Nearly Surface-Free Confinement of Excitons in Single GaAs/AlGaAs Core-Shell Nanowires

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Materials for 1-D Devices

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Applications

- Sensor development
- LED and Nanowire lasers
- Photo detectors
- Single electron devices

All depend on material quality

Surface/Volume → Large

Surfaces dominate NW properties

Recombination lifetimes

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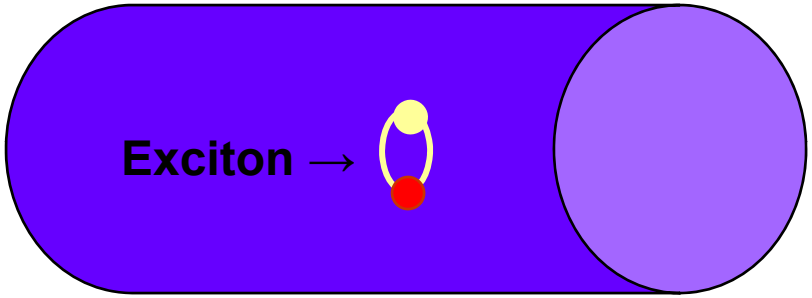
Large structures → Fewer surface interactions → Longer lifetimes

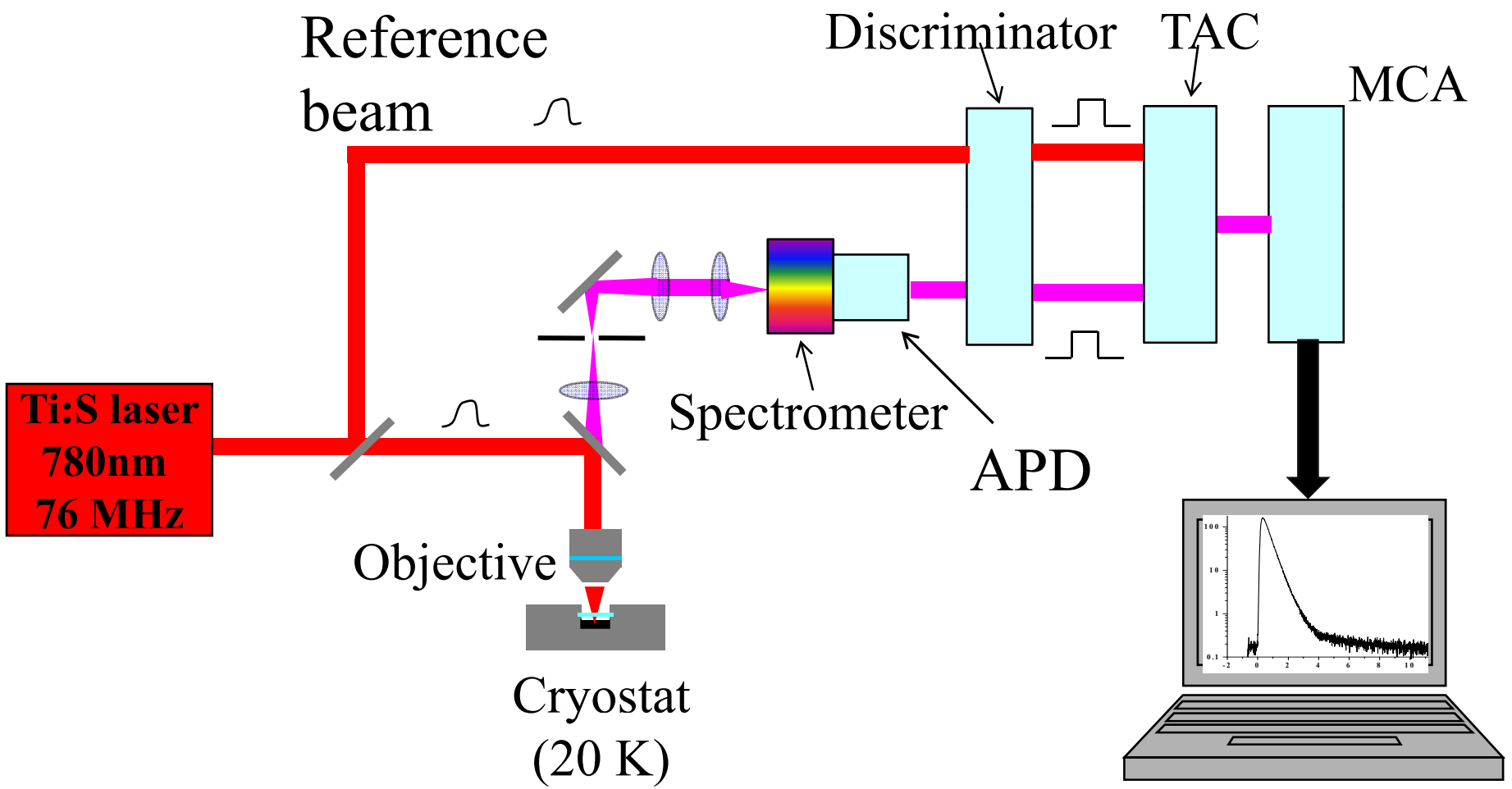


Small structures (wires) → More surface interactions → Shorter lifetimes

Surface recombination velocity (*S*) → characterizes effects of nonradiative surface states

Nonradiative recombination reduces quantum efficiency. Occurs at surfaces ($\tau_{NR} = d/2S$) and defects within wire.

Experimental Setup



InP nanowires

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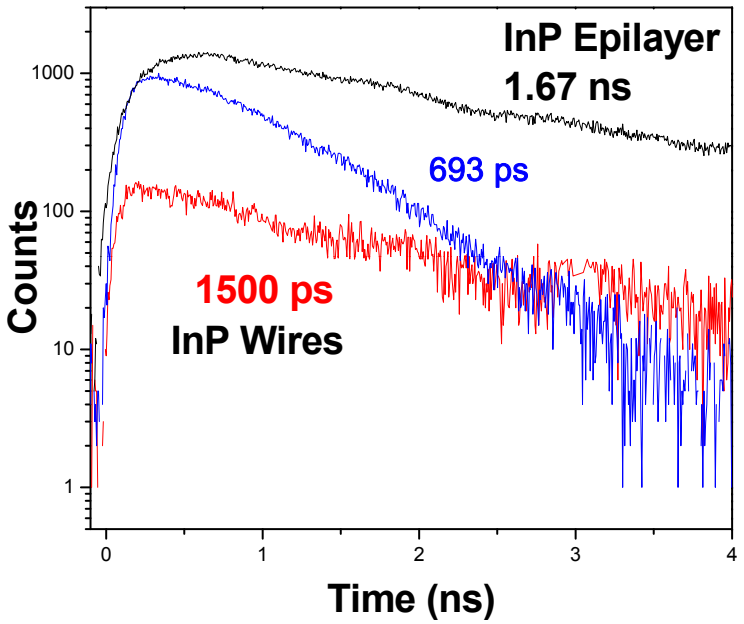
- Surface recombination velocity
  $S = 5 \times 10^3$ cm/s

- Non-radiative lifetime
  $\tau = d/2S = 2$ ns

- Experiments InP → 1.5ns

- Intrinsic (non surface dominated) properties visible

- Hole diffusion length = 1μm



InP PL time decays at peak energies

Nano Letters 7, 3383 (2007)

GaAs comparison

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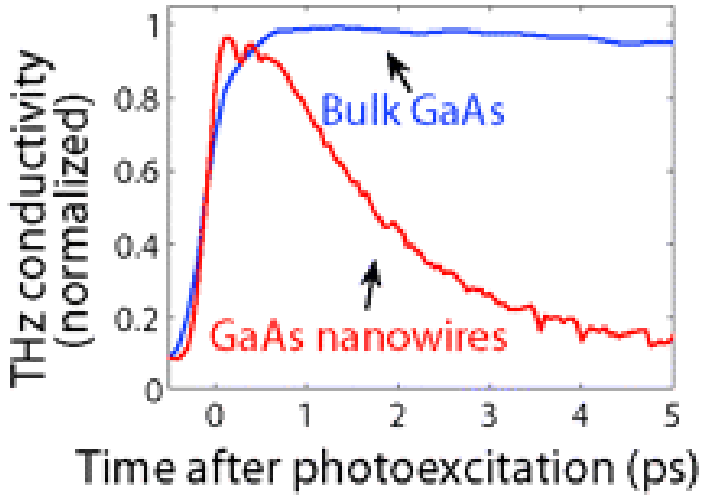
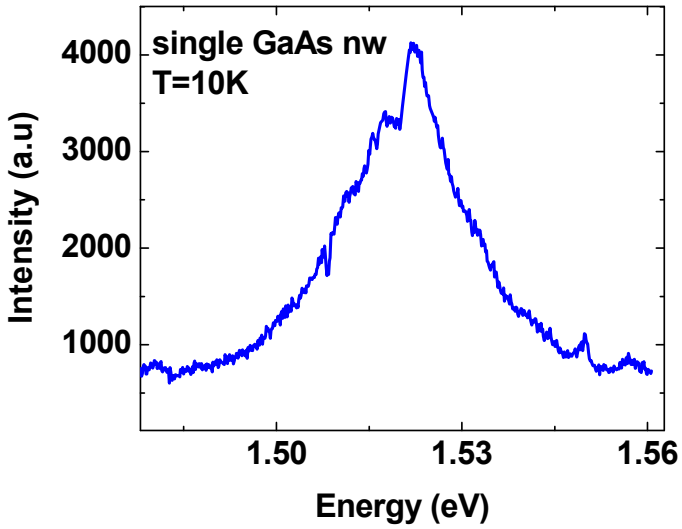
GaAs comparison

- **S = 10^6 cm/s!**
- **τ_{nr} = d/2S = 1.5ps**
- **Hole diffusion length = 3μm**
- **Experiments bare GaAs → 1ps**



Parkinson et al.
Nano Letters 7, 2162 (2007)

Bare GaAs nanowires:
low quantum efficiency due to non-radiative surface recombination



GaAs/AlGaAs Nanowires

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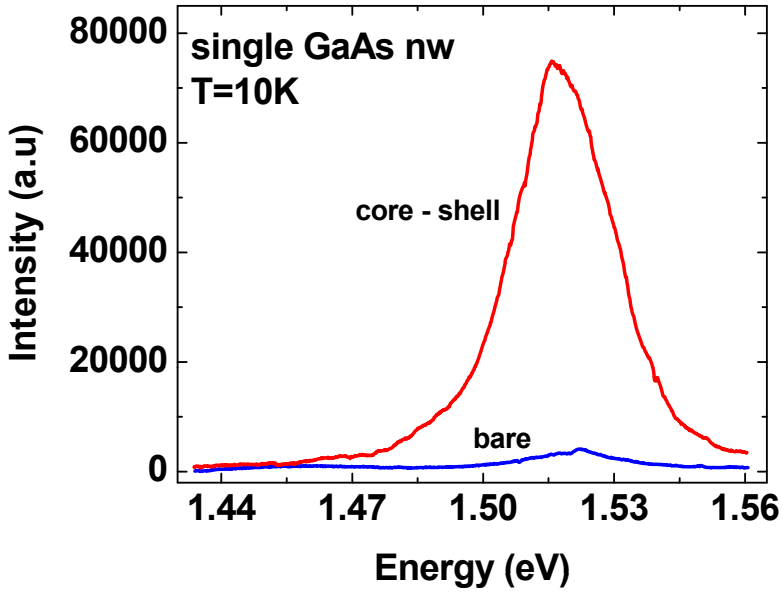
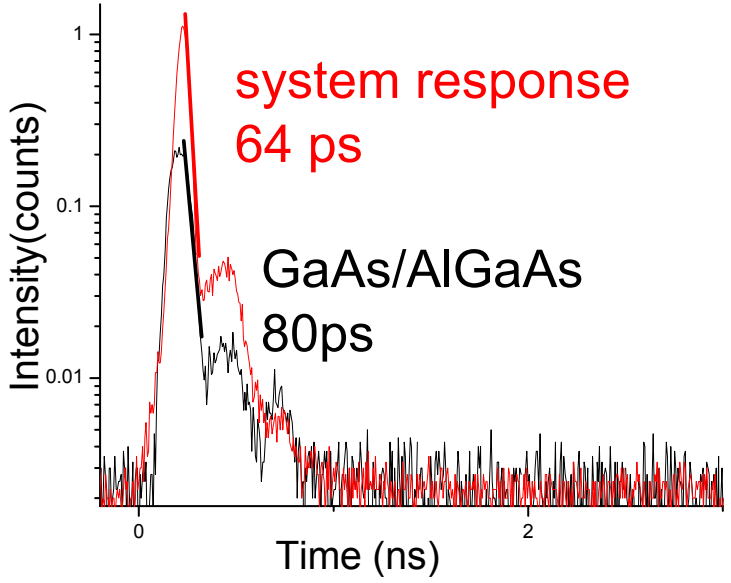
- **Core-shell GaAs-AlGaAs nanowires have much higher quantum efficiency (20-100x)**
- **But lifetime is still < 80 ps**
- **Significant nonradiative recombination centers remain…**





Appl. Phys. Lett. 89, 173126 (2006)

Potential problems with old samples…

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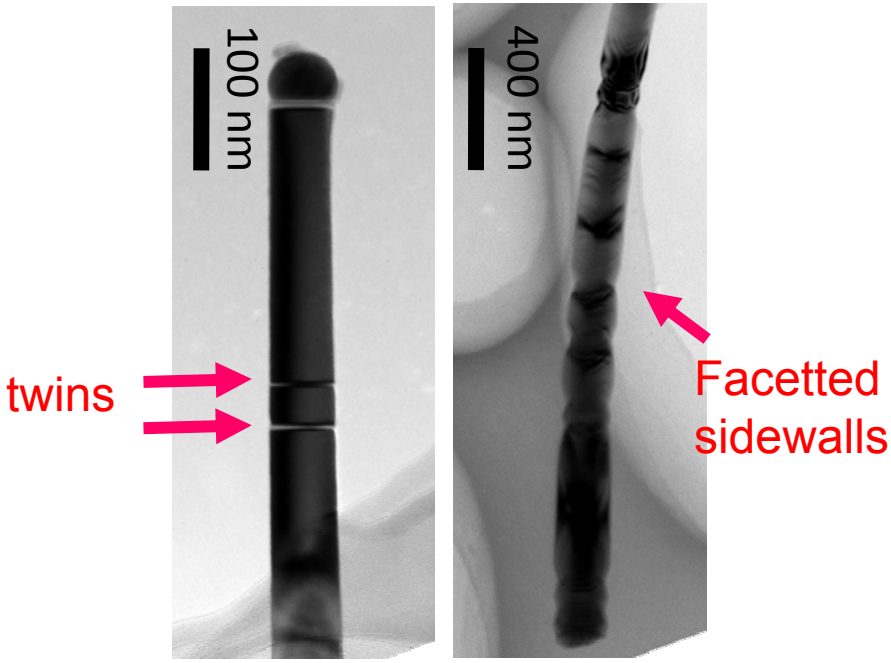
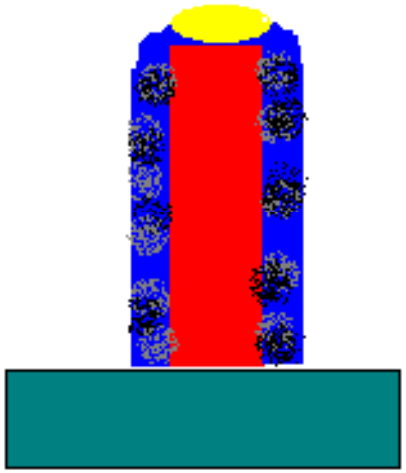
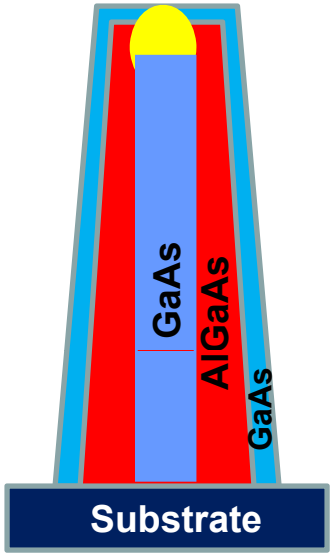
Twin defects

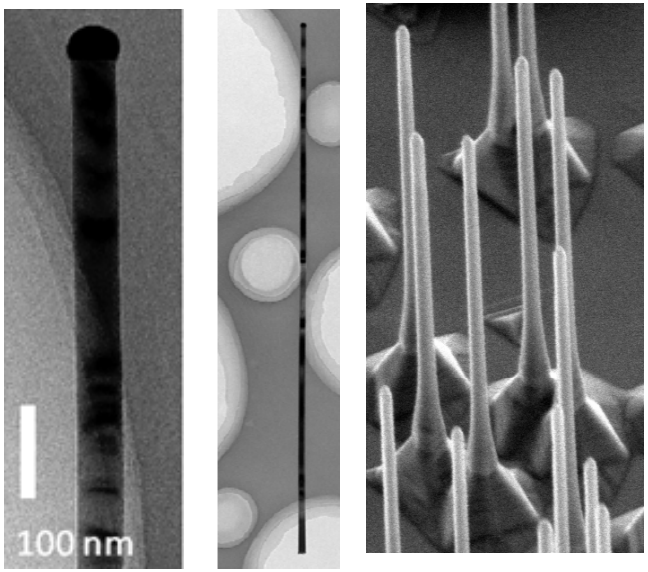


Oxidation of AlGaAs shell → Oxygen deep levels in GaAs



Two-temperature growth





1. **Twin Free Core Growth**

   - **High nucleation temperature,**
     T_n = 450 °C for 1 minute
   - **Low growth temperature,**
     T_g = 375°C for 30 minutes

2. **AlGaAs/GaAs shell/cap Growth**

   - **Temperature increased to T= 650°C**
   - **20nm AlGaAs shell, 5nm GaAs cap**

Lifetime Comparison

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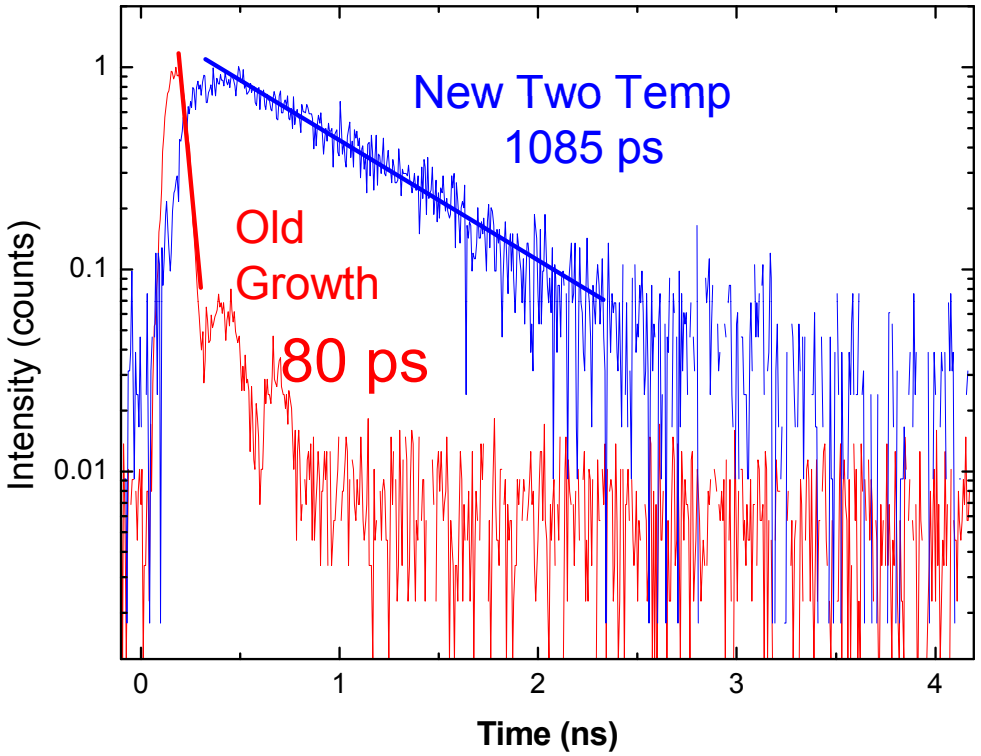
Excitation: 780nm, 200fs pulsed laser, low power.

Emission: Decay times measured at 1.51 eV free exciton peak



Time decay variablity

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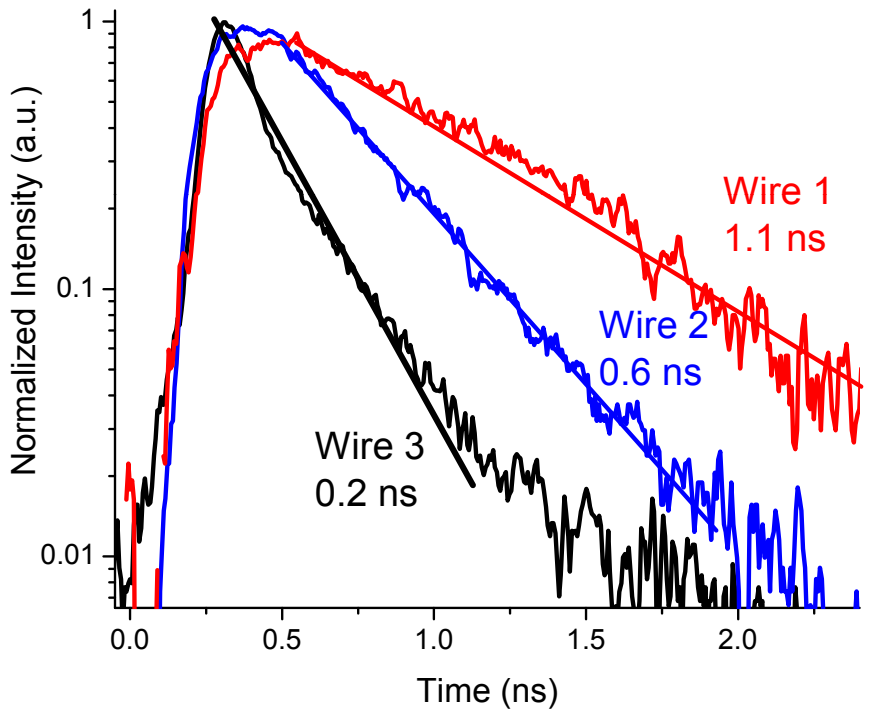
Majority of lifetimes ~1ns

Minority show shorter lifetimes → nonradiative recombination

- Isolated twin defects
- AlGaAs/GaAs interface

All lifetimes longer than old growth method



Core-shell lifetimes

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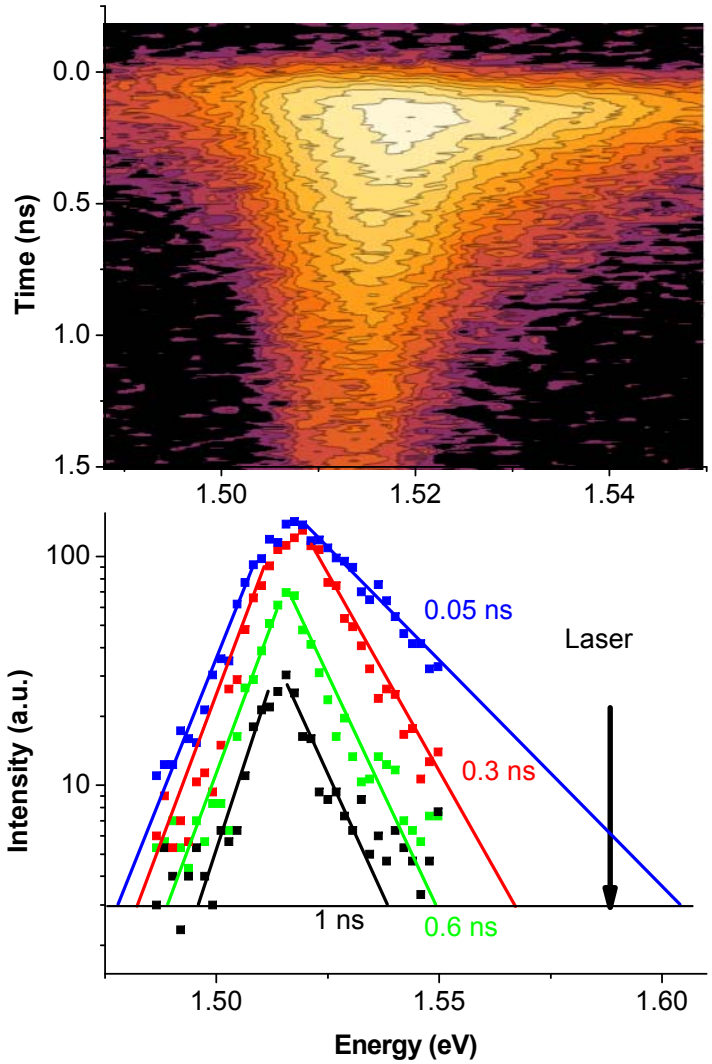
- Time decays → Almost intrinsic lifetime!

- possible to achieve NW optical qualities which approach that of the best 2D heterostructures

- fabrication of highly efficient 1D devices

Now let's look at the intrinsic properties…

Time Resolved Photoluminescence



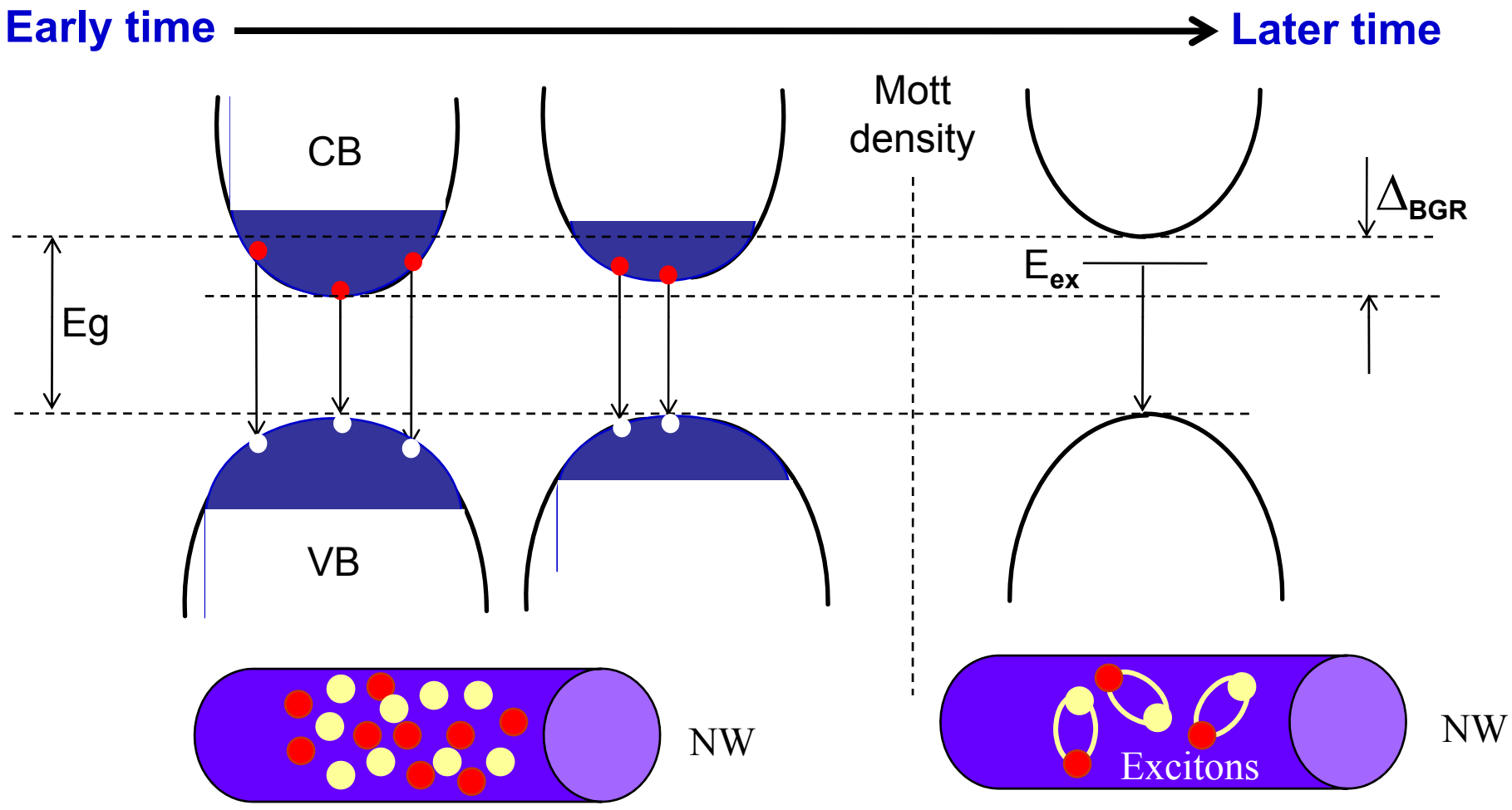
Early times:

- Asymmetric emission→ electron hole plasma

Later times:

- Symmetric emission→ excitons
- Carrier Density below Mott density

Band gap renormalization



high carrier density: electron-hole plasmas

Carrier density decreases below the Mott density: excitons appear

Summary

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GaAs/ AlGaAs core-shell Improvements

- Reduced surface defects with two temp growth
- Eliminated oxidation of AlGaAs shell with GaAs cap

Optical Characterization

- Quantum efficiency of PL greatly enhanced
- Exciton lifetimes increased from 80ps → 1ns
- State filling and many body effects observed

Work to be published in App. Phys Letters in the coming weeks