Silicon-Germanium Nanotechnology For Wireless Communications and Radars

Leonid Tsybeskov

Department of Electrical and Computer Engineering
New Jersey Institute of Technology
Newark, NJ

NJIT
New Jersey Institute of Technology

THE ELISHA YEGAL BAR-NESS
CENTER FOR WIRELESS COMMUNICATIONS
AND SIGNAL PROCESSING RESEARCH

Motivation:
Cost-Efficient, Highly Integrated RF Systems-on-a Chip

Two Solutions:

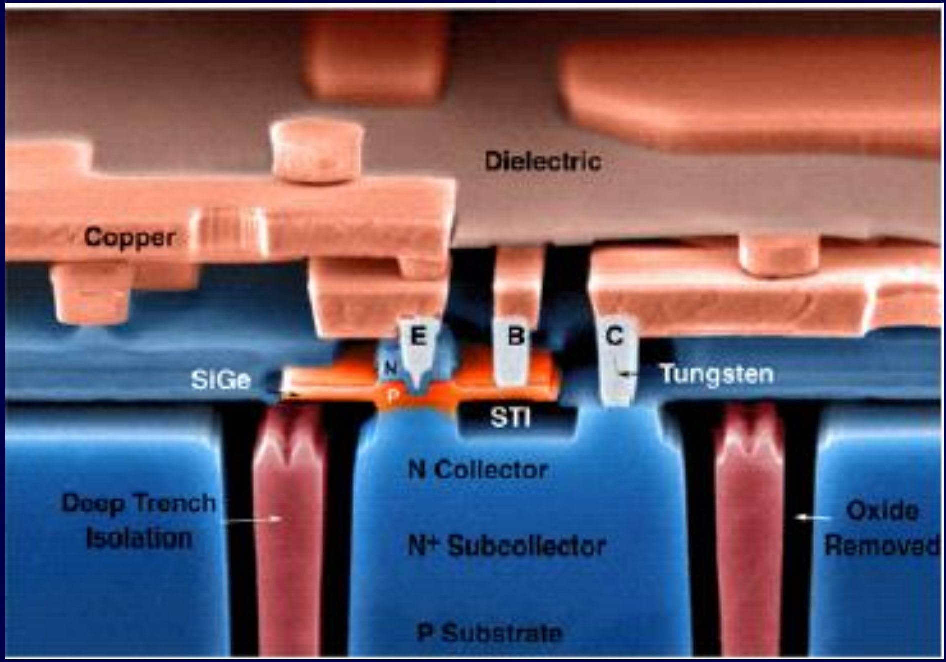
1. SiGe heterojunction bipolar transistors (HBTs): Mature technology

2. SiGe nanowire heterojunctions: New approach

2

Traditional RF Devices

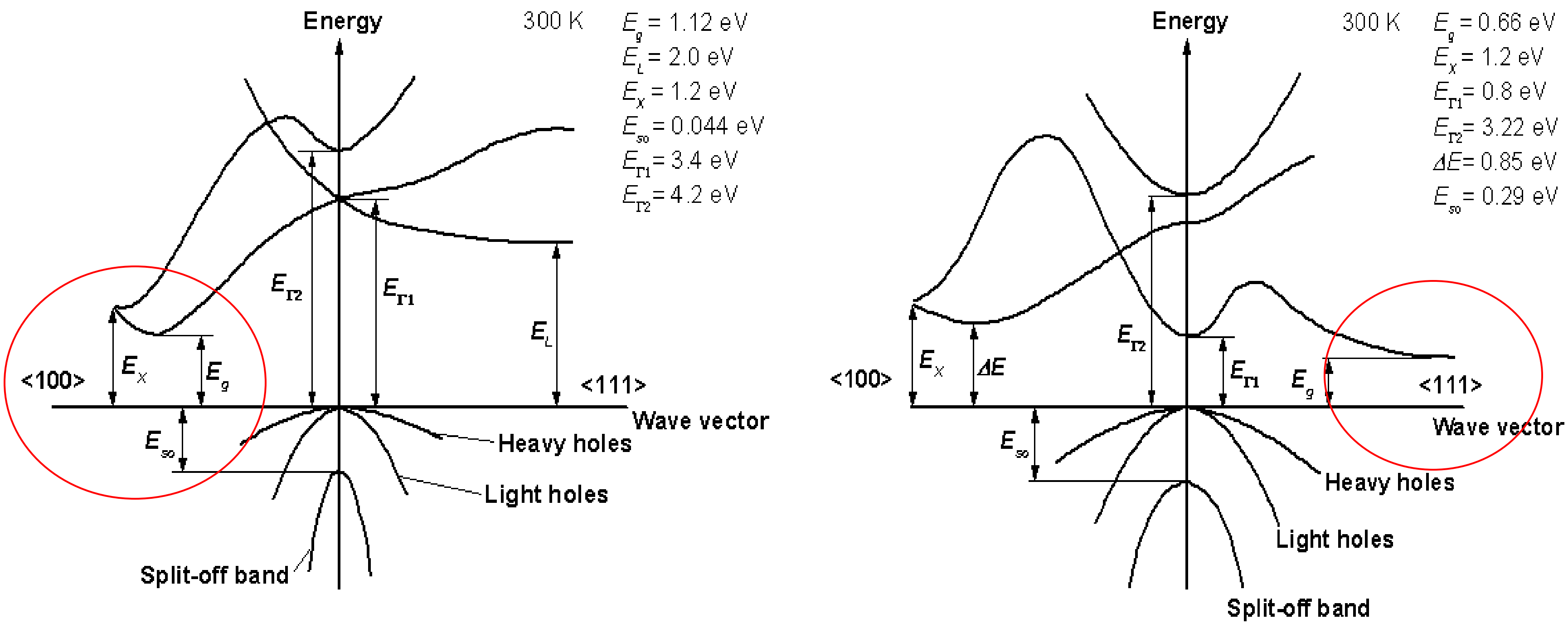
1. High-speed transistors (frequency and power/gain): integration versus individual device performance (0.5 – 200 GHz)



2. Gunn diodes: so far, exclusively III-Vs

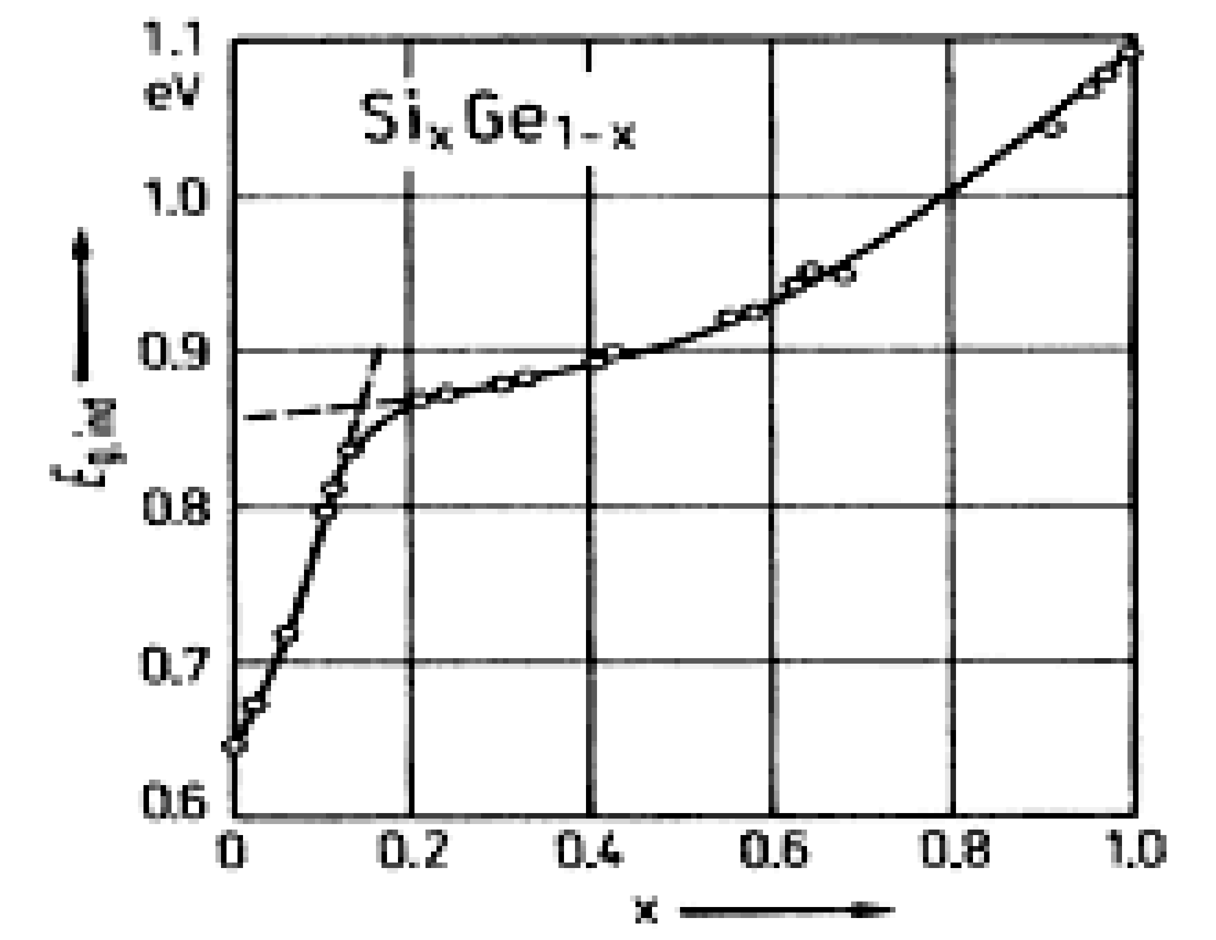
Traditional RF Devices: SiGe HBTs

Si, E_G=1.1 eV (T=300K) Ge, E_G=0.66 eV (T=300K)



Energy band diagrams for Si and Ge

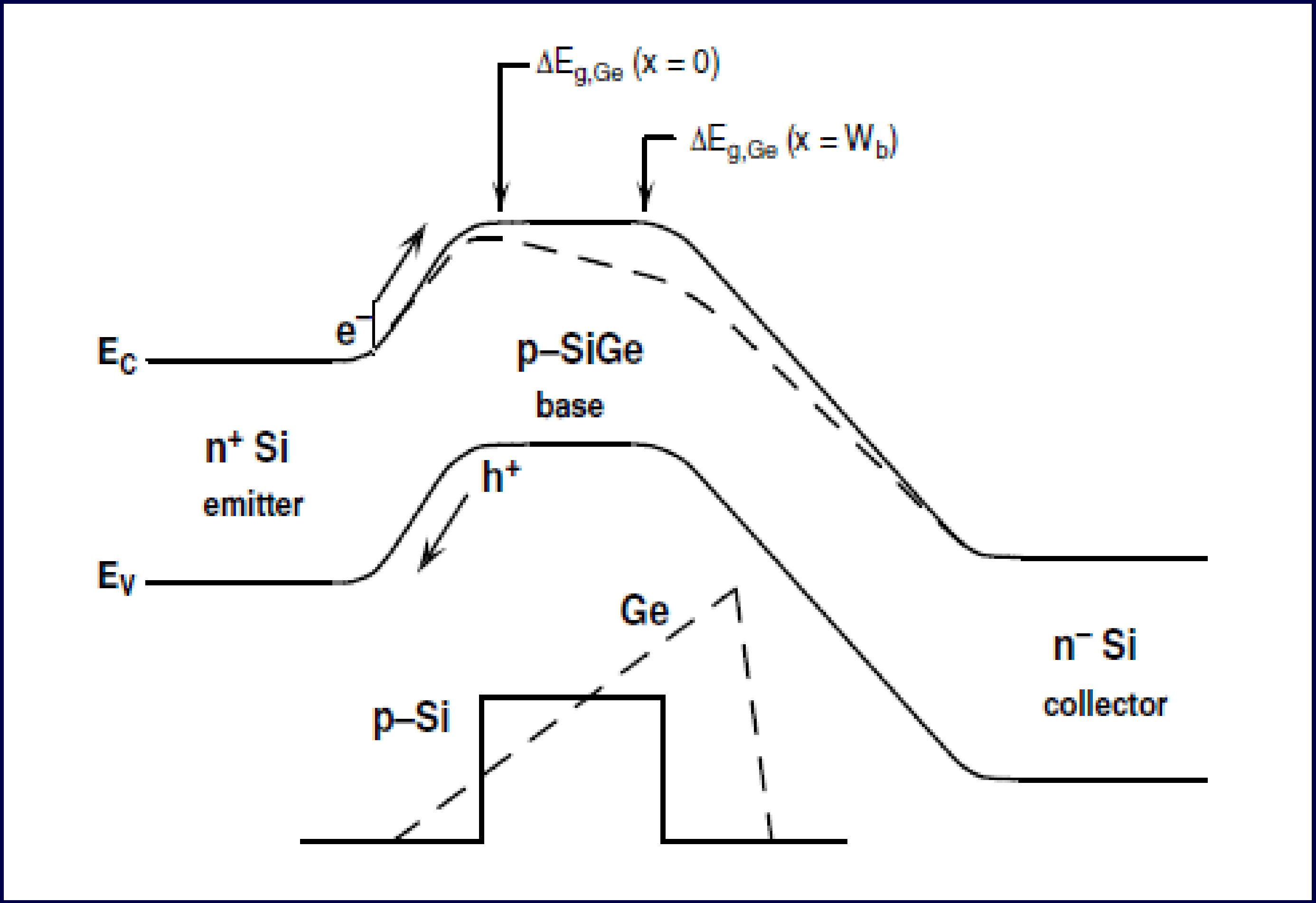
Traditional RF Devices: SiGe HBTs



Si_xGe_{1-x} alloys: Energy gap versus composition

5

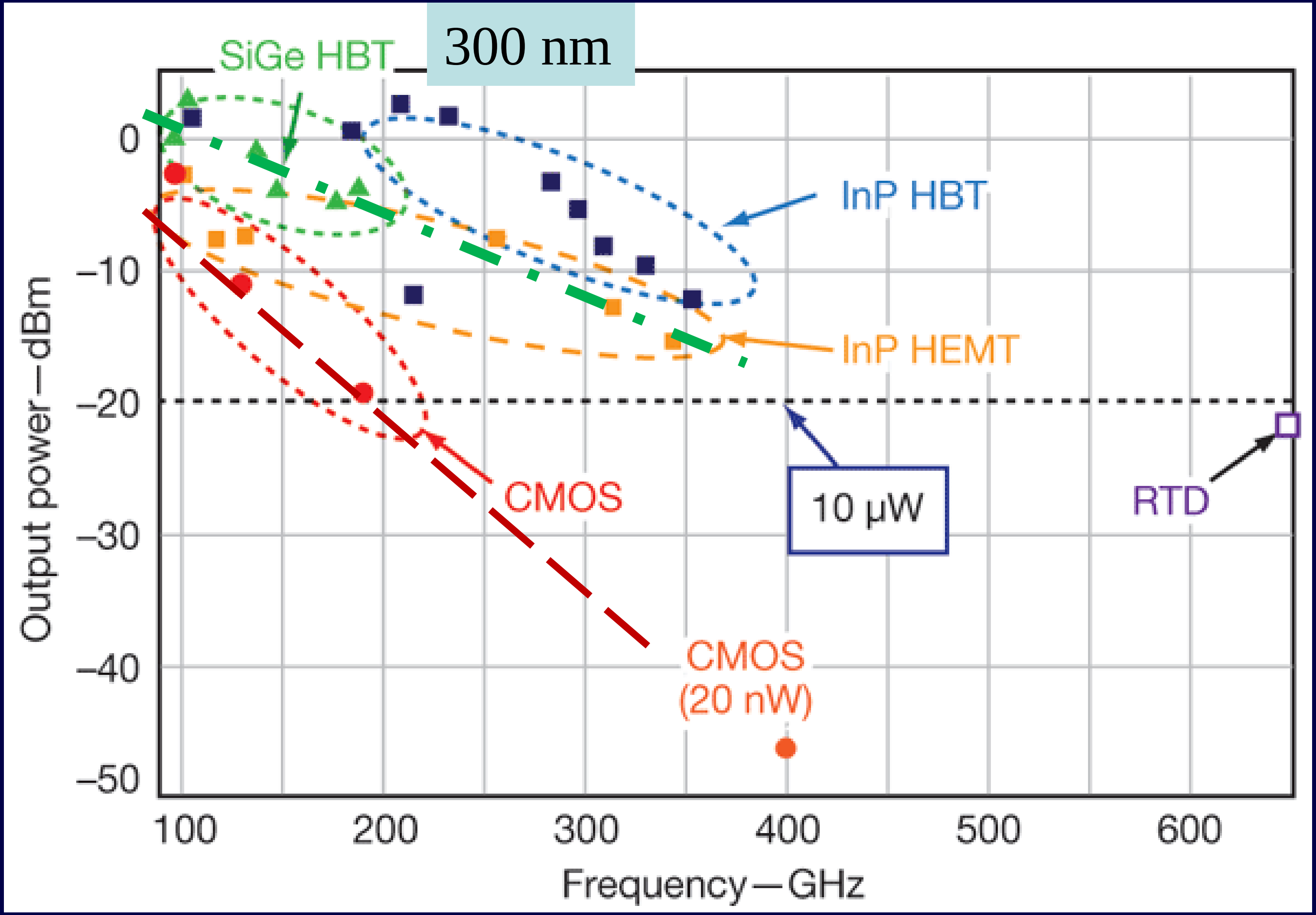
Traditional RF Devices: SiGe HBTs



Schematic of a SiGe HBT with a composition modulated base: drift versus diffusion

6

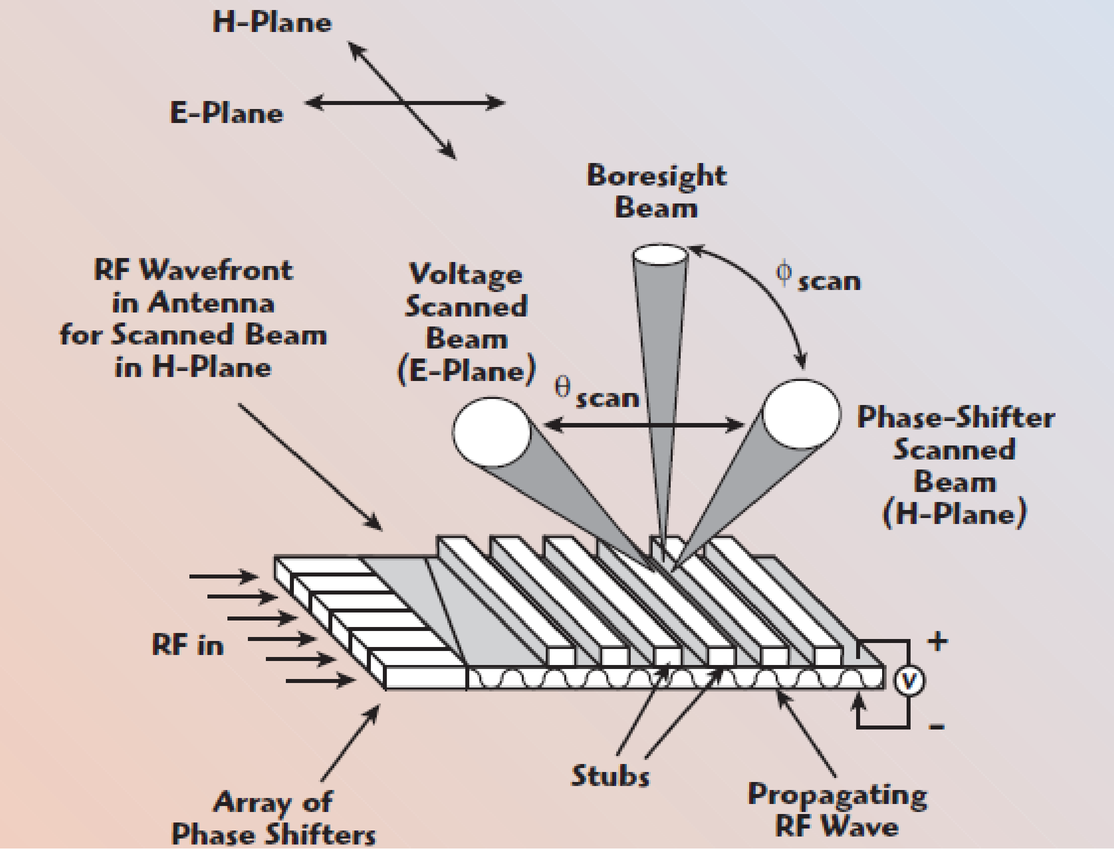
Traditional RF Devices



SiGe RF versus CMOS and III-Vs: same performance for lower cost

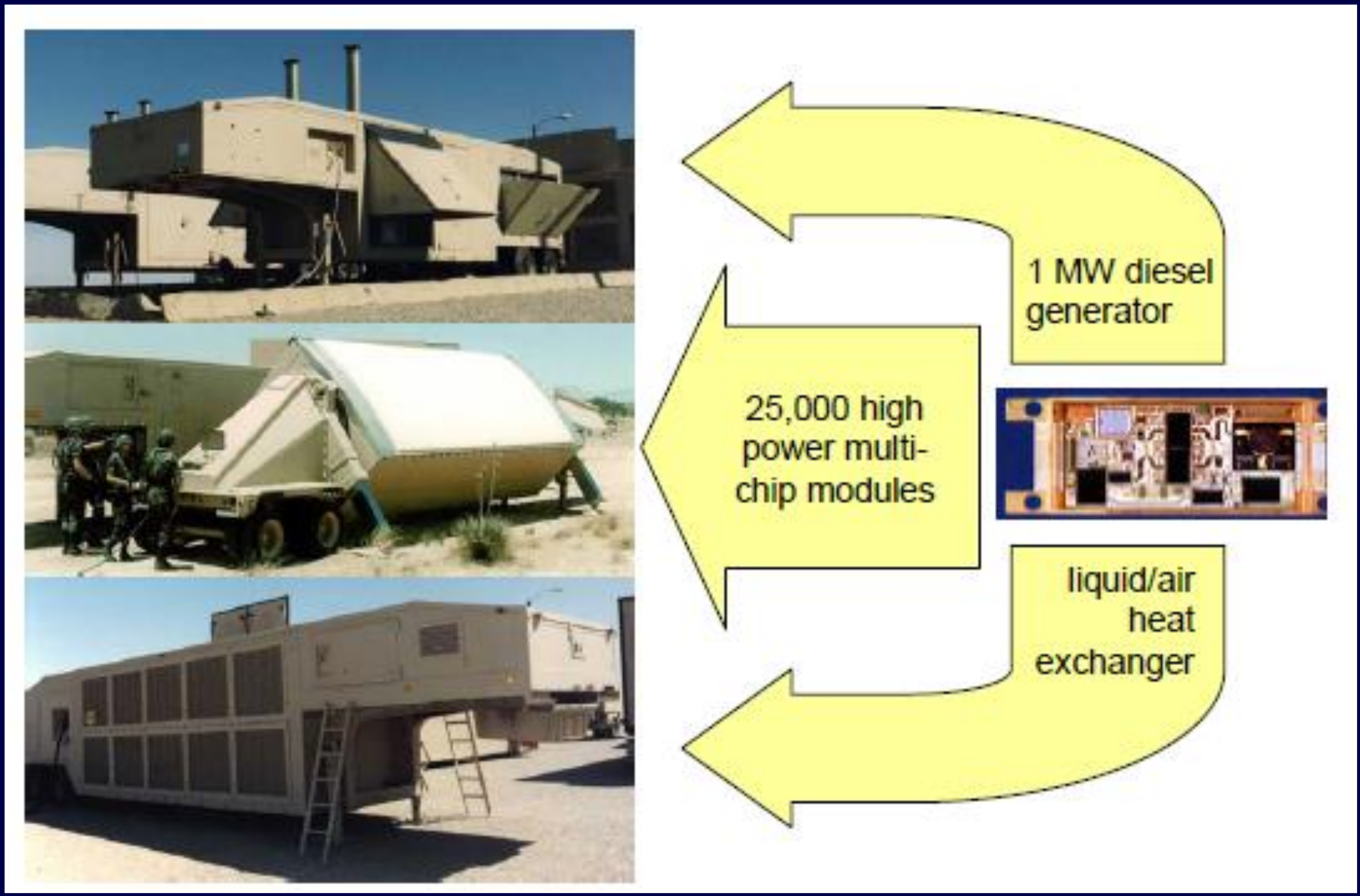
Opportunities for SiGe RF Devices

Phase Array Antenna



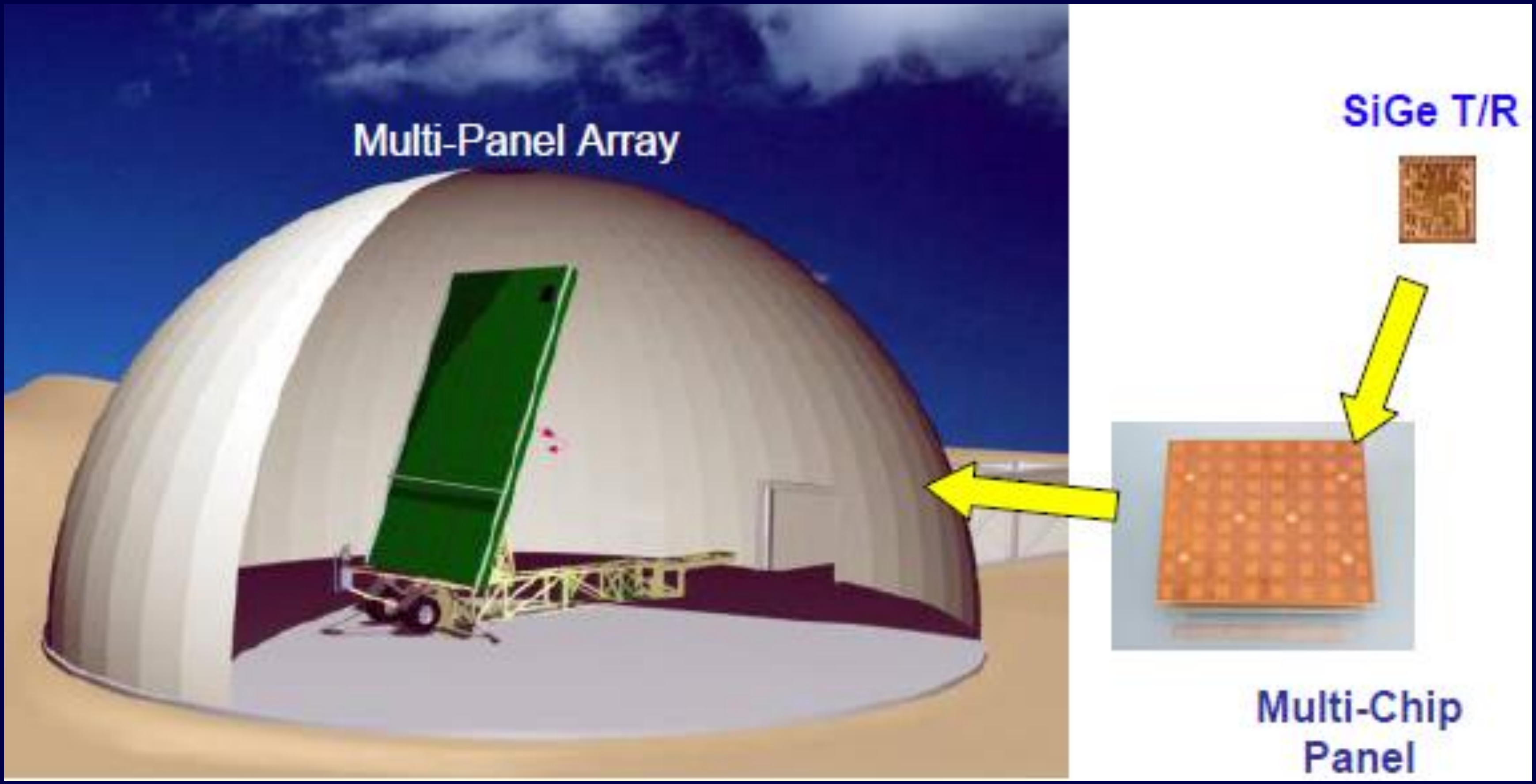
An array of radiating antenna elements transmitting and receiving active components at each element (T/R modules); enables digital beam forming using monolithic microwave integrated circuits (MMIC)

Opportunities for SiGe RF Devices



Phase Array Radars (PARs) are known since 1990 but were too costly to produce and operate

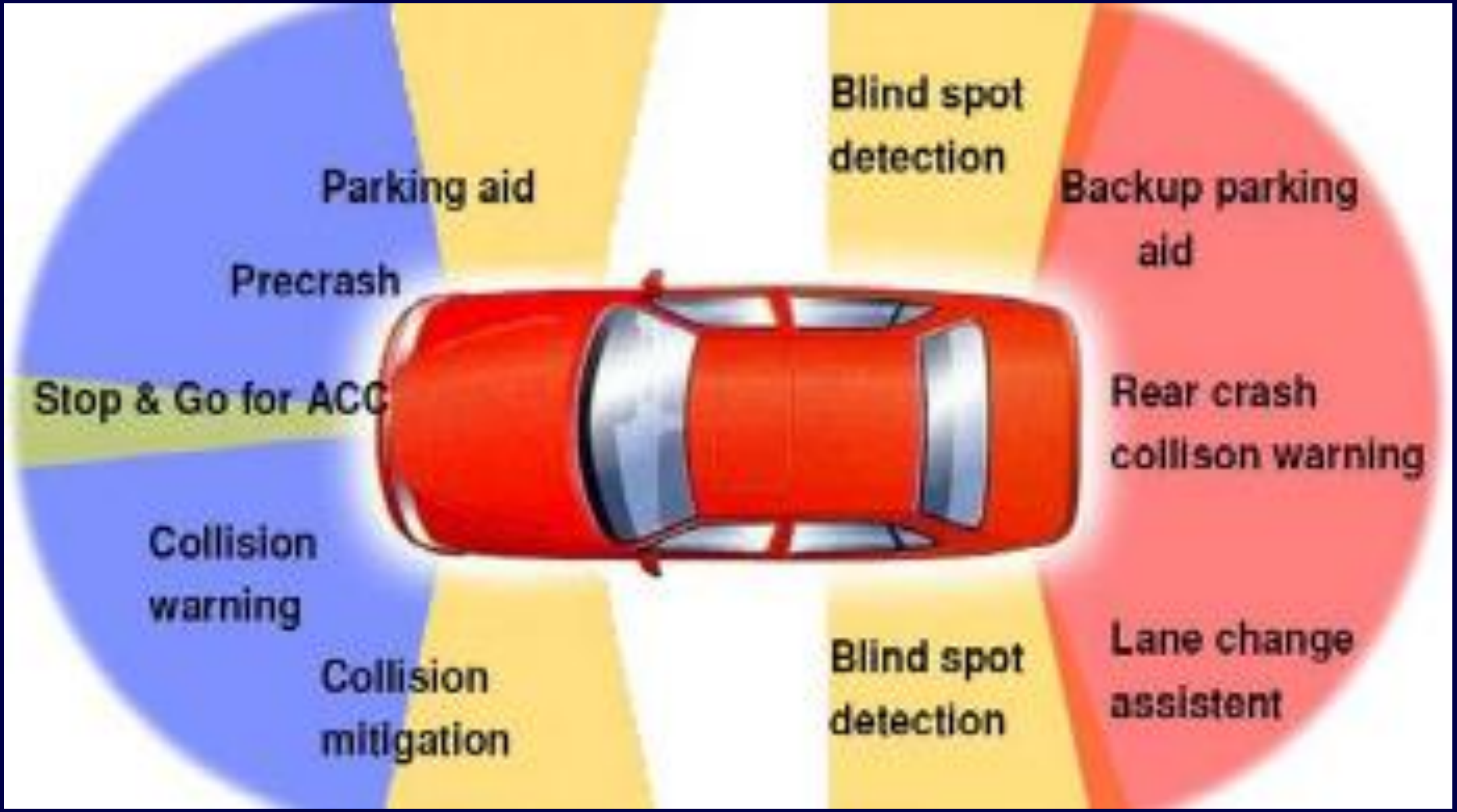
Opportunities for SiGe RF Devices



New generation of Phase Array Radars based on SiGe MMIC

10

Opportunities for SiGe RF Devices



Collision Avoidance Automotive Radars (CAARs): Standard within the next 5 years

11

Motivation:
Cost-Efficient, Highly Integrated RF System-on-a Chip

Solutions:

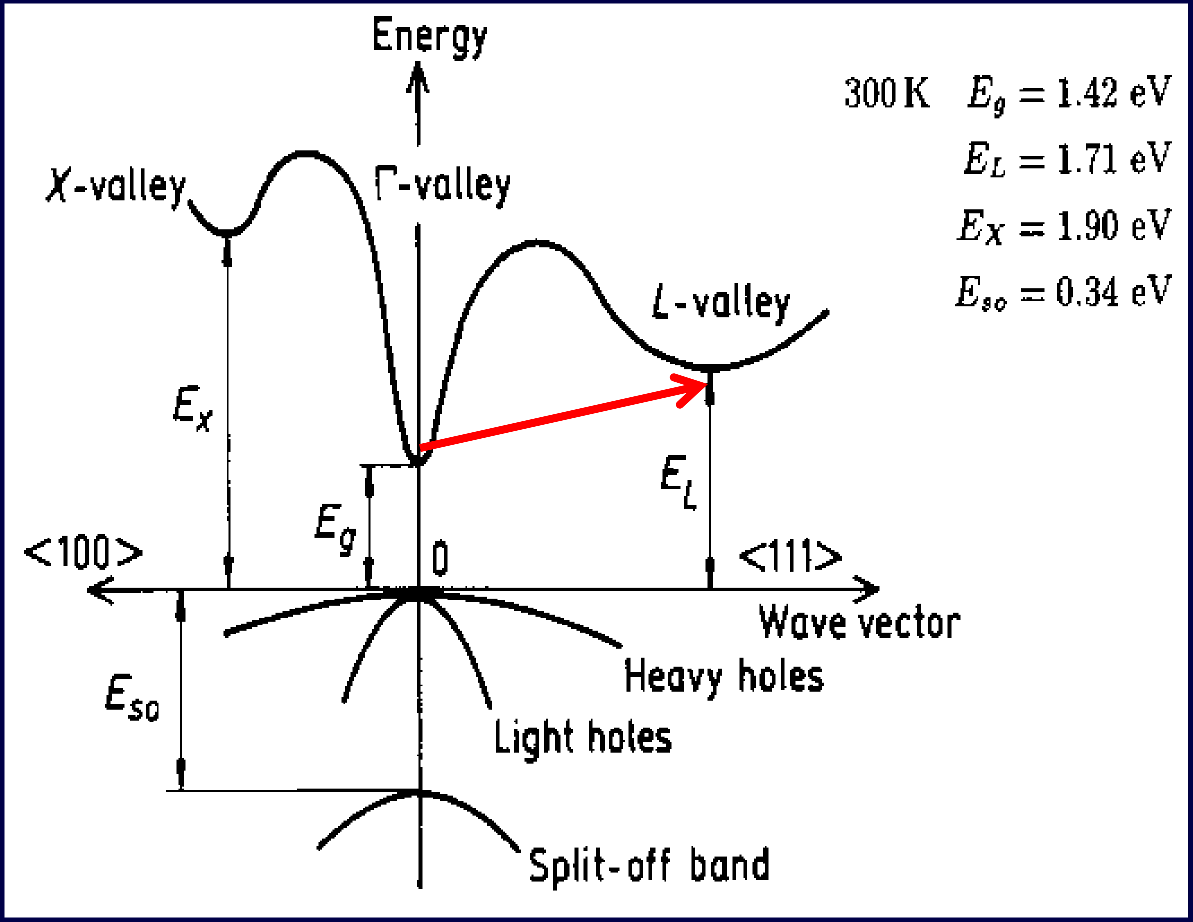
1. SiGe heterojunction bipolar transistors (HBTs): Mature technology

2. <u>SiGe nanowire heterojunctions: New approach</u>

12

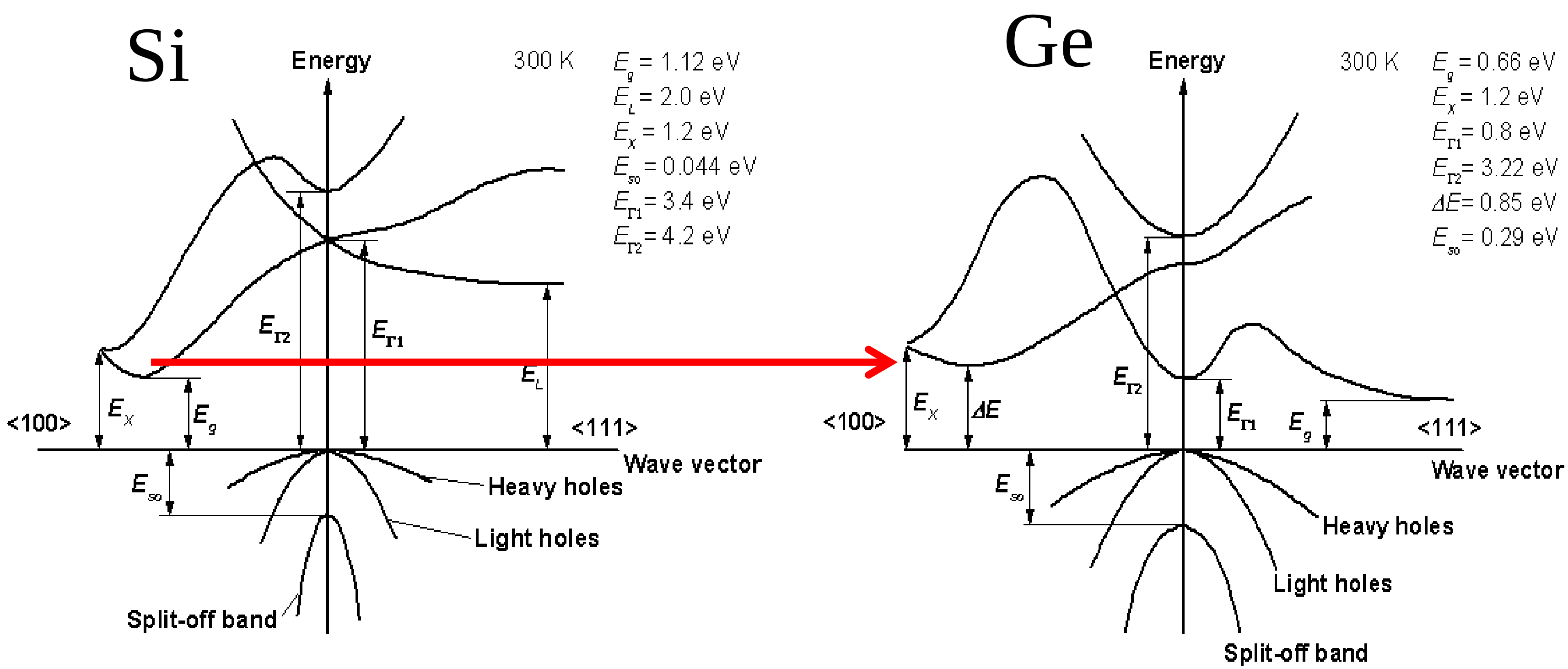
Brief Introduction to Gunn Effect

GaAs, InP, etc.



Inter valley electron transfer creates RF oscillations

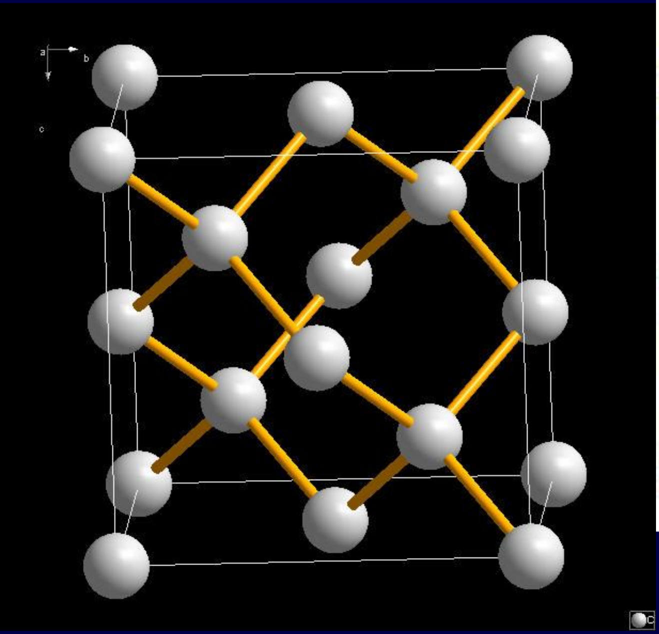
Si/Ge Heterojunction: Electron Momentum Mismatch - Similar to Gunn Effect



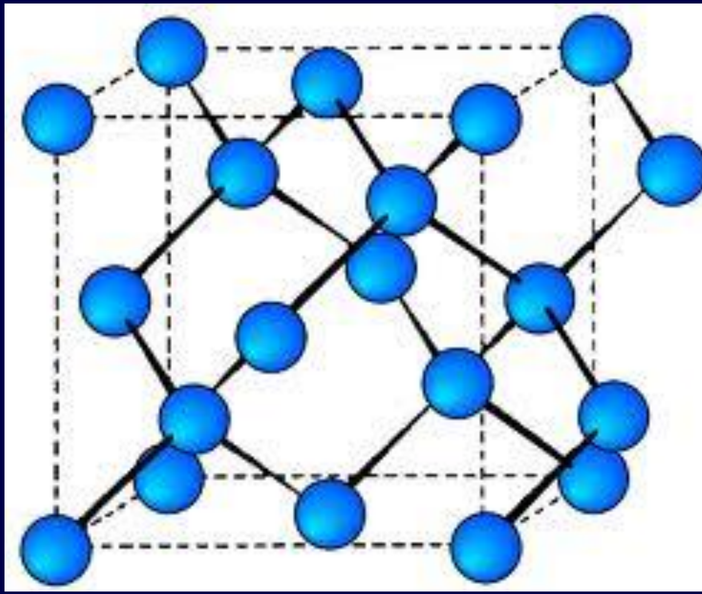
Electron transfer creates RF oscillations?

Materials Science: Si/Ge Lattice Mismatch

Si

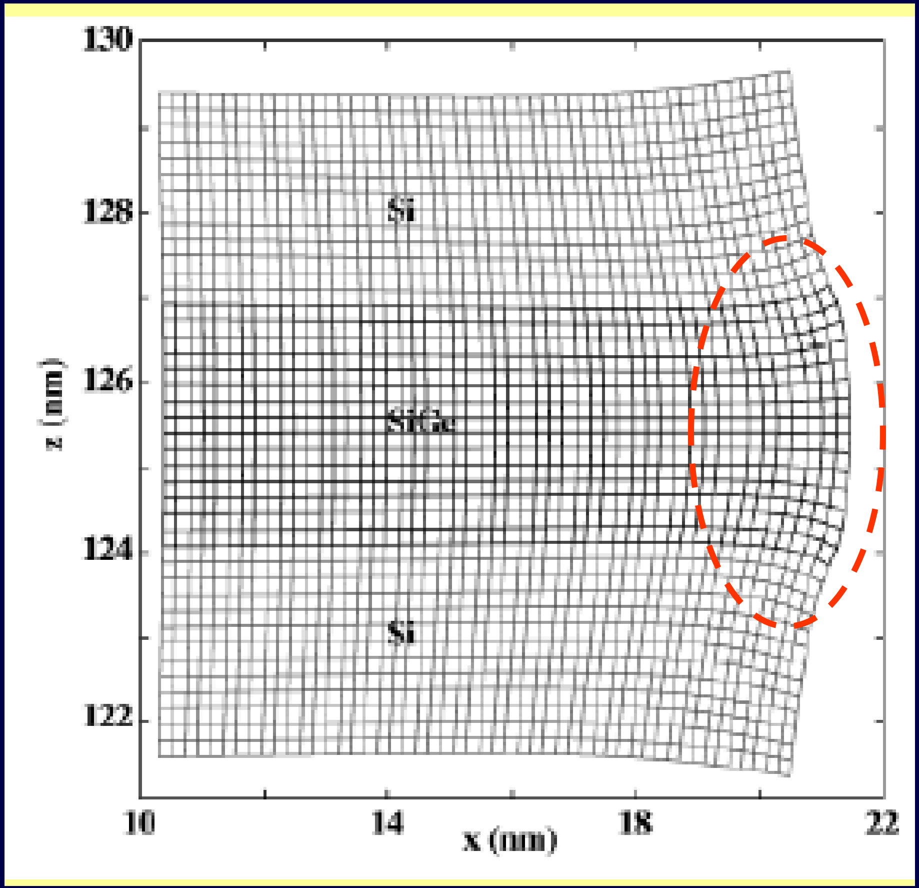


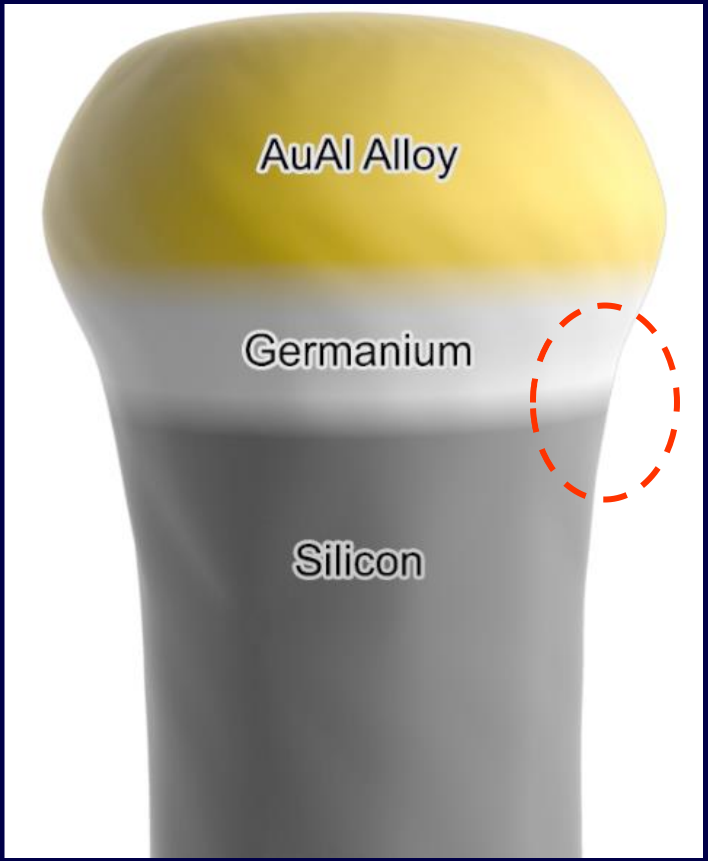
Ge (+ 4.2%)



Si and Ge are semiconductors with the lattice mismatch of 4.2 % (strain and defect formation)

Si/Ge Nanowire Heterojunction: Strain Relaxation via Lateral Expansion

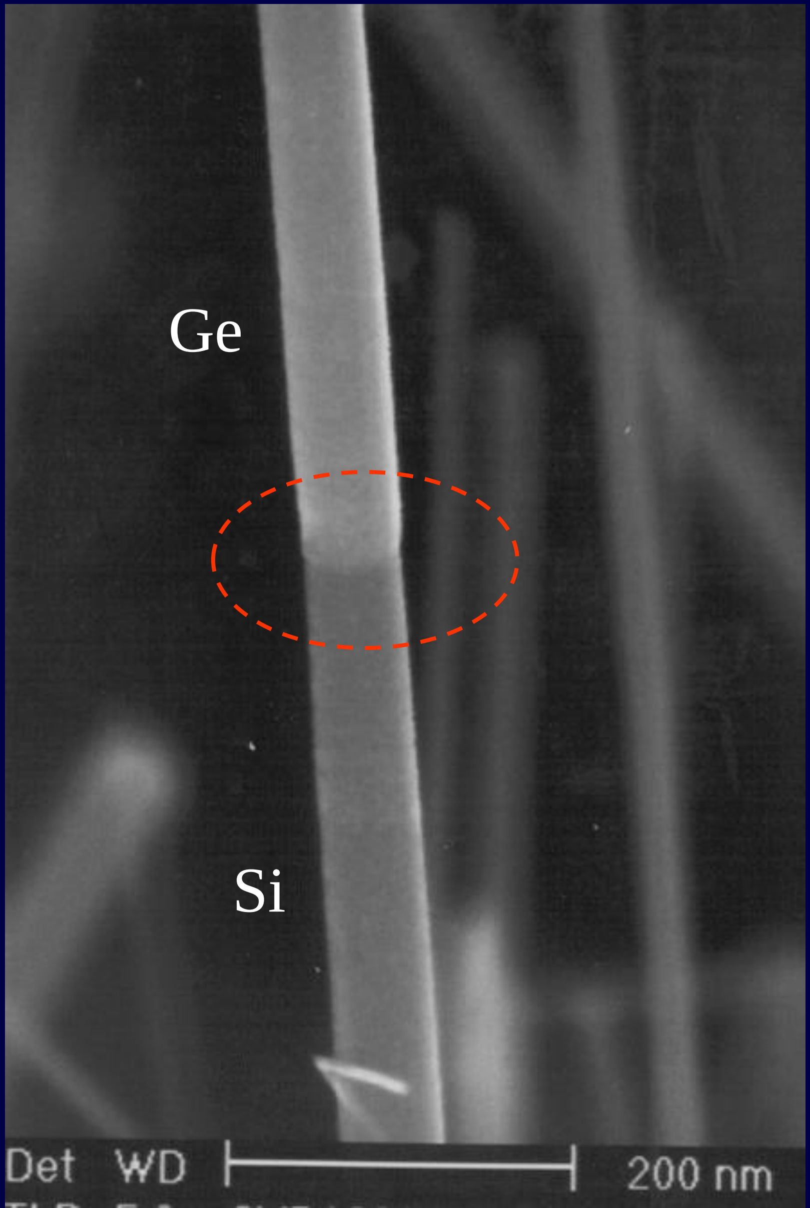




Strain relaxation in nanowires:

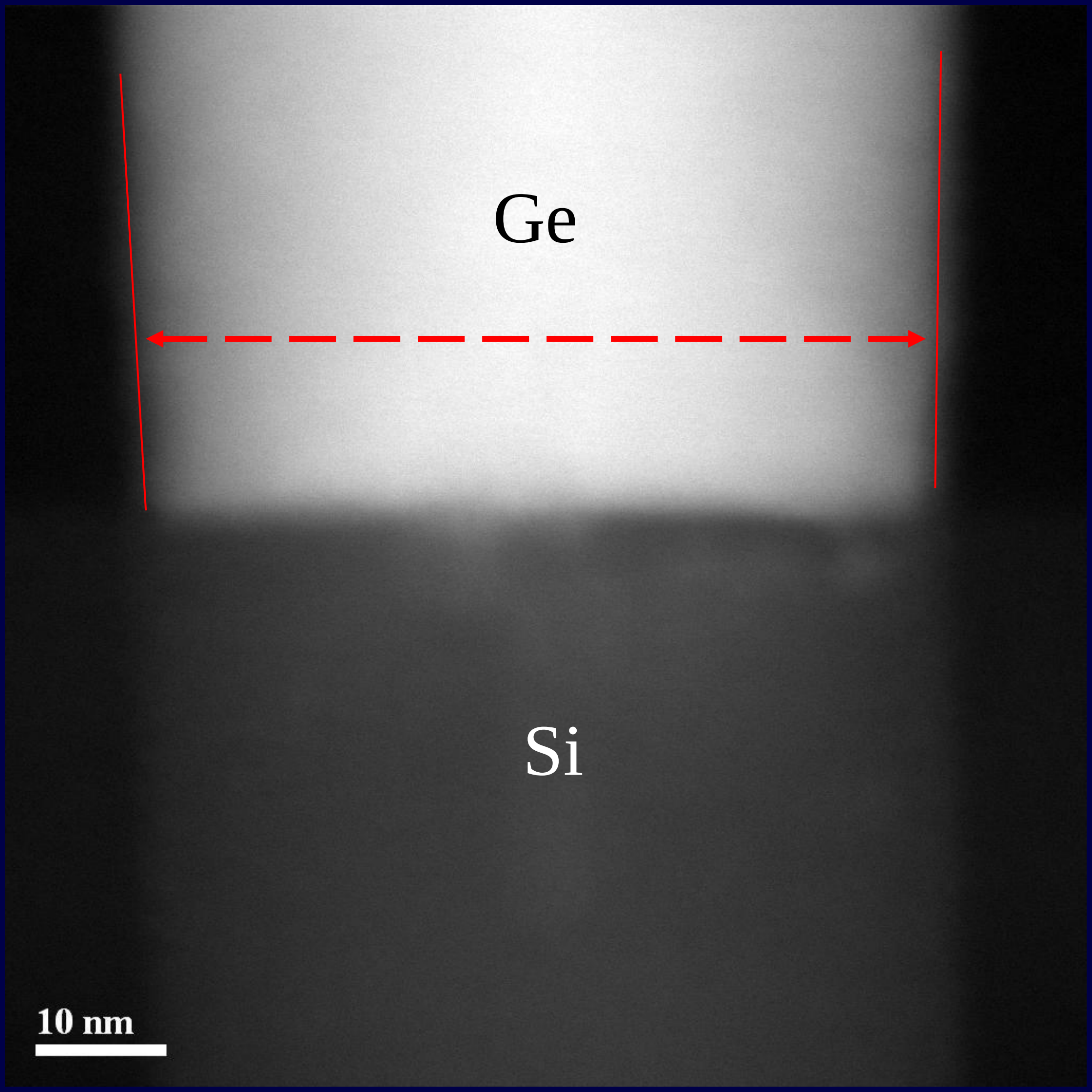
C.-Y. Wen, Science 2009.

Si/Ge Nanowire (NW) Growth: Structural Properties



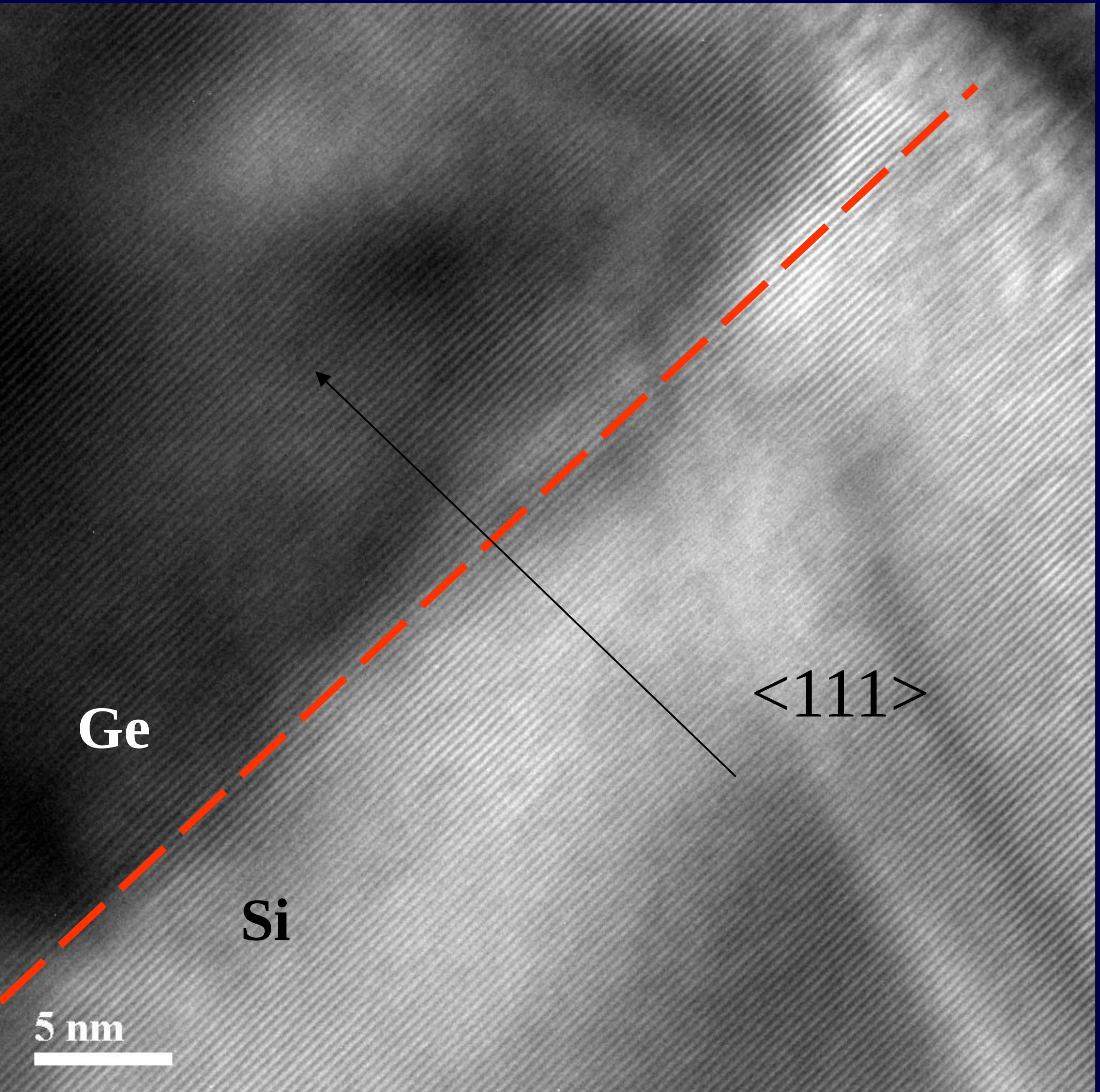
Straight, nearly constant diameter Si/Ge NWs with smooth surfaces and lateral expansion near the NW heterojunction (Tsybeskov's group, APL 2010, 20012, 2014)

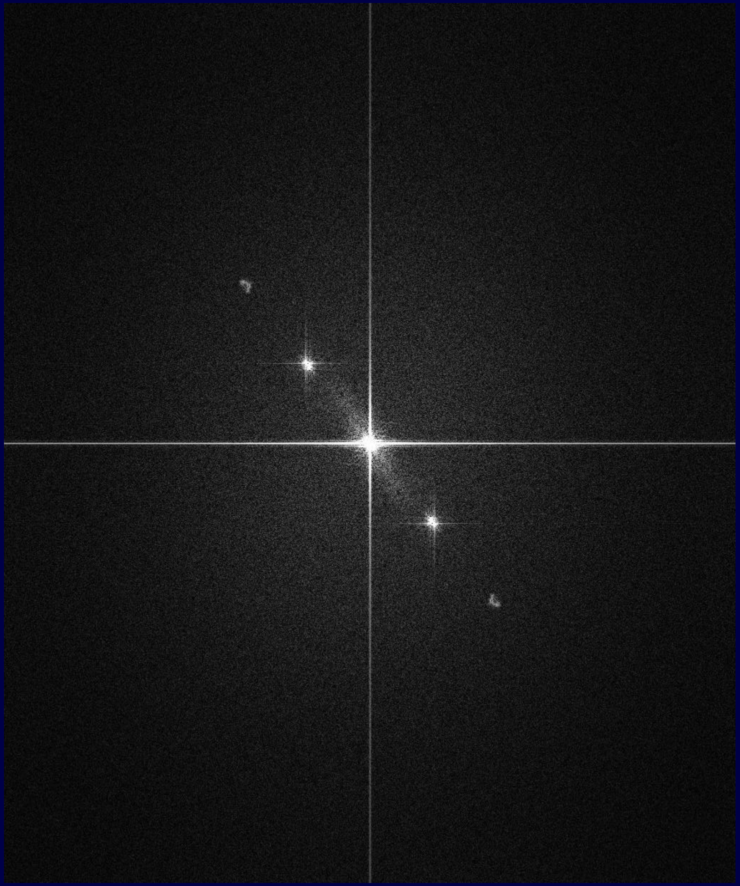
Si/Ge Nanowire VLS Growth: Microstructure and Optical Properties



Zooming in: … nearly constant diameter Si/Ge NWs with … lateral expansion near the NW heterojunction (ECS 2014)

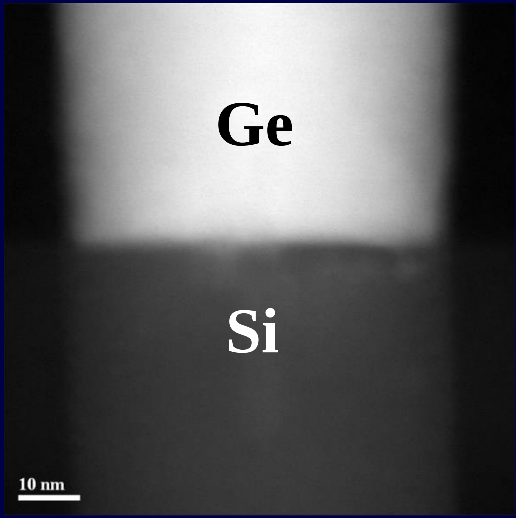
Si/Ge Nanowire Close to Center: HR TEM Image and FFT (Nearly Perfect)





FFT of lattice fringes

Brief Summary of Si/Ge Nanowire Heterojunction Electrical Properties



- **Disrupted flow of carriers**
- **Current oscillations at GHz frequencies**
- **Negative photoconductivity**
- **Other features related to the proposed conductivity mechanism**
- **<u>Natural integration with CMOS – low cost/high performance MMICs</u>**

Supported by US NSF and ARO