Non-Conventional Tunneling Devices and Applications

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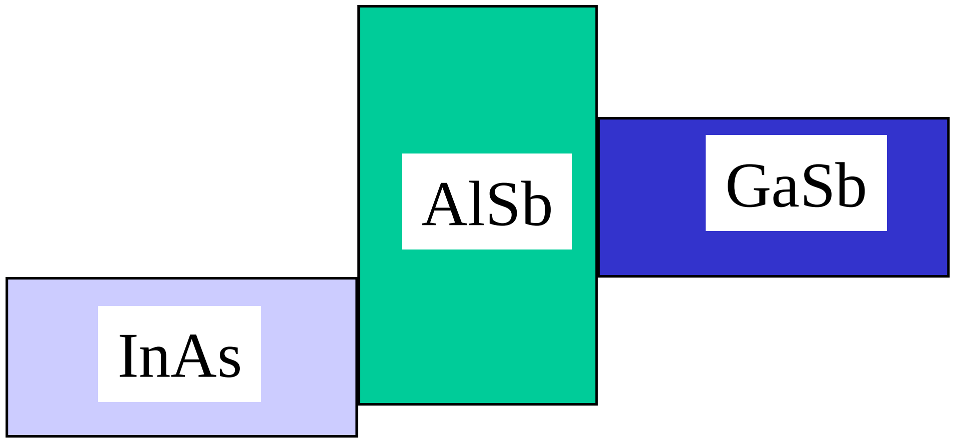
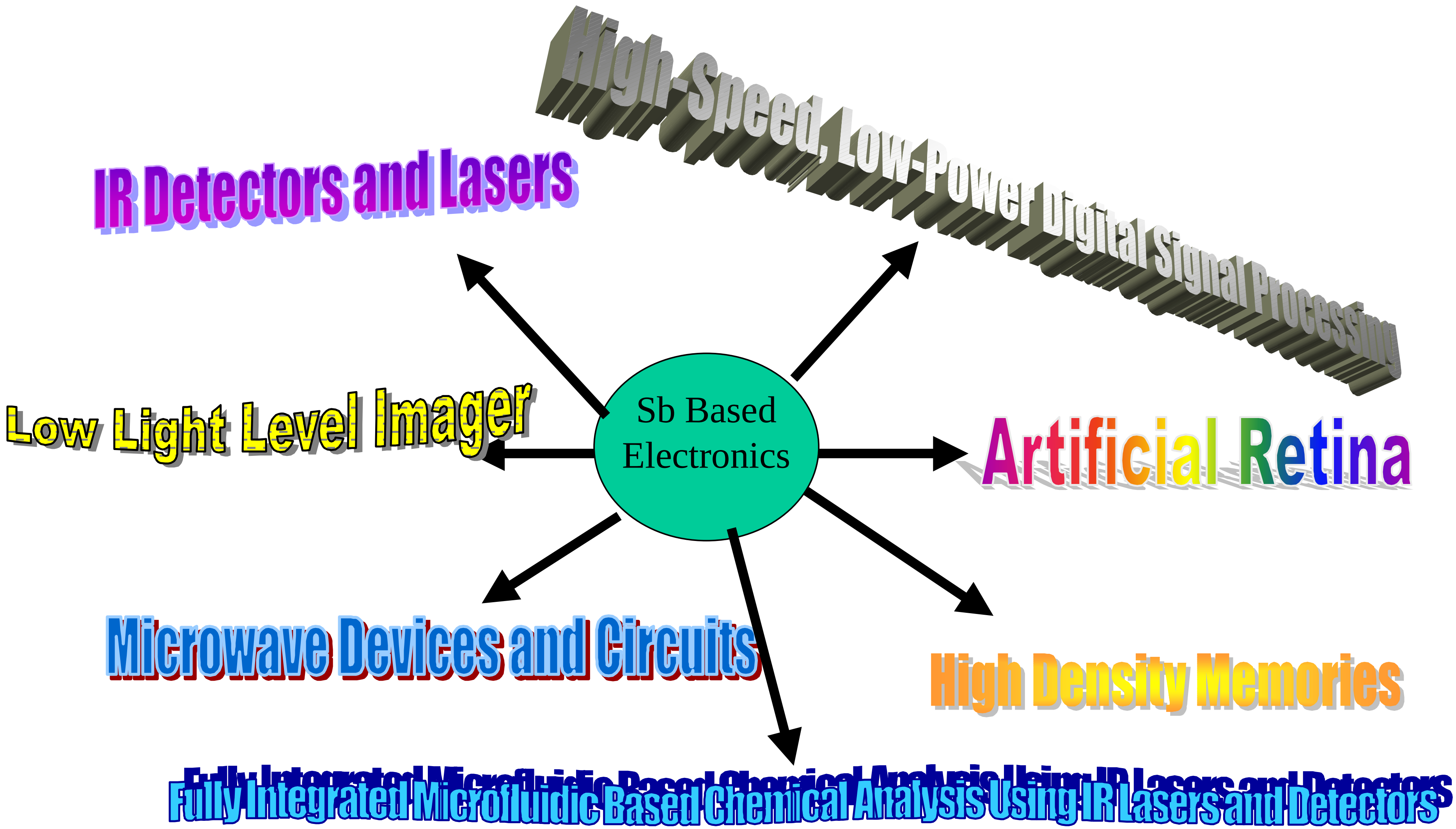
InAs/GaSb/AlSb Devices



- Near Lattice Match
- Unusual Band Lineups
- Very Novel Devices

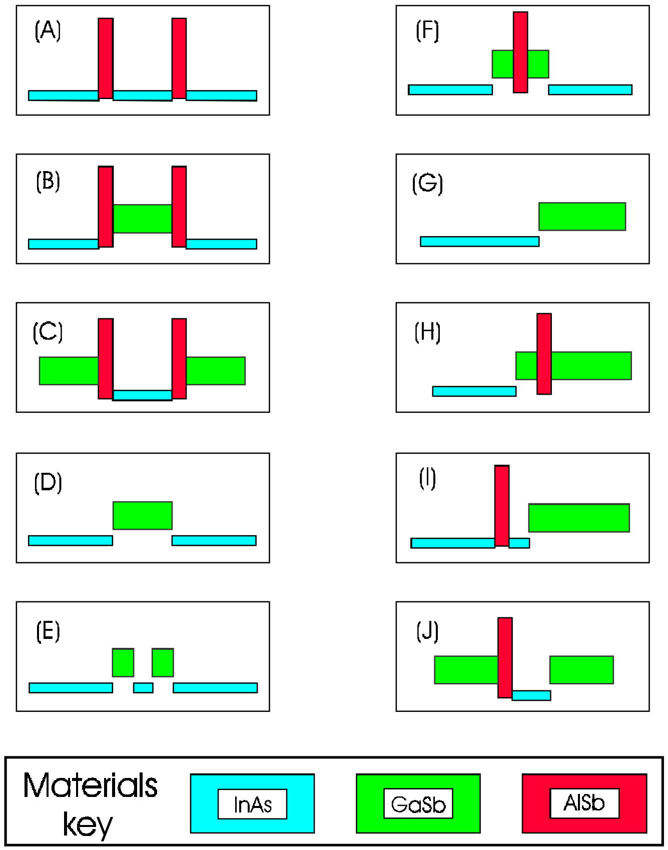
Sb Electronics One Stop Shopping for the Military



Outline

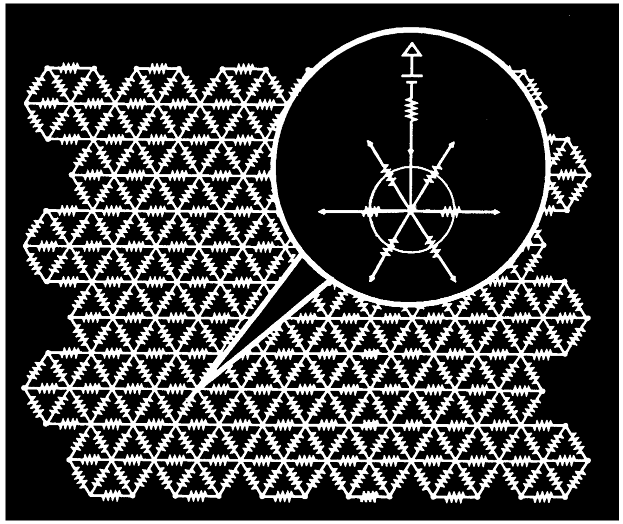
- Digital Signal Processing Circuits
- IR Systems
- Integrated Functional Systems

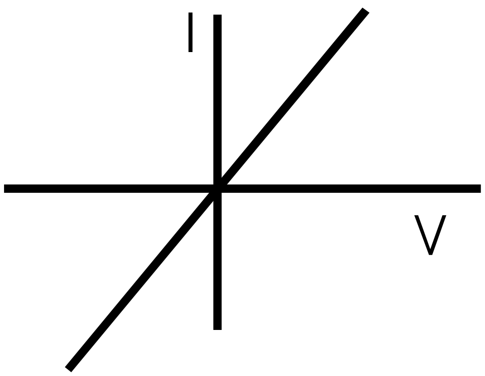
Zoo of Devices



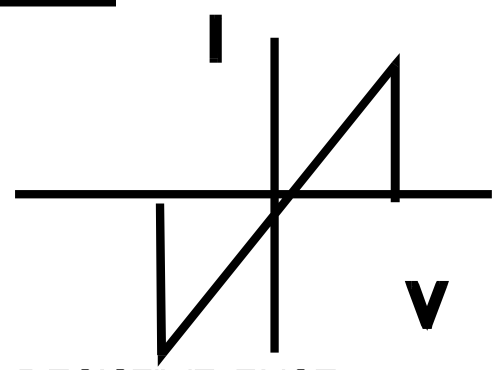
- Device A Holds High Frequency Record 720 GHz and Could Go to 1.4 THz
- Device B is the Basis for Retina and Very Low Power Digital Signal Processing

Artificial Retina Concept





PURE RESISTIVE
IV FOR LOCAL
AVERAGING

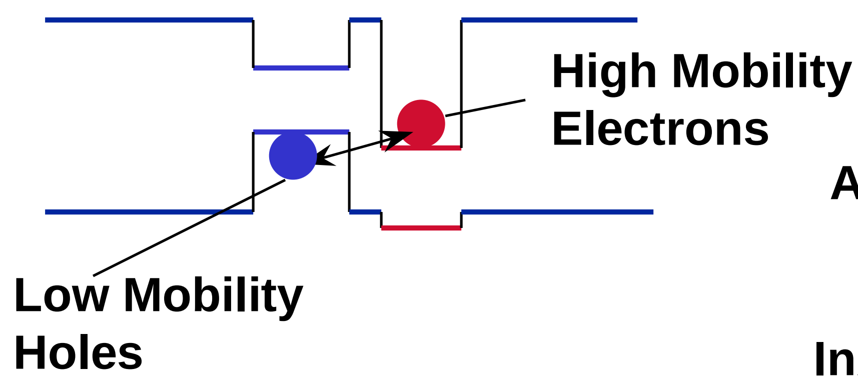


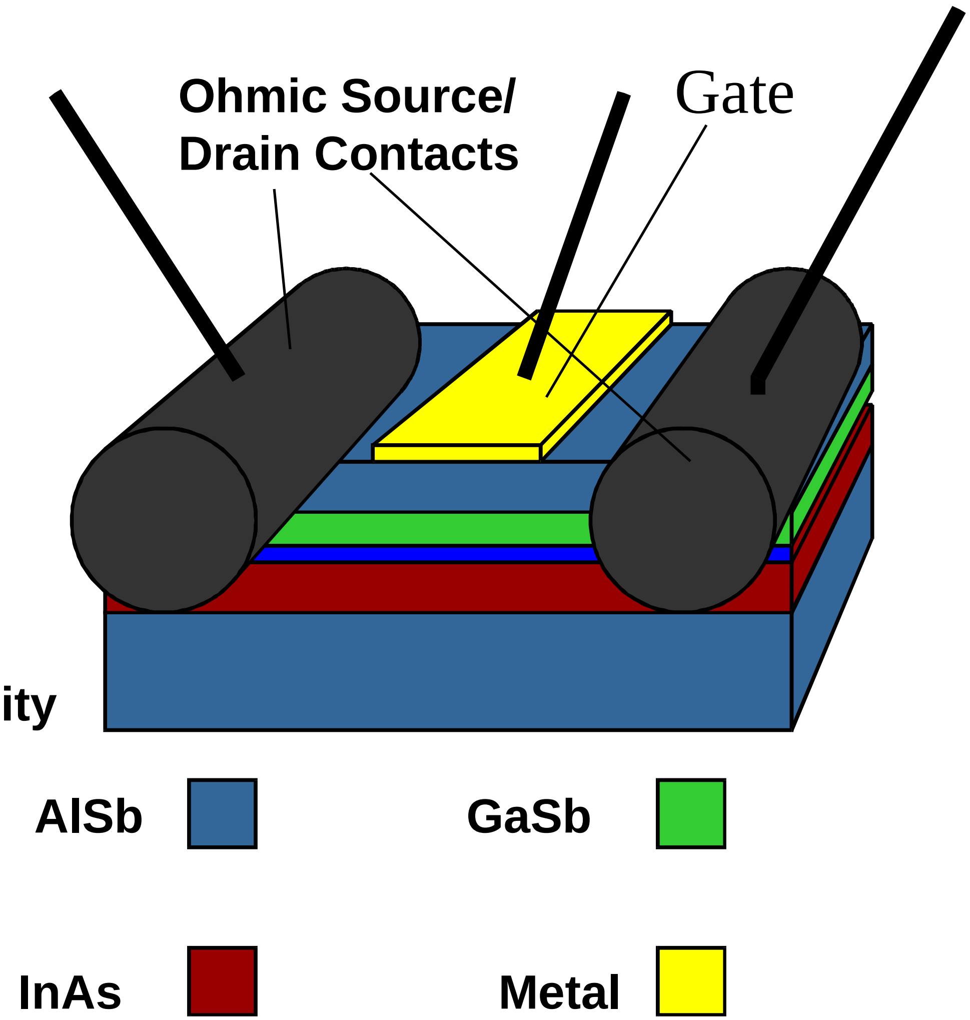
RESISTIVE FUSE
IV FOR LOCAL AVERAGING
AND EDGE DETECTION

Three Terminal Tunneling Device

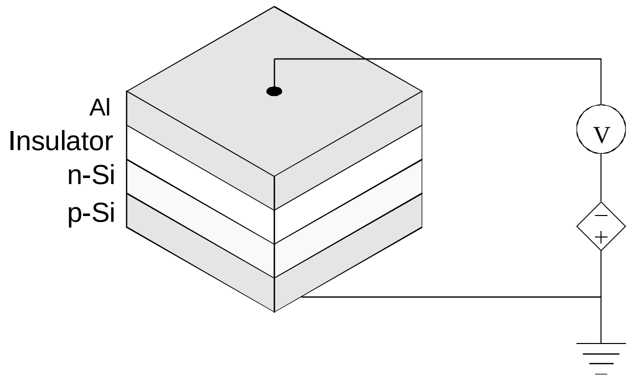
- High speed gate controlled modulation of source-drain IV
- High speed InAs channel
- Potentially interesting transport phenomena

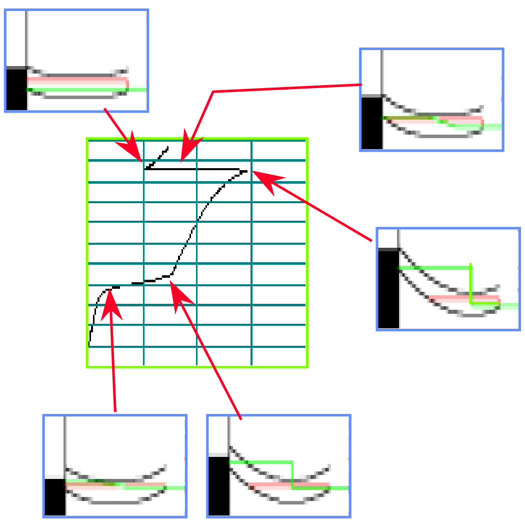
Band Diagram



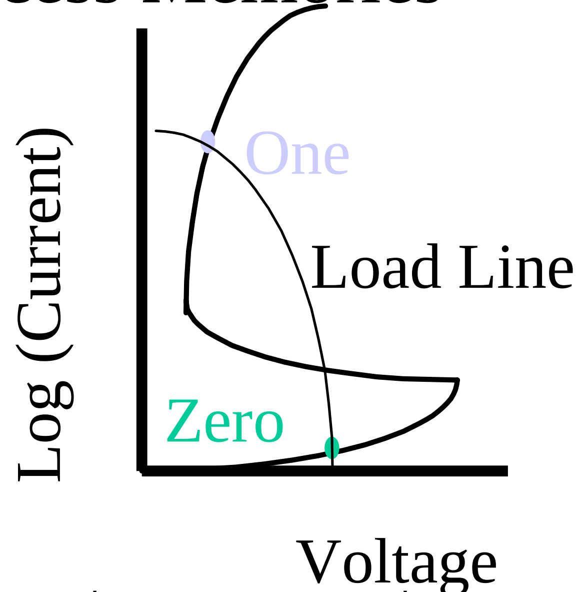


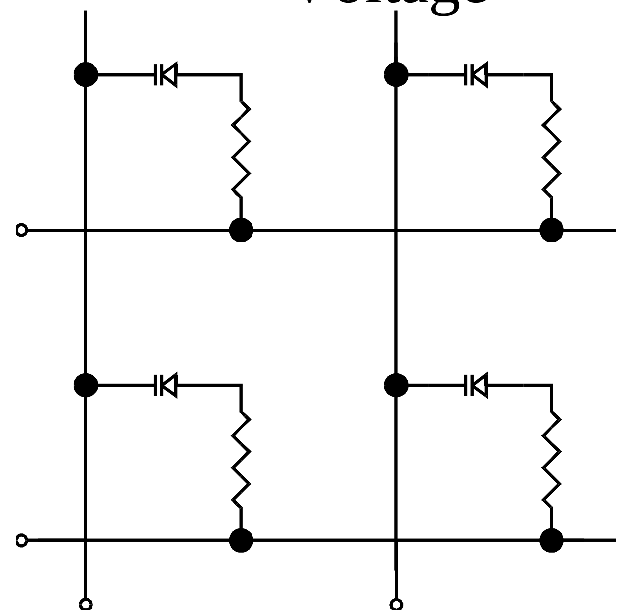
Transistorless Static Random Access Memories





- SRAM Major More than 50% of Area of Modern Microprocessor
- New Concept Gives Factor of Twenty Increase in Density
- High Speeds Like 1ns

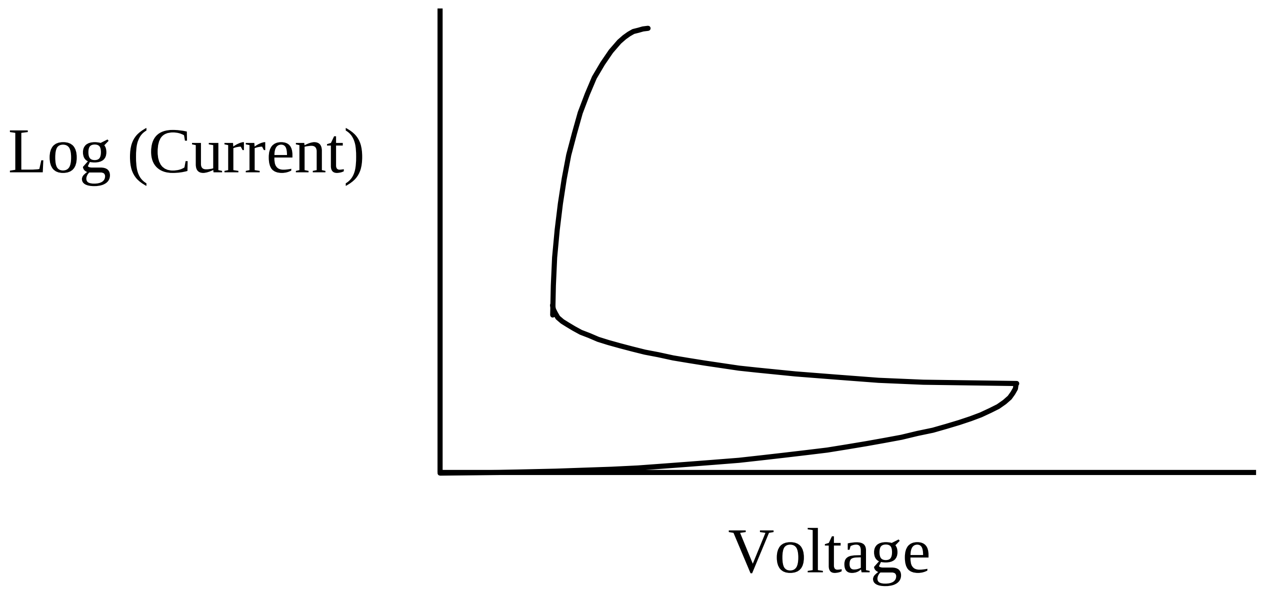




What We Have to Offer

- SRAM More than 50% by Area of Current Microprocessors
- New Approach to SRAM's
- Advantages
  - High Density (50-1000X Current SRAM)
  - SRAM Performance at DRAM Densities
- Risks
  - Processing Challenges
  - Uniformity of Device Performance

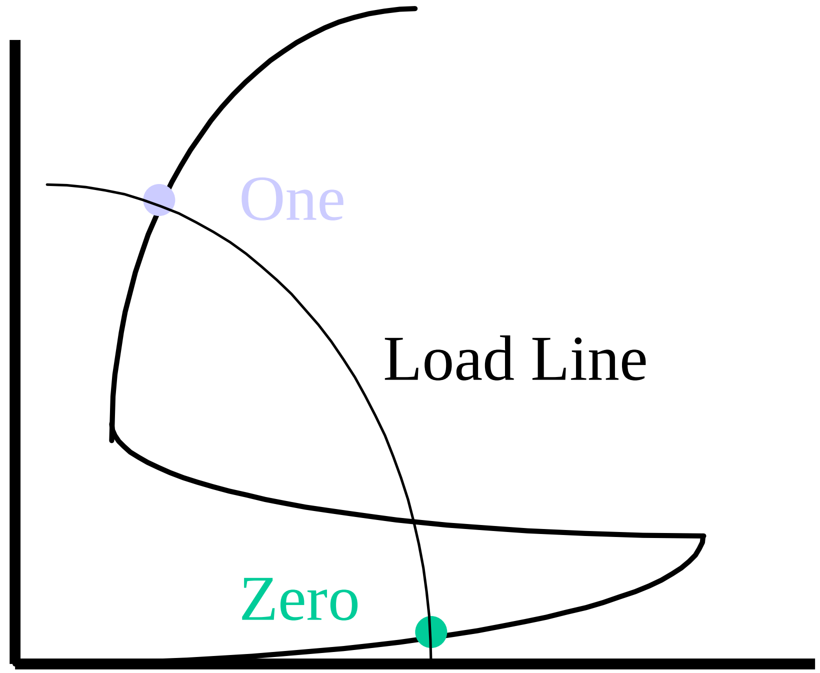
Thyrisistor As Memory



Use Multi-Valued IV Characteristic to Make a Memory

Load Line Circuit

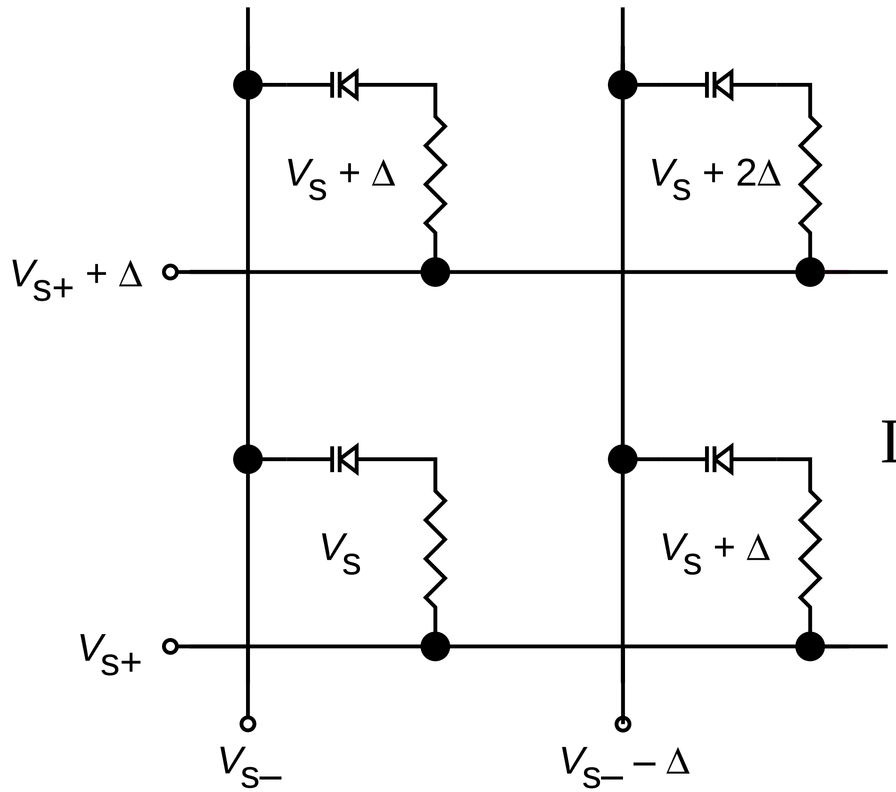
Log (Current)

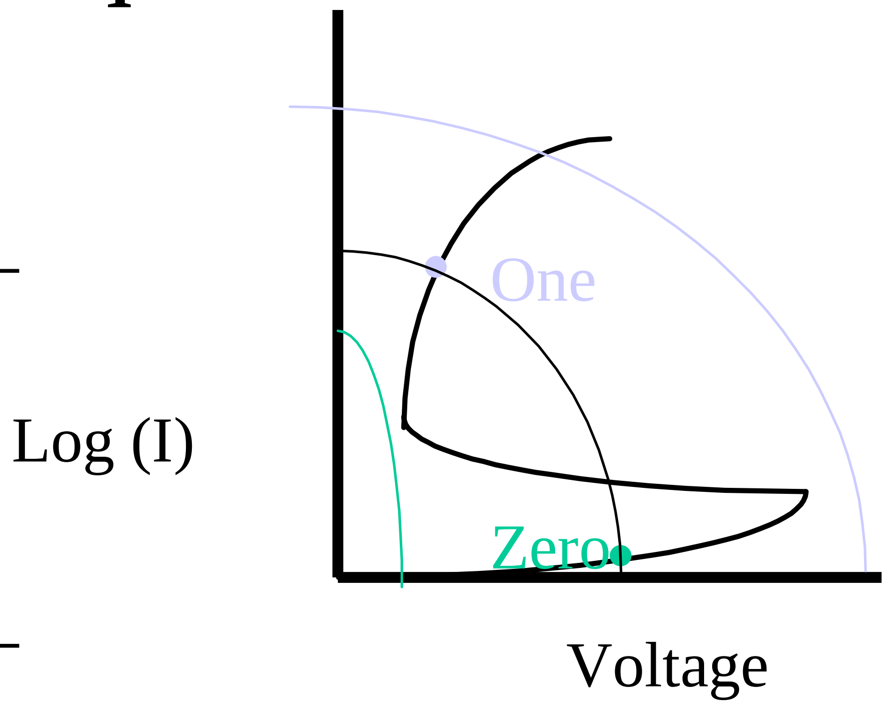


Voltage

Consider two values of voltage in

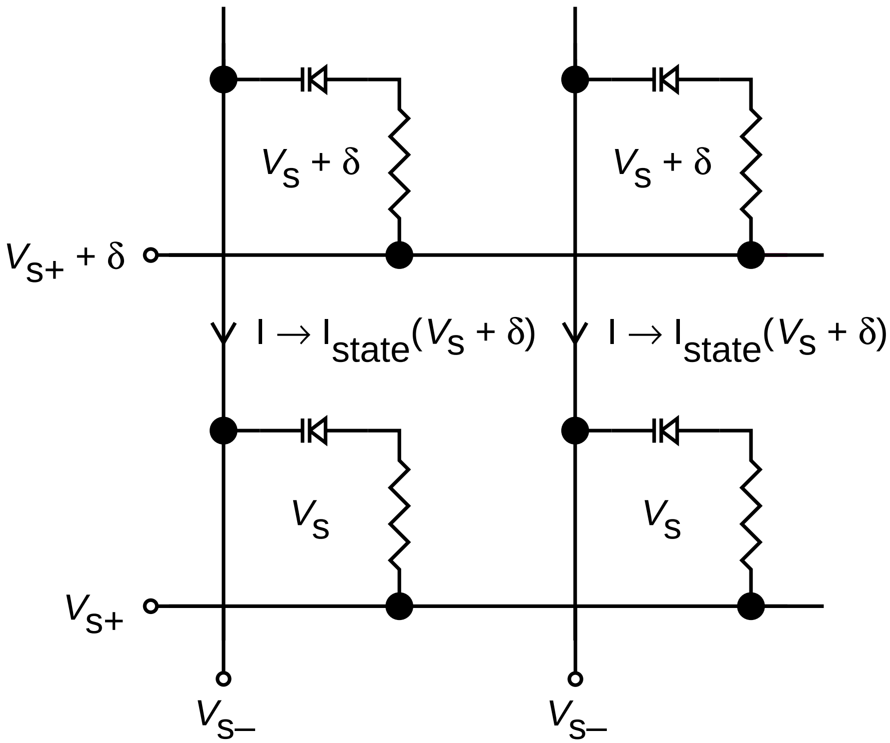
Write Sequence

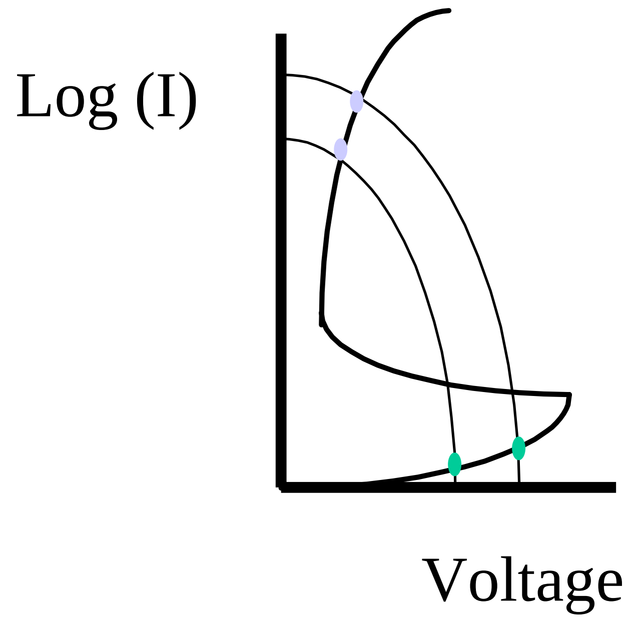




Apply Bias To Switch Into One Or Zero State

Read Sequence

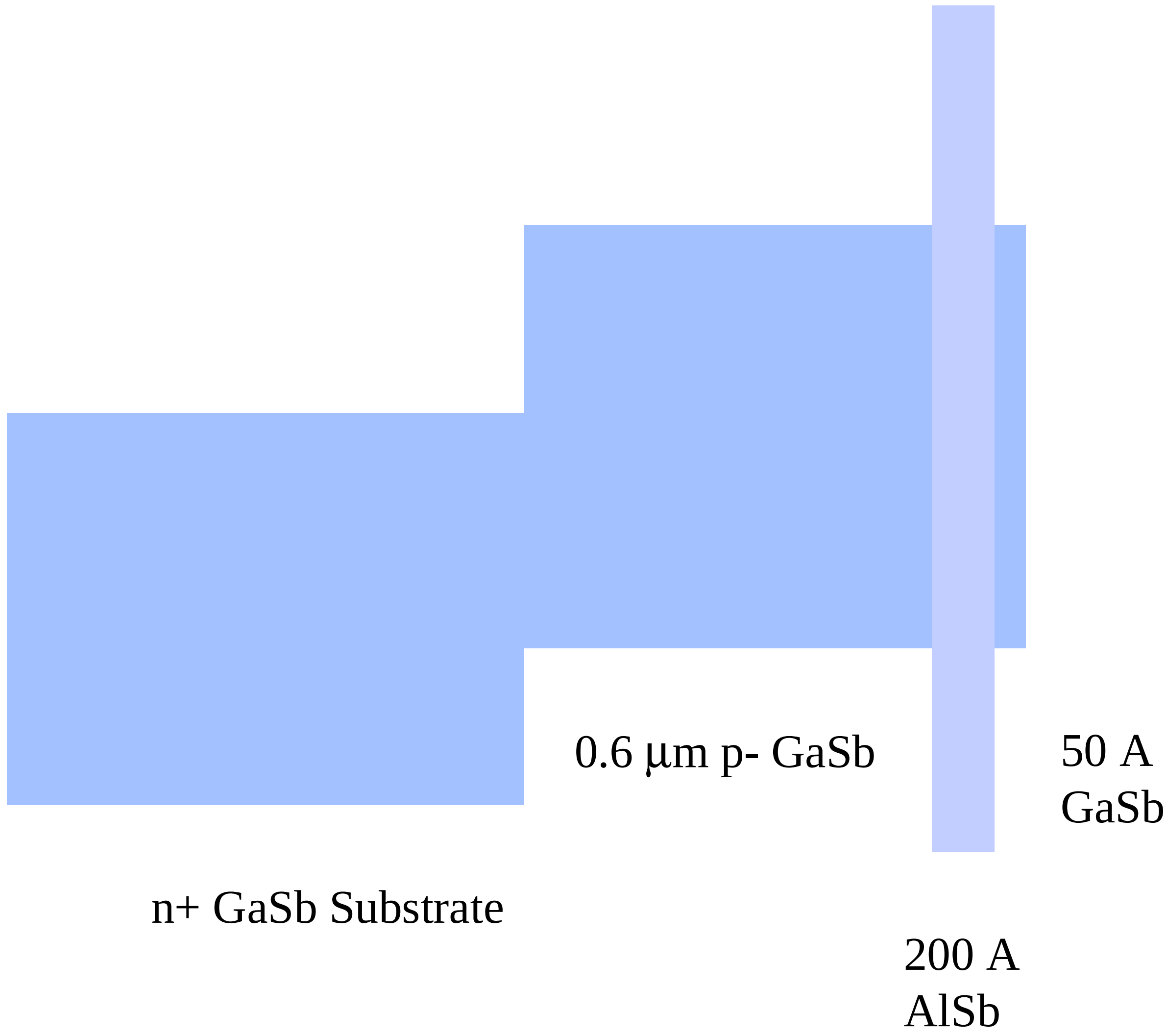




Read Zero Versus One By Current Difference

Read Time= (Charge for One)/(Current for One)

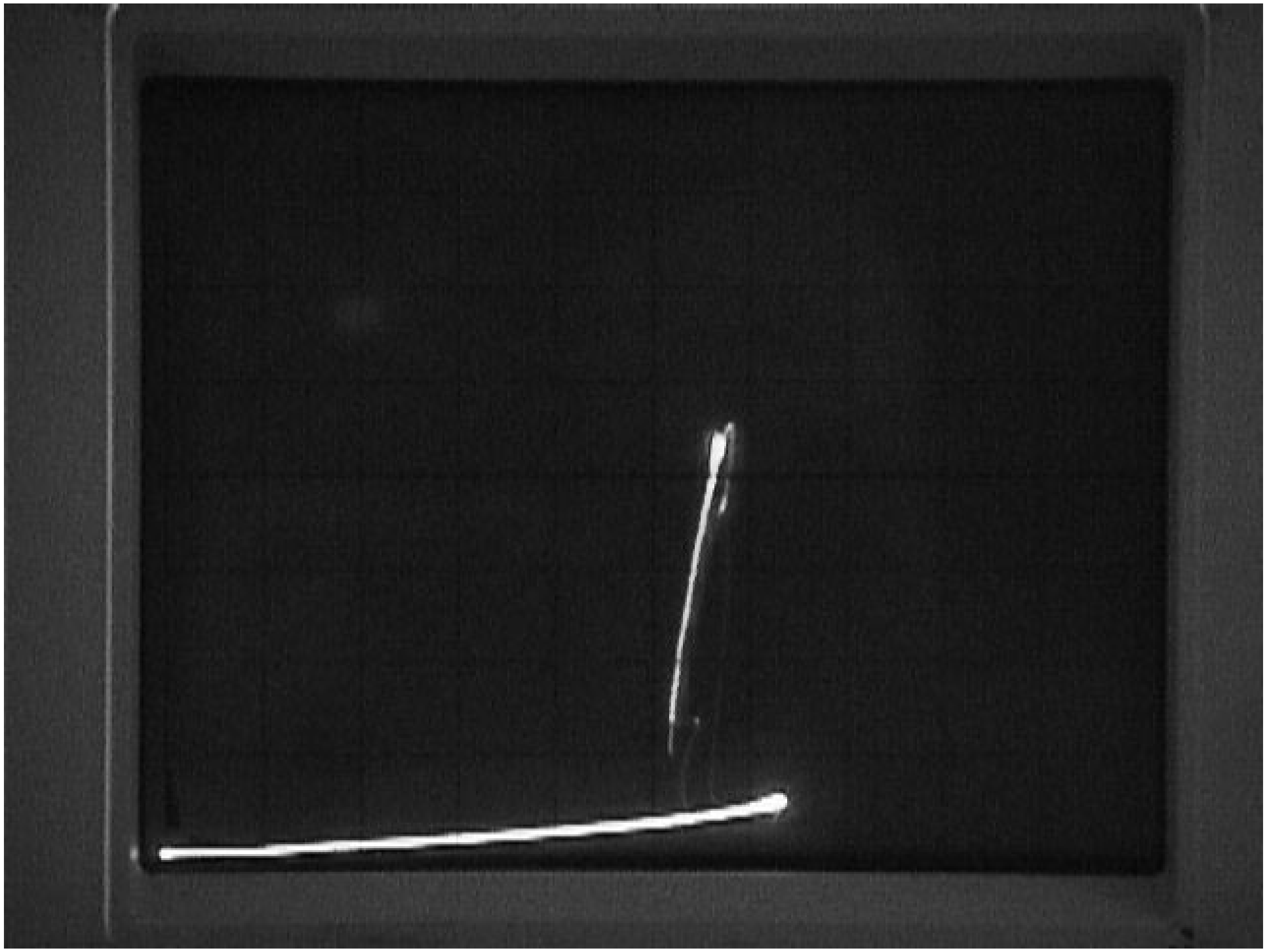
Sb Transistorless SRAM Structure



Preliminary Results

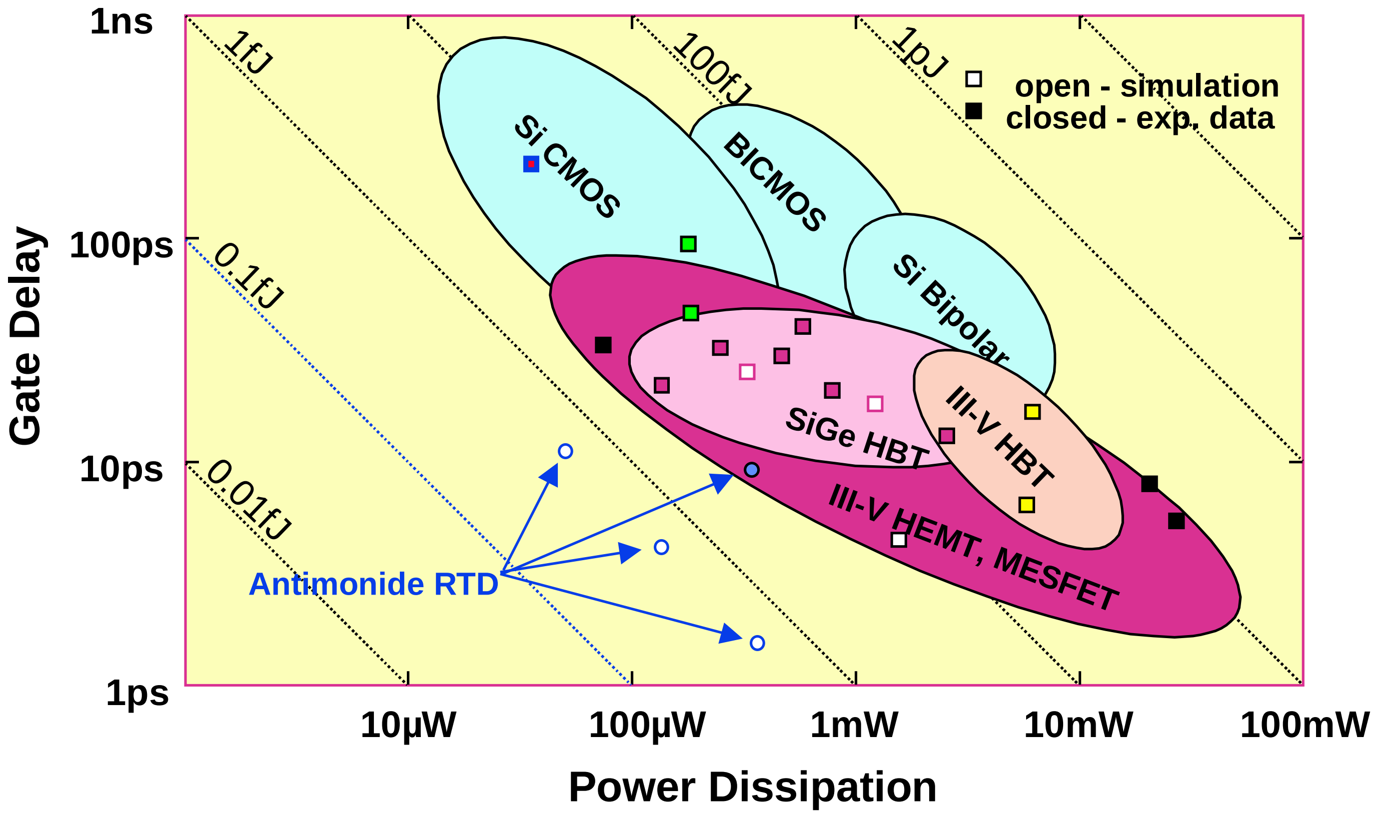
- 50A GaSb capping/200A AlSb barrier/0.6μm p-GaSb/n-GaSb substrate.

Current - 5 mA/div



Voltage - 0.5 V/div

Power - Delay Product for Digital IC Technologies



- data taken from U. König, et al., IEEE GaAs IC Symposium, pp14-18 (1995)
- Antimonide RTD data from W.Williamson et al., IEEE SSC **32**, 222(1997)
- Phillips, IEDM 95, p747; Siemans, op.cit. p739; NEC, IEDM 92, p. 397
- HRL, InP baseline and scaled process, 1997
- Vitesse FX and SCFX product data, GaAs MESFET, 1997
- Motorola, Complementary GaAs, GaAs IC Symp 95, p 18

Quantum Computing

- Number of Different Phenomena
  - High g value in InAs
  - Superconducting InAs
  - Self-Assembling Dots
  - Spin Based Properties in InAs/GaSb Structures
- Could be Basis for Quantum Computing

Mn in a III-V Zincblende

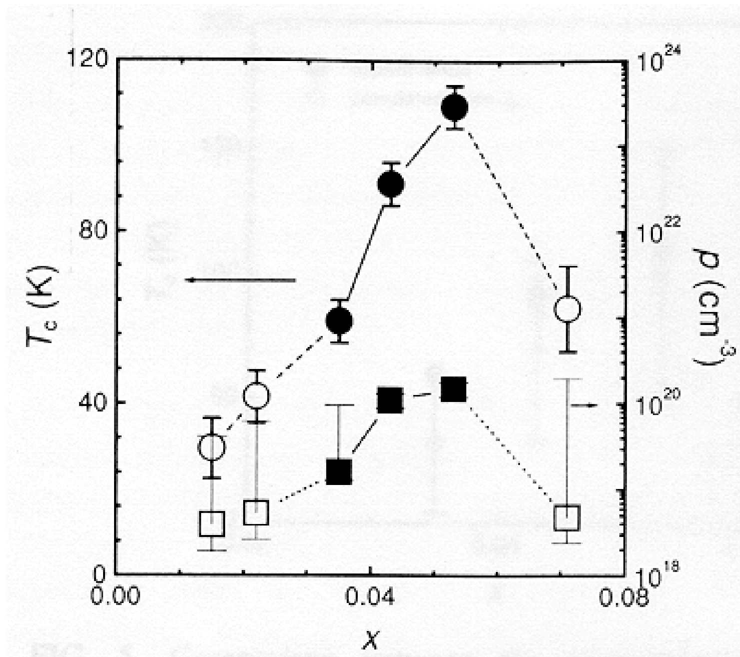
- Mn in GaAs
- Mn in InAs
- Mn in GaSb
- Most work in Japan

Magnetism in a III-V (Ga,Mn)As[1]

- (Ga,Mn)As 200 nm thick layers.
- Low temperature MBE (200-300°C).
- Alloy grade Mn concentrations, running from x=0.015 to x= 0.071 (relative to Ga).
- *p-type doping* is 15% of Mn concentration at most.

1: F. Matsukura *et al.* , Phys. Rev. B **57**, R2037 (1998).

Ferromagnetism in (Ga,Mn)As

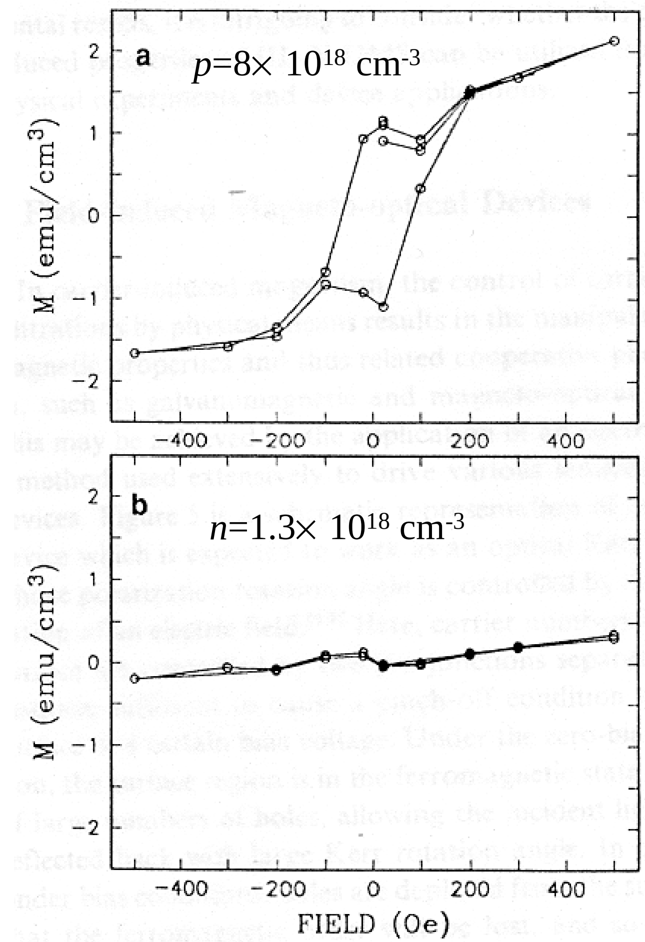


- Samples are ferromagnetic at low T.
- By applying appropriate strain, the easy axis of magnetization can be made to be in-plane or perpendicular to plane.
- T_C up to 110 K
- Ferromagnetism caused by RKKY (carrier mediated) interaction.

RKKY: Ruderman-Kittel-Kasuya-Yoshida

Magnetism in a III-V: (In,Mn)As

- Low T MBE on GaAs.
- It has been shown that the Mn interaction (direct exchange) in the cation sublattice of zincblende structure is antiferromagnetic[1].
- Low carrier concentration weakens RKKY[2].
- Low T_c (10K or less).
- Increased T_c in thin (In,Mn)As/(Ga,Al)Sb heterostructures due to magnetoelastic effects.



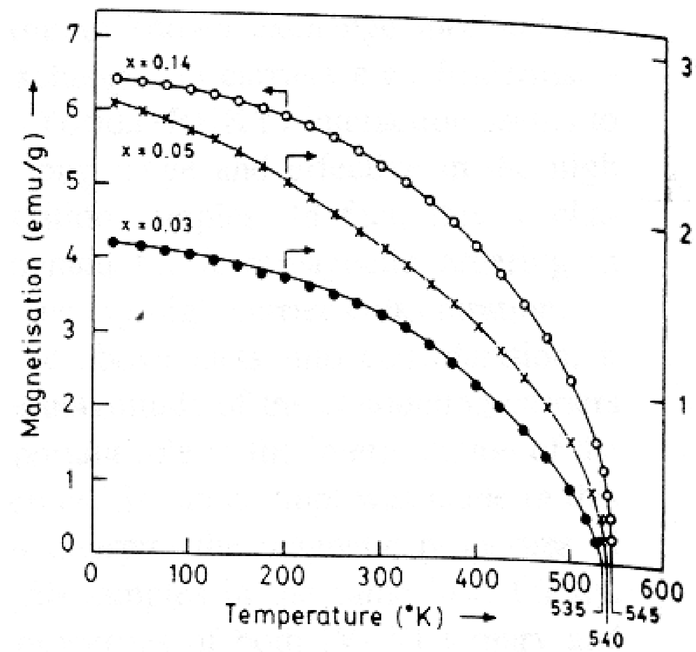
(In,Mn)As
T=2K

(In,Mn)As:Sn
T=2K

1: S. von Molnár *et al.* , J. Magn. Magn. Mater. **93**, 356 (1991).
2: H. Munekata, Adv. Mater. **1995**, 7, No. 1, p. 82.

Magnetism in a III-V: (Ga,Mn)Sb[1]

- Powdered sample.
- Ferromagnetic zincblende.
- High T_C.
- *p*-type semiconductor
- For x=0.05, p=1.12× 10^{10} (cm^{-3}) at room temperature.
- Again, RKKY is claimed as origin of ferromagnetic order.



1: T. Adiraki and S. Basu, J. Magn. Magn. Mater. **161**, 282 (1996).

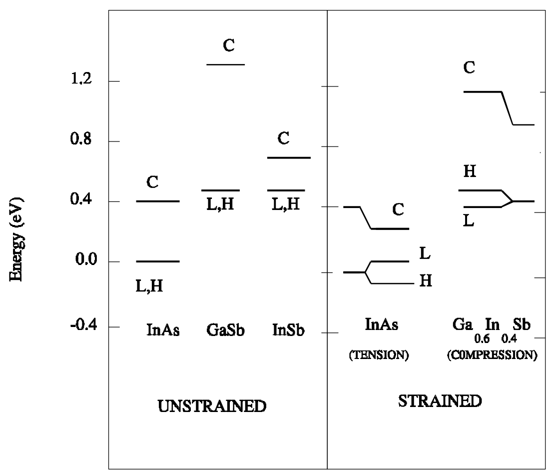
Quantum Computation?

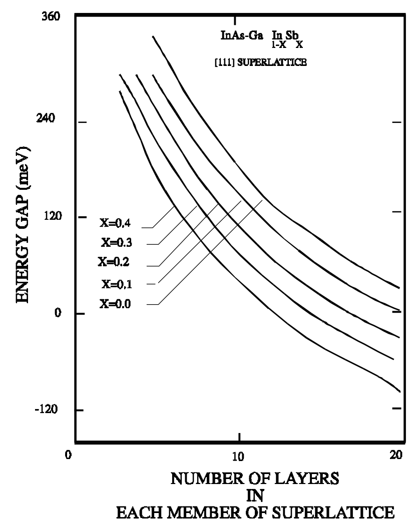
- Need longer spin lifetimes.
- Close spin scattering channels:
  - Presence of magnetic ions (?)
  - Limit interaction with other e^-
- Modulation of splitting by changes in pressure.
- Modulation of ferromagnetism by controlling carrier concentration.

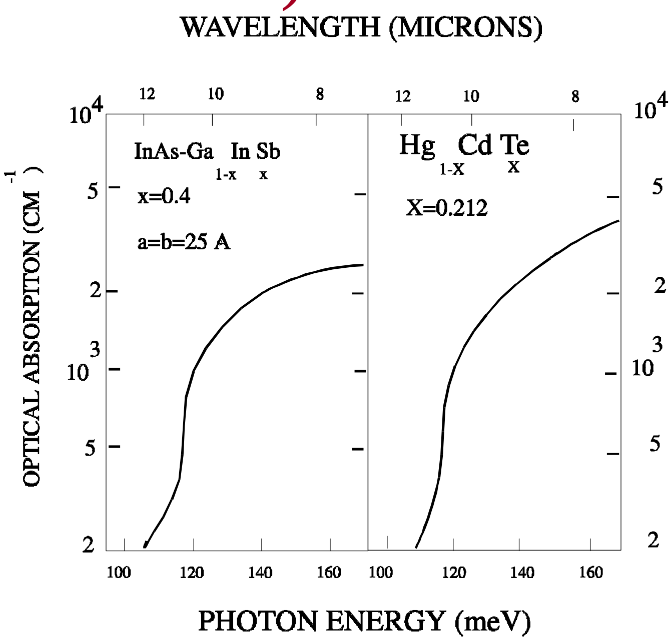
Infrared Superlattices

Basis of InAs/GaInSb Superlattice

(D. L. Smith and C. Mailhiot)





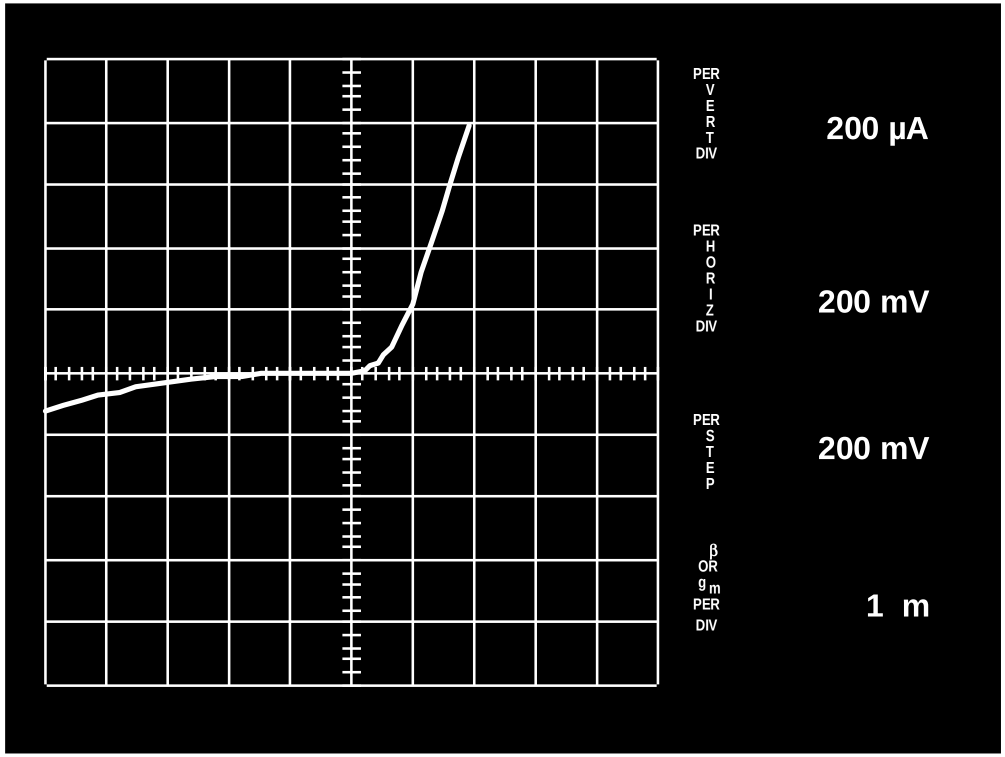


- Involves Electrons in Conduction Band of InAs and Holes in GaInSb
- All Band Gaps Can Be Reached
- Absorption As Large As For MCT

Auger Recombination Suppressed in InAs/GaInSb

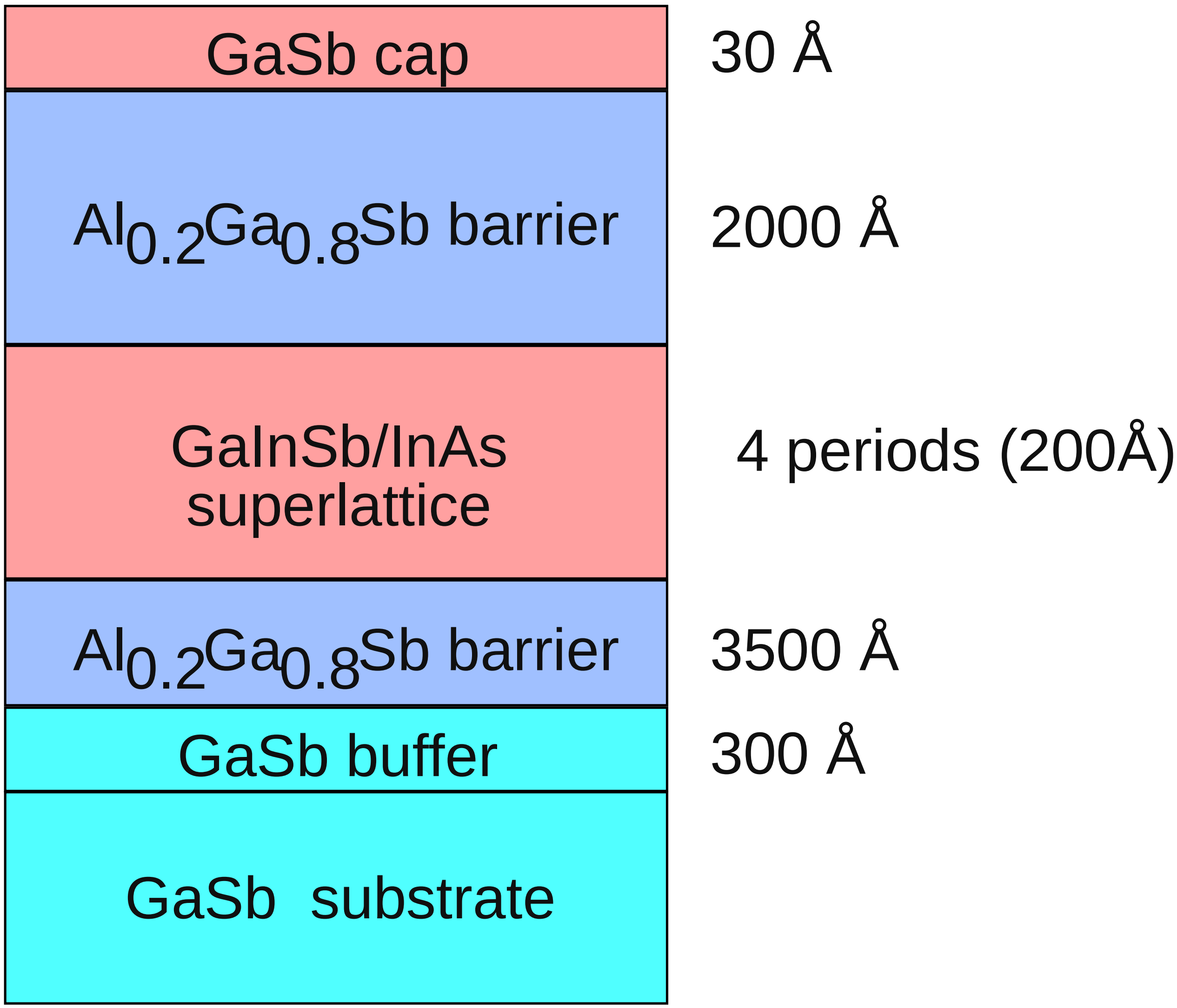
- **Theoretical Calculations by H. Ehrenreich and Co-Workers**
- Intrinsic lifetime demonstrated greater than in HgCdTe ⇒ higher ultimate operating temperature and/or performance
- Critical to further reduce extrinsic recombination at low excitation levels superlattice(Collaboration with Naval Research Laboratory)

Superlattice pn diode behavior
Richard Miles (HRL)



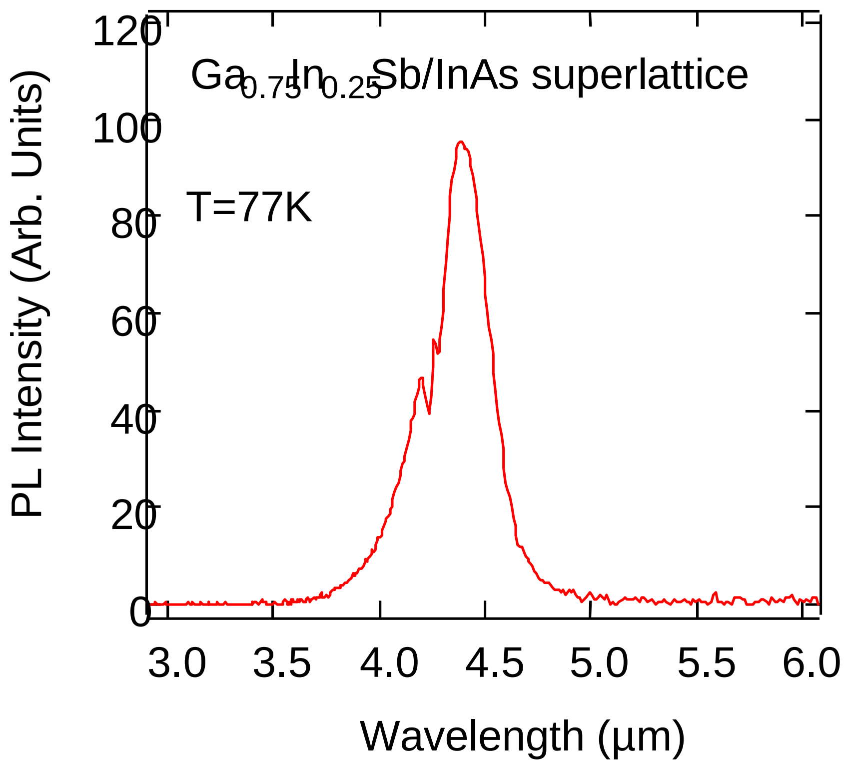
- R_0A=0.1-1 Ω-cm^2 (λc=12 μm @ 78K); η_c=10% ⇒ D*= 1x10^{10} cm^2 Hz$^{1/2}$/W
- R_0A=1-25 Ω-cm^2 (λc=7.5 μm @ 78K); ⇒ D*= 2x10^{10} cm^2 Hz$^{1/2}$/W

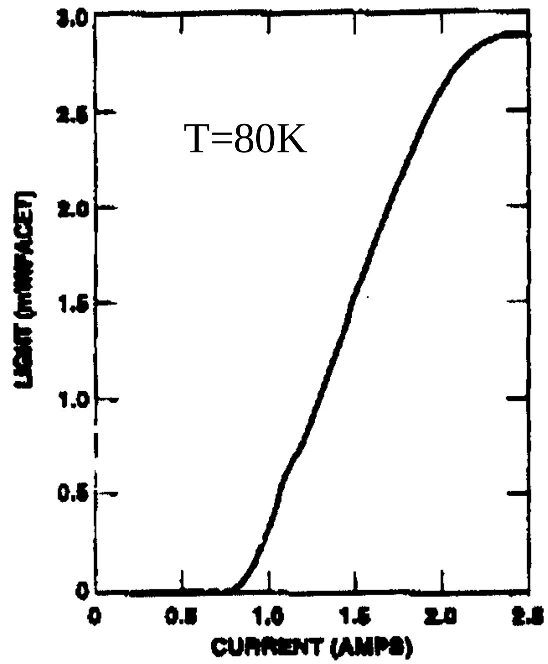
IR Lasers
(Richard Miles and David Chow (HRL)



- IR Superlattices based Lasers (3-5 μm)
- Complimentarty to Cascade Laser
- First Laser Based on Inter-Layer Transitions
  - Hole in GaInSb Layer
  - Electron in InAs Layer

Optical Properties of MWIR superlattice
(David Chow and Richard Miles)



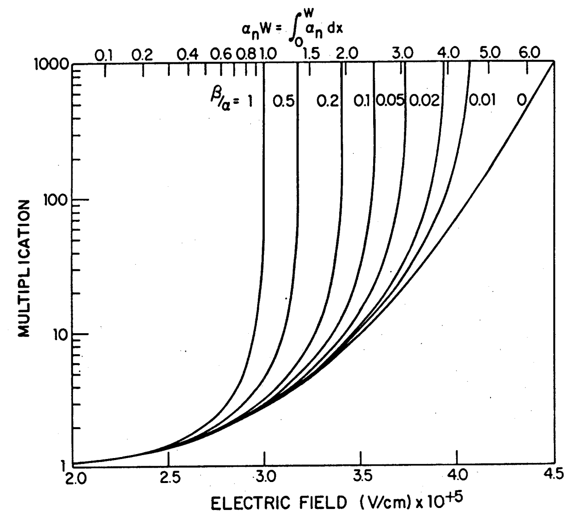


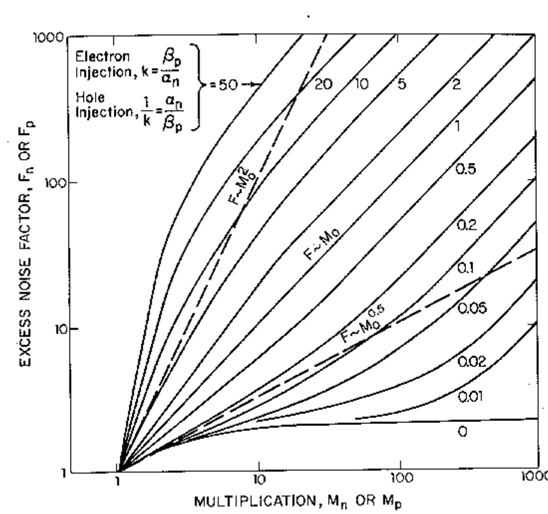
- Luminescence observed at 300K!
- Lasing at 3.28 μm at 170K and 3.90 μm at 84K

Avalanche Photodiodes for Low Light Level Imaging

Desired Characteristic: Impact Ionization by One Type of Carrier Only

- Better gain-bandwidth product
- Lower noise factor F
- Easier to maintain spatial uniformity in avalanche gain: less susceptible to micro plasma break down



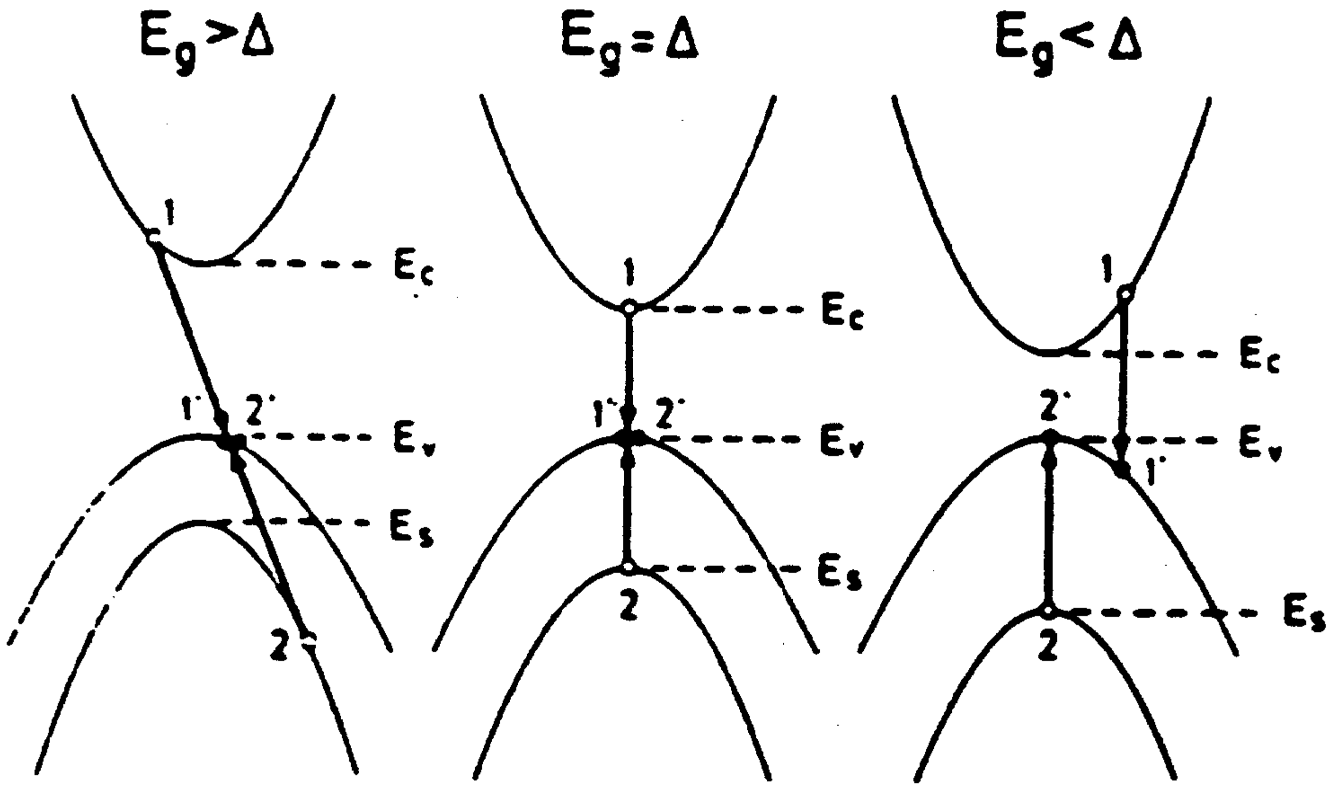


McIntyre, 1966

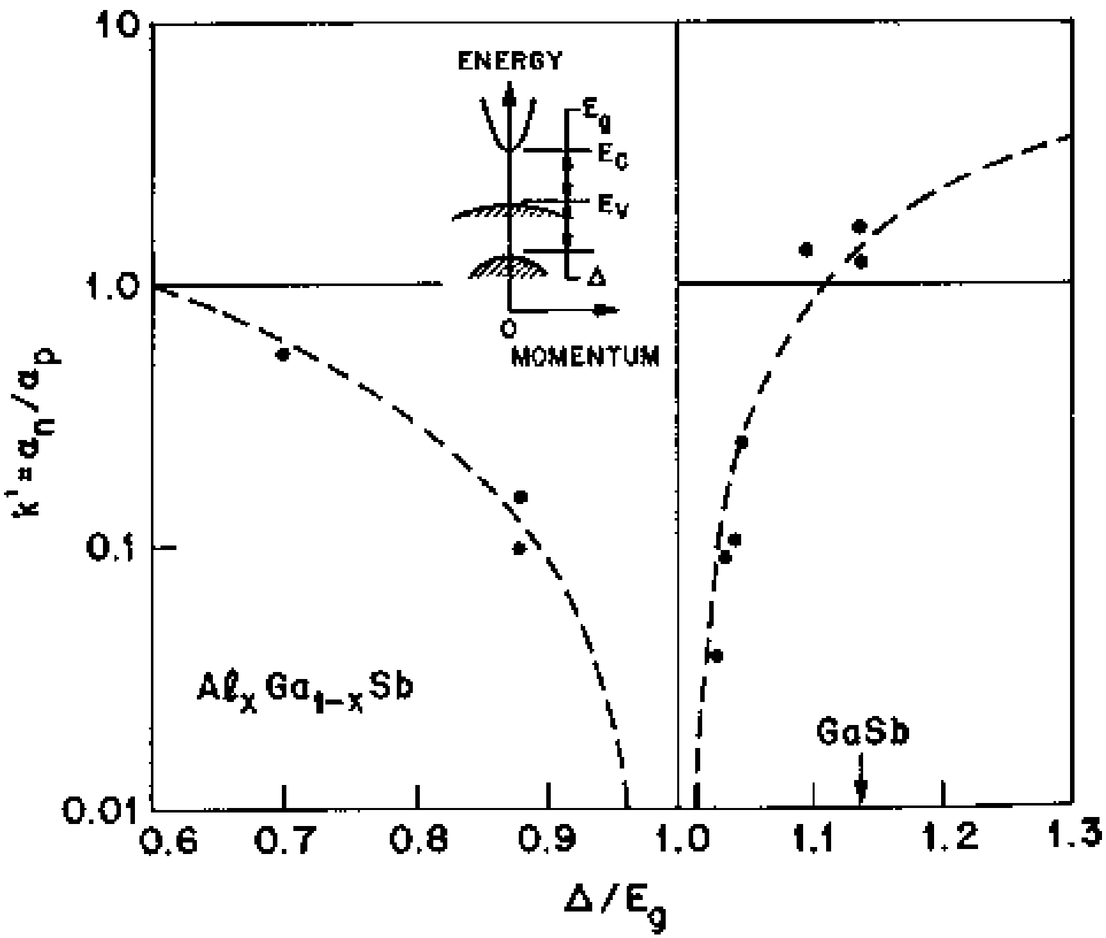
Best APD

- One Carrier Impact Ionization Process Dominates
- Seek to Enhance the Hole Impact Ionization Rate
- Seek to Enhance the Electron Impact Ionization Rate

Hole Impact Ionization



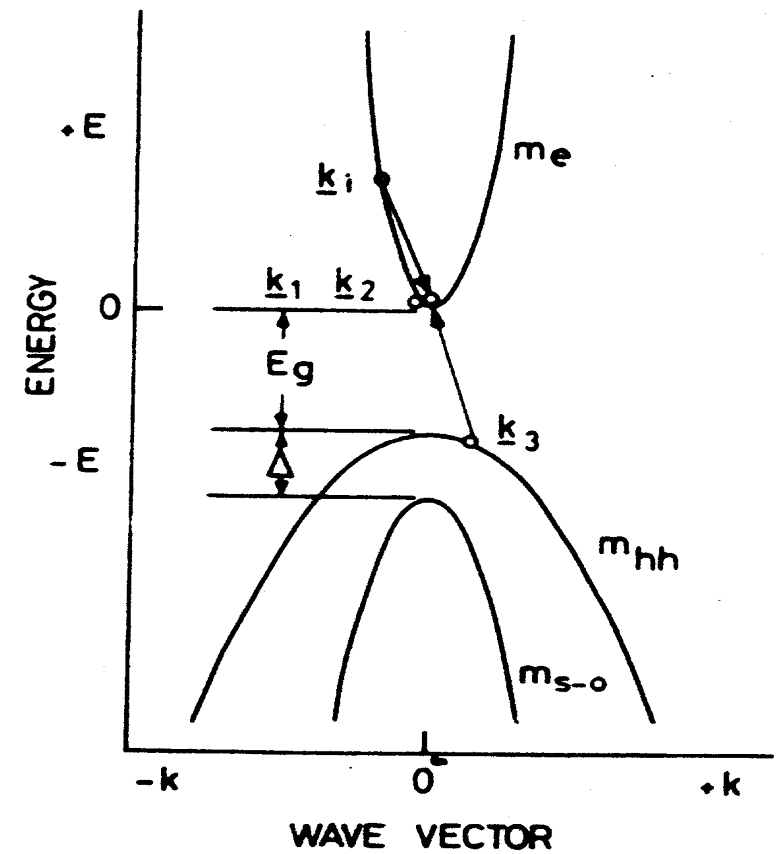
Split-off Band Resonant Enhancement of Hole Impact Ionization in AlGaSb



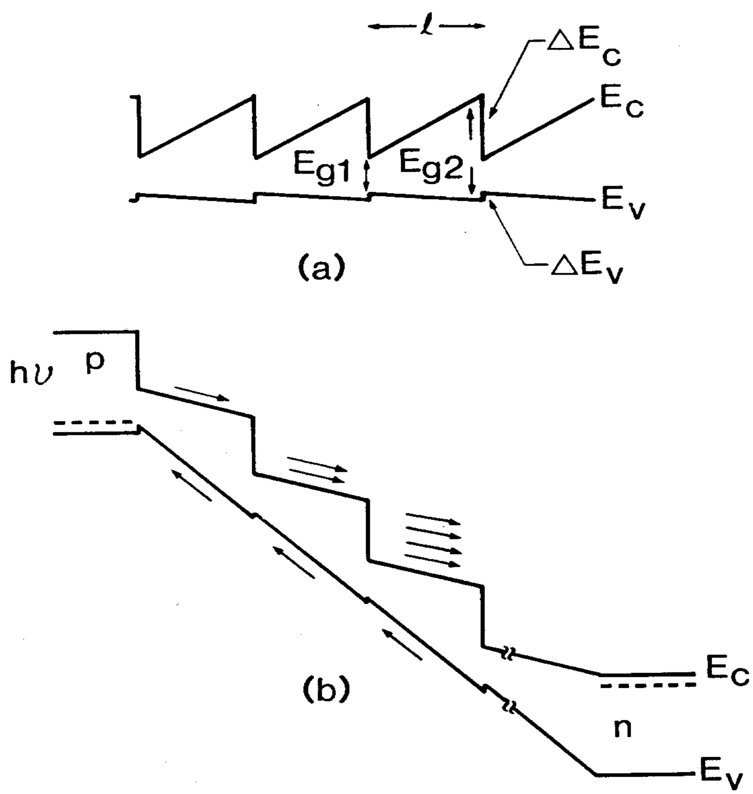
Hildebrand et al, 1981

Electron Impact Ionization

- Energy Conservation
- Momentum Conservation
- Equal group velocity for the three final particles



Enhancement of Electron Impact Ionization by Bandgap Engineering

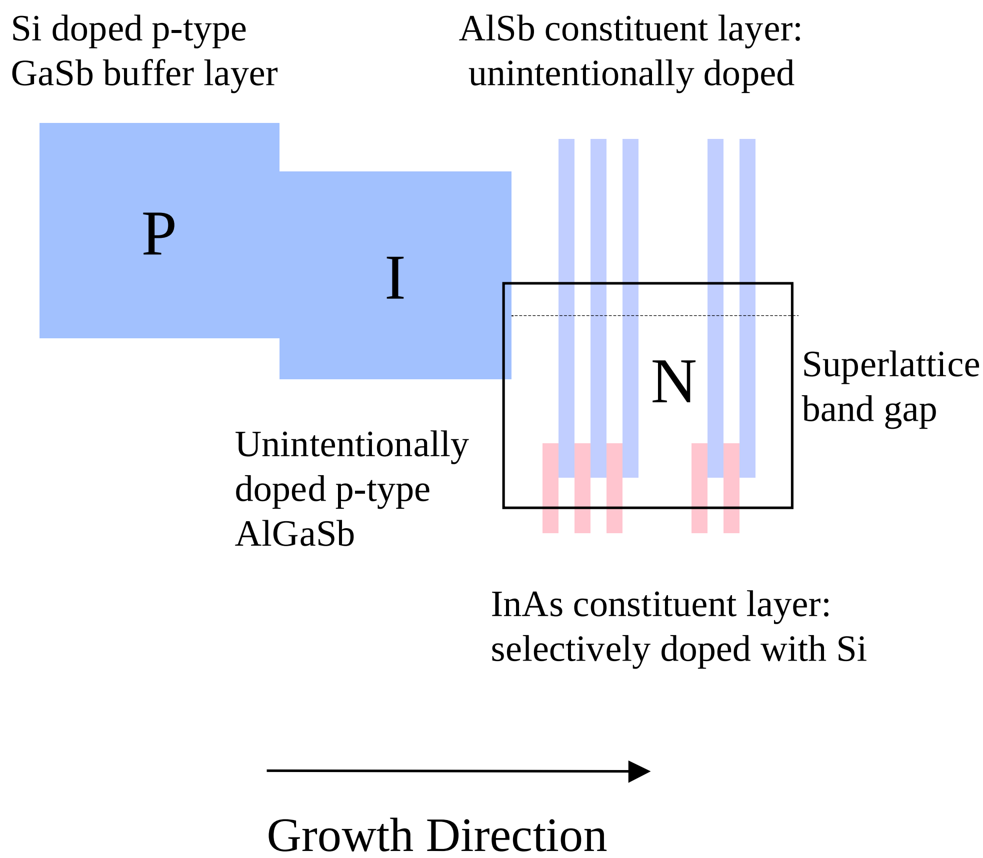


- GaSb/AlSb system
  - Conduction band offset: 0.65 eV
  - Valance band offset: 0.3 eV

Williams, Capasso, and Tsang, 1982

APD in the Antimonide System by MBE

- In bonded wafer
- Unintentionally doped p-type ($10^{17}/cm^3$) GaSb wafer
- Si doped p-type ($10^{18}/cm^3$) GaSb layer
- Unintentionally doped AlGaSb avalanche multiplication layer
- Selectively doped n-type InAs/AlSb superlattice for top contact
  - Substrate temperature lowered to 420 C, near the GaSb RHEED 1x3 to 1x5 transition point
  - InAs layer doped with Si
  - InSb like interface
  - As flux minimized by using valved cracker



Integration of Systems

- Overall Would like to Produce Integrated Functional System
- InAs/AlSb/GaSb Could be the Basis for a Number of Integrated Systems

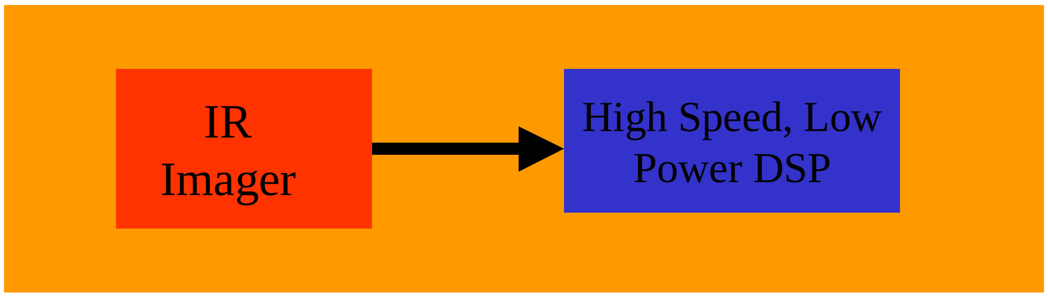
Integrated Infrared Detector System

Infrared Superlattice Detector Array

Artifical Retina for Edge Enhancement

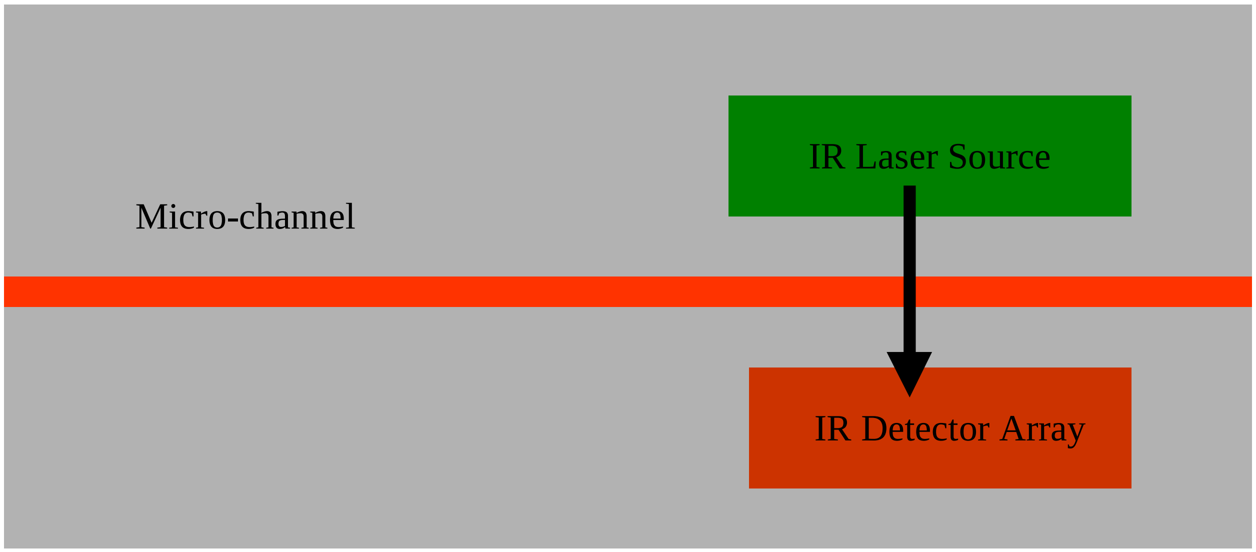
- Could Produce Multi-Spectra IR Imager
- Artifical Retina at Density for IR Pixels to Give Edge Enhancement

Integrated Imager and Digital Signal Processor



Use Single Subtrate to Fabricate IR Imager
High Speed, Low Power Digital Signal Processor

Microfludic Chemical Analysis



InAs/GaSb/AlSb systems ideal for microfludic analysis systems

Summary

- InAs/GaSb/AlSb is one of the most versatile Heterojunction System
- Wide Range of Devices of Interest to the Military
- Basis for Integrated Function Chip
- Single Stop Shopping for US Military