nanoHUB online simulation and more

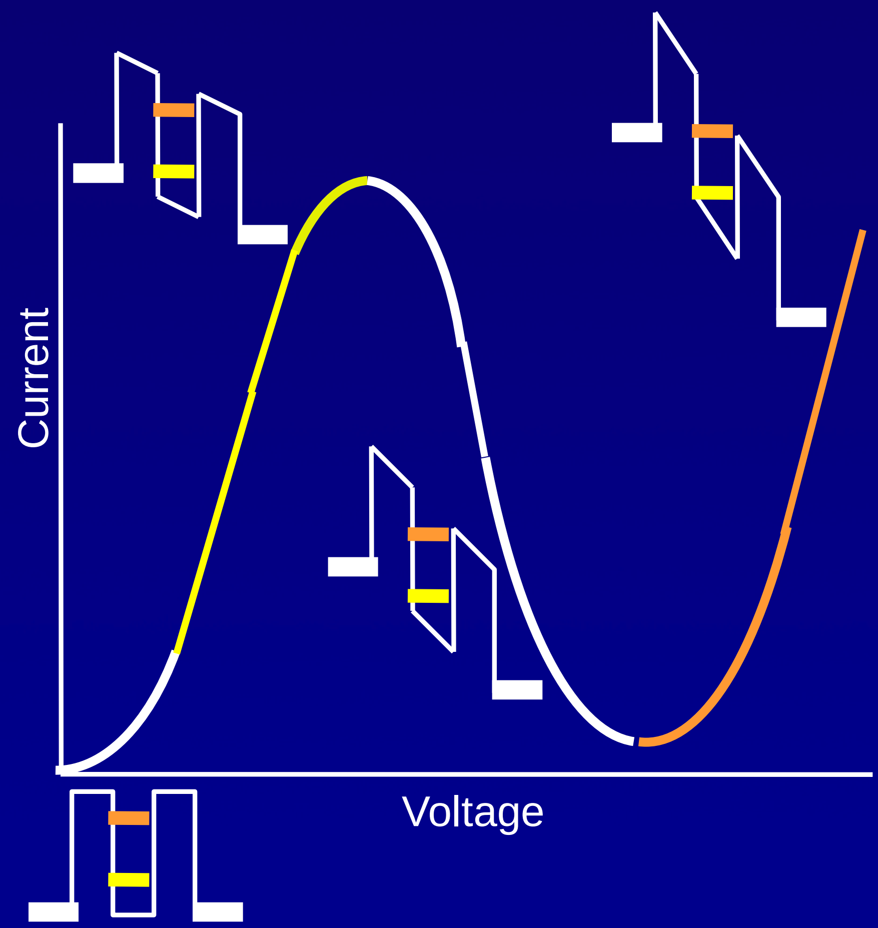
Network for Computational Nanotechnology (NCN)

Berkeley, Univ.of Illinois, Norfolk State, Northwestern, Purdue, UTEP

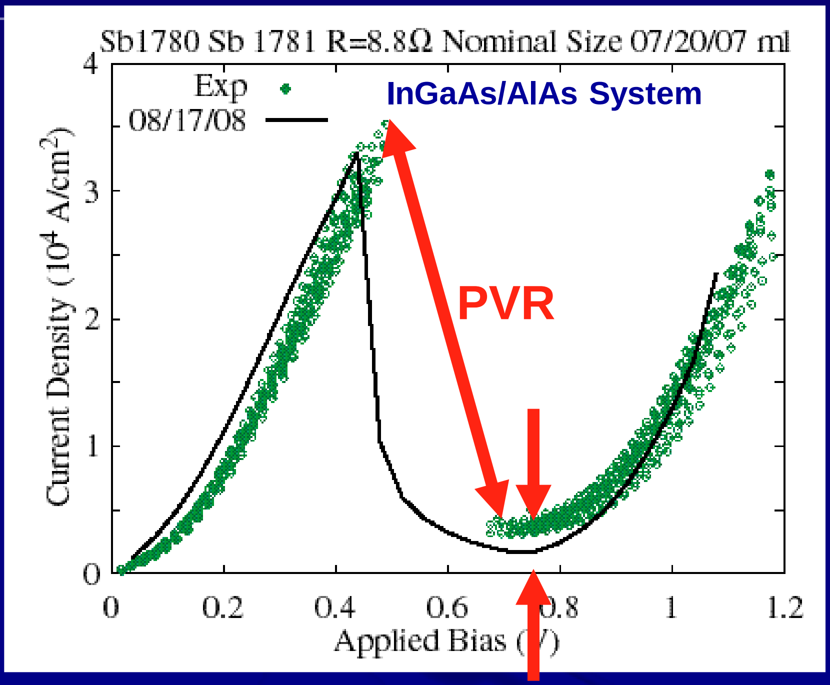
NEMO1D: Incoherent Scattering

Gerhard Klimeck

Basic Operation of a Resonant Tunneling Diode



Conduction band diagrams
for different voltages
and the resulting current flow



12 different I-V curves: 2 wafers, 3 mesa sizes, 2 bias directions

PVR – Peak-to-Valley-Ratio
1994: Best experiment PVR=80
=> On-Off-Ratio should to be >1,000

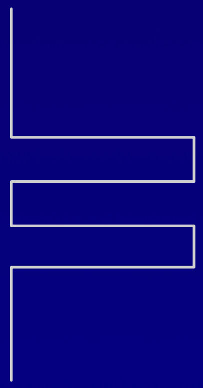
1994: What is the valley current physics?

1997: Can overlay experiment and theory.
What are the key insights?

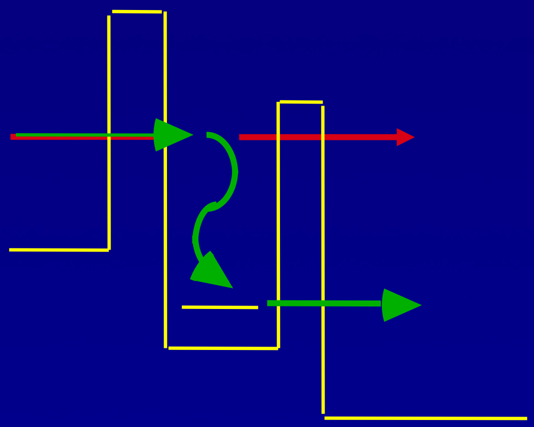
NCN

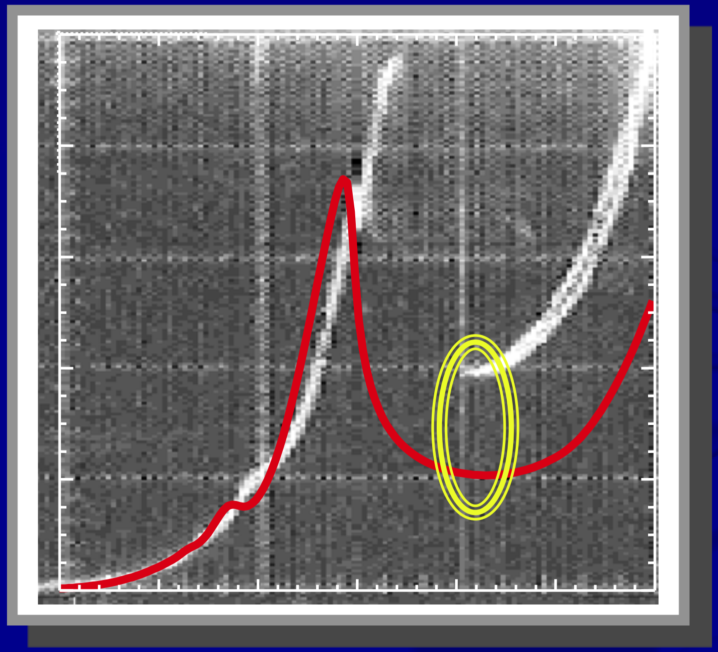
Where Does The Valley Current Come From? Scattering?

20 nm GaAs $N_D = 2\ 10^{18}\ cm^{-3}$
200 nm GaAs $N_D = 2\ 10^{15}\ cm^{-3}$
18 nm GaAs
5 nm $Al_{0.4}Ga_{0.6}As$
5 nm GaAs
5 nm $Al_{0.4}Ga_{0.6}As$
18 nm GaAs
200 nm GaAs $N_D = 2\ 10^{15}\ cm^{-3}$
20 nm GaAs $N_D = 2\ 10^{18}\ cm^{-3}$



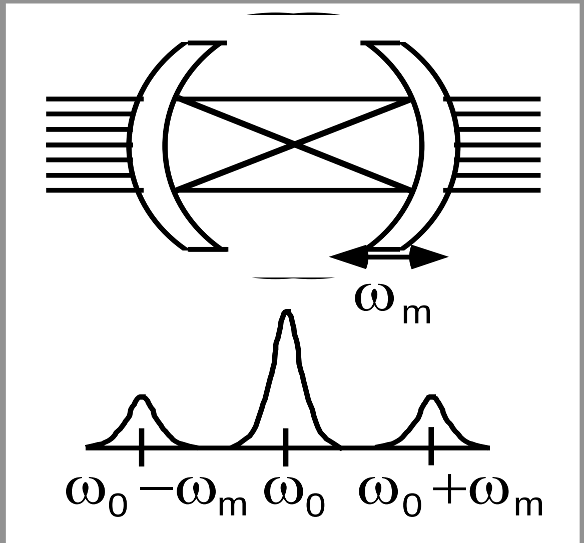
Scattering?

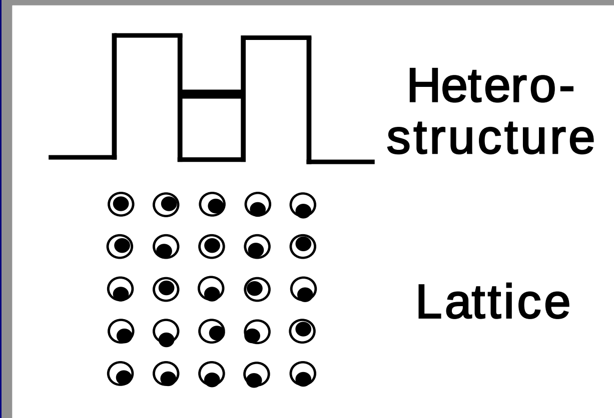


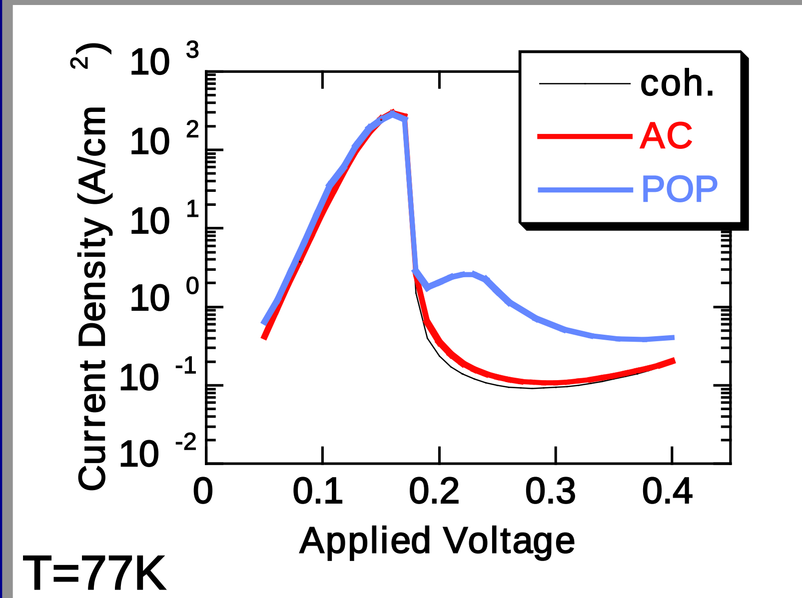


NCN

Electron-Phonon Interactions
Coupled Resonators





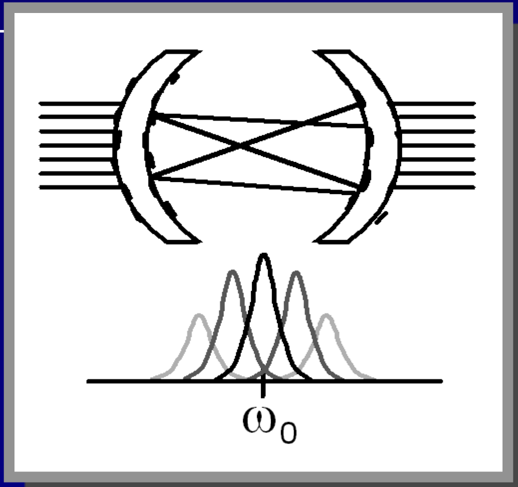


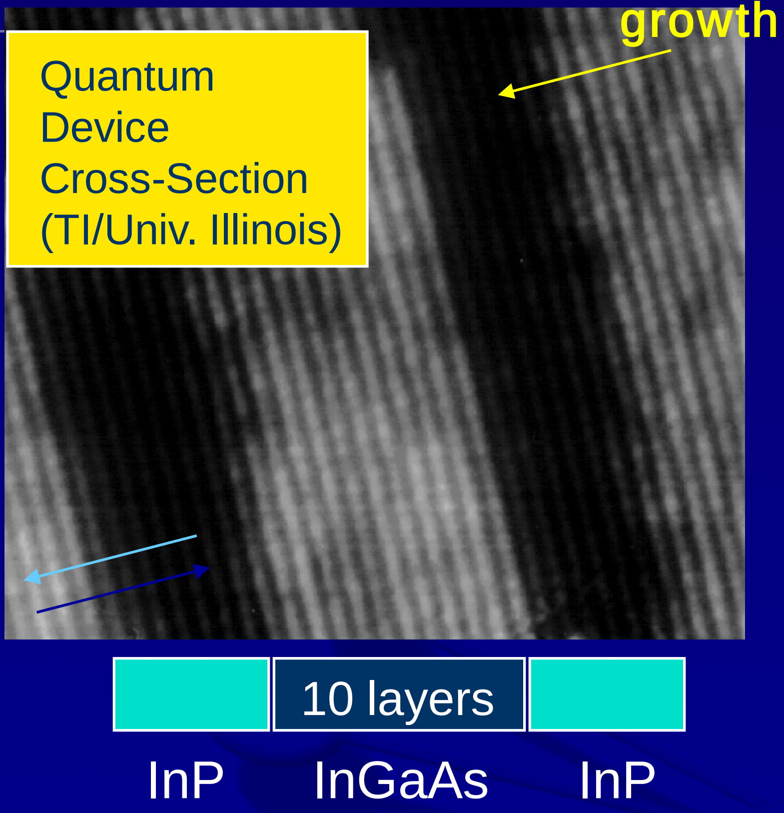
Self-consistent Born
(infinite sequential scattering)
treatment of
acoustic phonon-scattering

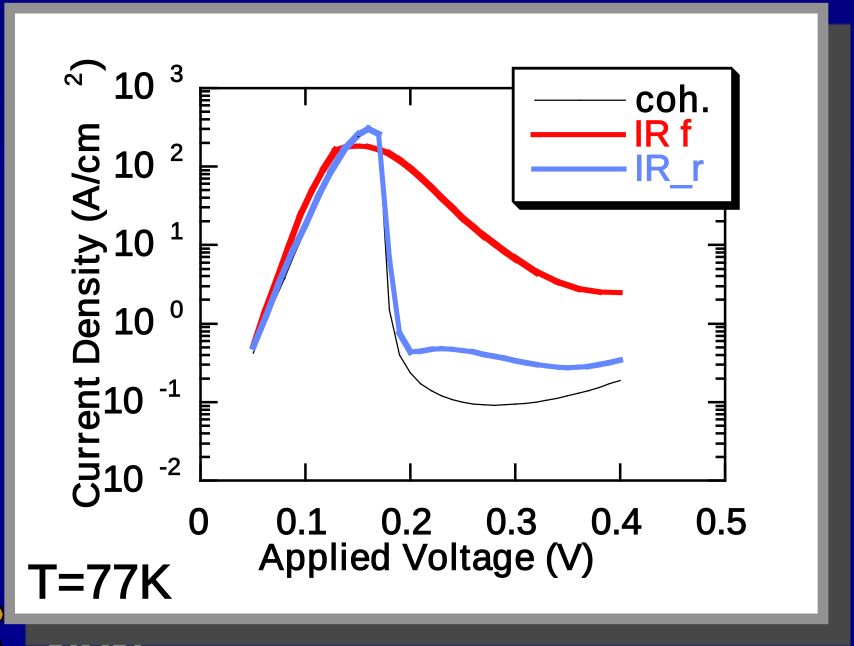
Single sequential scattering
treatment of
polar optical phonon scattering

NCN

Interface Roughness Scattering



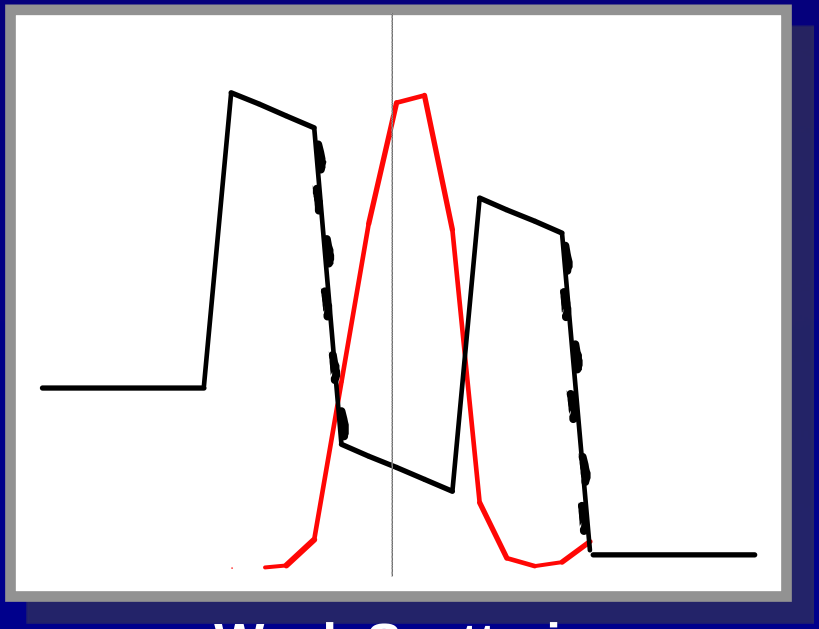




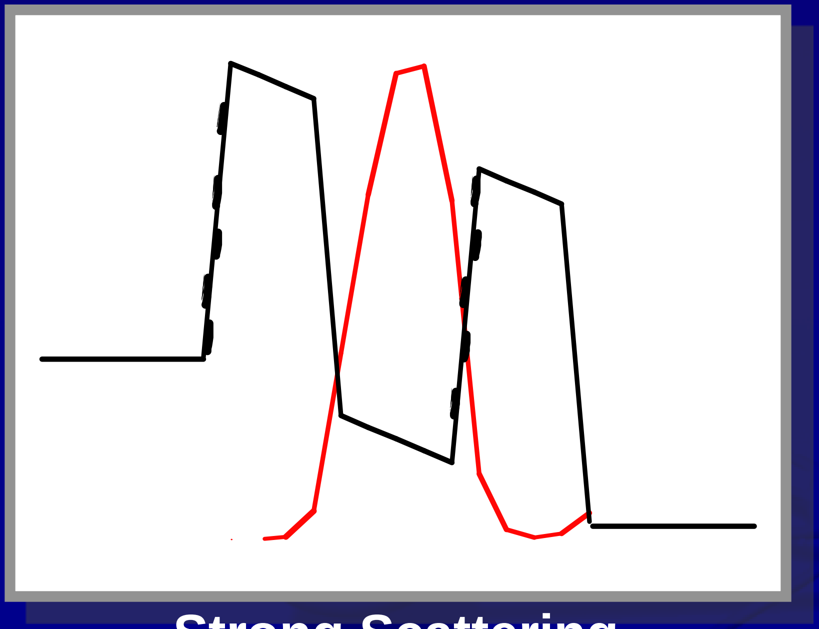
Self-consistent Born (infinite sequential scattering) treatment of IR-scattering

Why is the I-V-Characteristic Asymmetric with Interface Roughness Scattering?

Scattering rate is proportional to the density of states at the scattering interface.
Applied bias 'tilts' the density of states toward the lower potential



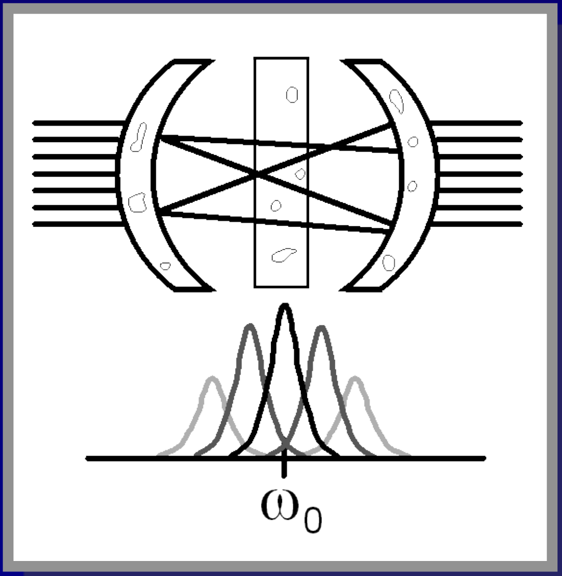
Weak Scattering



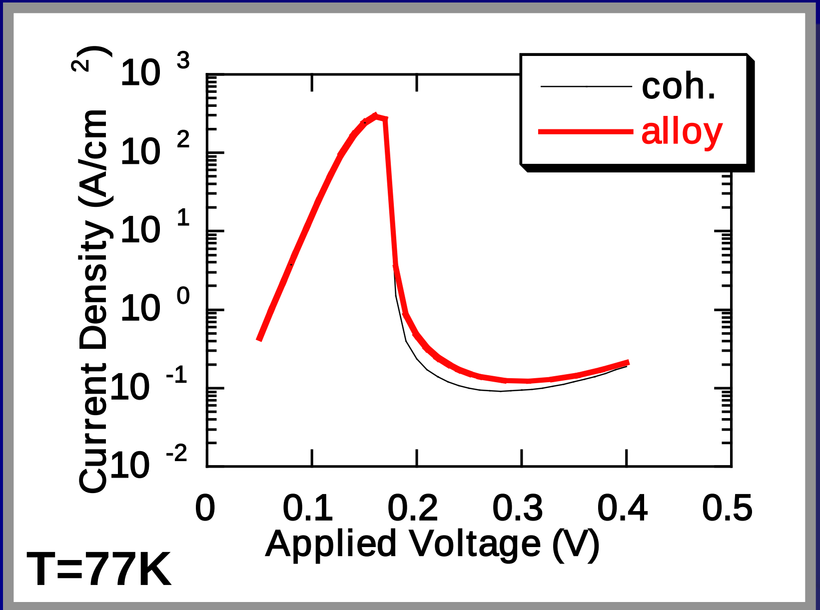
Strong Scattering

NCN

Alloy (Disorder) Scattering



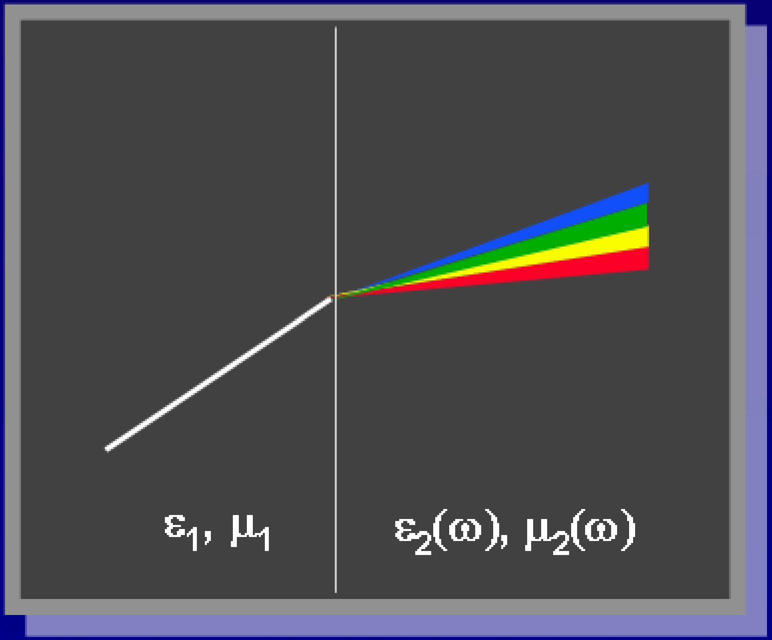
Disorder in the mirrors or the gain medium will spread out the resonator spectrum

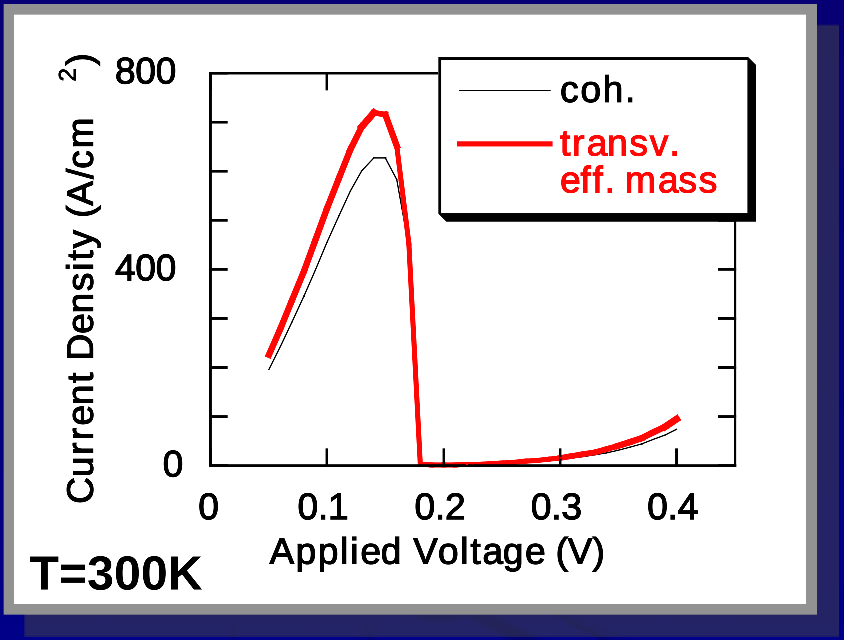


Self-consistent Born (infinite sequential scattering) treatment of alloy-scattering

Weak Effects in GaAs/AlGaAs

Non-Linear Media





Changing effective Mass Disperses carriers in 2D

Weak Effect

$$\nabla^2 \vec{E} = -\omega^2 \mu \varepsilon \vec{E}$$

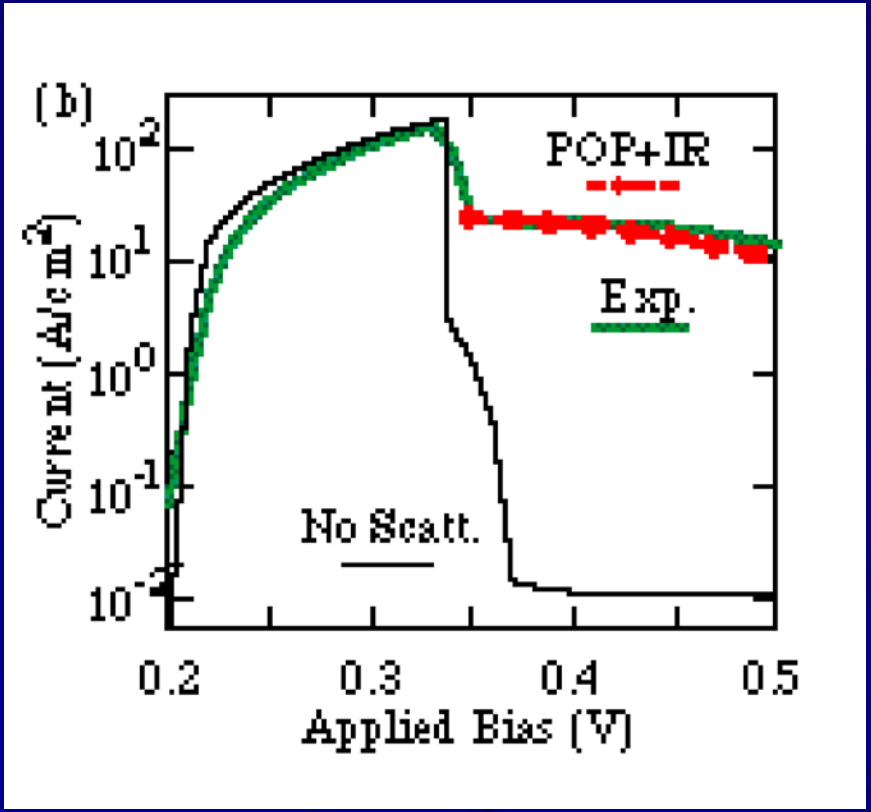
$$k^2 = \omega^2 \mu \varepsilon$$

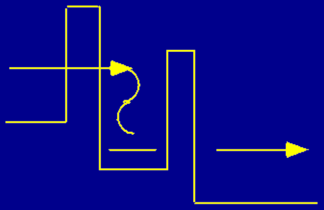
$$\nabla^2 \Psi = -\frac{2m}{\hbar}(E-U)\Psi$$

$$k^2 = \frac{2m}{\hbar}(E-U)$$

NCN

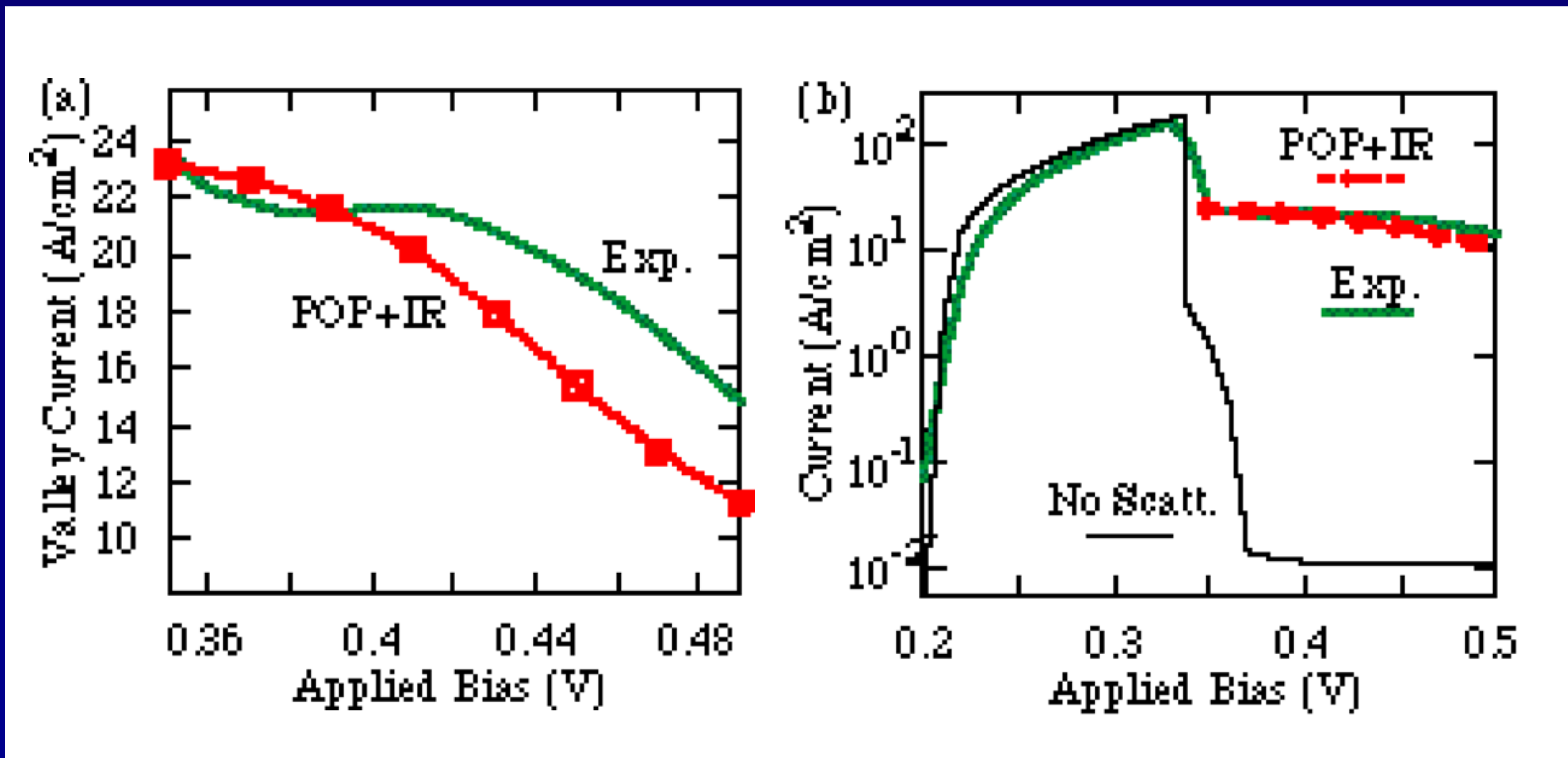
Low Temperature: Polar Optical Phonon and Interface Roughness Scattering

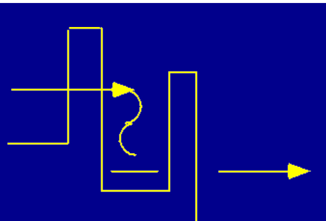




NCN

Low Temperature: Polar Optical Phonon and Interface Roughness Scattering





scattering raises valley current by several orders of magnitude

NCN

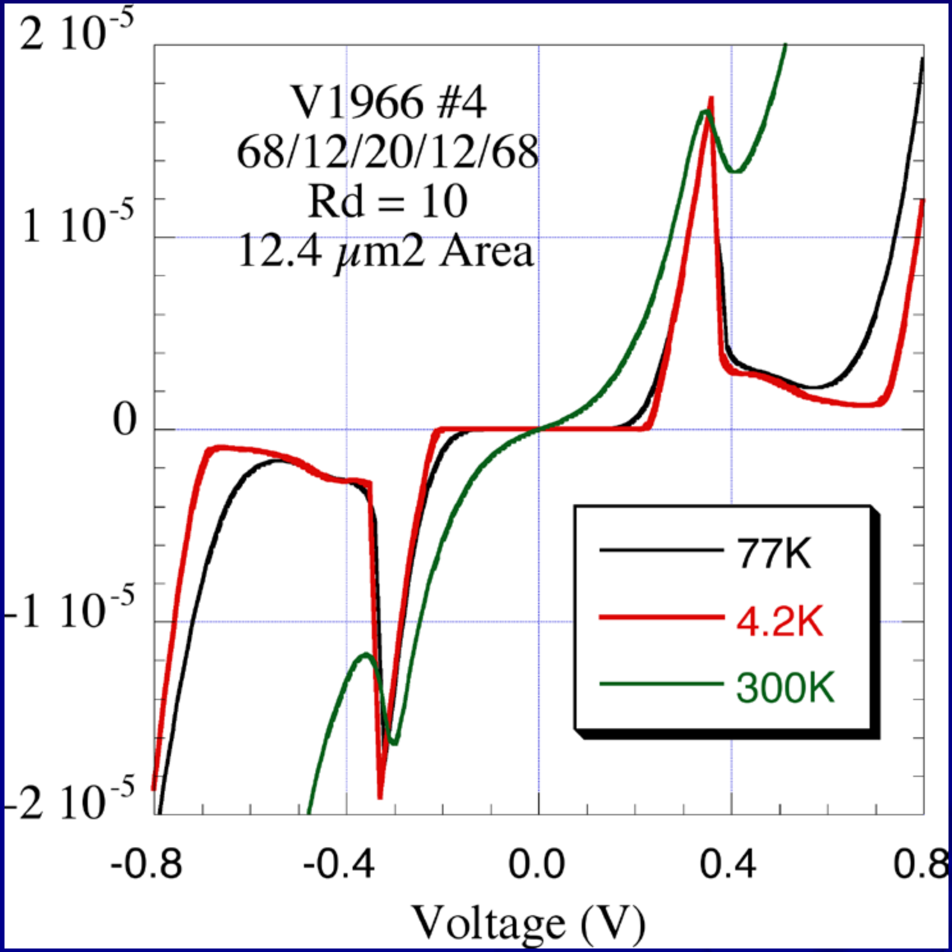
Yet: Scattering is NOT the Answer!

Scattering important:

- Low temperature
- "Physicist devices"

Scattering does not explain

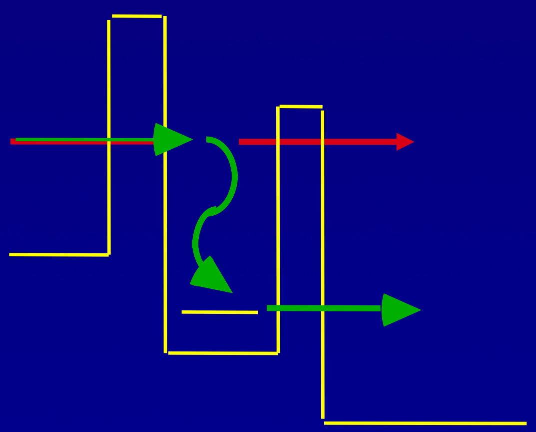
- High performance devices



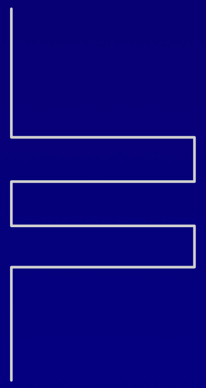
Where Does The Valley Current Come From? Scattering?

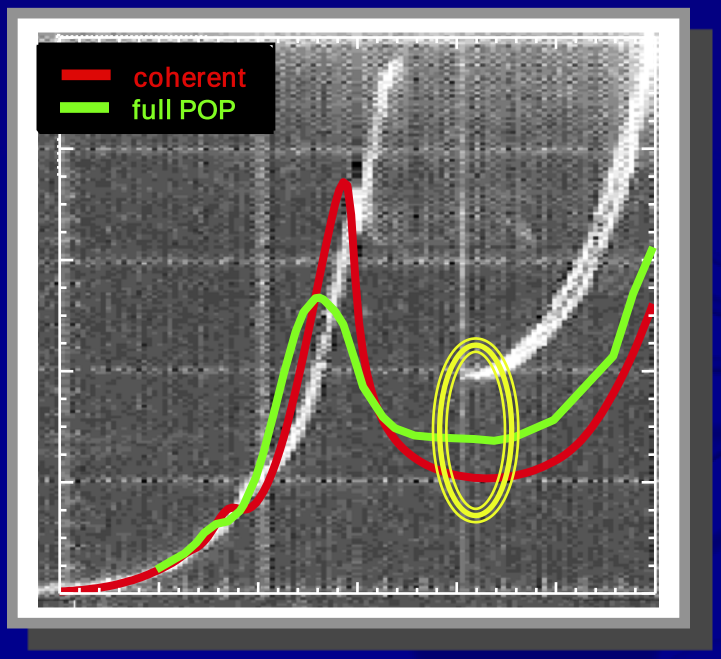
At Room Temperature

Scattering?



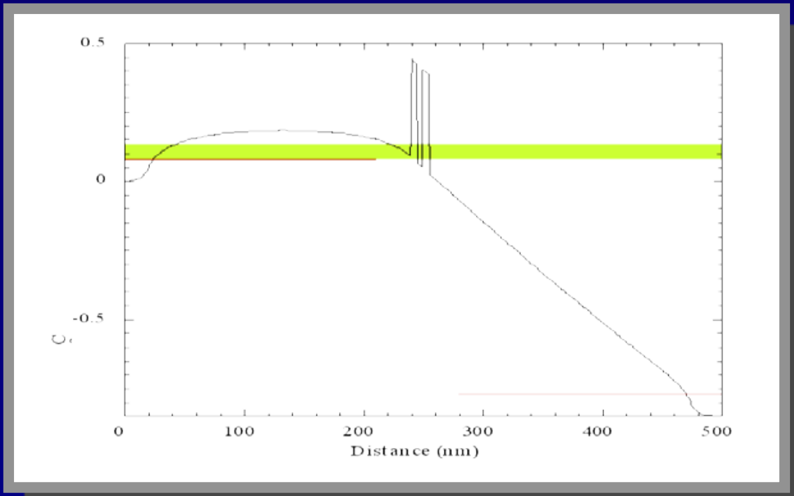
20 nm GaAs $N_D = 2\ 10^{18}\ cm^{-3}$
200 nm GaAs $N_D = 2\ 10^{15}\ cm^{-3}$
18 nm GaAs
5 nm $Al_{0.4}Ga_{0.6}As$
5 nm GaAs
5 nm $Al_{0.4}Ga_{0.6}As$
18 nm GaAs
200 nm GaAs $N_D = 2\ 10^{15}\ cm^{-3}$
20 nm GaAs $N_D = 2\ 10^{18}\ cm^{-3}$





NCN

Where Does The Valley Current Come From? Bandstructure



20 nm GaAs $N_D = 2\ 10^{18}\ cm^{-3}$
200 nm GaAs $N_D = 2\ 10^{15}\ cm^{-3}$
18 nm GaAs
5 nm $Al_{0.4}Ga_{0.6}As$
5 nm GaAs
5 nm $Al_{0.4}Ga_{0.6}As$
18 nm GaAs
200 nm GaAs $N_D = 2\ 10^{15}\ cm^{-3}$
20 nm GaAs $N_D = 2\ 10^{18}\ cm^{-3}$