Dynamics of strongly degenerate electron-hole plasmas and excitons in single InP nanowires

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InP nanowires

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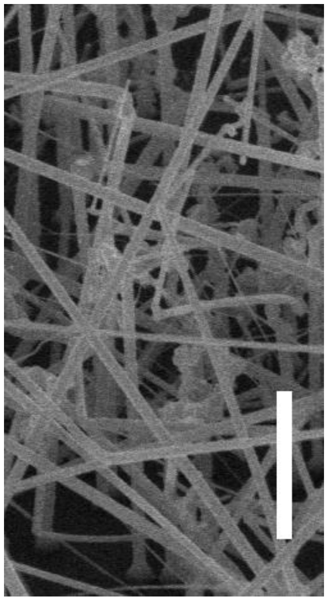
Vapor-Liquid-Solid mechanism

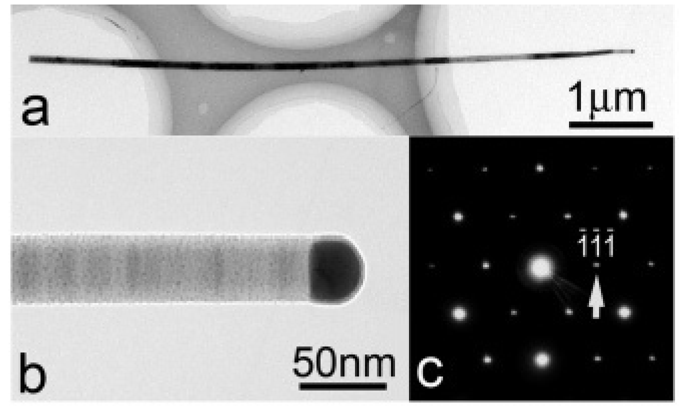
420°C

V/III=110



40° tilted FESEM images

TEM



Zincblende

Nanowires were removed from the growth substrate into methanol solution and deposited onto a silicon substrate

Single wires: diameter 30 nm - 150 nm, 5-10 μm

- **wire's diameter > Bohr exciton diameter (~10 nm for InP): no significant quantum confinement**

Electron-hole plasmas and excitons

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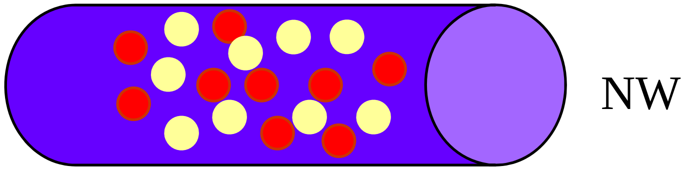
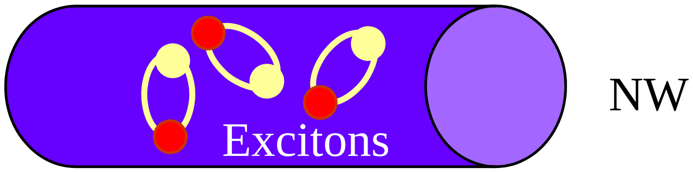
High excitation density

Early time:



high carrier density: electron-hole plasmas

Later time:

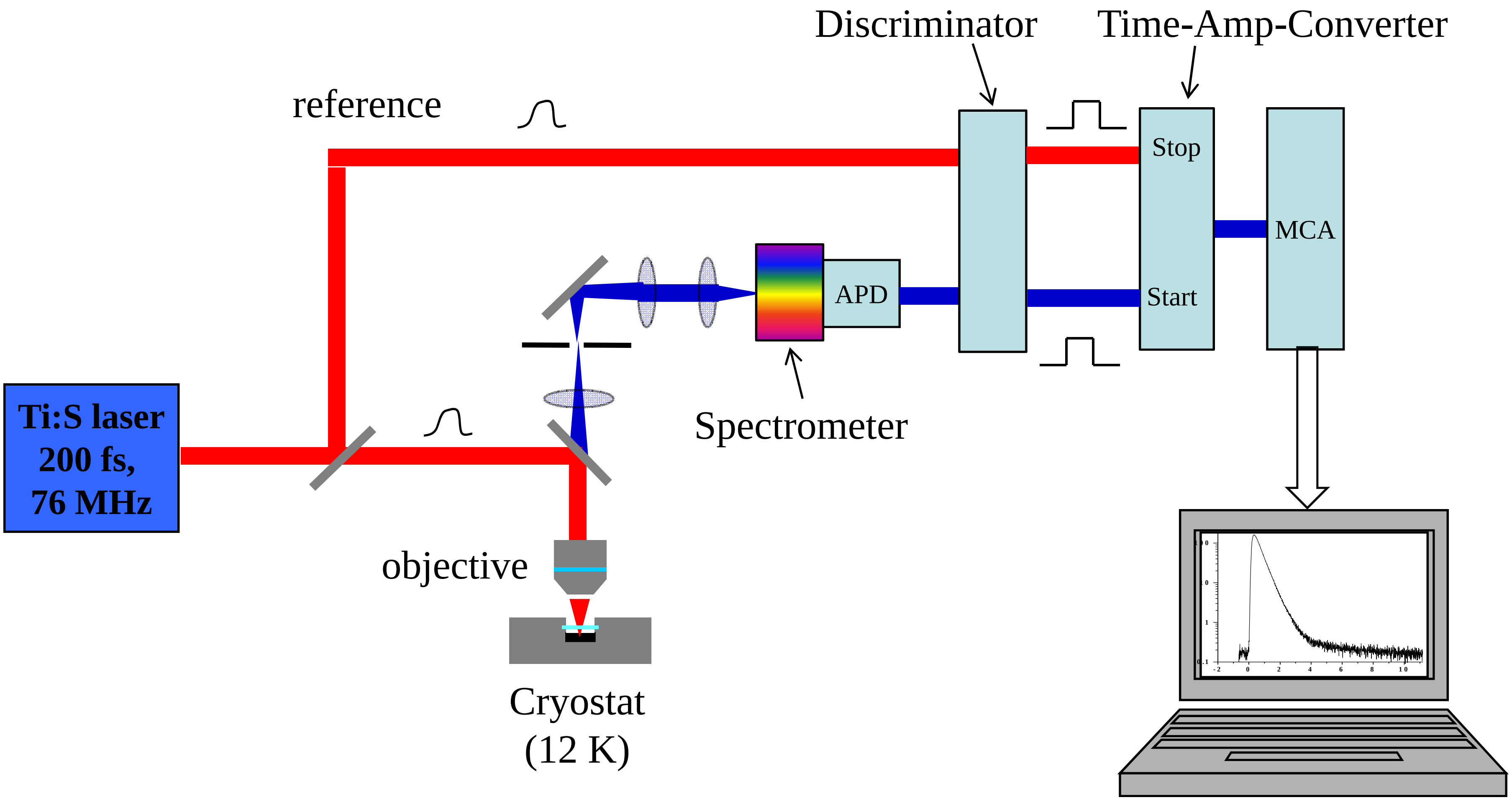


lower carrier density (below Mott density):
electron-hole correlation creates excitons

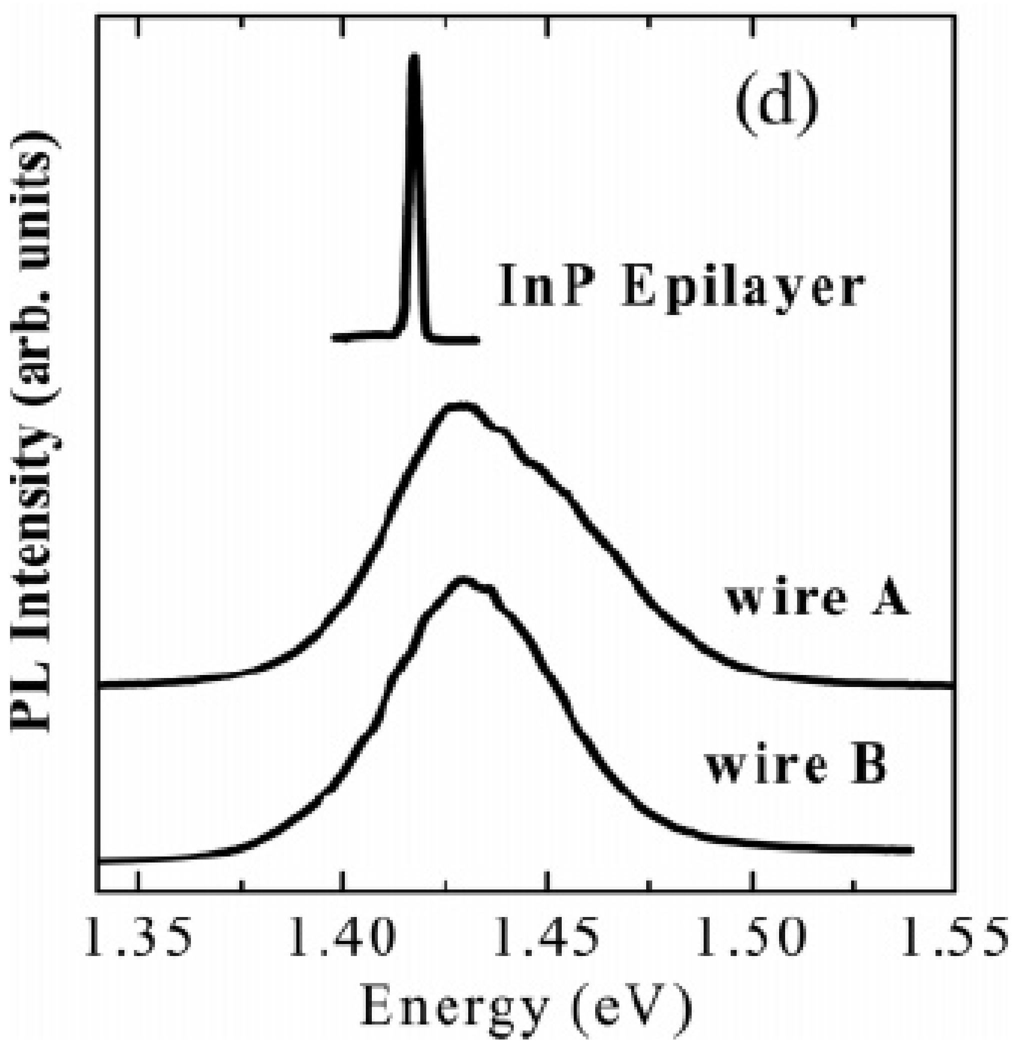
We are interested in carrier dynamics in single nanowires!

Experimental setup

Time-correlated single photon counting



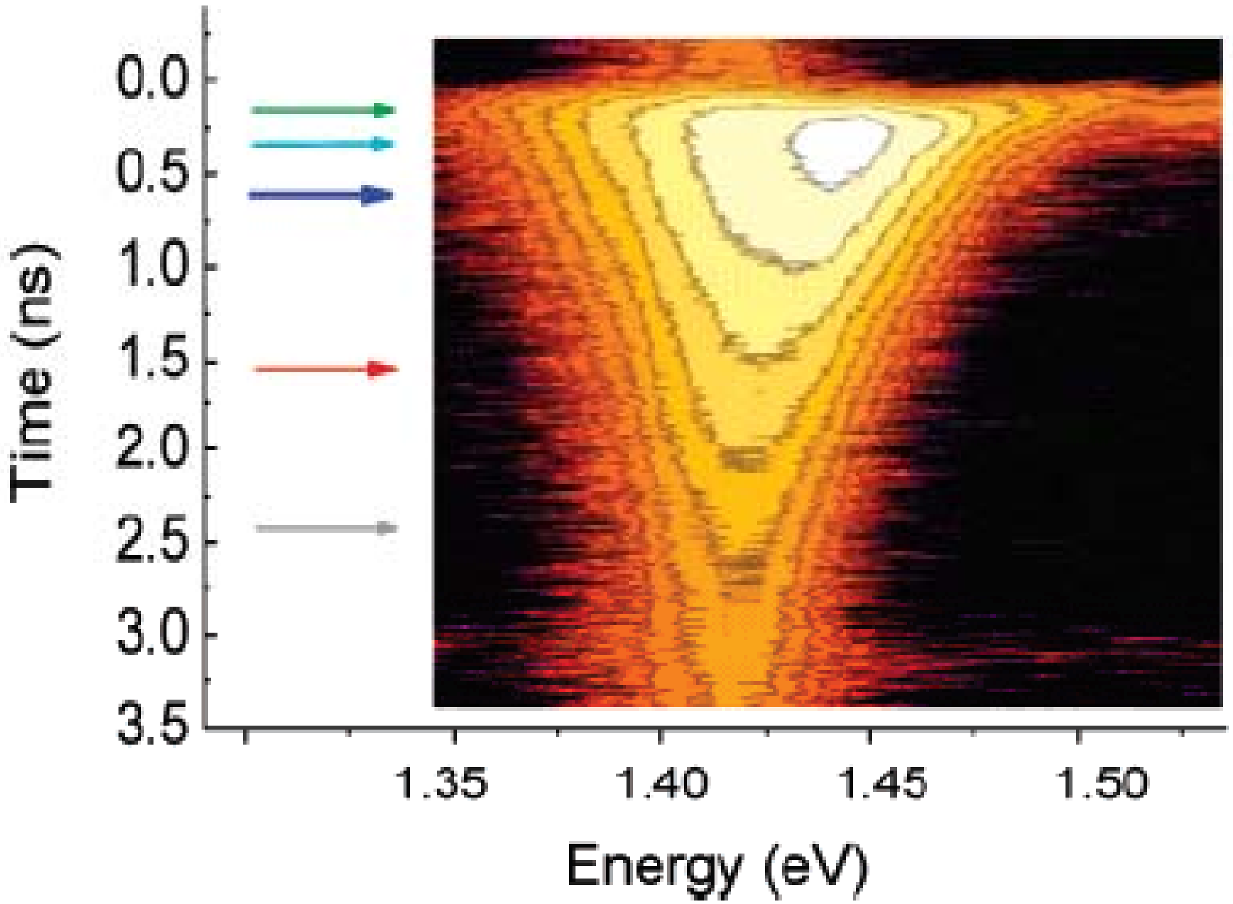
Low temperature PL



InP NWs:

- **high quantum efficiency**
- **broader emission band, higher energy peak compared to epilayer**

Band Gap Renormalization and State Filling Effects



Early times: **emission at both higher and lower energies than the exciton peak at 1.418 eV.**

Later time: **PL converges toward the exciton peak energy**

Band gap renormalization

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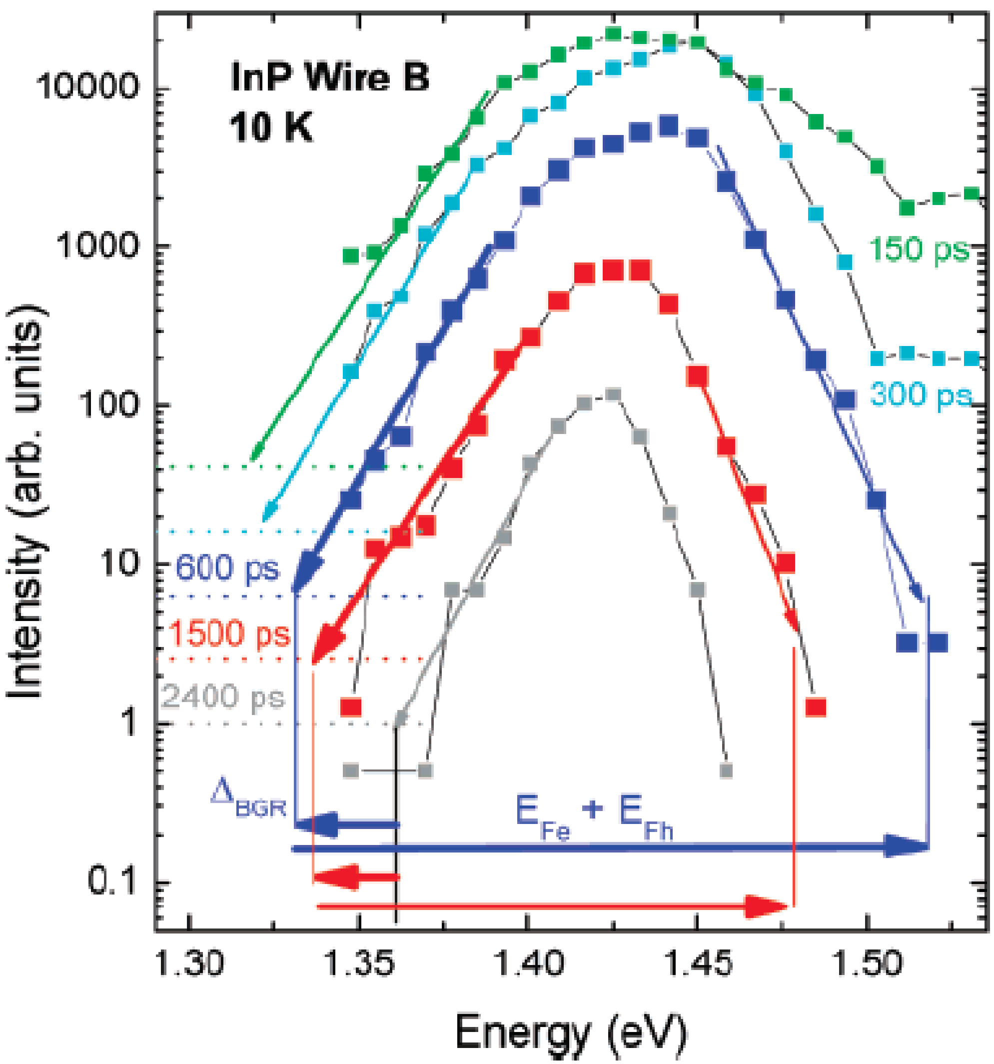
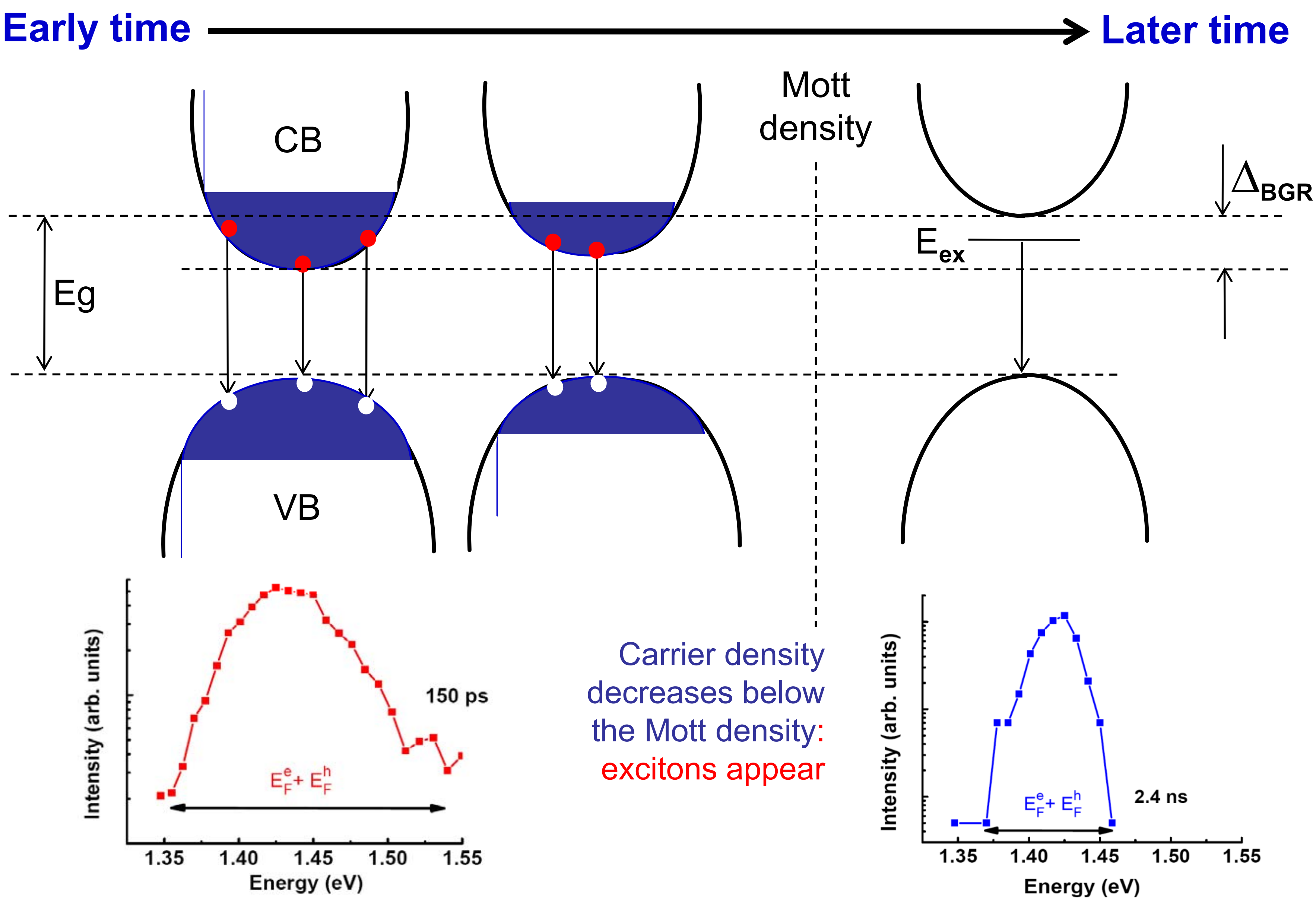


Low energy side: Bottom of the emission band gets closer to free exciton energy at later times

High energy side: PL drops to background quickly ~600 ps (electrons and holes rapidly cool)

degenerate electron-hole plasma → band gap renormalization

Band gap renormalization



Carrier density decreases below the Mott density: excitons appear

Energy dependence of lifetime

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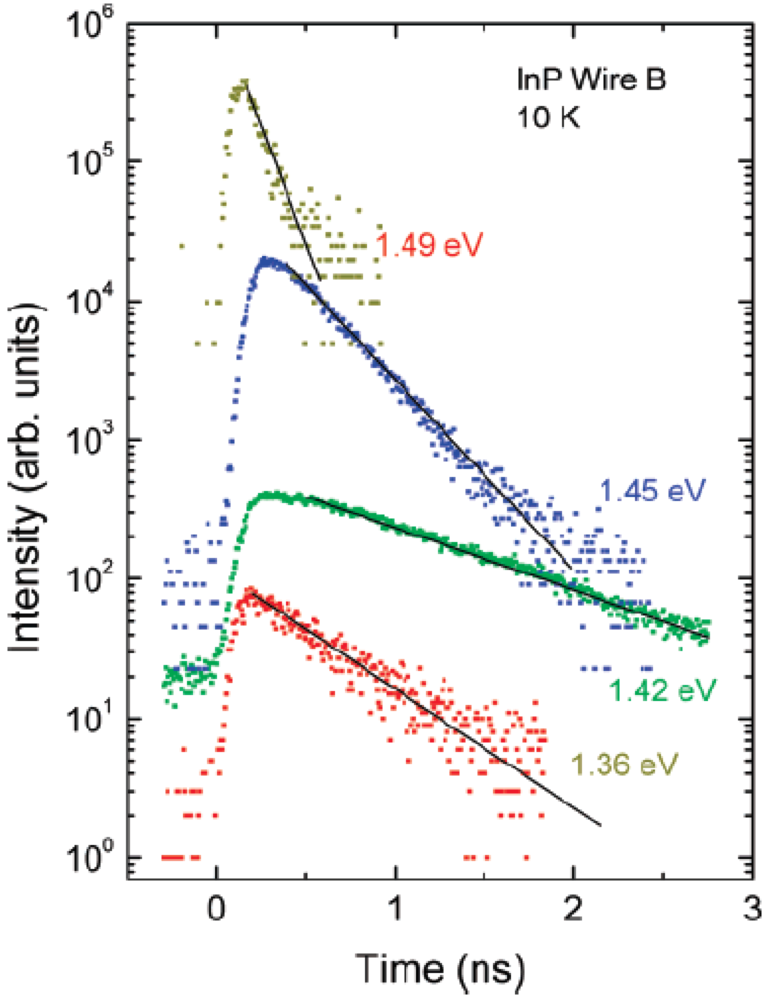
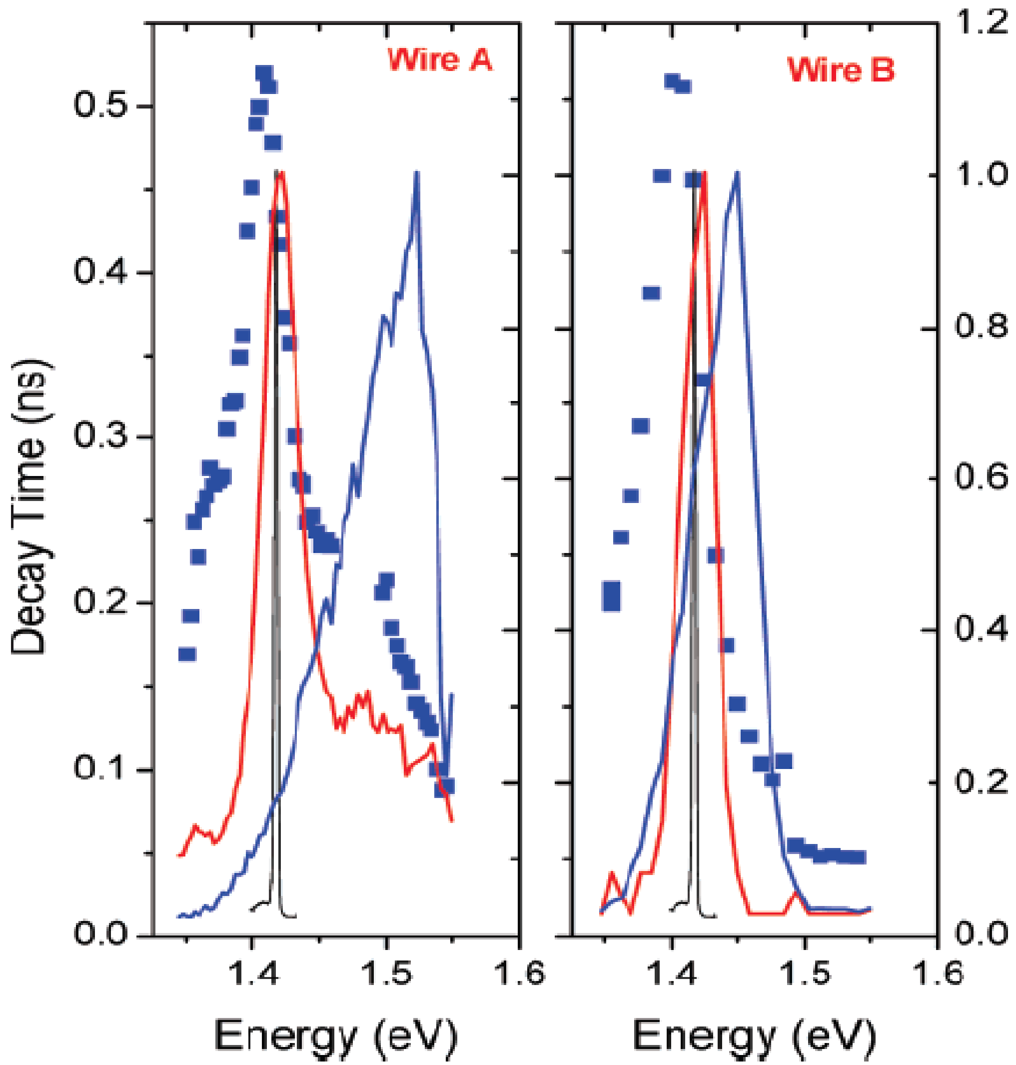


Highest energy 1.49 eV: ~90 ps (limited by system response)

Lower energy 1.36 eV: ~300 ps

Near exciton energy 1.42 eV: ~700 ps

Band Gap Renormalization and State Filling Effects



- recombination lifetime
- epilayer
- PL spectra at 300 ps
- PL spectra at 2.4 ns

- High energy: electronic state filling and subsequent relaxation to exciton energy
- Low energy: band gap renormalization

Radiative lifetime is the longest at the epilayer exciton emission energy!

*(Nano Letters **7** 3383, 2007)*

Summary

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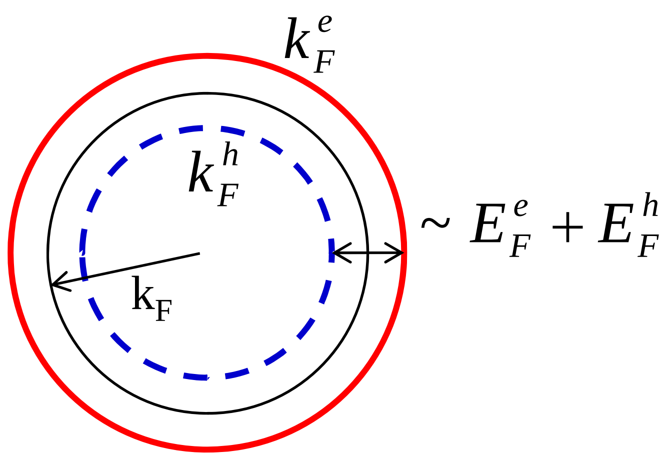
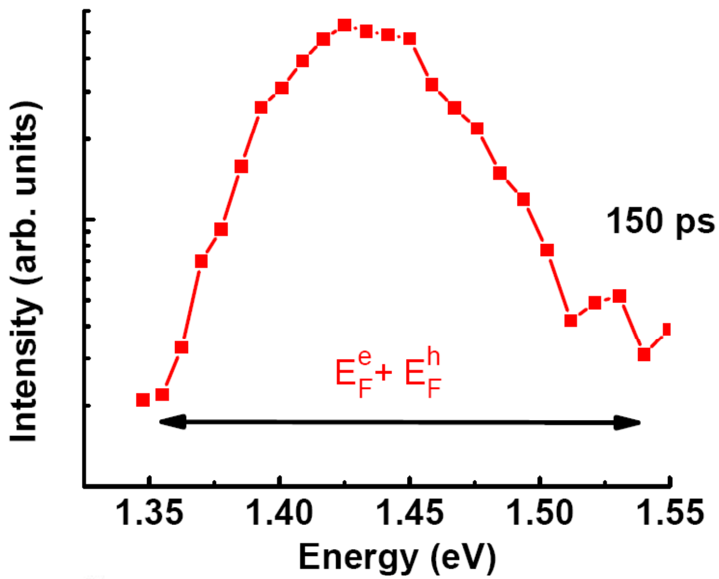
Single InP nanowires under high excitation density:

- High quantum efficiency
- Broad emission band at early time, converges toward free exciton emission band at later time
  - Electronic state filling at high energies and subsequent relaxation to exciton energy
  - Low energy: band gap renormalization
- Observed single InP nanowire radiative lifetimes: 90 ps – 1.1 ns

Fermi energies

Early time (~150 ps):





Later time (>600 ps):