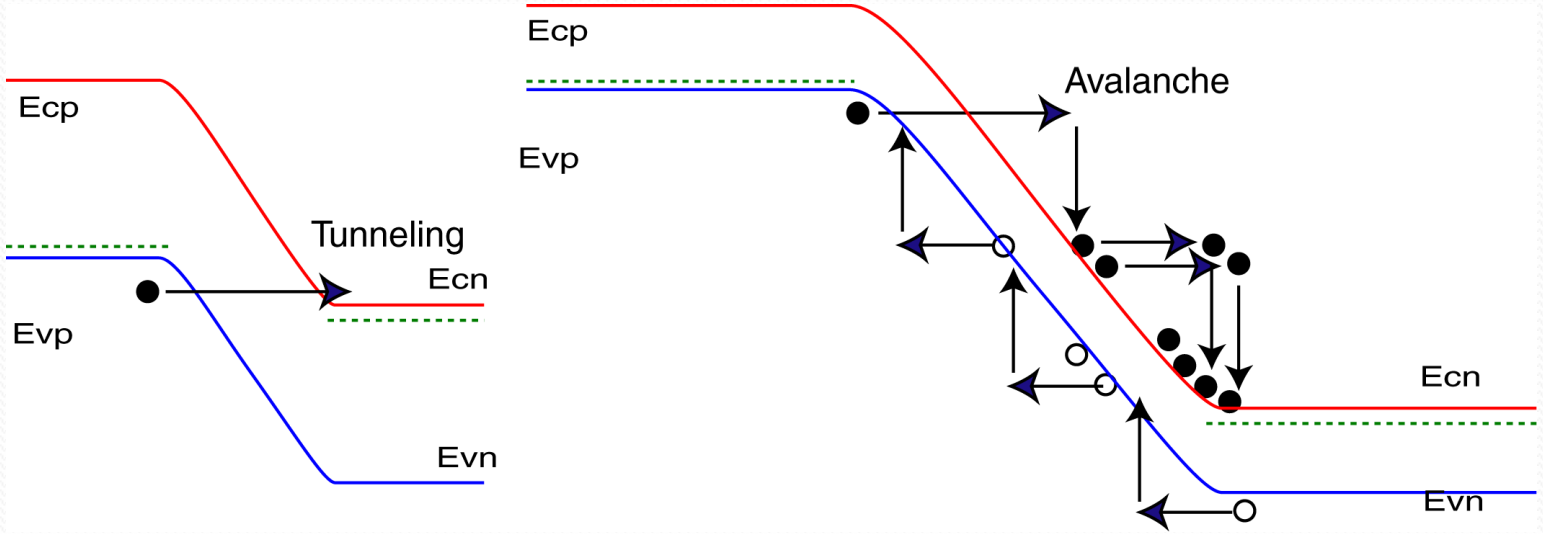
- Breakdown: Not the same as broken- although many diodes can be damaged with large reverse breakdown current
- A regime where simply the low voltage drift and diffusion current model is NOT sufficient
- Involve quantum tunneling effect and high field transport effects (non classical behaviors)

Large reverse bias (cont.)

Two major effects:

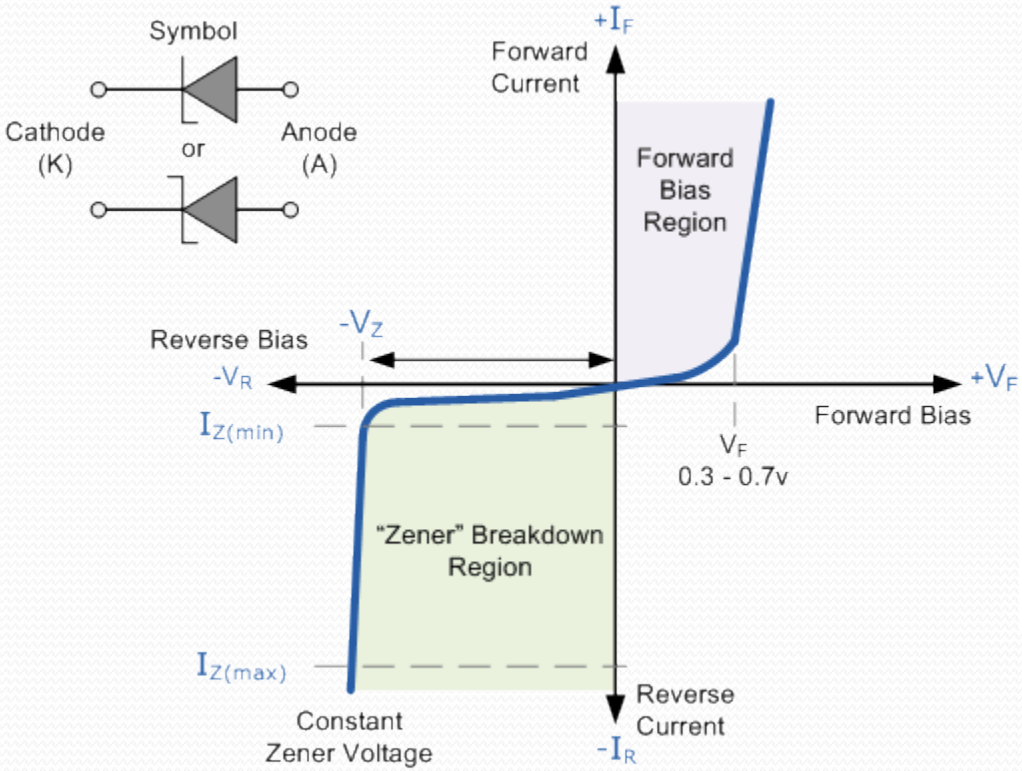
- Tunneling through the band; Zener
- Avalanche: impact ionization

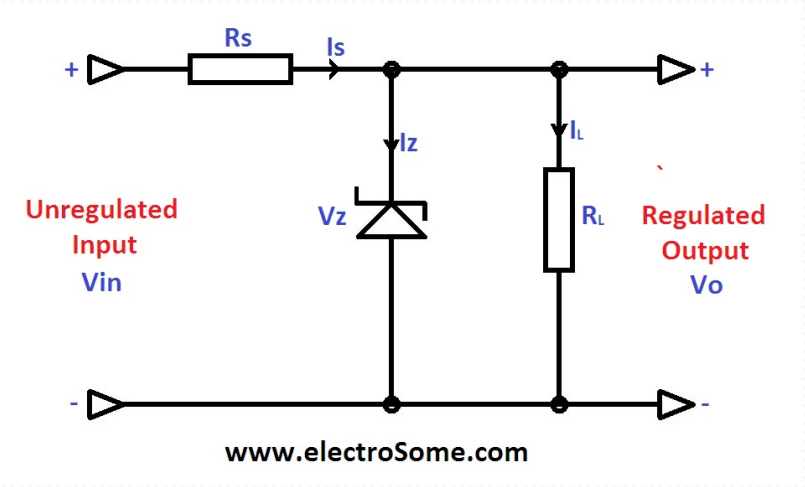
Both are quantum mechanical effects – cannot be explained with classical transport. Tunneling involves coherent wavefunction: particles do not change energy in the process; avalanche is a relaxation process, particles lose energy to excite others.



Zener diodes

Operate in reverse/breakdown mode





Avalanche diodes

Avalanche region is undoped or very lightly doped (so as not to quench carriers)

One significant application is photodetection

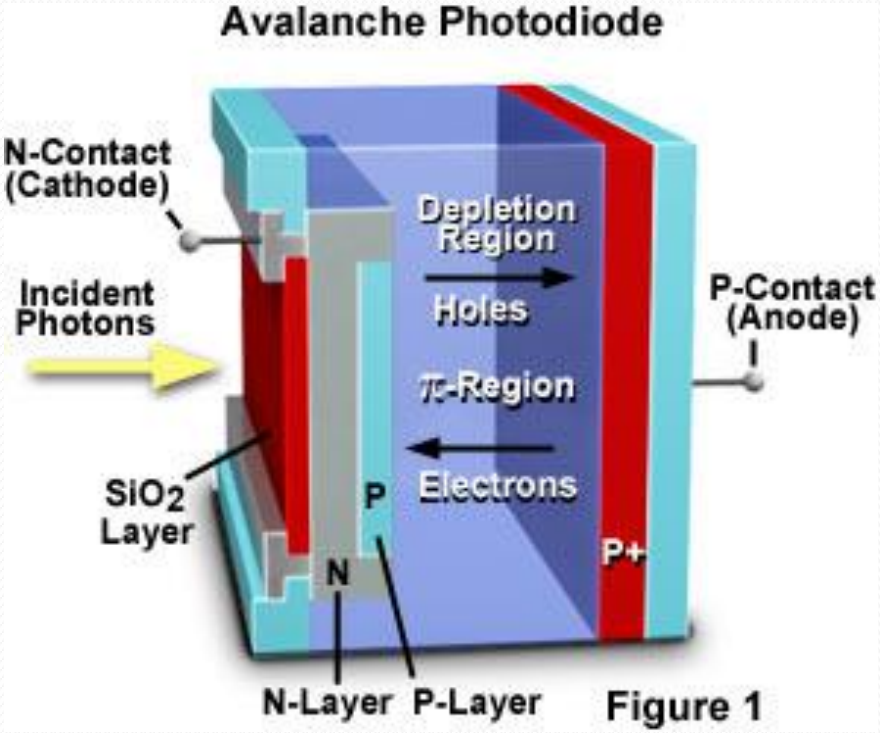
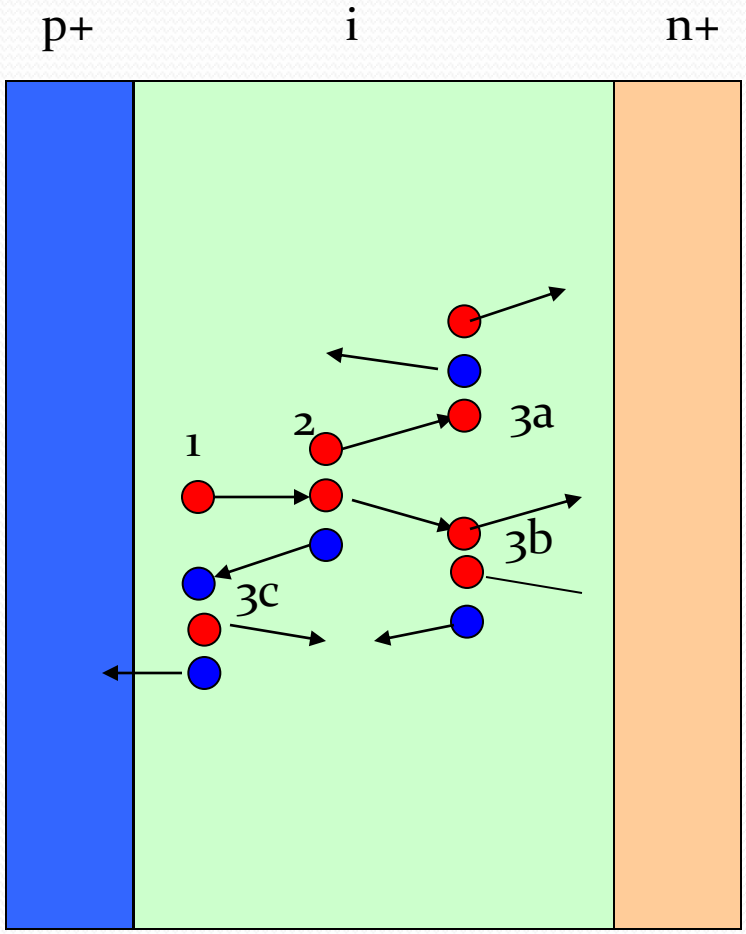
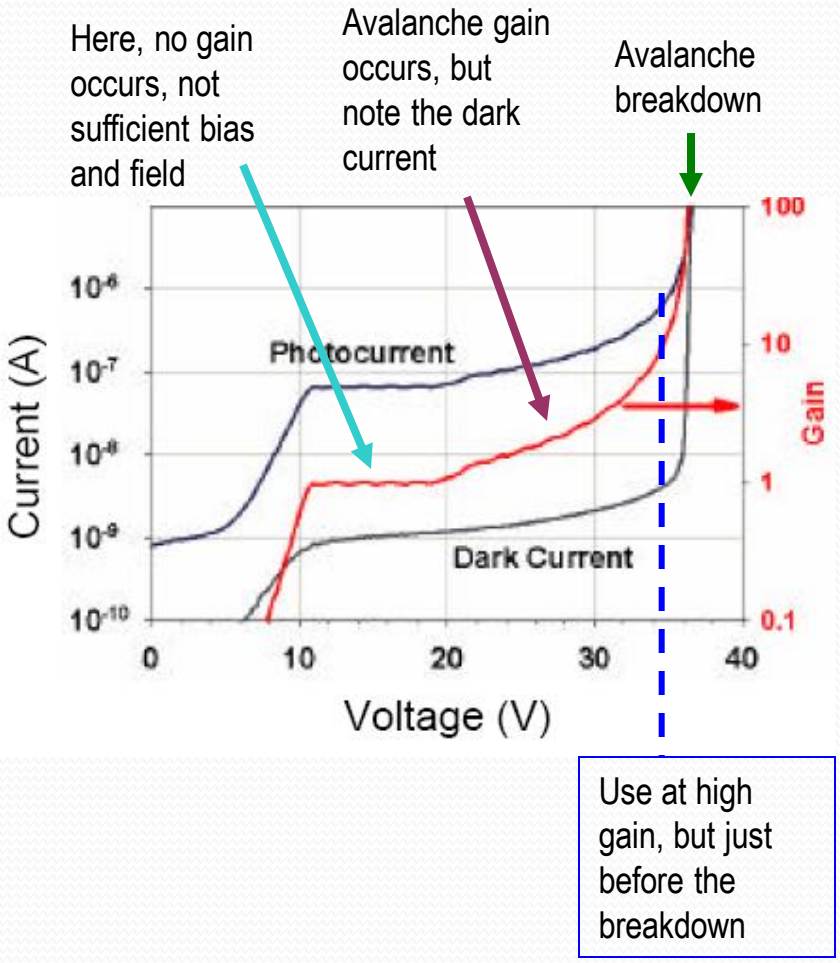


Figure 1

Note: Temperature behavior (Zener vs. avalanche)
- How can one tell which breakdown mechanism is dominant

Basics of PIN and APD





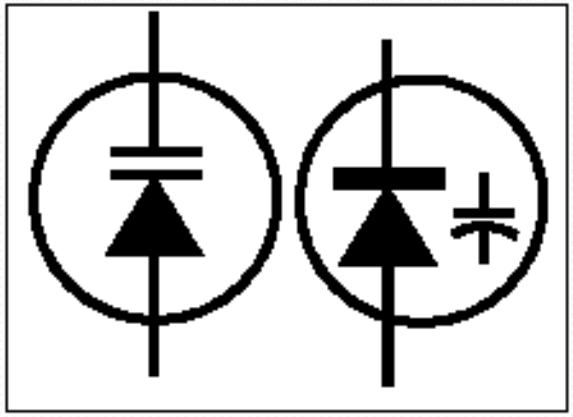
Use at high gain, but just before the breakdown

Switching Diodes

- Going from “ON” (conducting) to “OFF” (non-conducting) and vice versa
- Design preference for either speed or power (less common than speed applications)
- A DC bias voltage can be used to switch a signal through or block it.
  - How fast can the switch be operated?
  - What is the signal bandwidth?
- Most common: from low/medium frequency (e. g. audio) to RF (some special types for microwave)
- Ultrahigh speed (nanosecond to sub-ns switching time)
- Design considerations:
  - How to make it so fast? short-base configuration, short carrier lifetime

Varactors

- Specialized design for applications: VCO (voltage-controlled oscillators), amplifiers, tuners and frequency synthesizers, PLL (phase-locked loop).
- Non-constant doping profile
- Designed for range and voltage dependence behavior (power coefficient)
- Designed for high frequency applications (microwave)



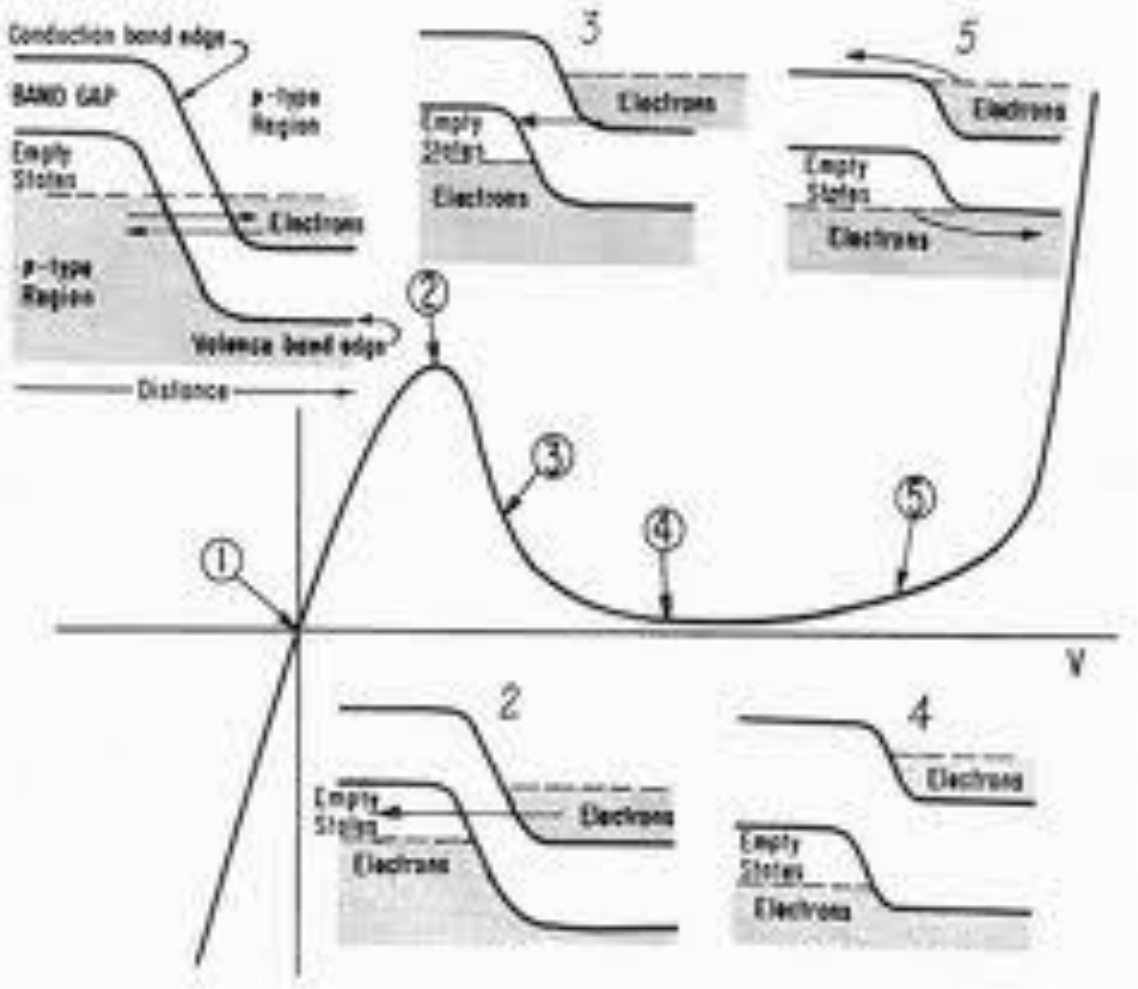
Varactor Design & Apps

- Use in low current mode (reverse)
  - A voltage-tunable capacitor, from a few pF to 1000's of pF)
  - Circuit parameterization formula:

$$C_J \propto V_R^{-n}$$

- Varactor diodes can be used for frequency multiplying in RF or microwave band; sometime used as active filter (fine tuning the poles of the filter)
- Engineering design considerations:
  - How to make a large dynamic range? (large range of capacitance)
  - Doping profile to design voltage dependence (e. g. n=2). Linear, graded, abrupt, hyperabrupt.

Esaki Tunneling Diodes



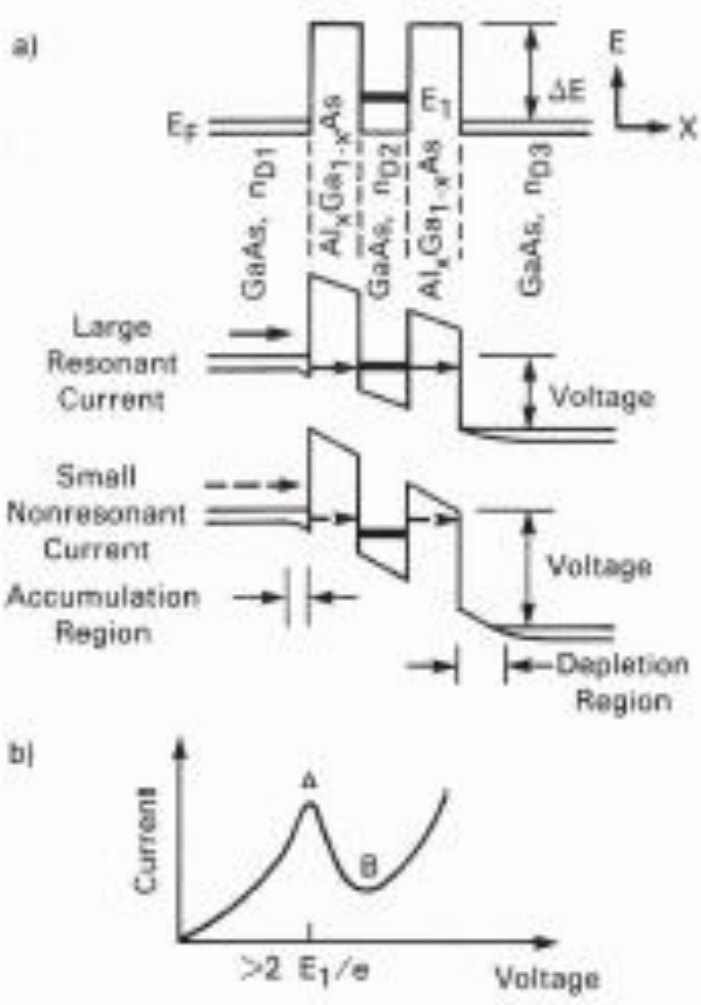
Semiconductor History Museum of Japan

日 本 半 導 体 歴 史 館

T.C.L.G. SOLLNER, E.R. BROWN, and H.Q. LE

Microwave and Millimeter-Wave Resonant-Tunneling Devices

Applications: switching, high-speed oscillators



AIP | Applied Physics Letters

Observation of millimeter-wave oscillations from resonant tunneling diodes and some theoretical considerations of ultimate frequency limits

T. C. L. G. Sollner[1], E. R. Brown[1], W. D. Goodhue[1] and H. Q. Le[1]