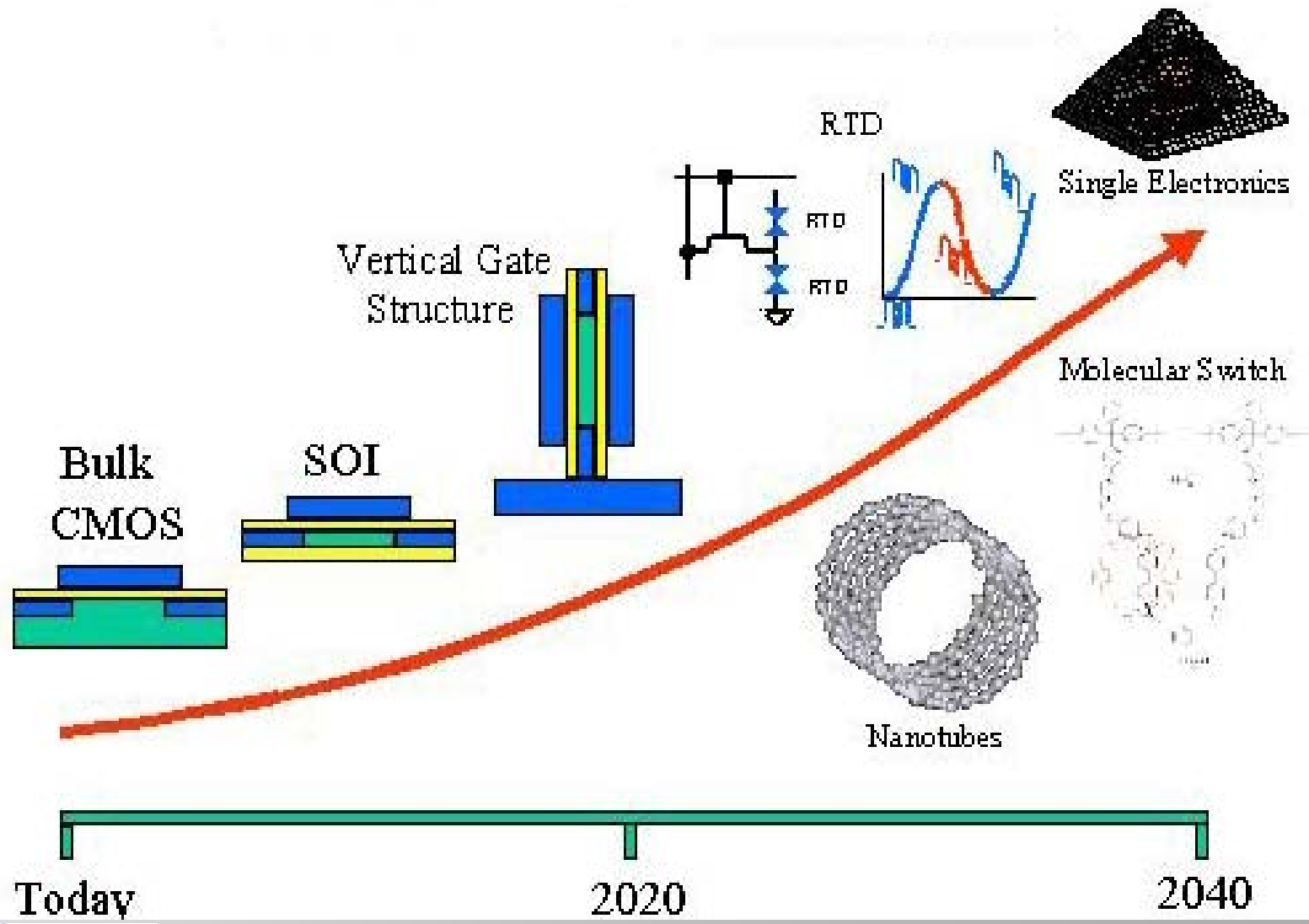




QUANTUM DEVICES

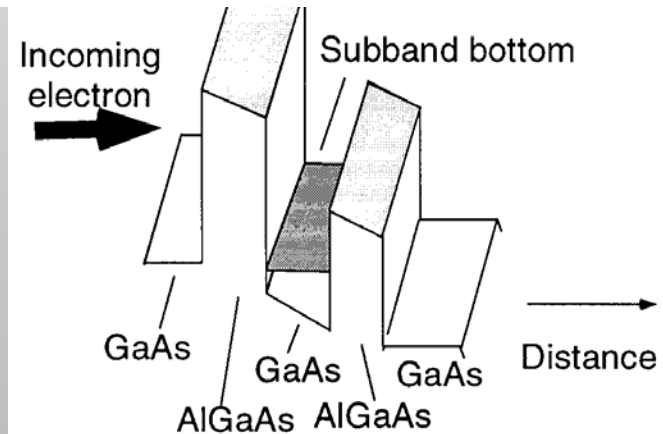
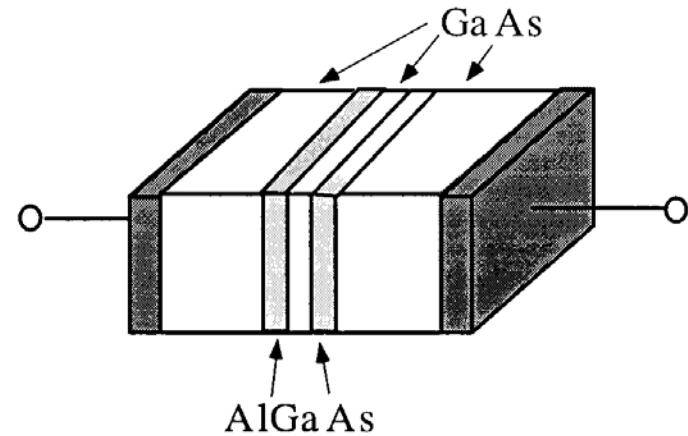
Nanoelectronics Roadmap



Towards THz frequencies: RTD

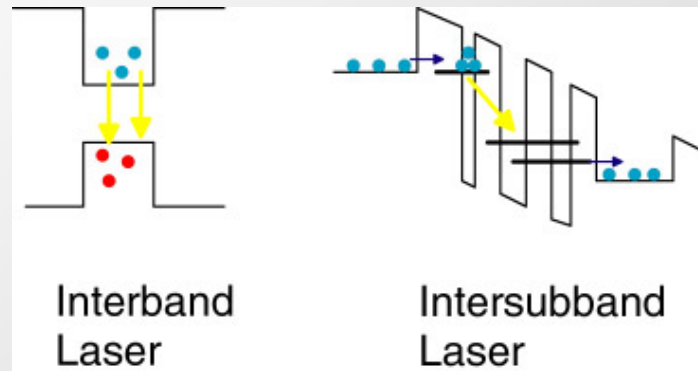
Operation based on resonant tunneling across a double barrier structure

Very high intrinsic cutoff frequency (~ 1 THz)



Quantum Cascade Laser

A semiconductor laser freed from "bandgap slavery"



Compared to conventional (interband) lasers, the quantum cascade laser has the following advantages:

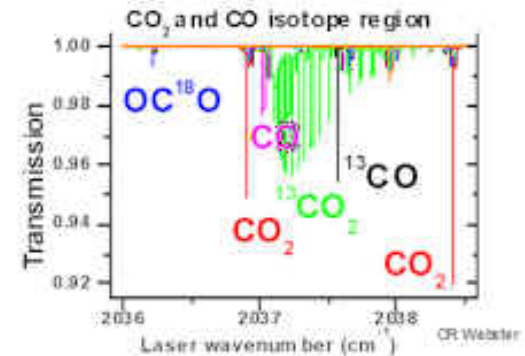
- The same semiconductor material whose technology is very well mastered can be used to manufacture lasers operating across the whole mid-infrared (and potentially even farther in the Far-Infrared, see our project FIR quantum cascade lasers)
- It is based on a cascade of identical stages (typically 20-50), allowing one electron to emit many photons, emitting more optical power.
- It is intrinsically more robust (no interface recombination)
- Since the dominant non-radiative recombination mechanism is optical phonon emission and not Auger effect (as it is the case in narrow-gap materials), it allows intrinsically higher operating temperature.

Quantum Cascade Laser

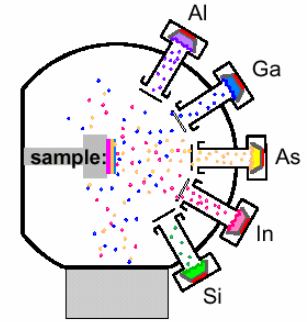
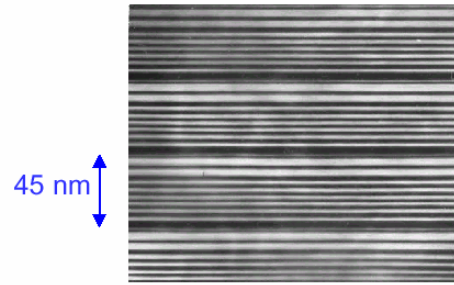
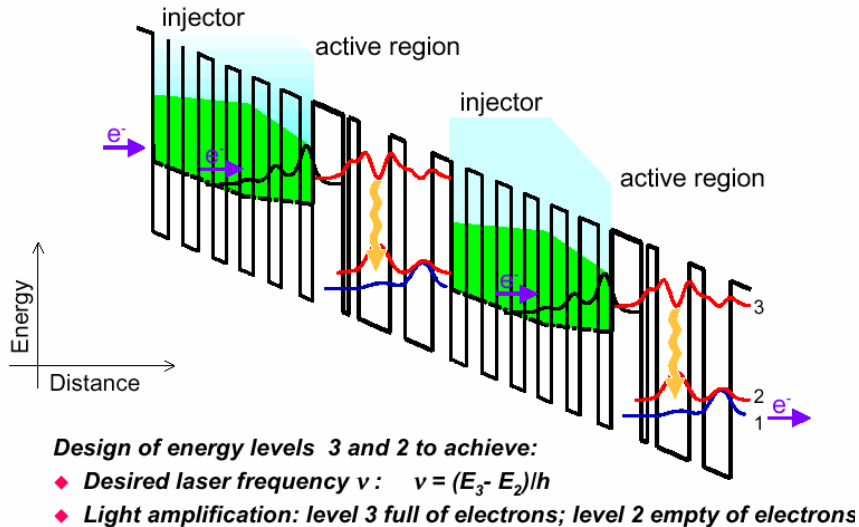
Quantum-Cascade Laser Spectrometer for *in situ* Measurement of Atmospheric and Evolved Gases on Mars, Titan, Venus and Europa

New generation of miniature tunable laser **mid-IR spectrometers operating at room temperature** for *in situ* measurement of atmospheric and evolved planetary gases. The all-solid-state spectrometer will be based on newly-available room-temperature **quantum-cascade (QC) laser** sources in the 3-12 μm wavelength region. The QC laser spectrometer would have immediate applications to Mars, Titan, Venus and Europa missions, could be operated on a descending or penetrating probe, lander, rover, or aerobot, would consume only a few watts of power, and weigh less than one kilogram. Because it directly accesses the wavelength region of strong vibration-rotation spectral lines, the QC laser spectrometer has wide-ranging and immediate application to measuring concentrations of several planetary gases such as H_2O , CH_4 , CO , CO_2 , C_2H_2 , HCN , C_2H_6 , C_2N_2 , HC_3N , O_3 , OCS , H_2S , and SO_2 , and numerous stable isotopes. Such measurements could be made to study atmospheric photochemistry and transport, mineralogical and biological experiments (e.g. quantification of evolved gases and their isotopic fractionation from thermal decomposition of minerals or ice), and respiratory or hazardous gas monitoring for human exploration of the solar system.

"Quantum-cascade laser measurements of stratospheric methane (CH_4) and nitrous oxide (N_2O)", C.R. Webster, G.J. Flesch, D.C. Scott, J. Swanson, R.D. May, W. S. Woodward, C. Gmachl, F. Capasso, D.L. Sivco, J.N. Baillargeon, A.L. Hutchinson, A.Y. Cho, accepted for *Applied Optics*, 2000.



Quantum Cascade Lasers



Cross-section of a few stages of QC-laser crystal crystal growth one atomic layer at a time

- ◆ Many (~ 500), few-atoms thick layers of alloy materials (Al, Ga, As, In);
- ◆ atomic control of layer thickness, 1 nanometer (nm) = 4 atomic layers
- ◆ atomically flat layer interfaces

- ◆ Wavelength (“color”) determined by layer thickness rather than by material composition
- ➔ all mid-infrared spectrum covered by the same material
- ◆ Each electron creates N laser photons in traversing an N-stage cascaded structure (N = 20 - 75)
- ➔ intrinsically high power lasers
- ◆ High reliability: low failure rate, long lifetime and robust fabrication

- ◆ Laser wavelength covers entire range from 3.4 to 17 μm
- ◆ High peak power (0.5 W) at room temperature in pulsed mode
- ◆ High power (0.2 W) at liquid-nitrogen temperature in continuous mode
- ◆ High spectral purity (single-mode laser)
- ◆ Wide single-mode tuning for high resolution spectroscopy
- ◆ Demonstration of gas sensing capability

Molecular diode

