Hot-Carrier Effects in Narrow Gap InAs & GaSb Materials: Potential for Next Generation Photovoltaics

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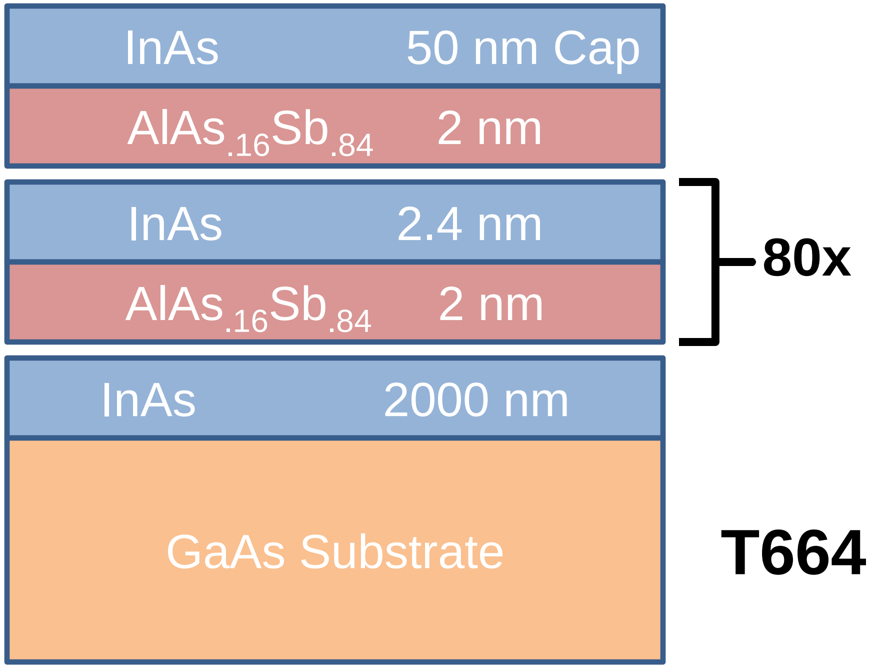
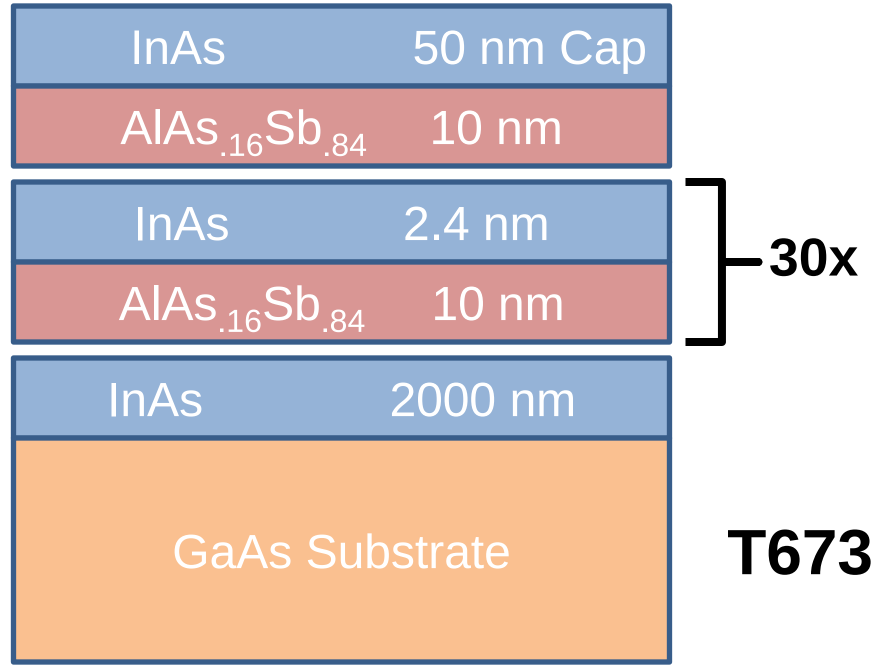
- **InAs QW optical design**
- **Photoluminescence measurements: Temperature and Power Dependence**
- **Hot Carrier Effects: Red and Blue laser excitation**

InAs Based Optical Structures

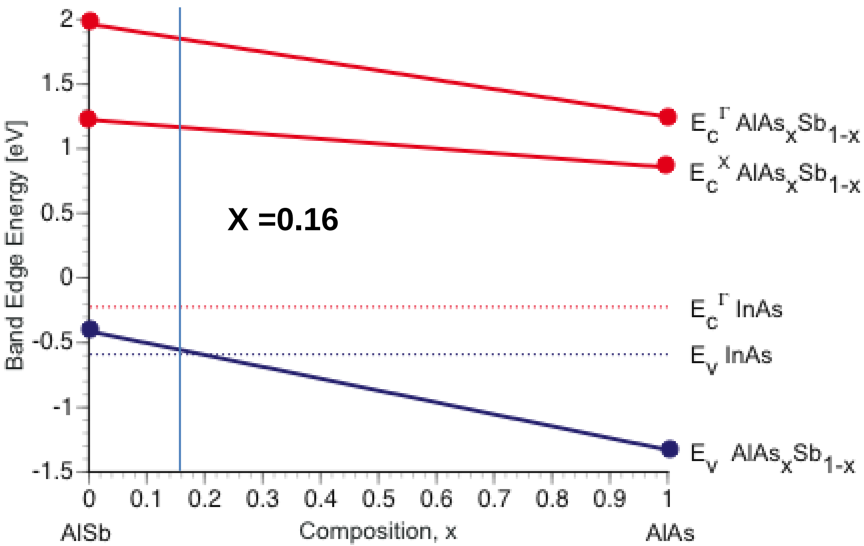




- **GaAs substrate as trial**
- **$AlAs_{.16}Sb_{.84}$ latticed matched to InAs**
- **InAs buffer layer 2 microns thick to minimize strain**

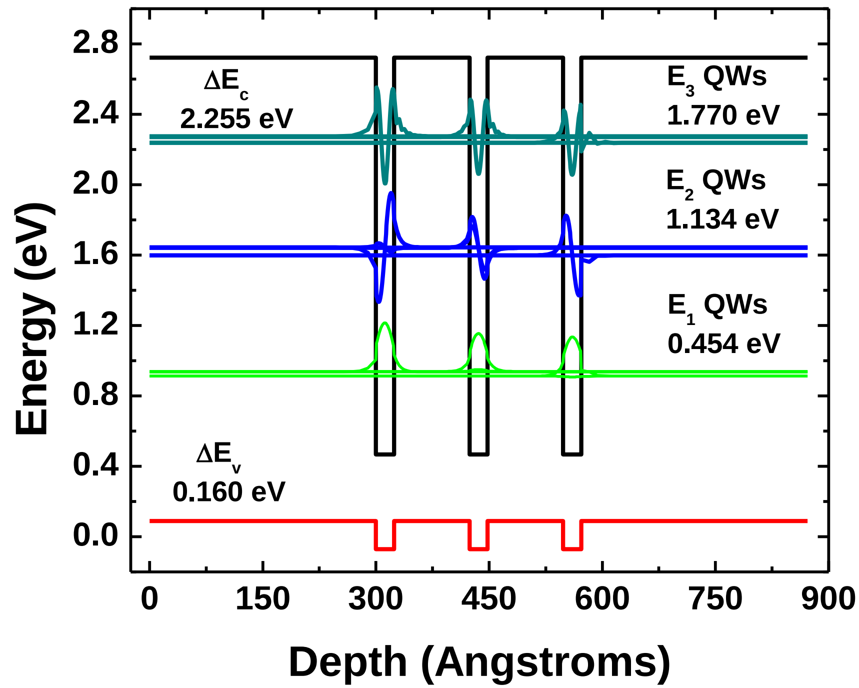
- **X and L valley energy separation: InAs > GaAs**
  Desirable to not pump higher energy states
- **Effective band gap tunable to 0.7 eV**

Conduction & Valence Band Offsets



http://hdl.handle.net/1802/12773, J.R. Pedrazzani
Thesis (Ph. D.)--University of Rochester. Institute of Optics, 2010

T673: 2.4 nm InAs QWs
10.0 nm AlAsSb Barrier

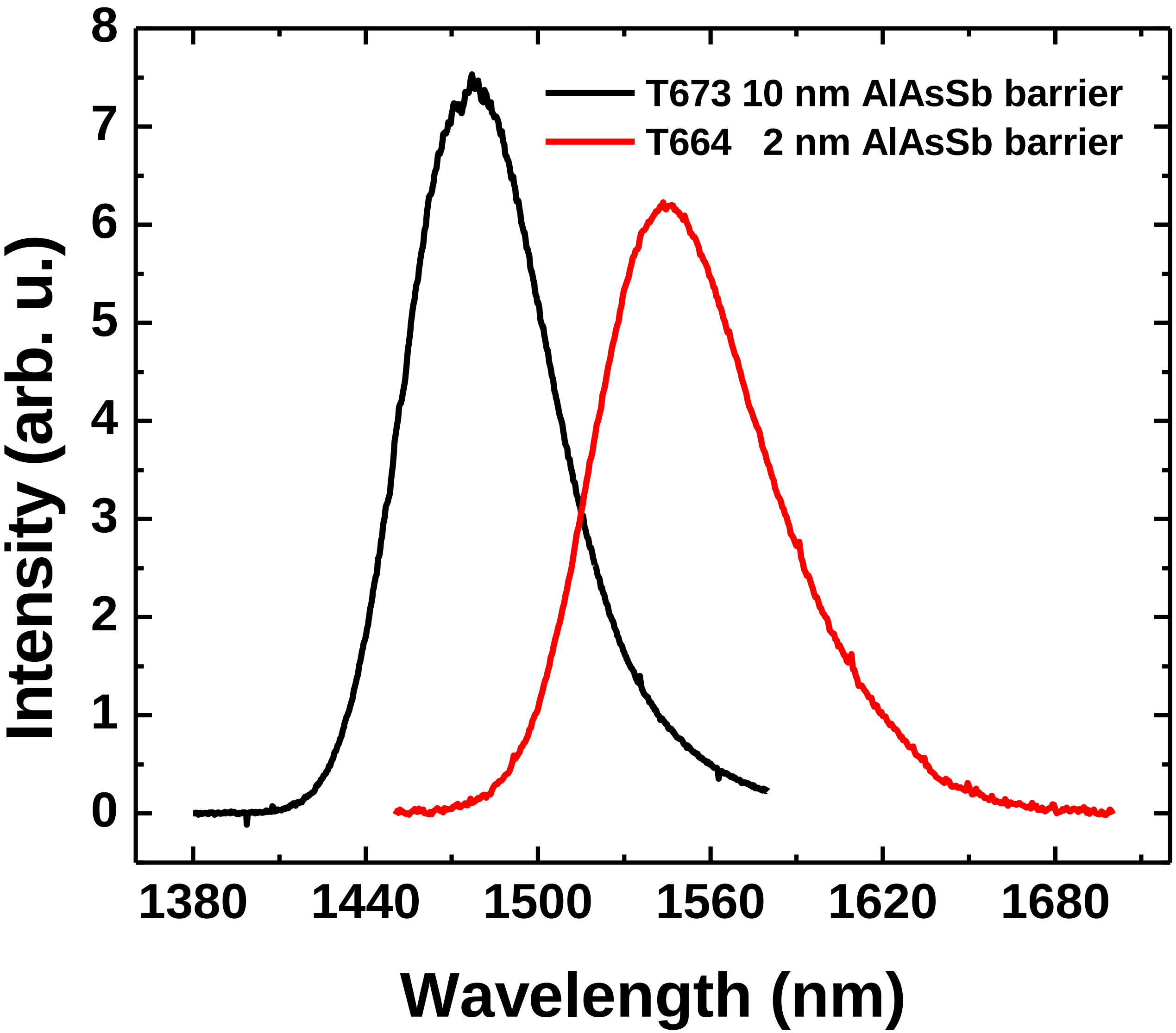


x = 0.16
Indirect band gap ~ 1.7 eV
Direct band gap ~ 2.5 eV

Thin barriers expect direct band gap absorption to dominate

Multiple confined states:
Good for impact ionization
Complication for selective extraction of hot carriers

InAs 2.4 nm Superlattice and MQW PL



2 nm Barrier

Max Temp 632 nm - 120 K

Max Temp 442 nm - 85 K

10 nm Barrier

PL Room Temp

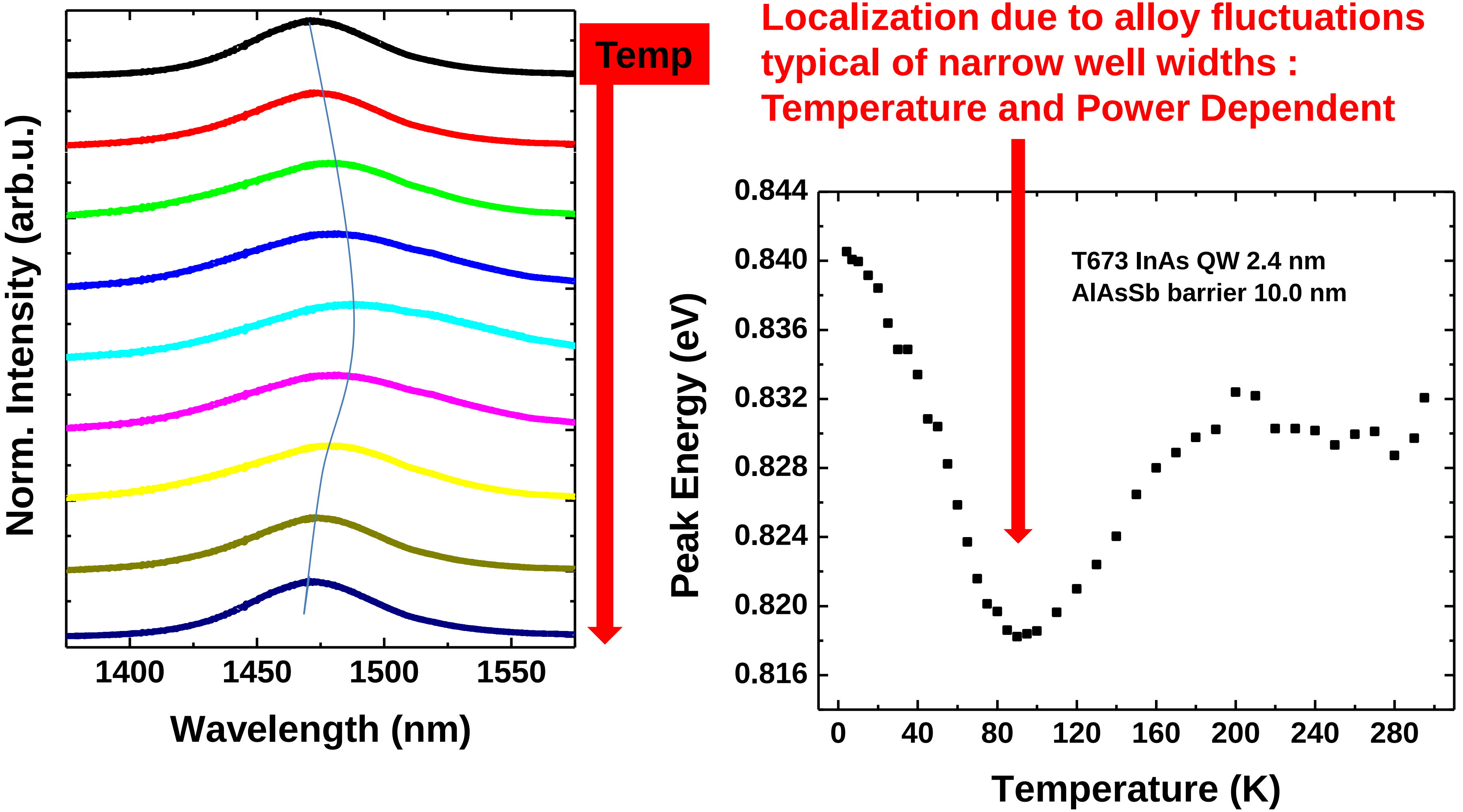
50 meV increase in Peak Energy

10 nm :: 2 nm

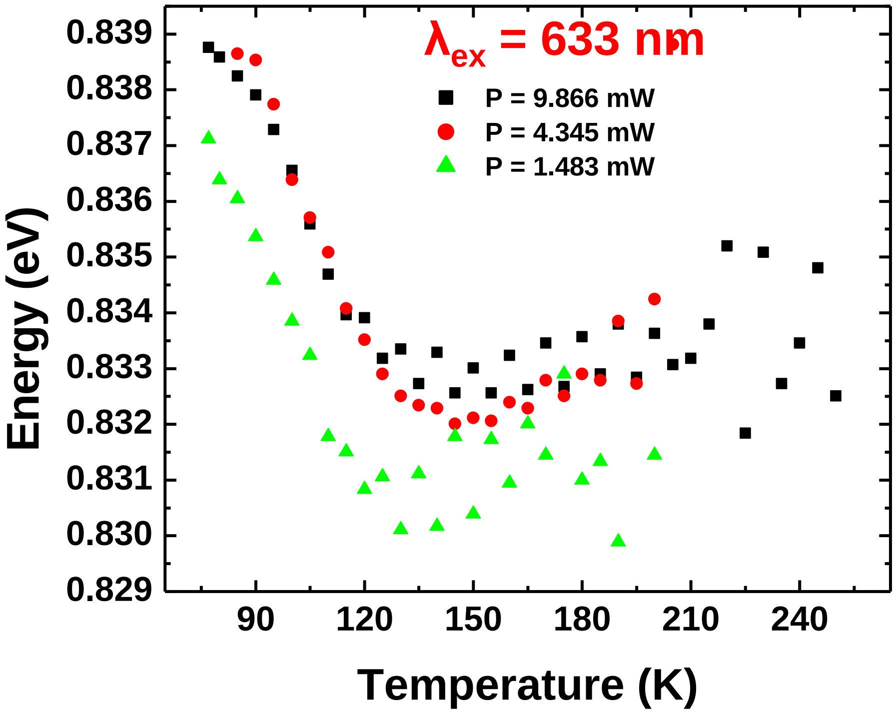
840 meV :: 790 meV

InAs MQW E vs T

Localization due to alloy fluctuations typical of narrow well widths : Temperature and Power Dependent



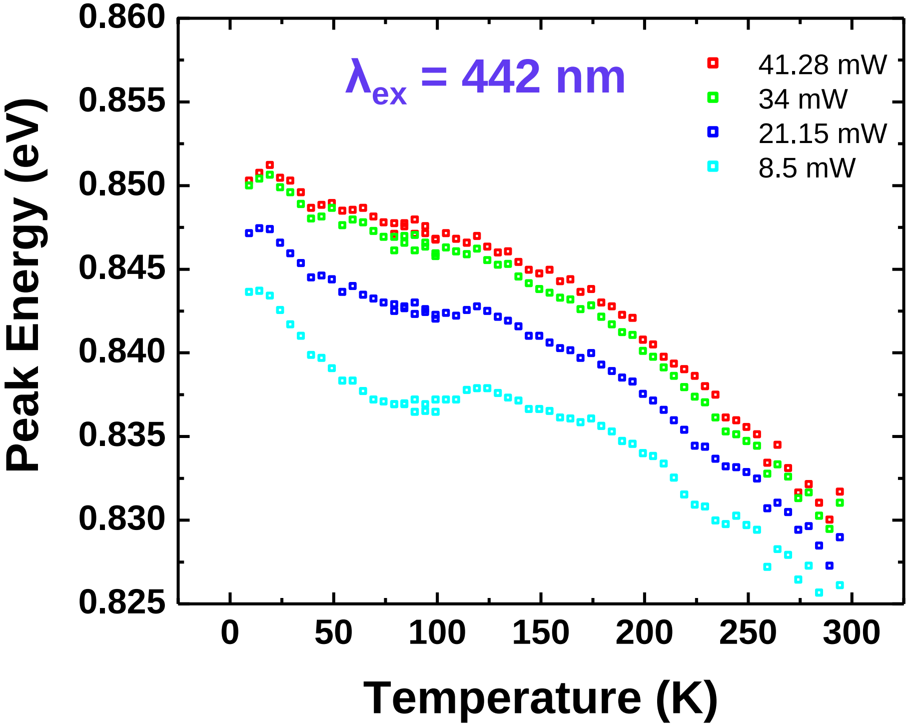
InAs MQW Temperature and Power Dependence



λ_{ex} = 442 nm

Minima in energy shifts observed for lower power

localization effects observed below 100 K

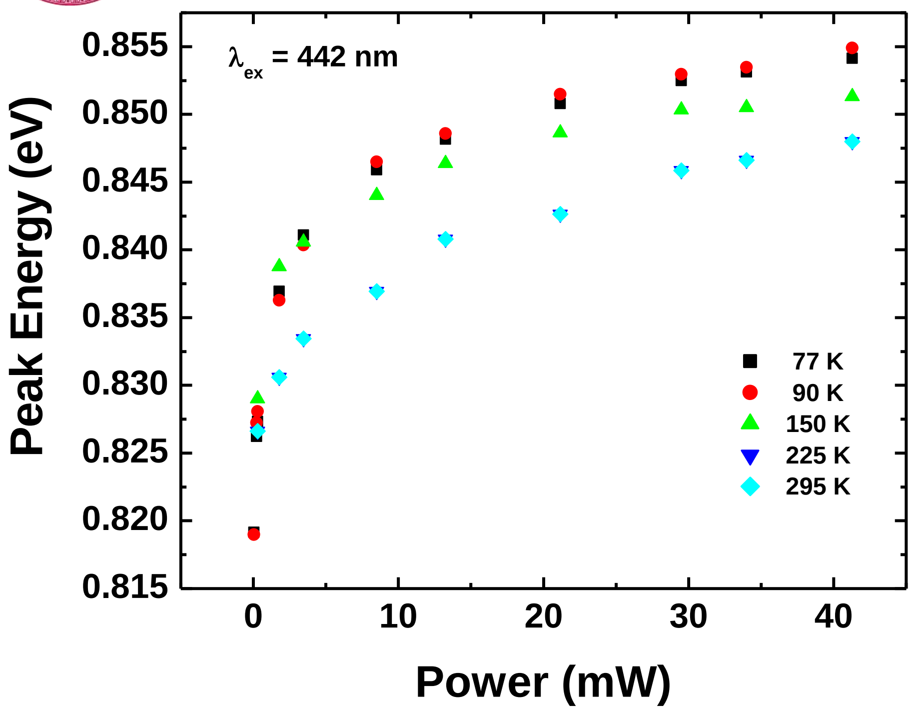


λ_{ex} = 633 nm

minima observed for all powers

Minima in energy shifts to lower temperature as power decreases

InAs MQW Power Dependence

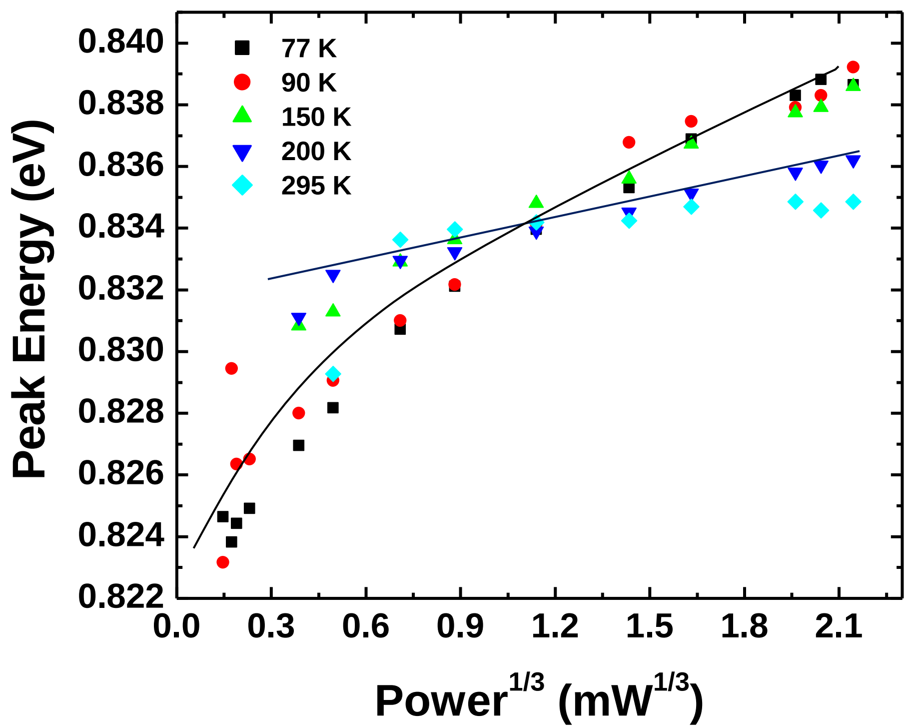


Type II power dependence based on triangular quantum well

$$\varepsilon \propto \sqrt{I}$$

$$E_e = const\ \varepsilon^{2/3} \equiv bI^{1/3}$$

Ledentsov et al., PRB Vol. **52,** (19) 14058, C. Weisbuch, B. Vintner, Quantum Semiconductor Structures, p. 20 (Academic, Boston, 1991)



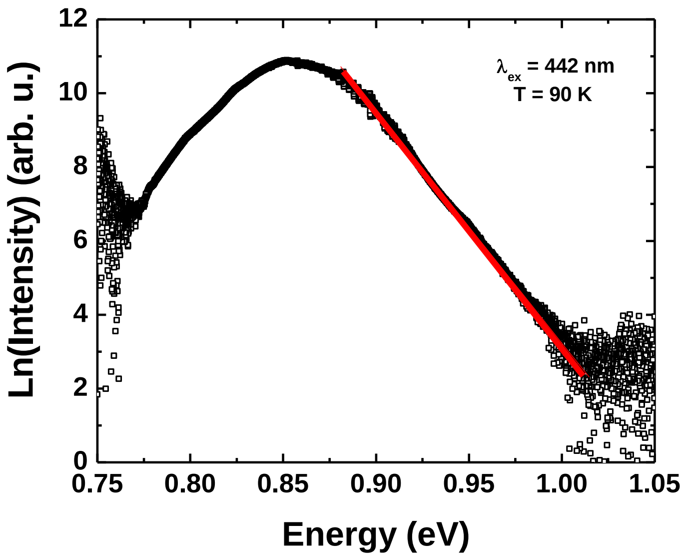
Low powers rapid change in peak energy

Higher powers leveling off of peak energy

77 K & 90 K power dependence behaves more like type II

200 K and 295 K more like type I

InAs QWs fitting methods



Maxwell-Boltzmann like distribution of carriers:

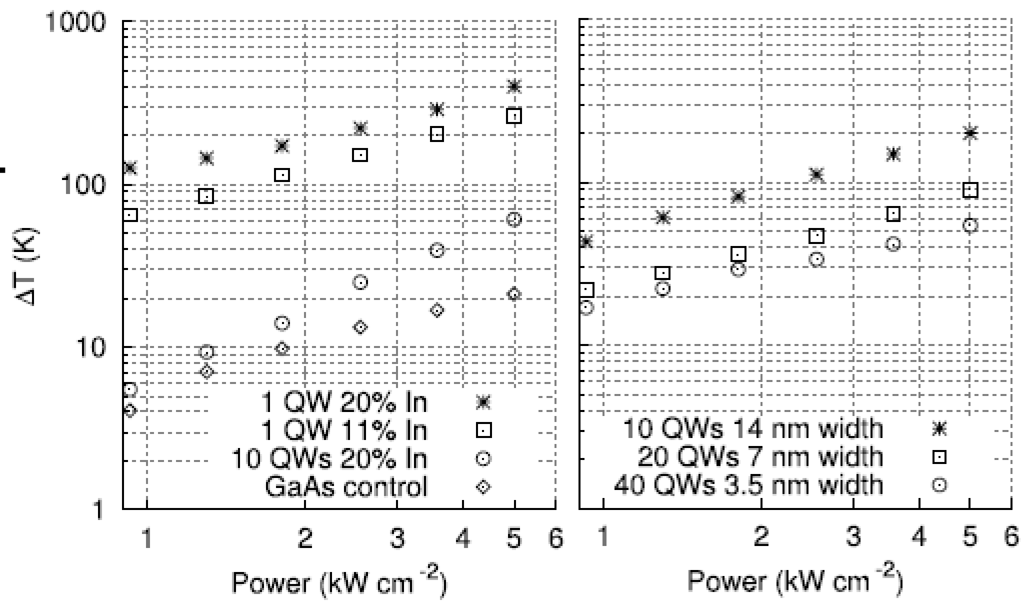
$$I_{pl}(h\nu) \propto \exp(-h\nu / k_b T_H)$$

I_{pl} - PL intensity
$h\nu$ - photon energy
T_H - carrier temperature

A. Le Bris et al., Energy & Environmental Science DOI:10.1039/c2ee02843c

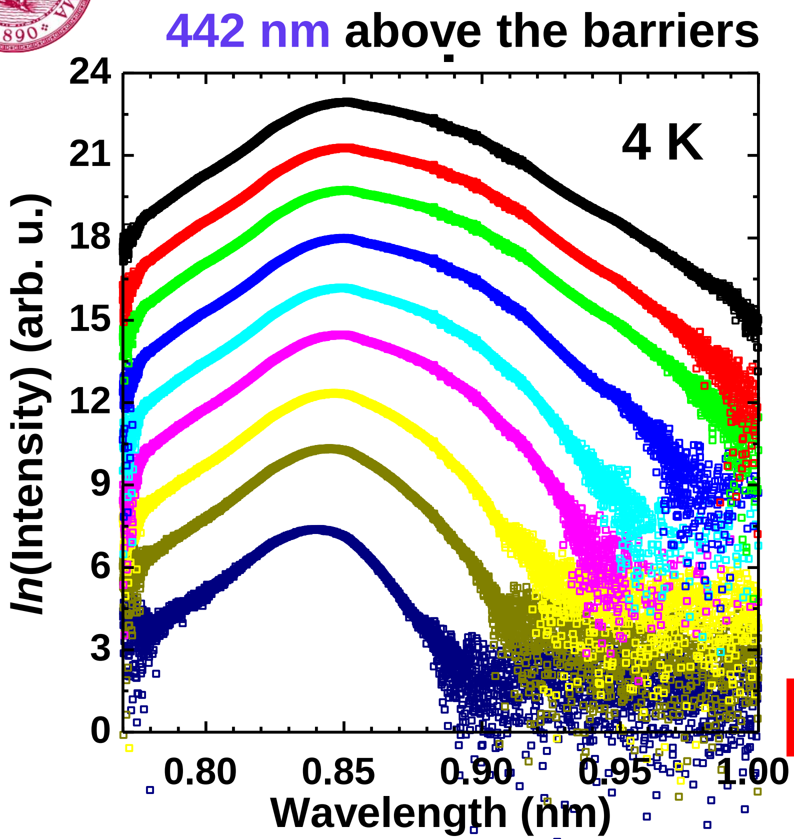
Increasing power → Increasing ΔT

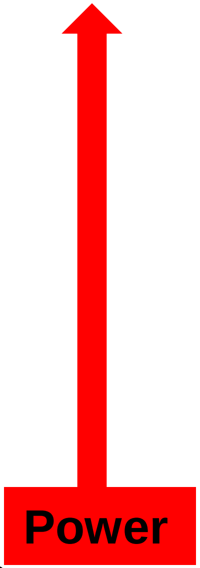
HE slope of PL decreases corresponds to increasing ΔT

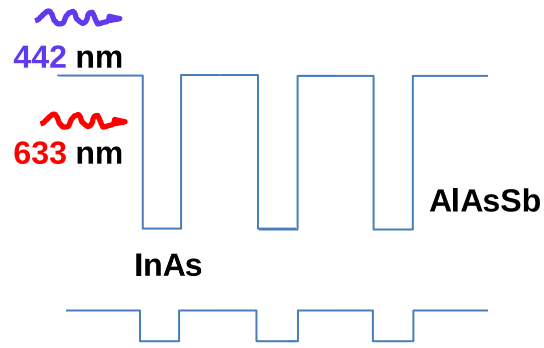


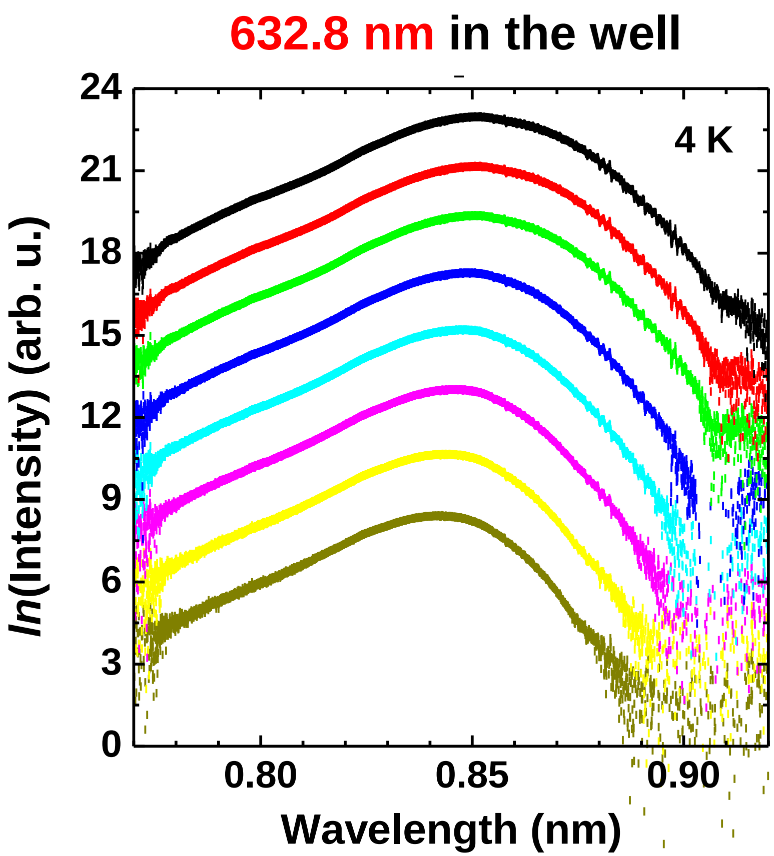
Hirst et al., IEEE J. of Photovoltaics, Vol. 4, No. 1, January 2013

InAs QWs Laser excitation comparison







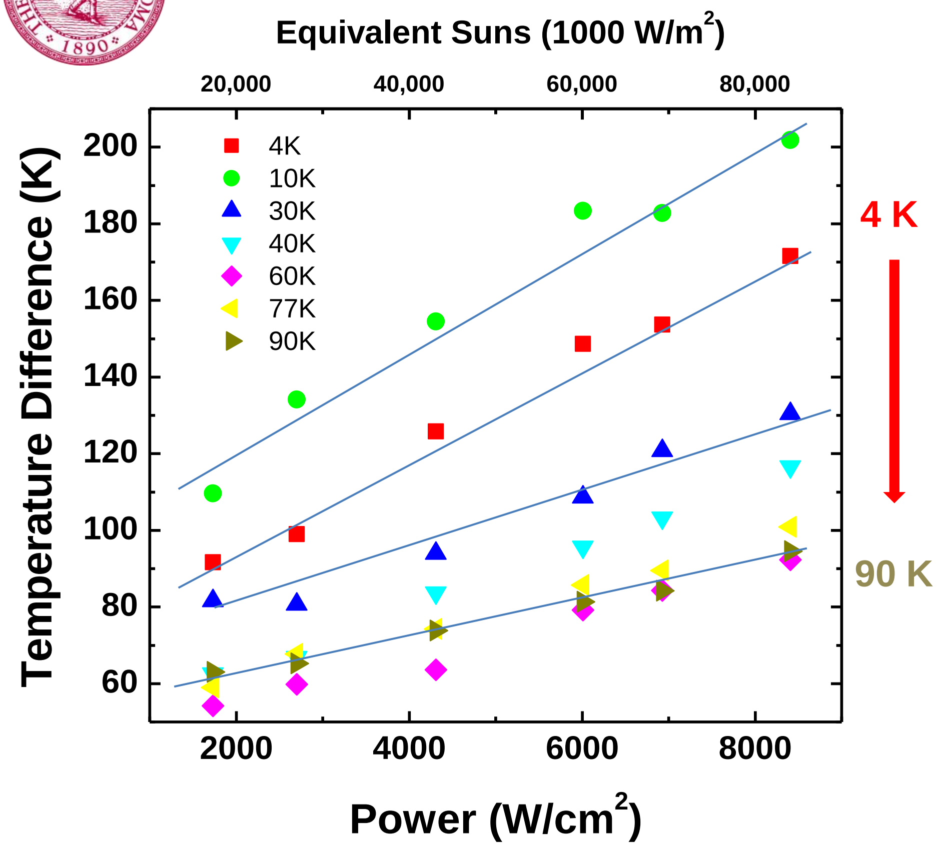


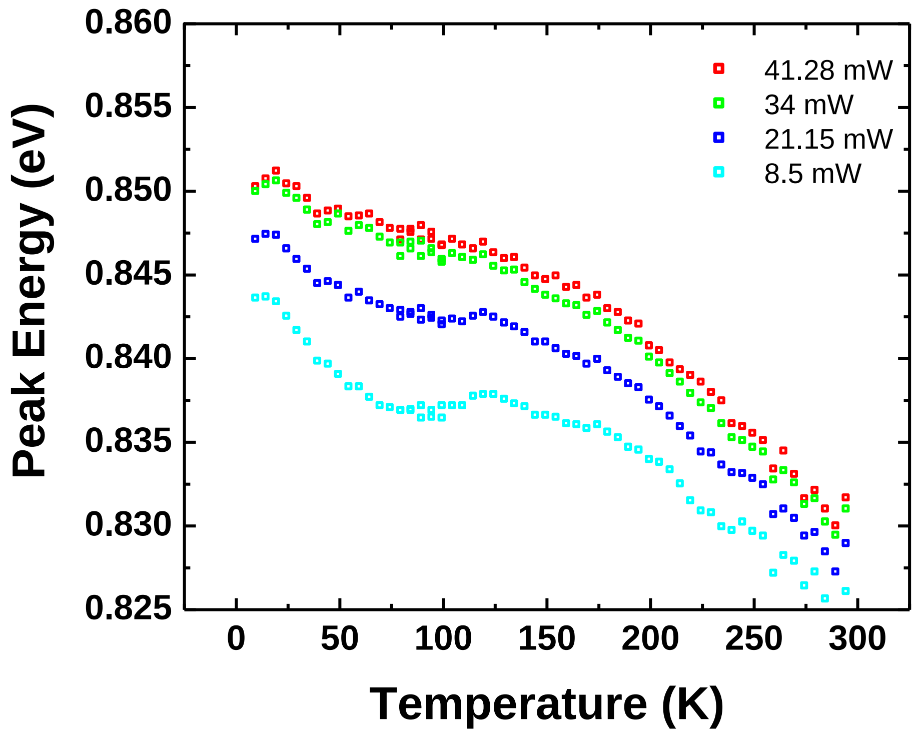
High energy tail is more pronounced when excited by higher energy higher power blue laser.

Only a single QW is excited by blue laser

Typical change in slope of high energy tail (broadening) as a function of power

InAs QWs Carrier Temperature





Low Temperature Regime:

Increasing ΔT wrt Power for all Temp

Temp increases slope of ΔT decreases

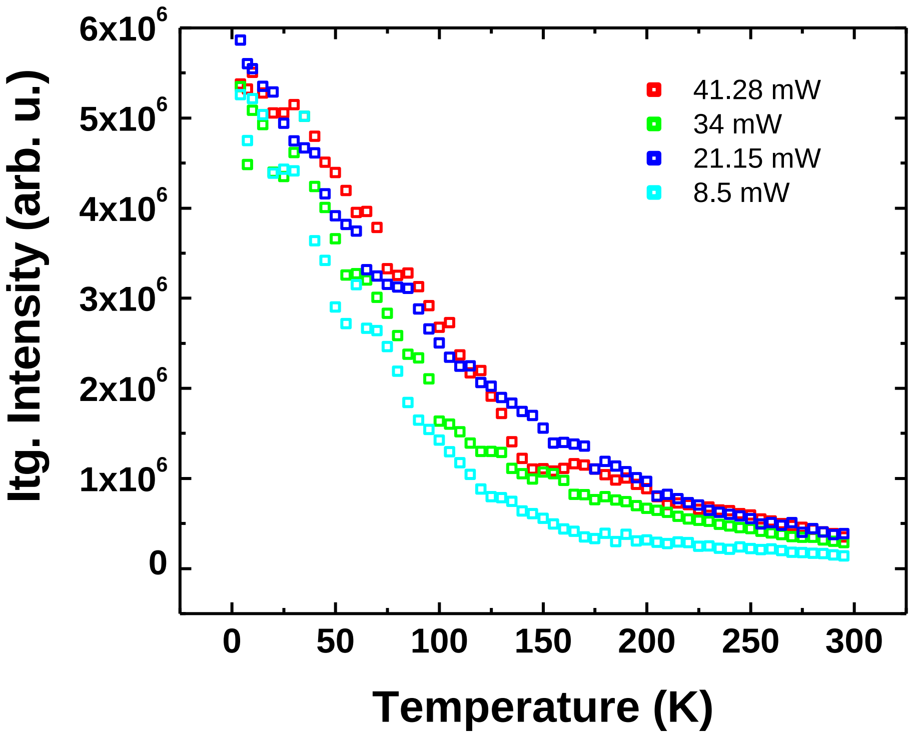
High Temperature Regime:

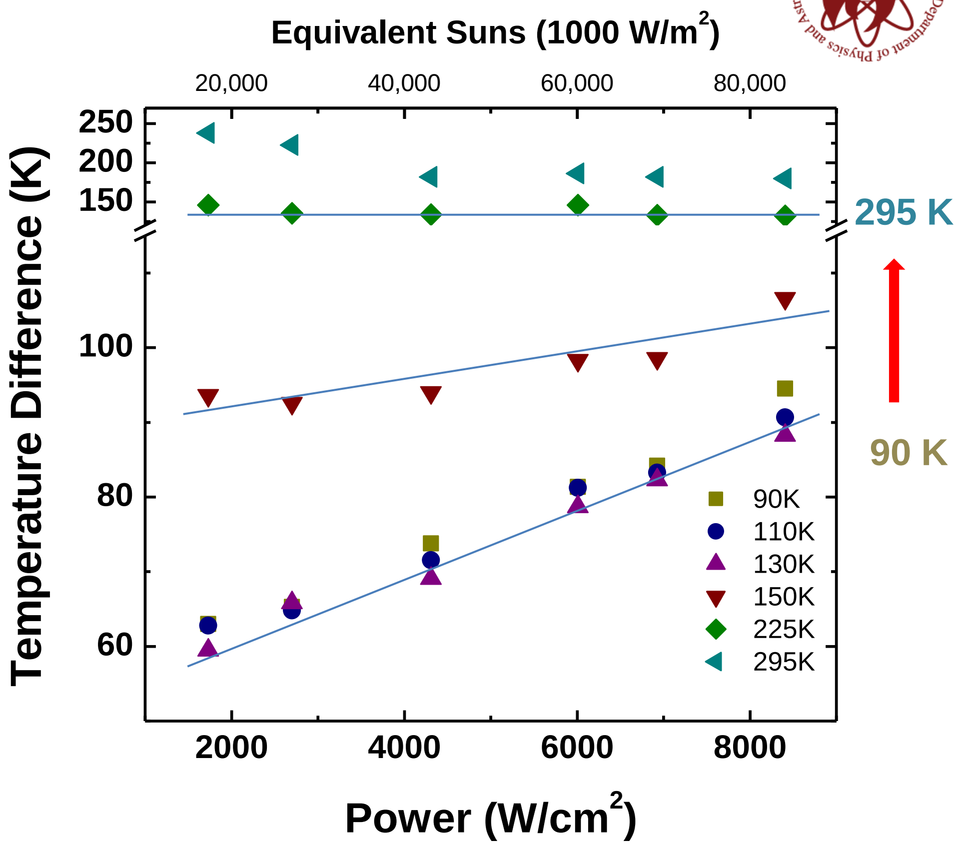
Holes delocalized ⇒ electron pileup

ΔT wrt Power nearly independent

Temp increases slope of ΔT becomes level

InAs QWs Carrier Temperature





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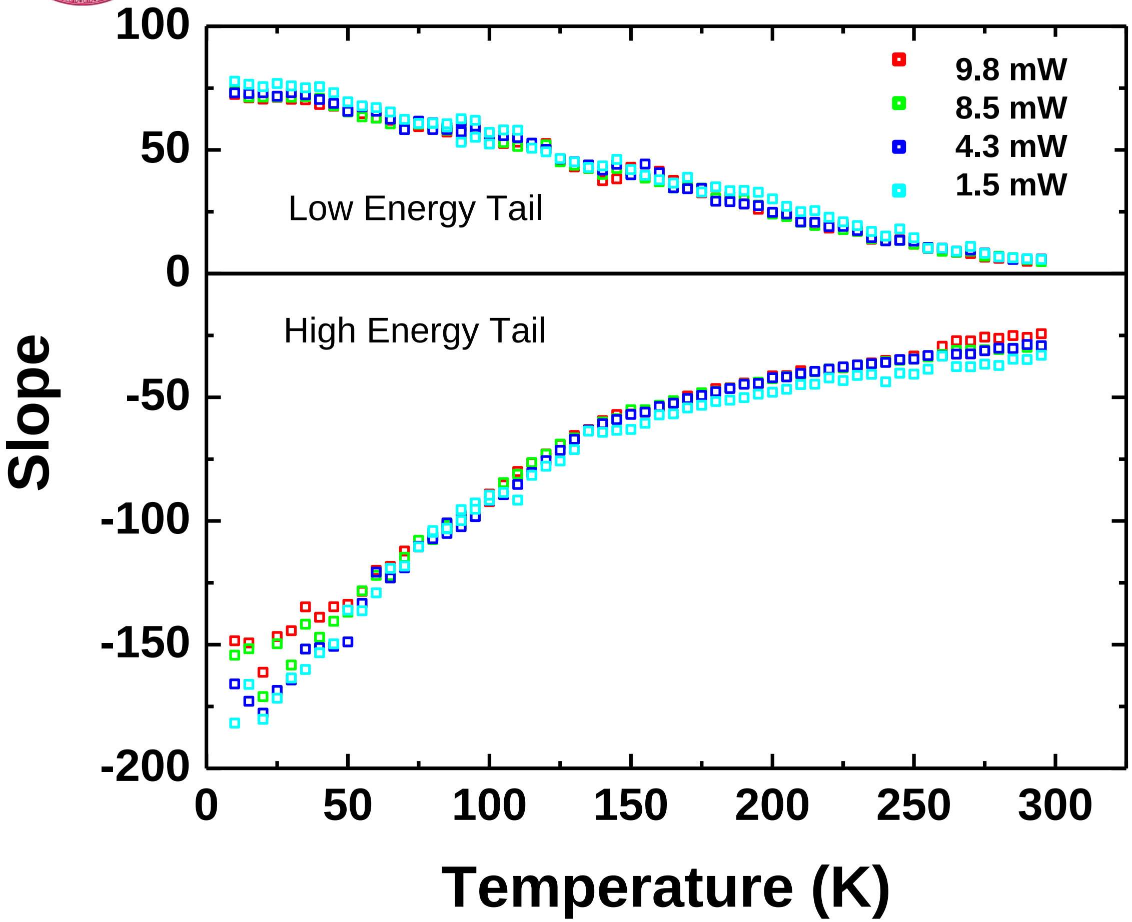
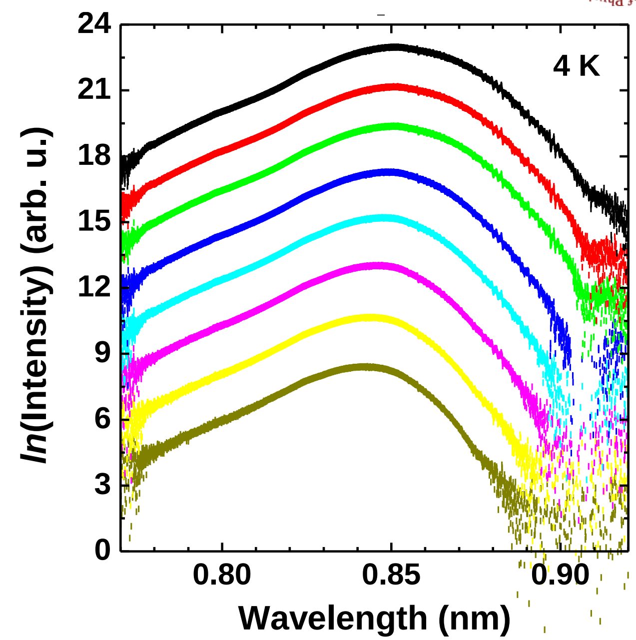
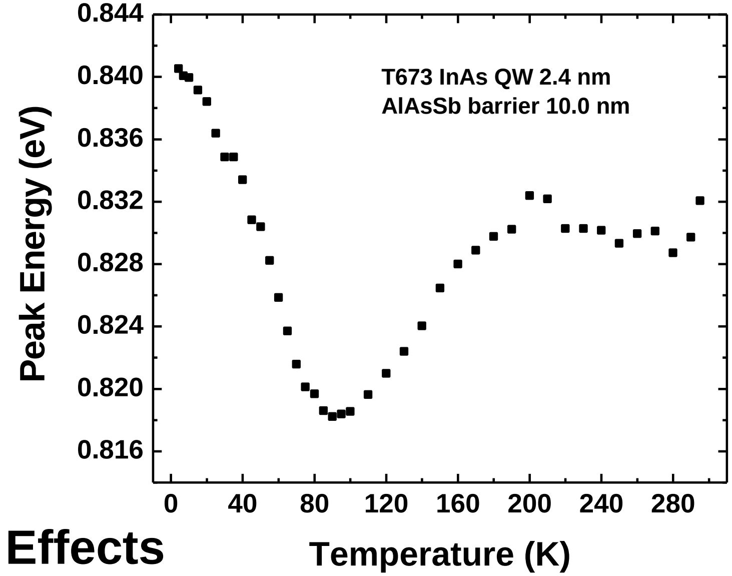
InAs QWs 633 nm Hot Carriers







Strong correlation Carrier Temperature/HE slope and localization observed in PL peak energy

Red laser pumps more QWs ⇒ weaker Hot Carrier Effects

Summary

Future measurements:

Repeat with 975 nm laser line to confirm trends that have been observed with 442 and 633 nm lines

Magnetic field measurements to probe the nature of localization confinement

Preliminary results for hot carrier optical studies:

InAs QW structure can be tuned to 0.7 eV band gap for hot carrier solar cells

Band offsets for AlAsSb/InAs superlattice structure are such that there are energy states in QW suitable for Impact ionization

Blue laser shows more pronounced effects than red laser
Carrier temperature appears to be correlated to localization
Temperatures > 150 K leveling of carrier temperature wrt laser power