Effects of hot carriers at elevated temperatures in Type-II InAs/$AlAs_{0.84}Sb_{0.16}$ quantum wells

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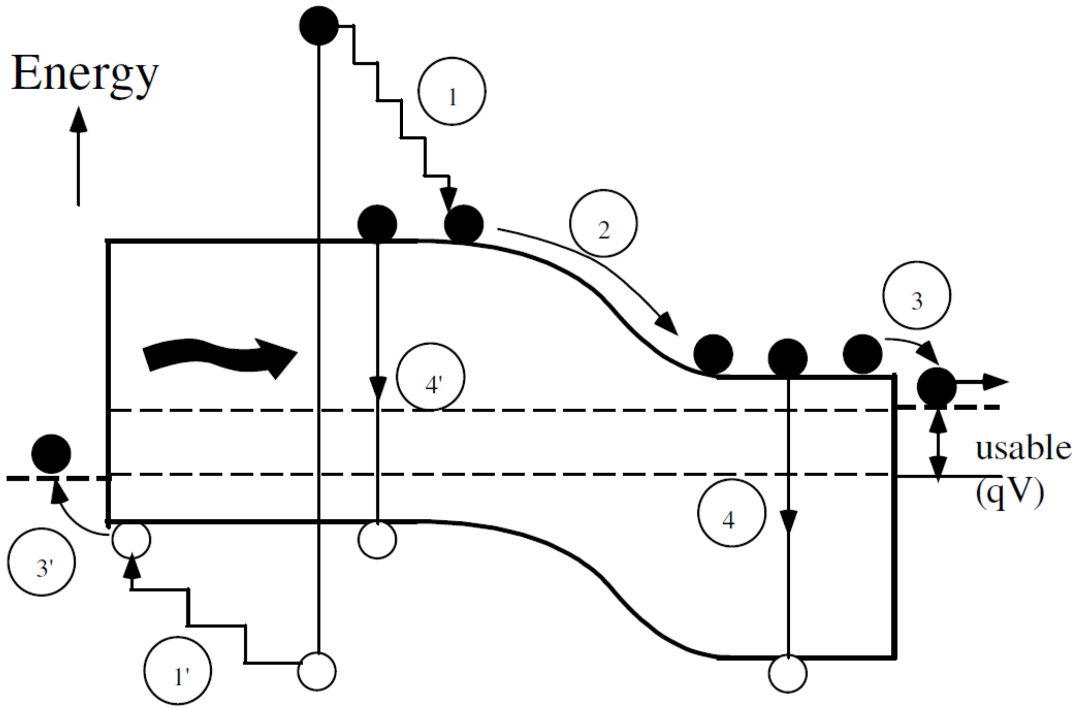
Overview

- Introduction: Potential of hot carrier solar cells/ previous work
- InAs/AlAsSb QWs: optical design and properties
- Optical Properties/PL: Evidence for alloy fluctuations
- Analysis of hot carriers at elevated temperatures in type-II system

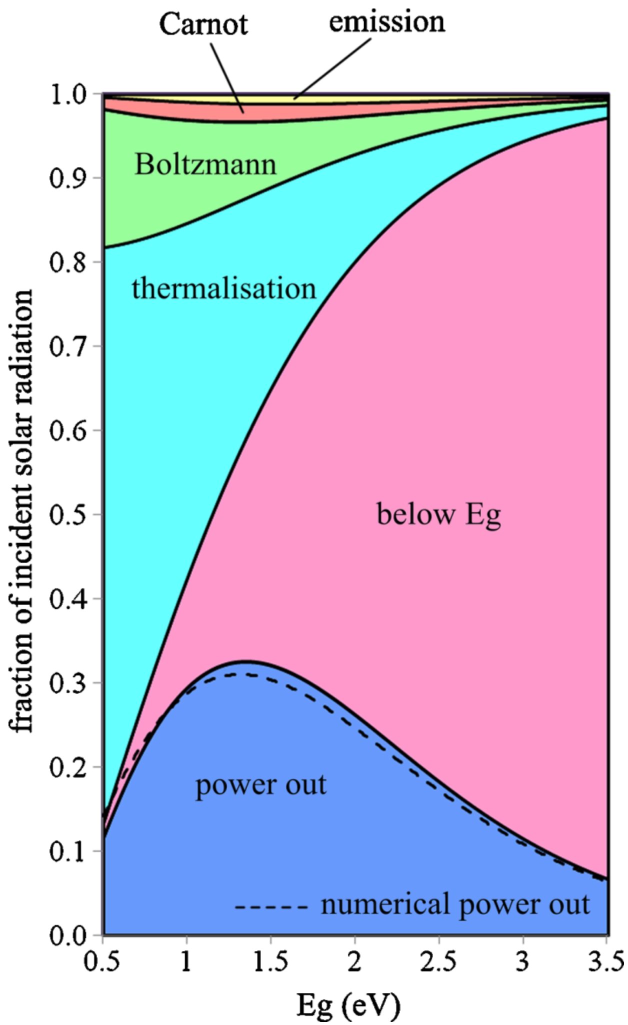
Photovoltaics Materials & Device Group, University of Oklahoma: http://www.nhn.ou.edu/~sellers/group/index.html

Introduction: Loss Mechanism



Energy conversion loss processes in a standard single-junction solar cell: (1) lattice thermalization loss; (2) junction loss; (3) contact loss; (4) recombination loss. A fifth arises from photons that have insufficient energy to be absorbed by the cell.

Green, Third generation photovoltaics, p. 35 (2006)



Hirst & Ekins-Daukes, Prog. PV. 19, 286 (2010)

Hot Carriers in Quantum Wells: Recent (*and earlier work…*)

Several papers suggesting hot carriers are most robust in quantum confined systems:

J. F. Ryan *et al*. PRL **53**, 1841 (1984)
J. Shah *et al.* PRL **54**, 2045 (1985)
N. Balkan *et al*. Semi. Sci. Techn. **4**, 852 (1989)
K. Leo *et al*. PRB **38**, 1947 (1988)

Potential for Solar Cells:

Energy & Environmental Science

Dynamic Article Links

Cite this: DOI: 10.1039/c2ee02843c

www.rsc.org/ees

PAPER

Thermalisation rate study of GaSb-based heterostructures by continuous wave photoluminescence and their potential as hot carrier solar cell absorbers†

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Progress in PHOTOVOLTAICS

PROGRESS IN PHOTOVOLTAICS: RESEARCH AND APPLICATIONS
Prog. Photovolt: Res. Appl. (2013)
Published online in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/pip.2444

ACCELERATED PUBLICATION

Demonstration of a hot-carrier photovoltaic cell

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IEEE JOURNAL OF PHOTOVOLTAICS 1

Enhanced Hot-Carrier Effects in InAlAs/InGaAs Quantum Wells

Louise C. Hirst, Michael K. Yakes, Christopher G. Bailey, Joseph G. Tischler, Matthew P. Lumb, María González, Markus F. Führer, N. J. Ekins-Daukes, and Robert J. Walters

Le Bris *et al*. APL 97, 113506 (2010)

Hirst *et al*. IEEE JPV 4, 244 (2014)

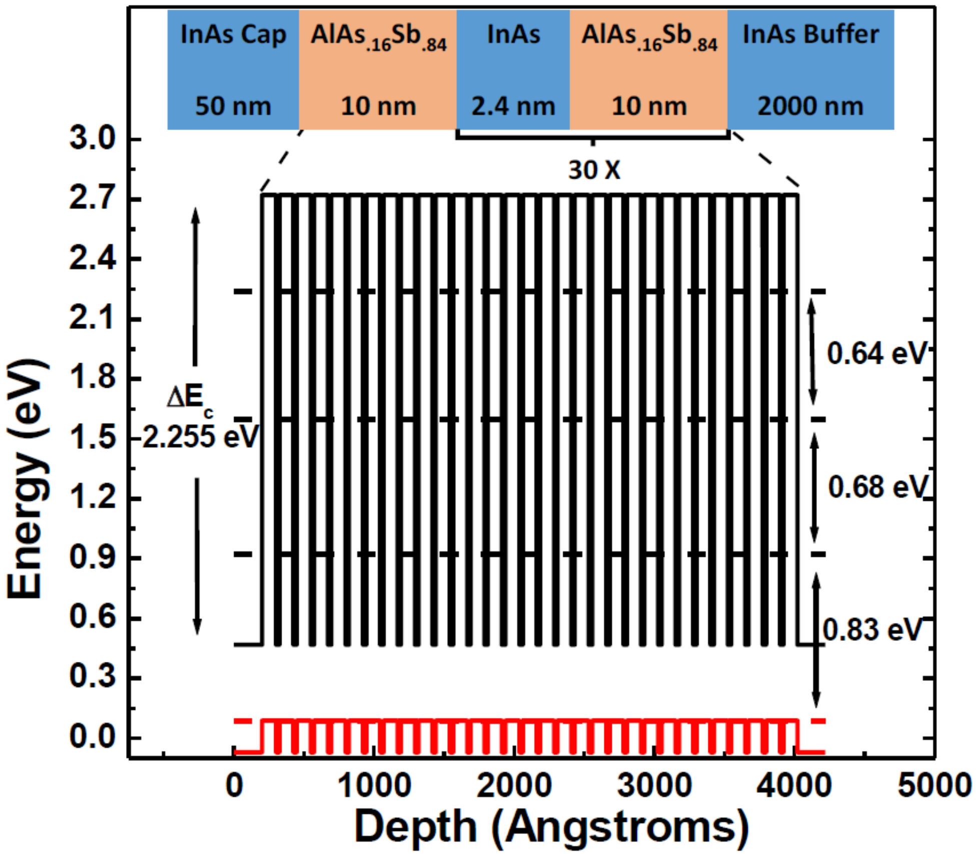
Hirst *et al.* APL 104, 231115 (2014)

Dimmock et al. Prog. PV, v 22, p 151- 160 (2014)

Conibeer et al. solmat 135, p 124 – 129 (2015)

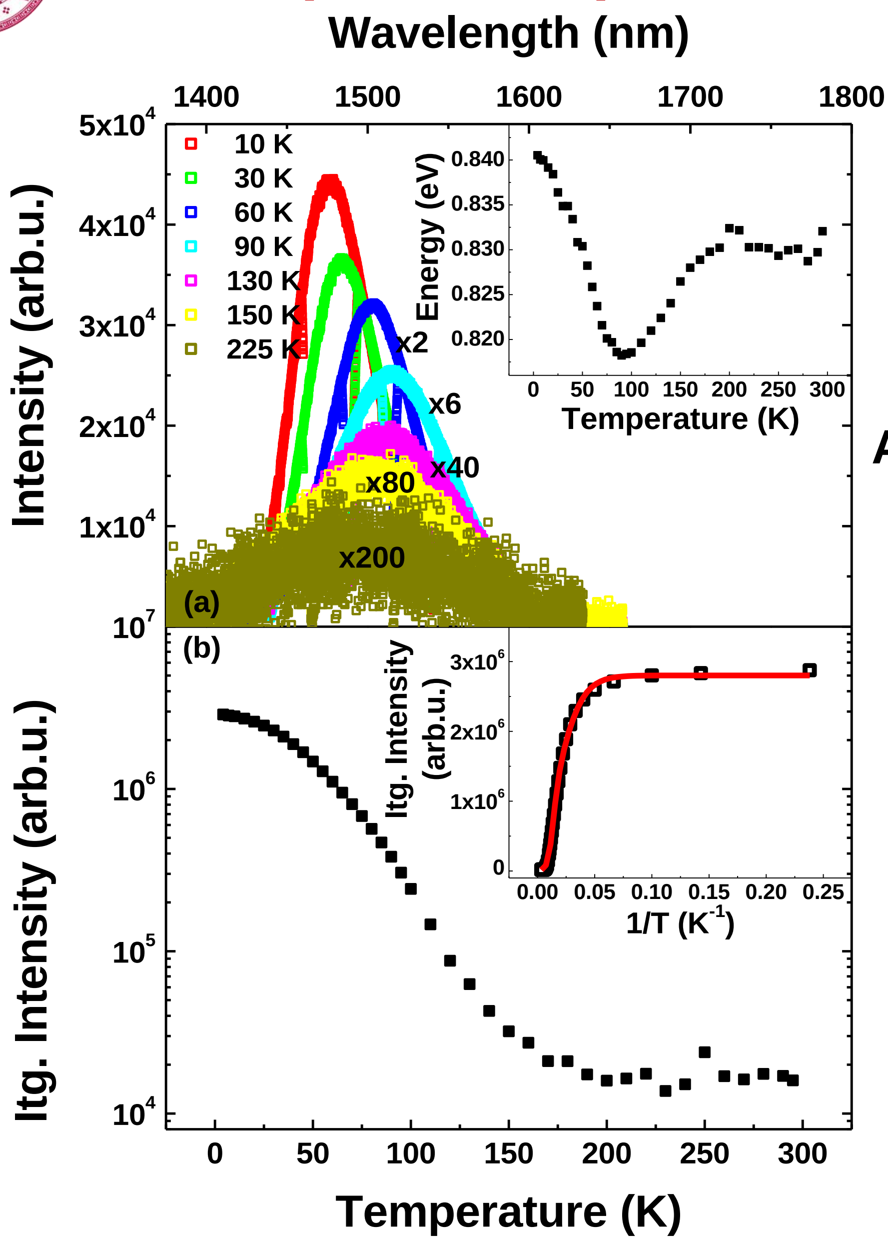
Tang, IRS, *et al.* APL 106, 061902 (2015)

InAs/Al$_x$As$_{1-x}$Sb quantum wells

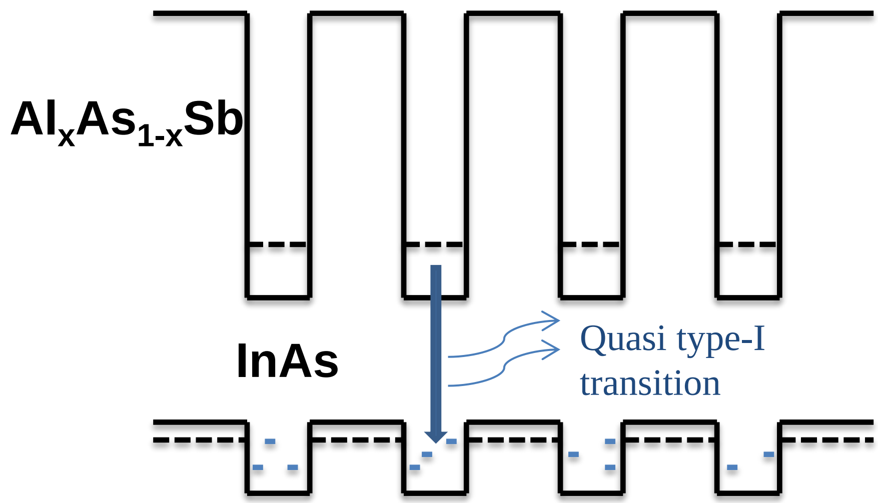


- Narrow QWs under strong confinement
- Type II structure
- Low quantum confinement in valence band
- Potential of creating resonant tunneling through a super lattice structure

Optical Properties: Photoluminescence

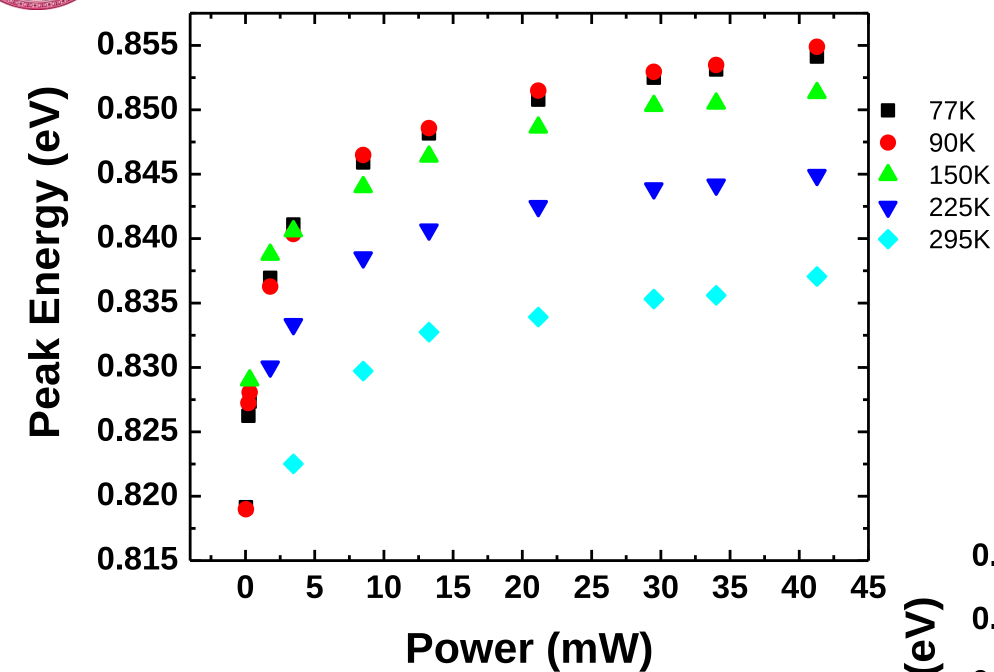


T. Nuytten, *et al.* PRB 84, 045302 (2011)
L.C Hirst, *et al.* JAP 117, 215704 (2015)



Two activation energies 8 meV ~ 92 K
41meV ~ 476 K

Further Evidence of localization

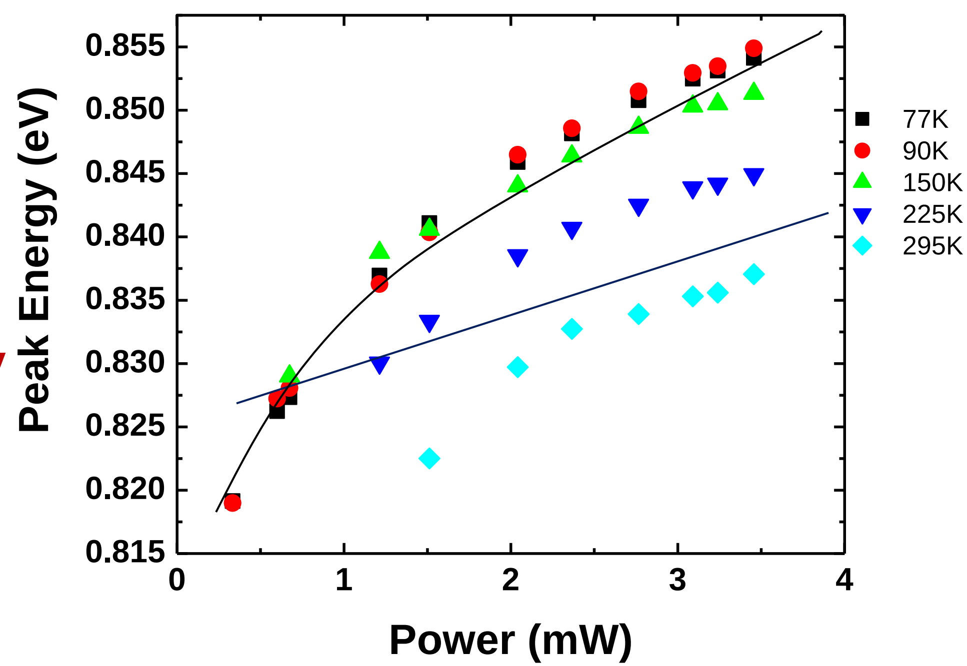


Type II power dependence based on triangular QW

$$e\mu \sqrt{I}$$

$$E_e = const \times e^{2/3} \; o \; bI^{1/3}$$

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

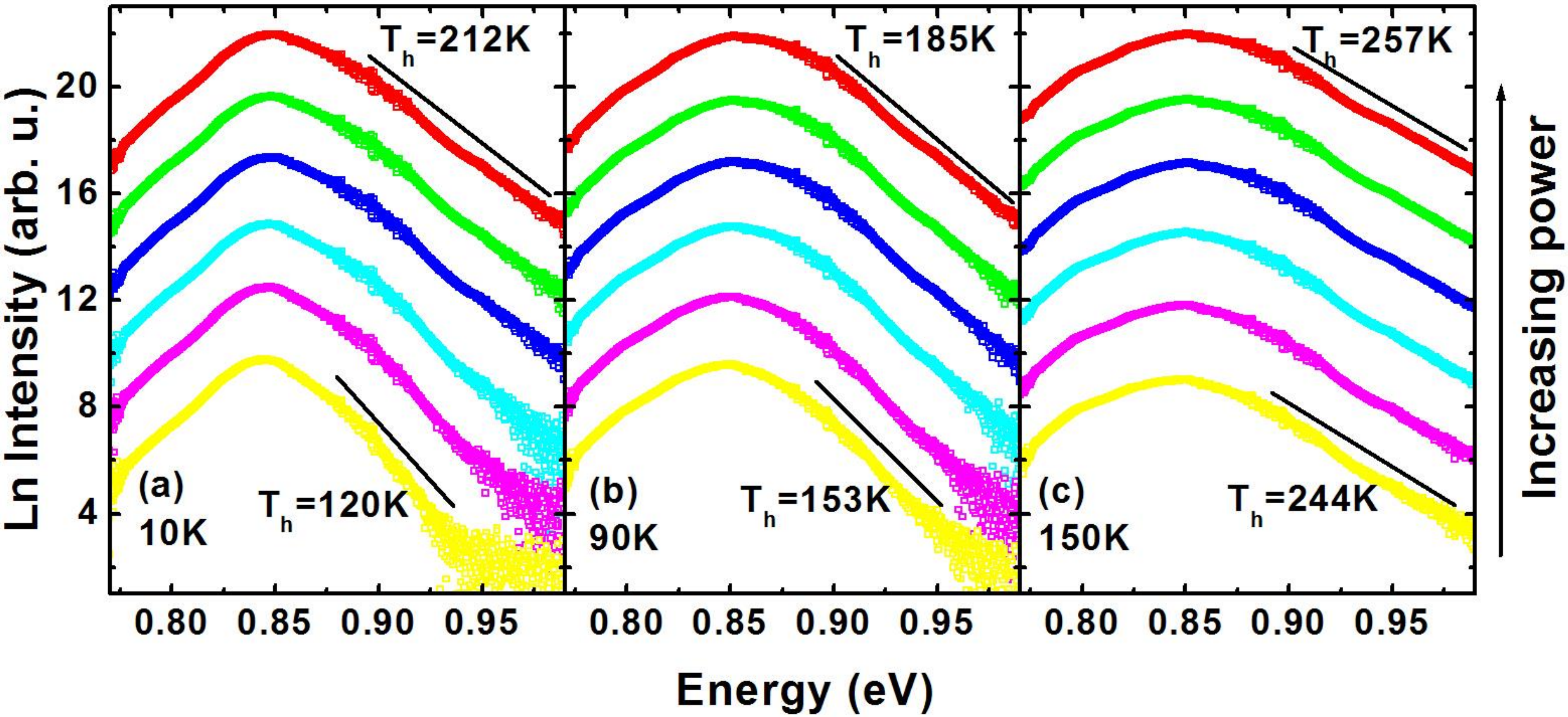
Higher powers leveling off of peak energy

Indicative of localization

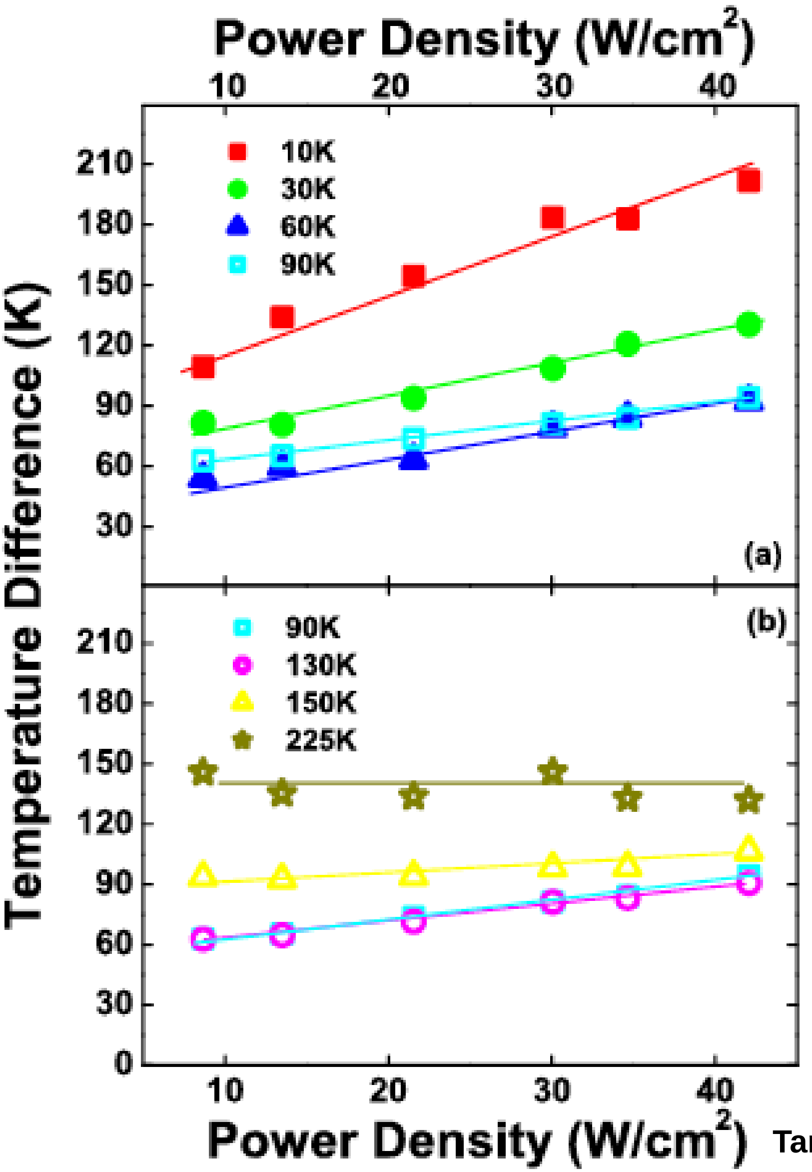
200 K and 295 K more like type I

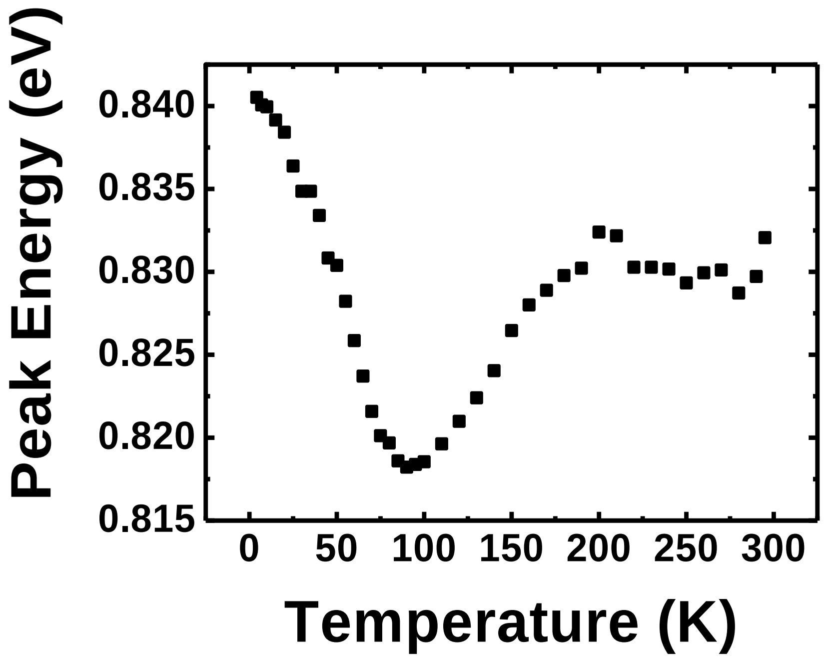
Analysis of "Hot Carriers"

$$I_{pl}(hv) \propto \exp\left(-\frac{hv}{K_B T_H}\right)$$



Temperature Dependence of "Hot Carriers"

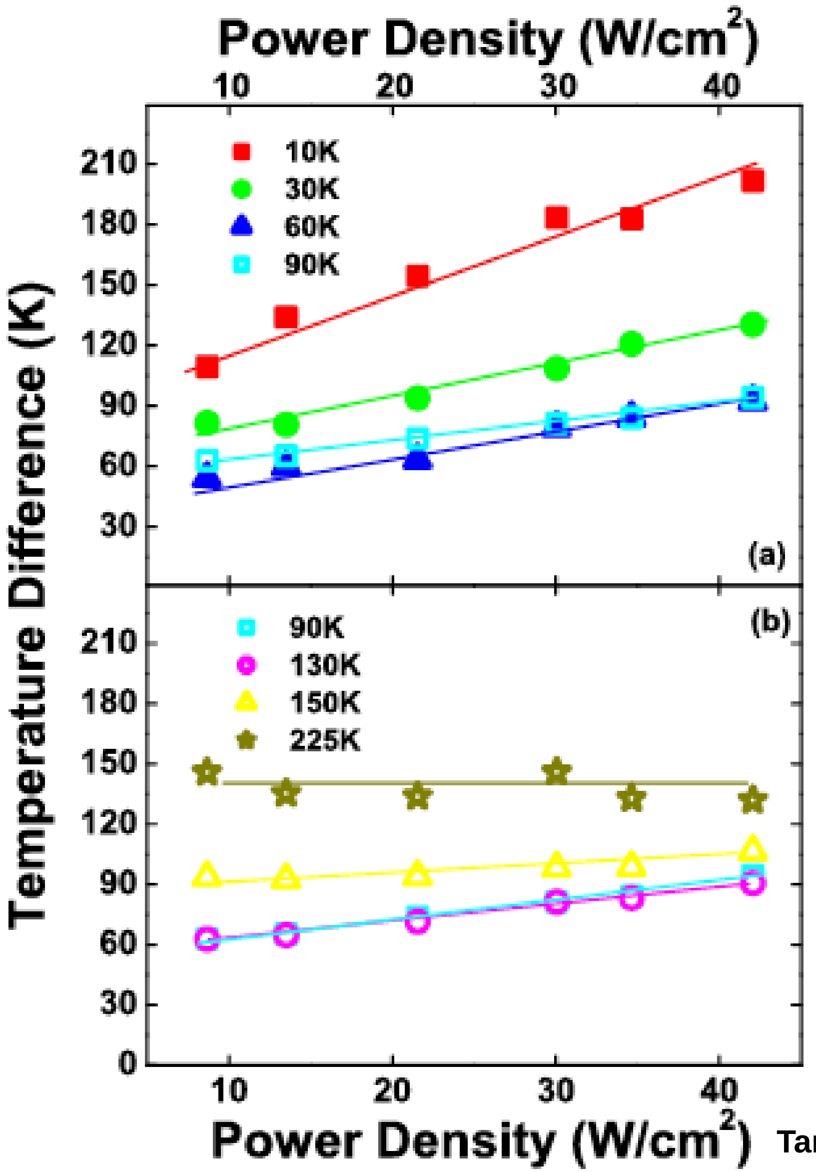


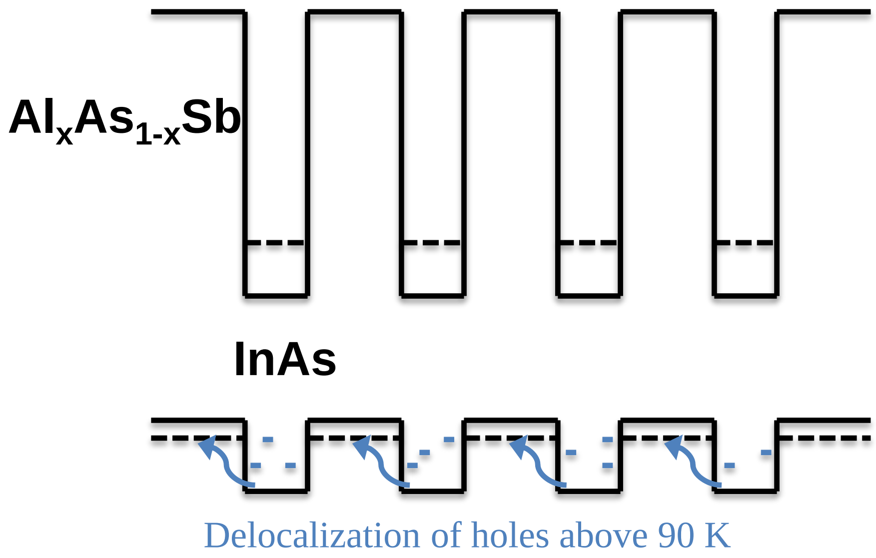


- **Change in carrier temperature matches the localization of carriers**
- **High carrier temperature despite relatively low excitation density**

Tang, IRS, *et al.* APL 106, 061902 (2015)

Temperature Dependence of “Hot Carriers”





Tang, IRS, *et al.* APL 106, 061902 (2015)

- **Expected behavior for type-II alignment**
- **Carrier accumulation due to reduction in recombination efficiency**

Thermalization Rate

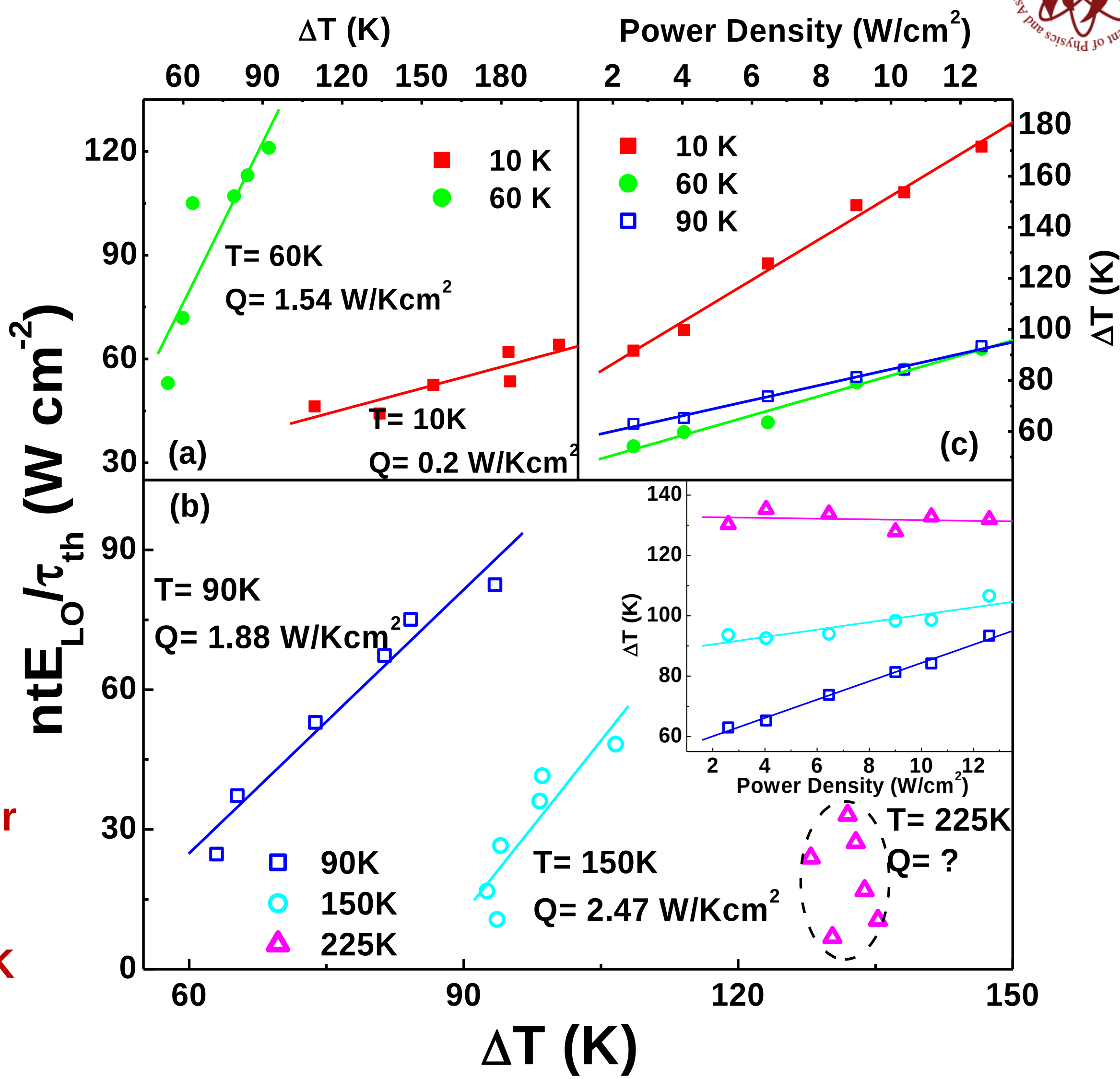
A. Le Bris et al., Energy Environ. Sci., 2011

$$P = P_{abs} - P_{emit} - P_{th}$$

$$P_{th} = \frac{t\, n\, h\nu_{LO}}{\tau_{th}} \exp\left(-\frac{h\nu_{LO}}{K_B T_H}\right)$$

At V_{OC}, P=0

$$P_{abs} = P_{th} = Q(T_H - T)\exp\left(-\frac{h\nu_{LO}}{K_B T_H}\right)$$



- **Conventional behavior at lower temperatures**
- **Debatable Q value above 225 K**

Summary

- $InAs/Al_xAs_{1-x}Sb$ quantum wells offer potential as active absorber in hot carrier solar cells
- This system has materials issues related to alloy fluctuations that are displayed in the peak energy of the PL
- The behavior is strongly related to the delocalization of carriers and an increase in the radiative lifetime of the electrons
- Thermalization factor analysis appears unsuitable for the proposed mechanism at higher temperatures
- Further analysis of absorption, radiative lifetime, and higher power of excitation energy dependence required