Thermalisation losses in solar cells and key issues relevant to thermoelectrics

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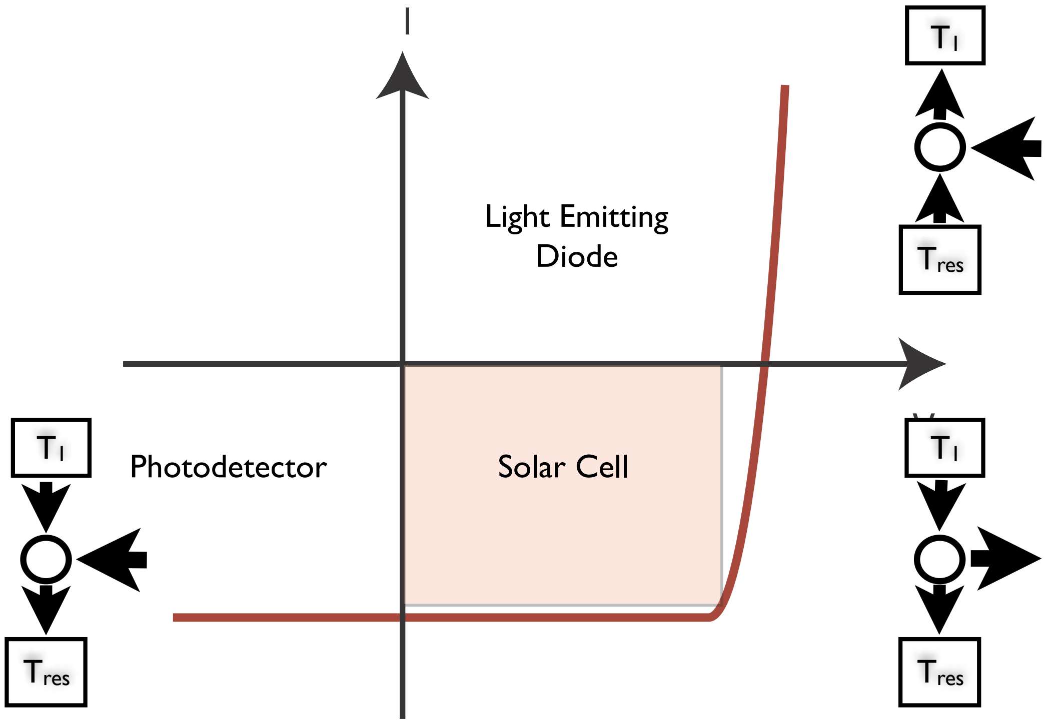
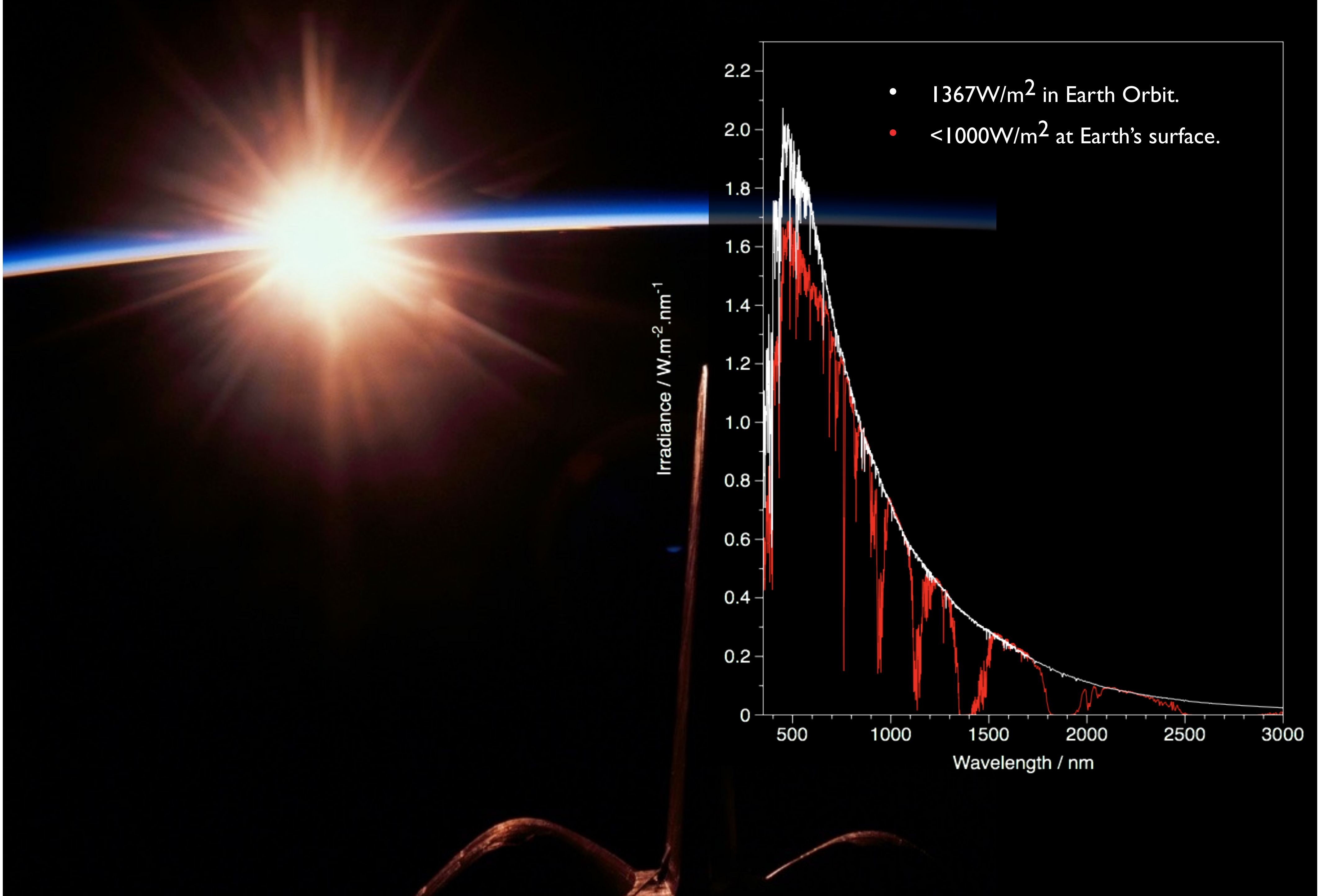
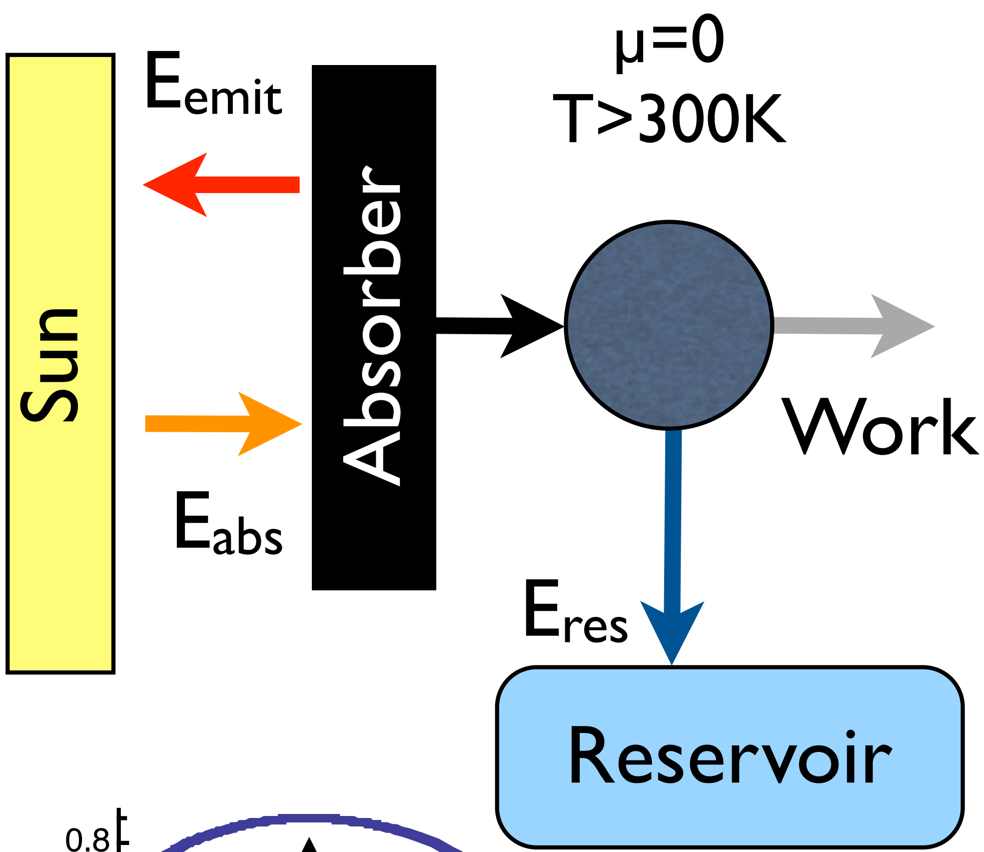


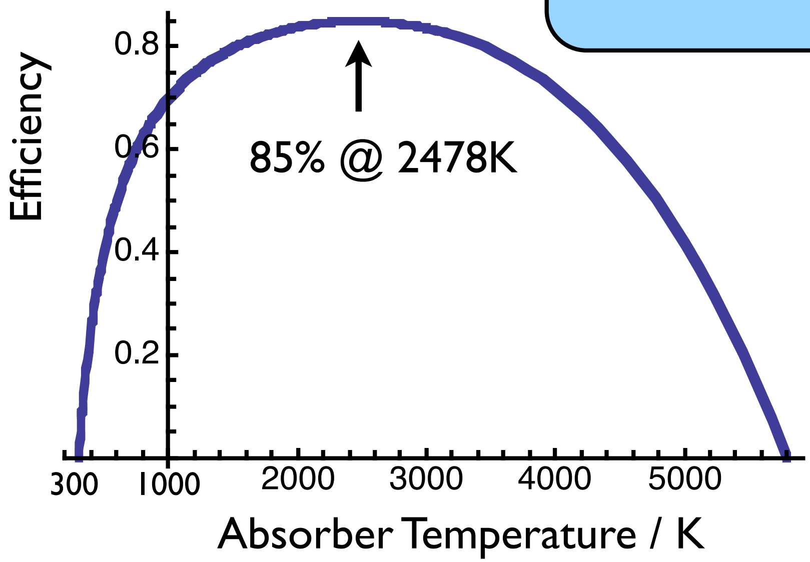
The Sun



1367W/m^2 in Earth Orbit.
<1000W/m^2 at Earth's surface.
Irradiance / W.m^{-2}.nm^{-1}
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
500
1000
1500
2000
2500
3000
Wavelength / nm

General Solar Collector

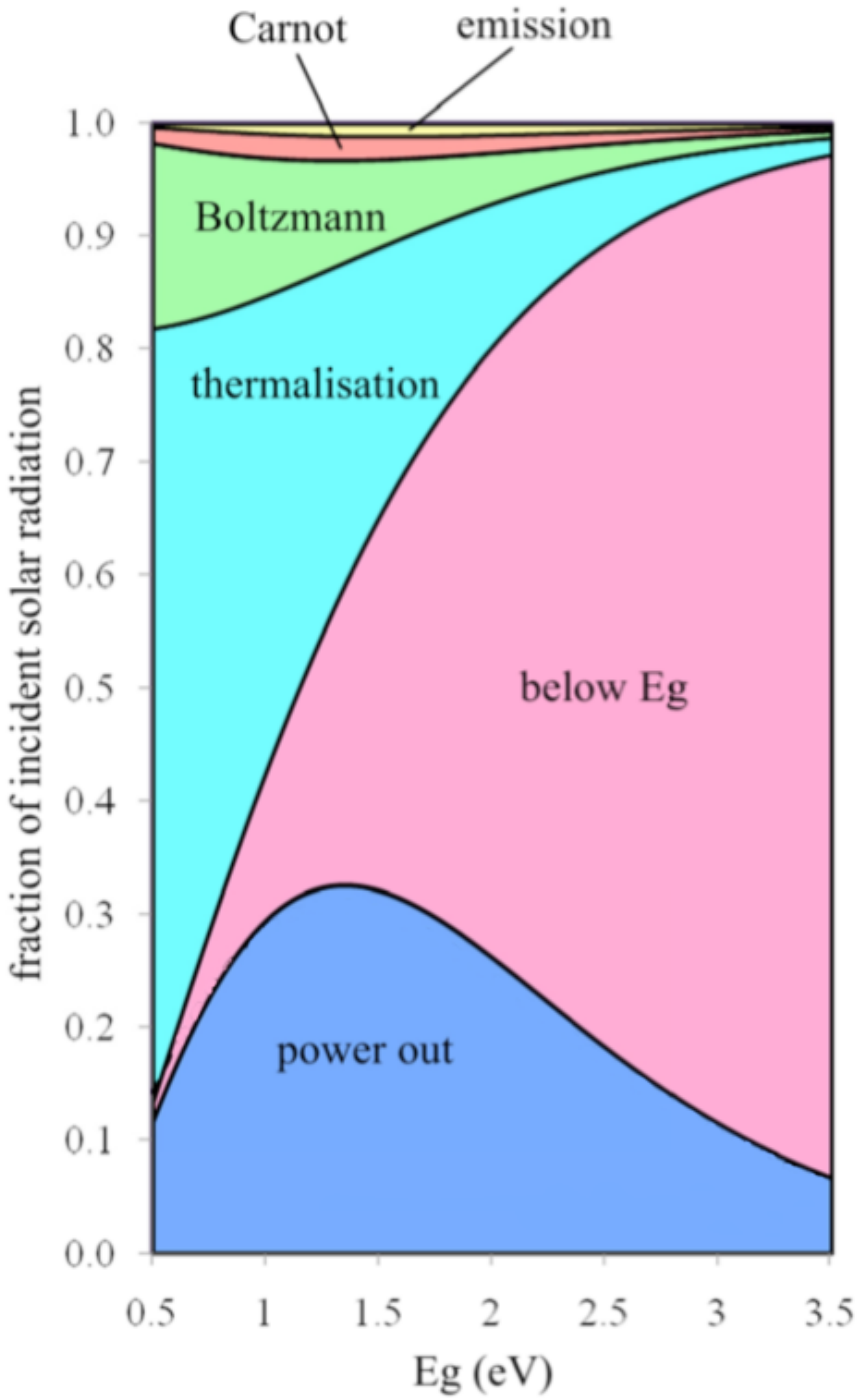


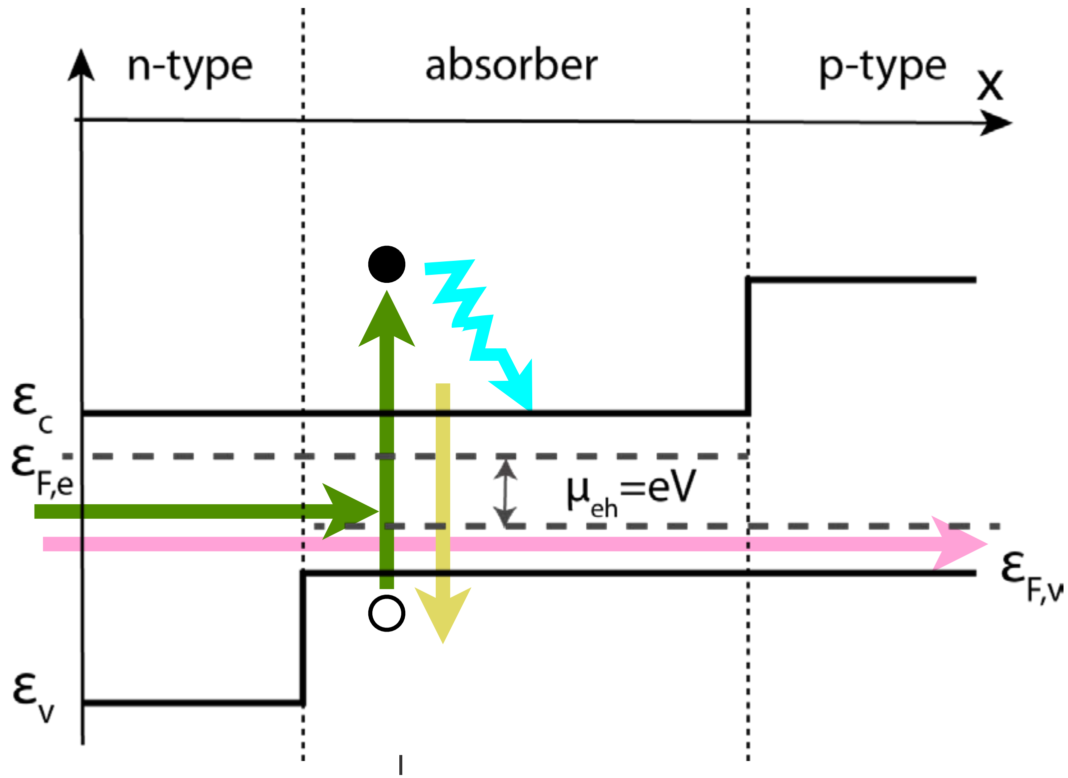


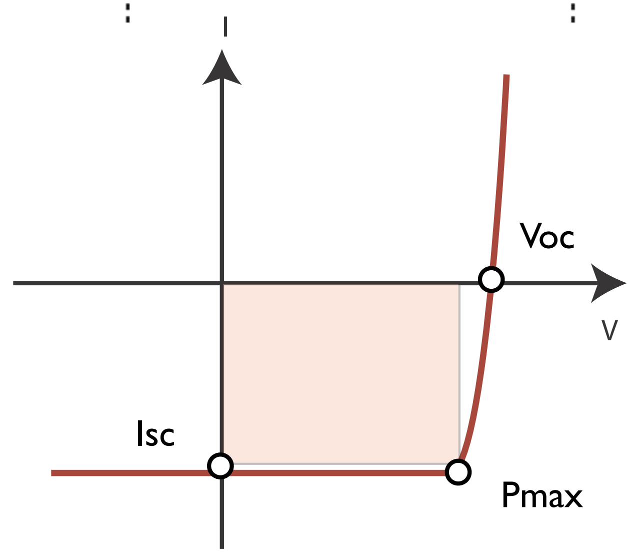
SEGS - Mojave Desert, California

Solar Two - Mojave Desert, California

The Shockley-Queisser Efficiency limit.







Louise Hirst & N.J.Ekins-Daukes, "Fundamental Losses in Solar Cells"
Progress in Photovoltaics, (2011) 19: p286

PV-T Collector

- Combined PV/Thermal collector
- Lower PV temperature

✓ Higher efficiency

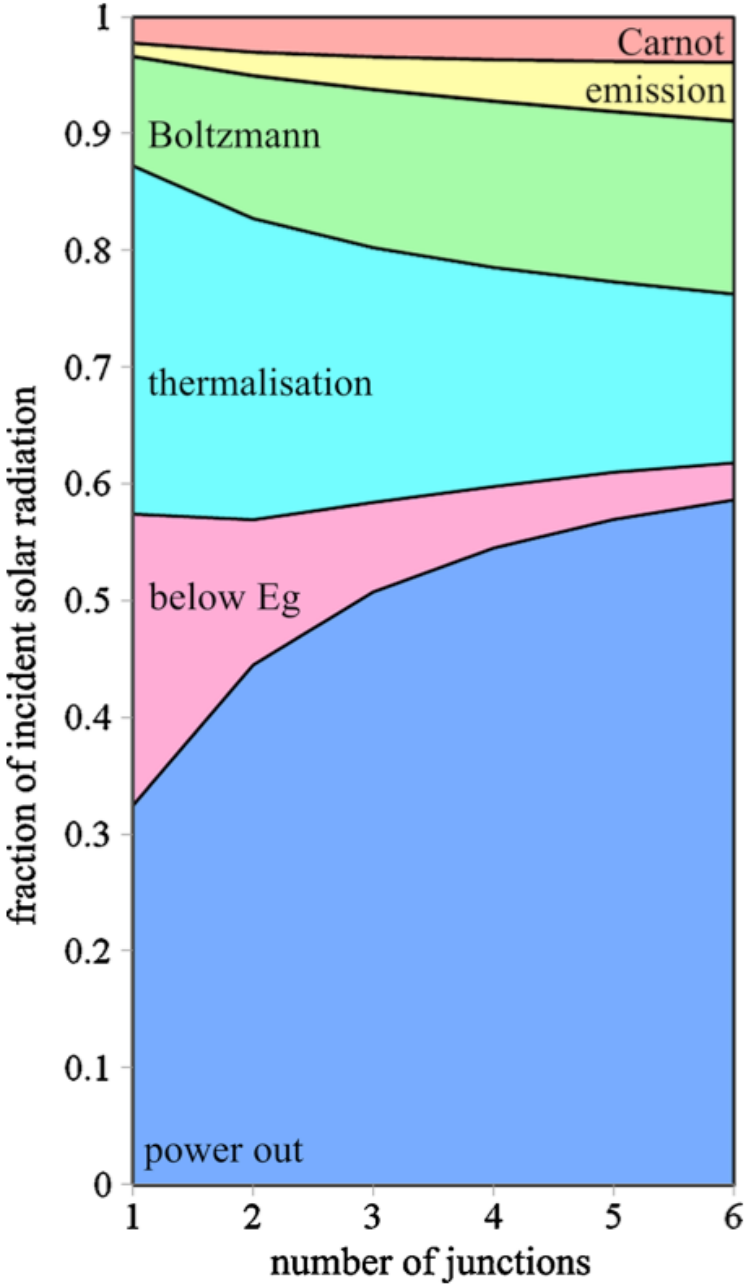
+ Hot water

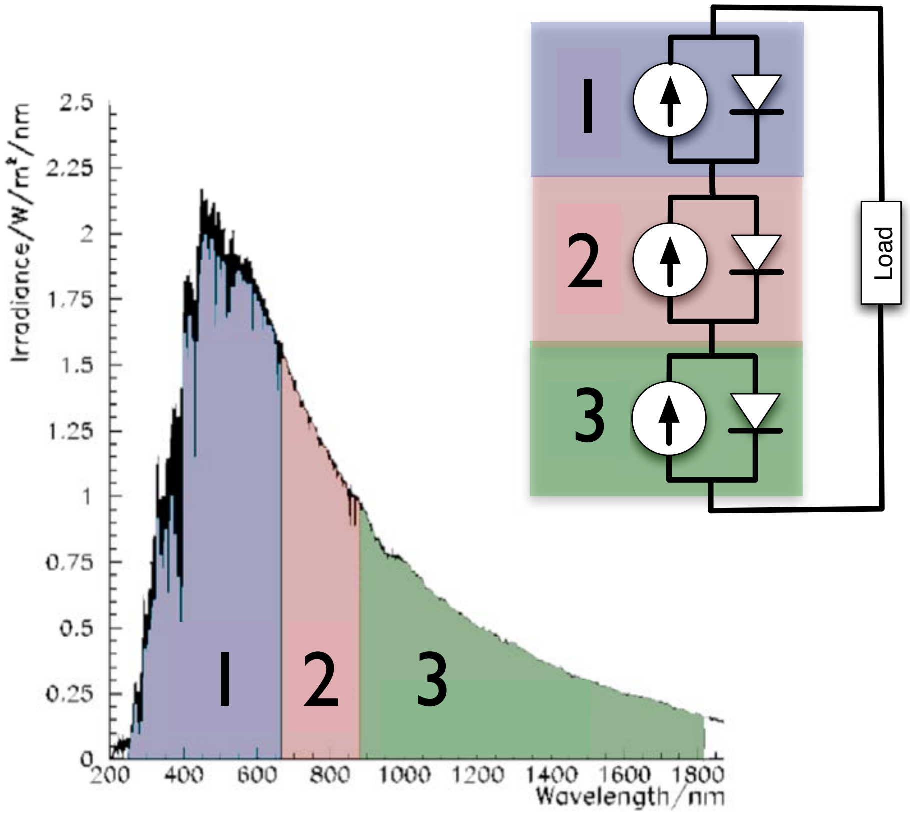
www.nakedenergy.co.uk

EPSRC PV-T projects:

PI Knox EP/K022156/1 Scalable Solar Thermoelectrics and Photovoltaics. (SUNTRAP)
PI Ekins-Daukes EP/M025012/1 High Temperature, High Efficiency PV-Thermal Solar System

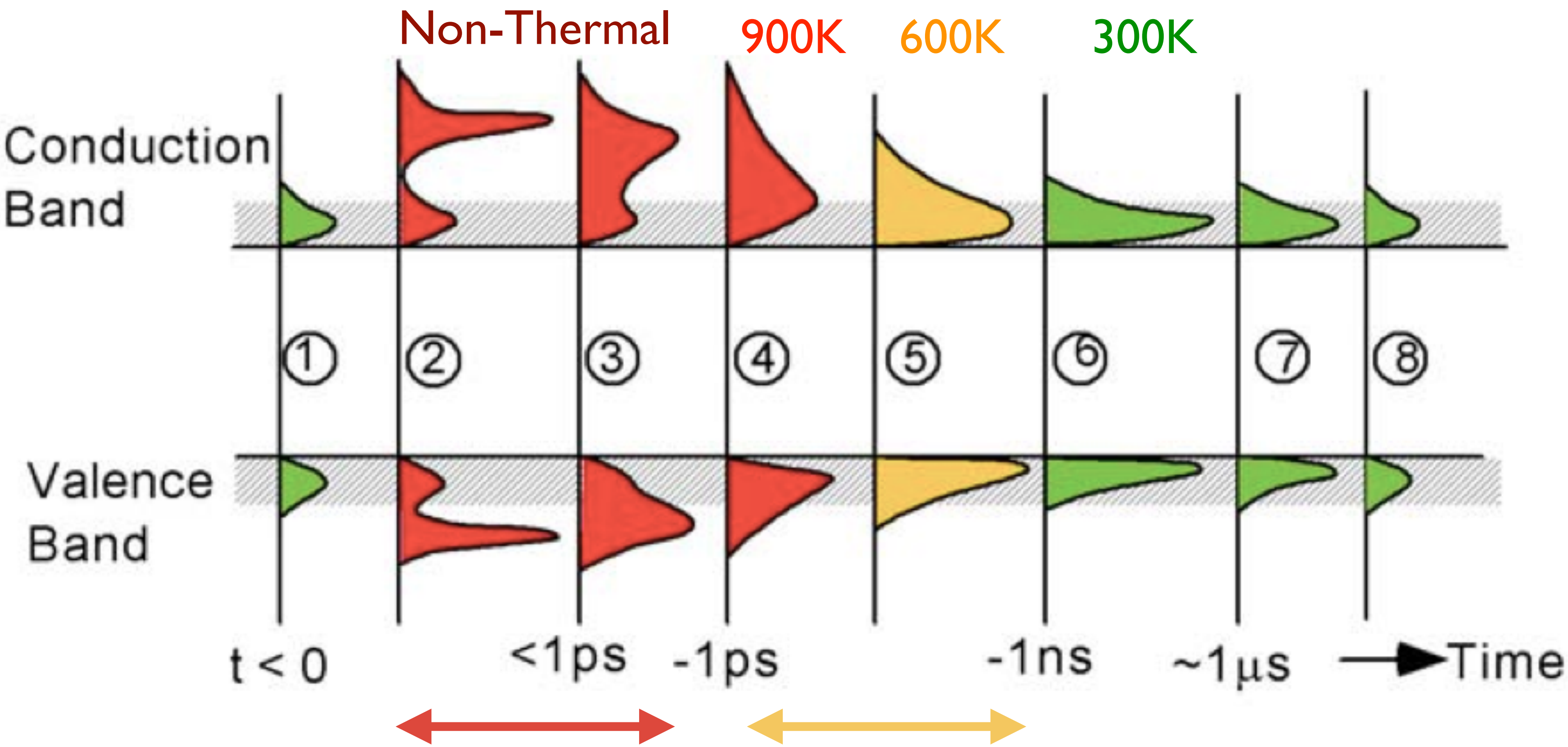
Multi-Junction Cell Concept





L. Hirst , Progress in Photovoltaics, (2011) 19: p286

Carrier Thermalisation

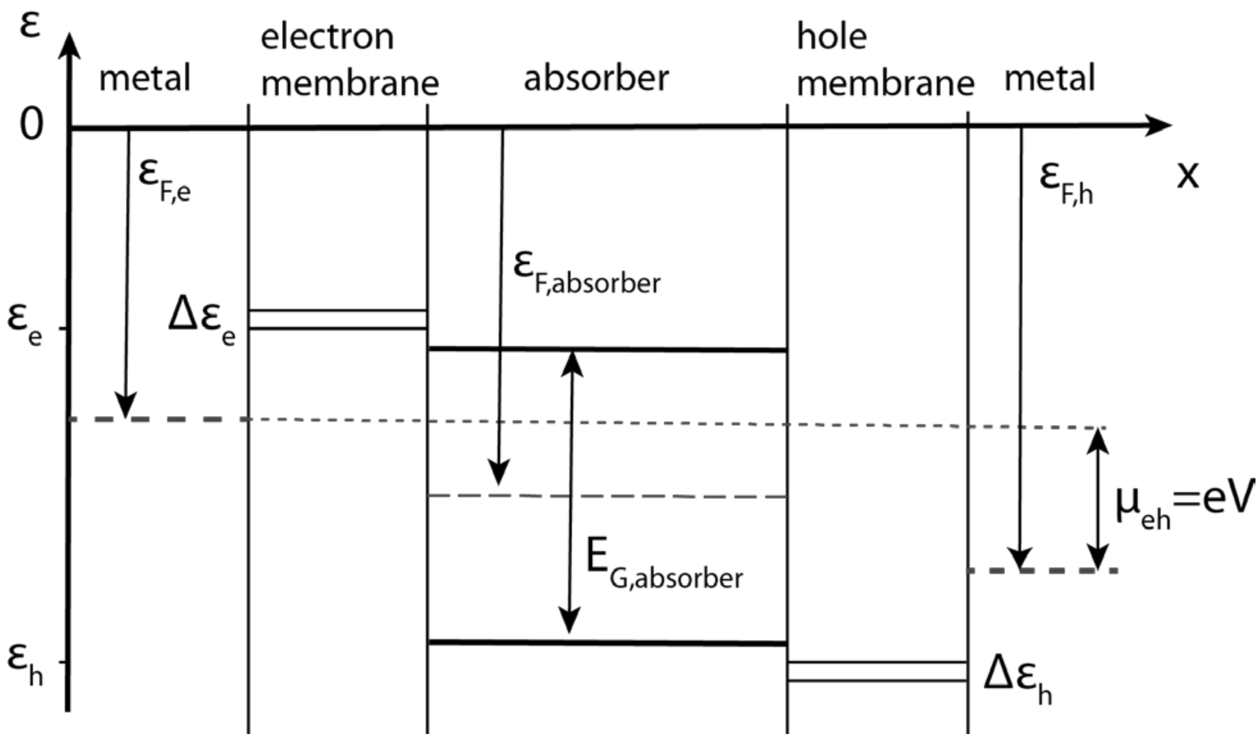


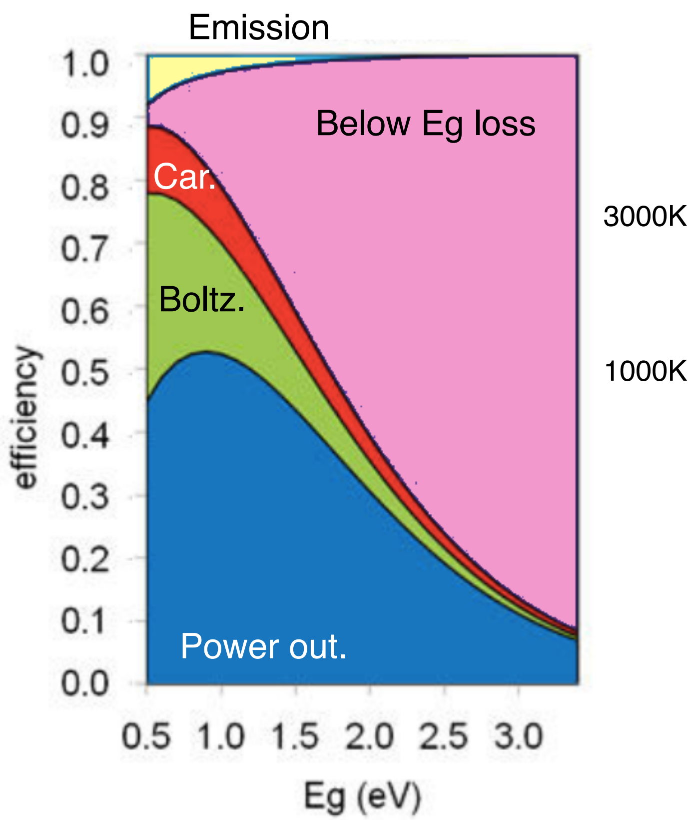
LO phonon - LA phonon decay

Electron - Electron scattering

Electron - LO phonon equilibration

Hot Carrier Solar Cell

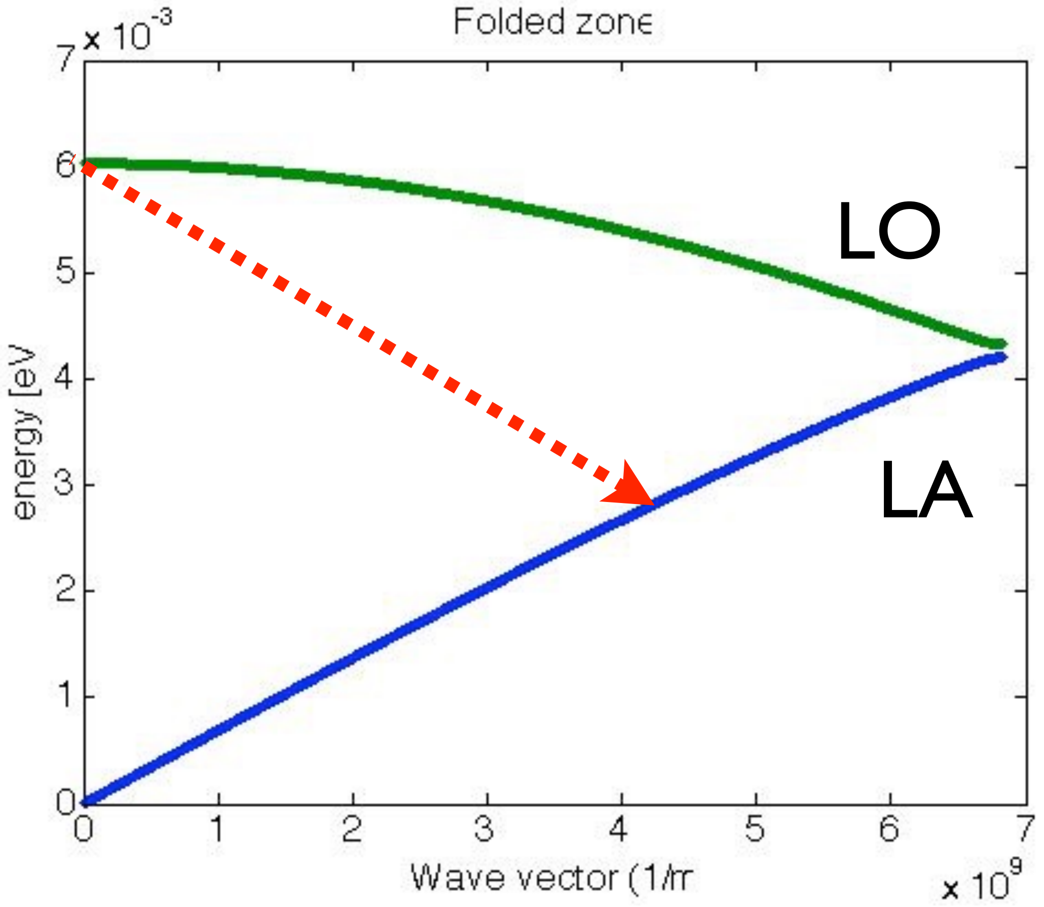


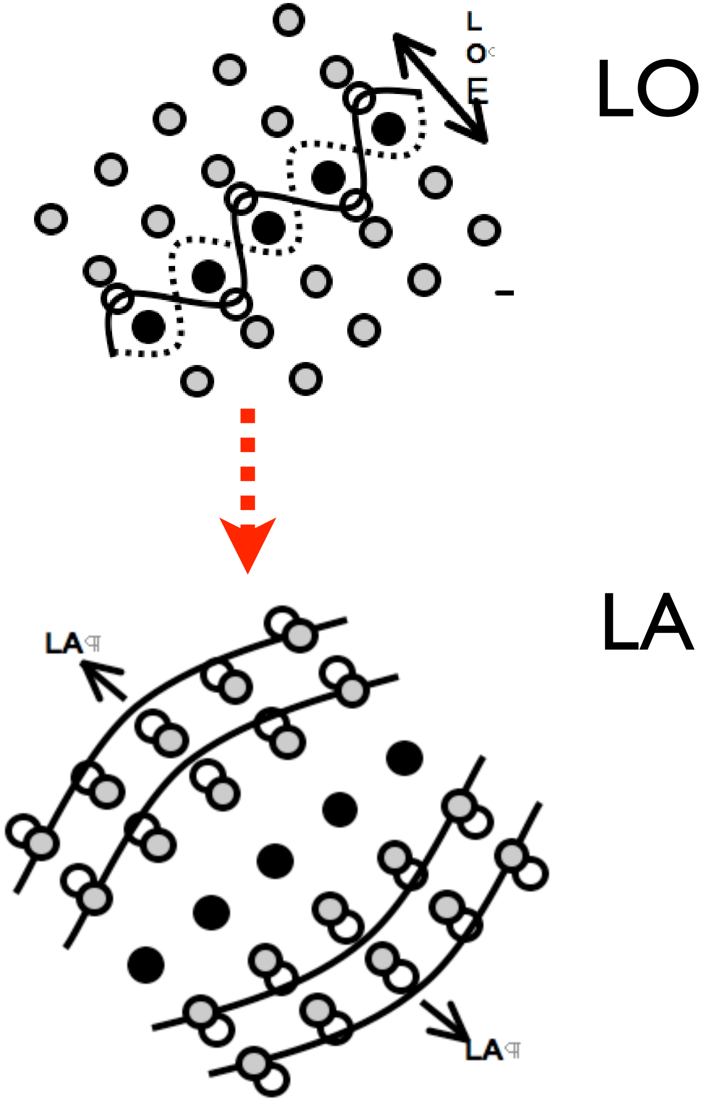


Wurfel, P., 1997. *Solar energy conversion with hot electrons from impact ionisation.*
Solar Energy Materials And Solar Cells, 46(1), pp.43–52.

Hirst, L.C. et al.,. Proc. 37th IEEE Photovoltaic Specialists Conf. p. 3302. (2011)

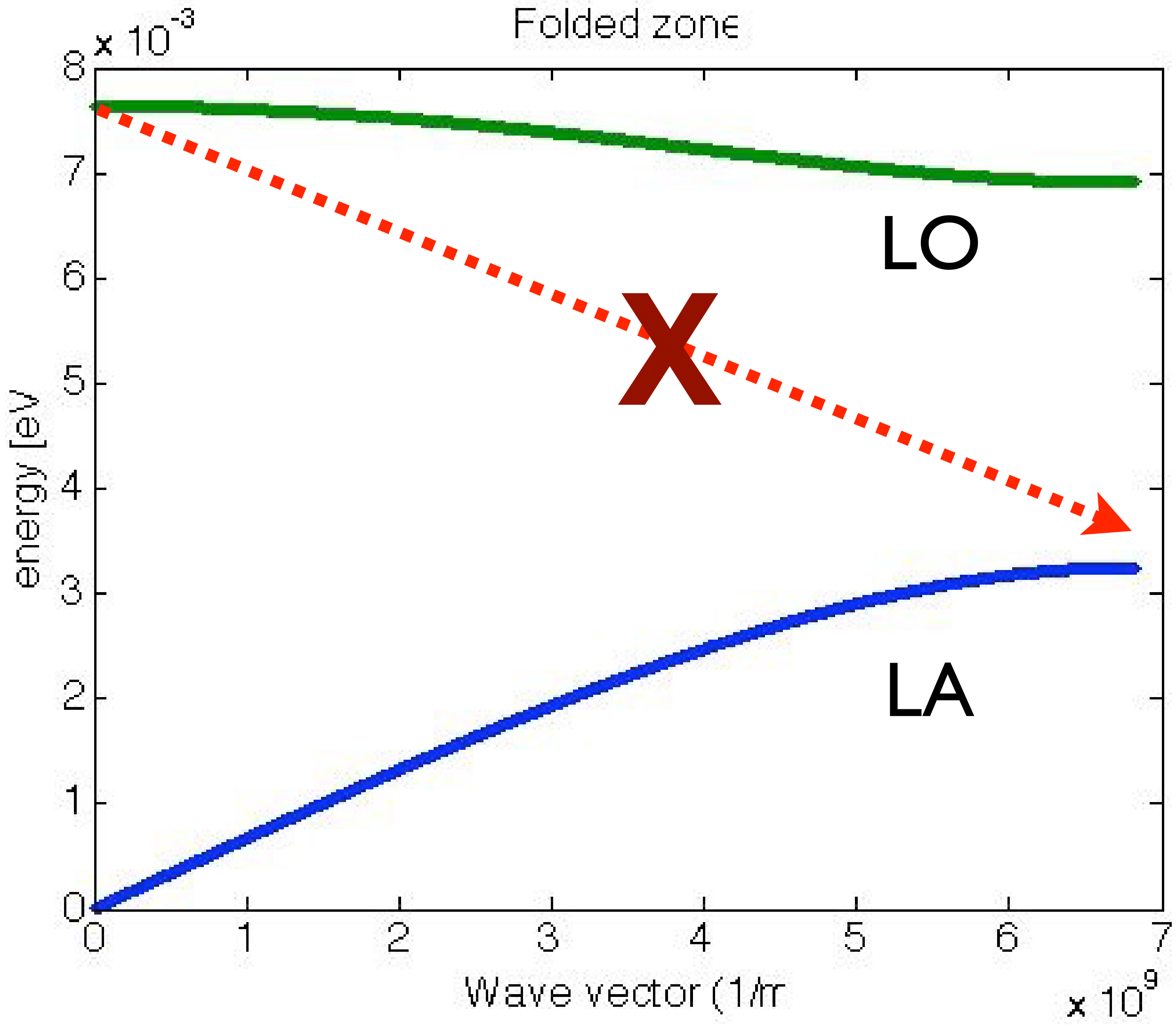
Phonon decay in GaAs

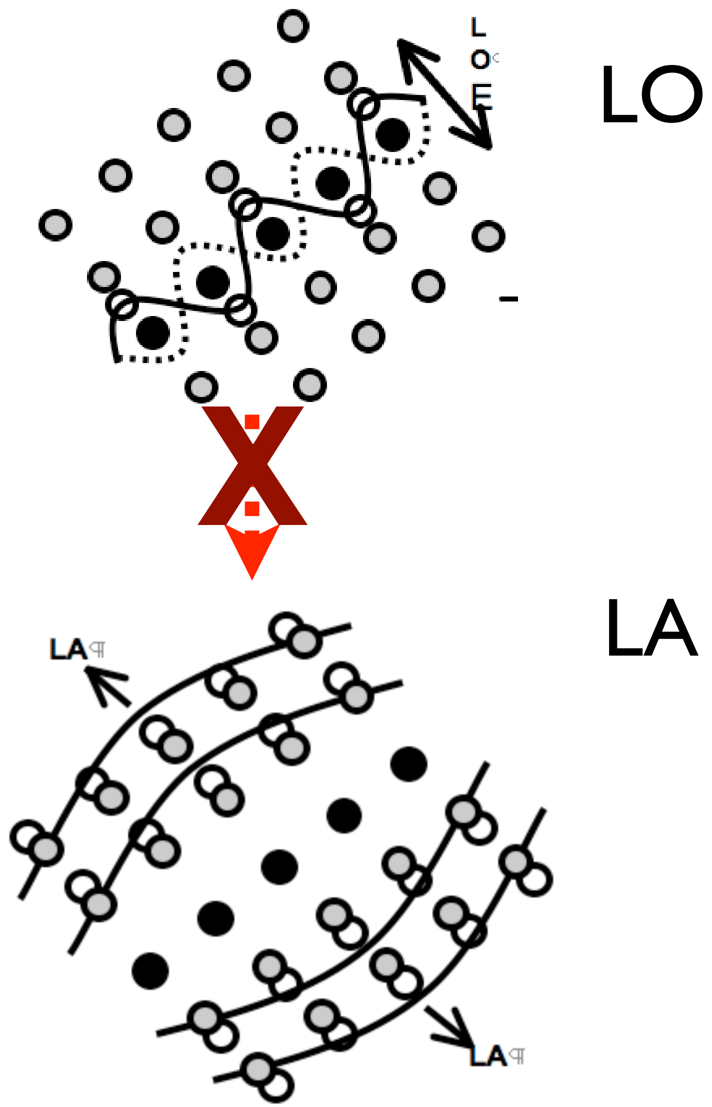




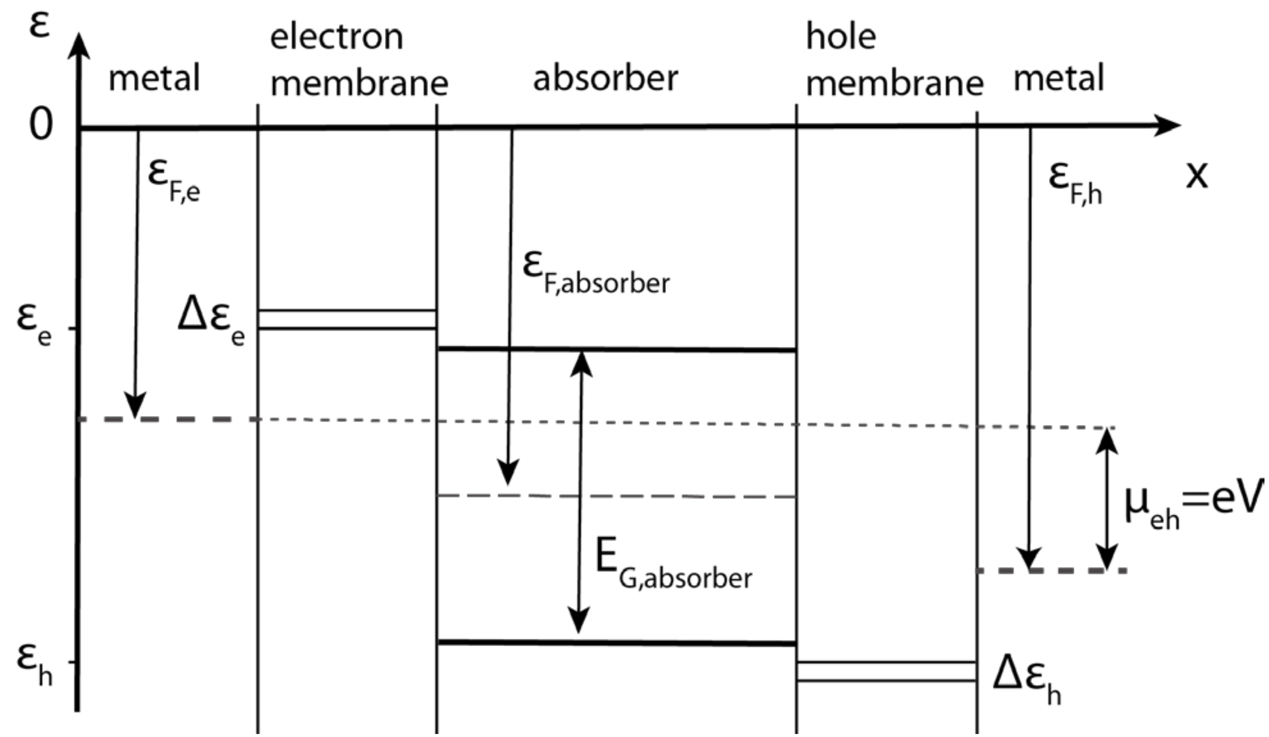
Clady, R. et al., *Progress In Photovoltaics*, 20(1), pp.82–92 (2012)

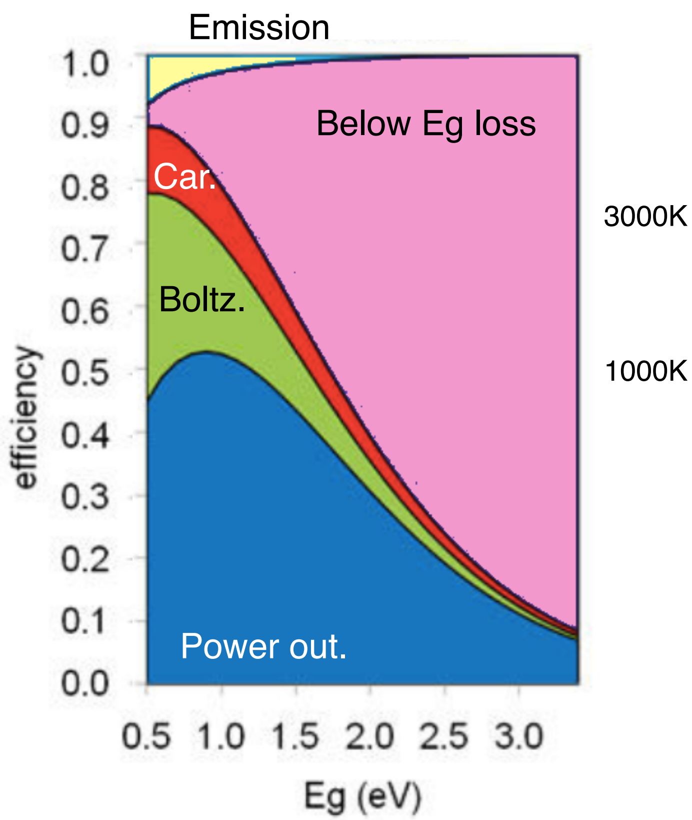
Phonon decay in AlSb





Hot Carrier Solar Cell

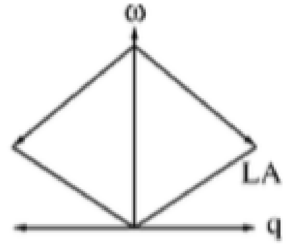




Wurfel, P., 1997. *Solar energy conversion with hot electrons from impact ionisation.*
Solar Energy Materials And Solar Cells, 46(1), pp.43–52.

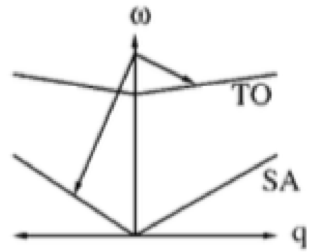
Hirst, L.C. et al.,. Proc. 37th IEEE Photovoltaic Specialists Conf. p. 3302. (2011)

LO Optical Phonon lifetime

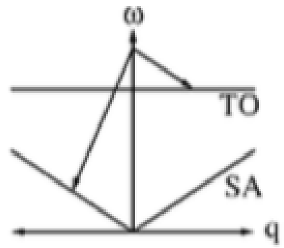


(a) Klemens's channel

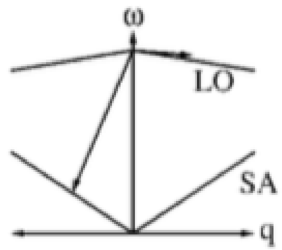
	τ (ps)		Klemens's channel (%)	Ridley's channel (%)	Vallée-Bogani channel (%)
	Present theory	experiment			
Low temperature (6 K)					
InN	0.5			100	
GaN	4.4			100	
AlN	0.45		30	70	
BN	0.44		82	18	
GaAs	8.7	16.5,[a] 9.2,[b] 8.5[f]	66	8	26
InP	39.3	24.1[a],[a] 40.0[c]		100	
AlSb	224.0			100	
HgSe	28.0		90	10	
Diamond	2.54		100		
Room temperature					
InN	0.21			100	
GaN	2.5			100	
AlN	0.32		30	70	
BN	0.39	1.45[e]	77	23	
GaAs	2.3	2.1,[c] 2.39[f]	52	15	33
InP	6.1	7.6,[c] 6.65[f]		100	
AlSb	21.0			100	
HgSe	4.7		80	20	
Diamond	2.30	2.46[d]	100		



Ridley's channel with dispersive TO bran



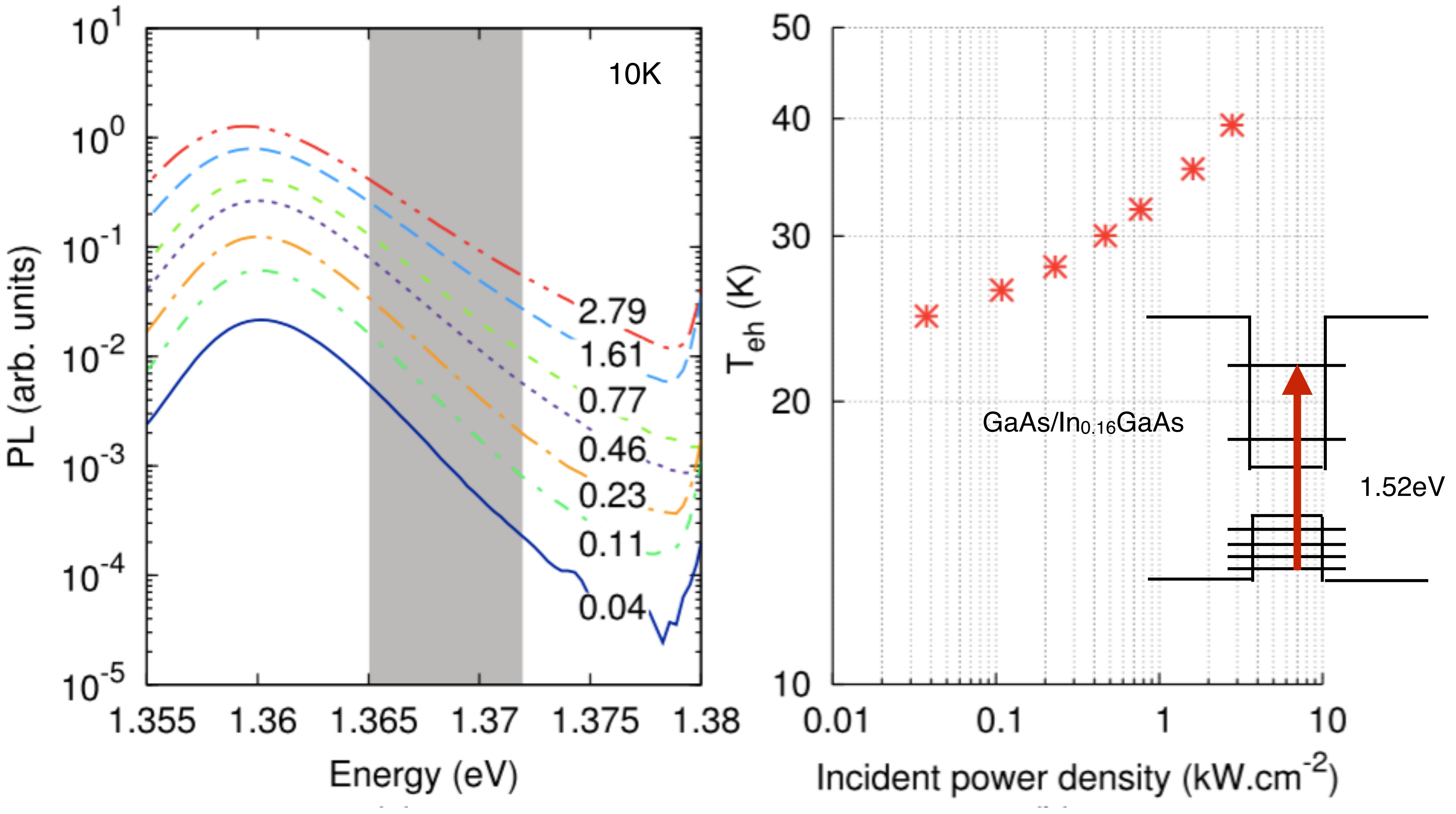
(b) Ridley's channel with flat TO brancl



ranch (d) Vall'ee–Bogani's channel

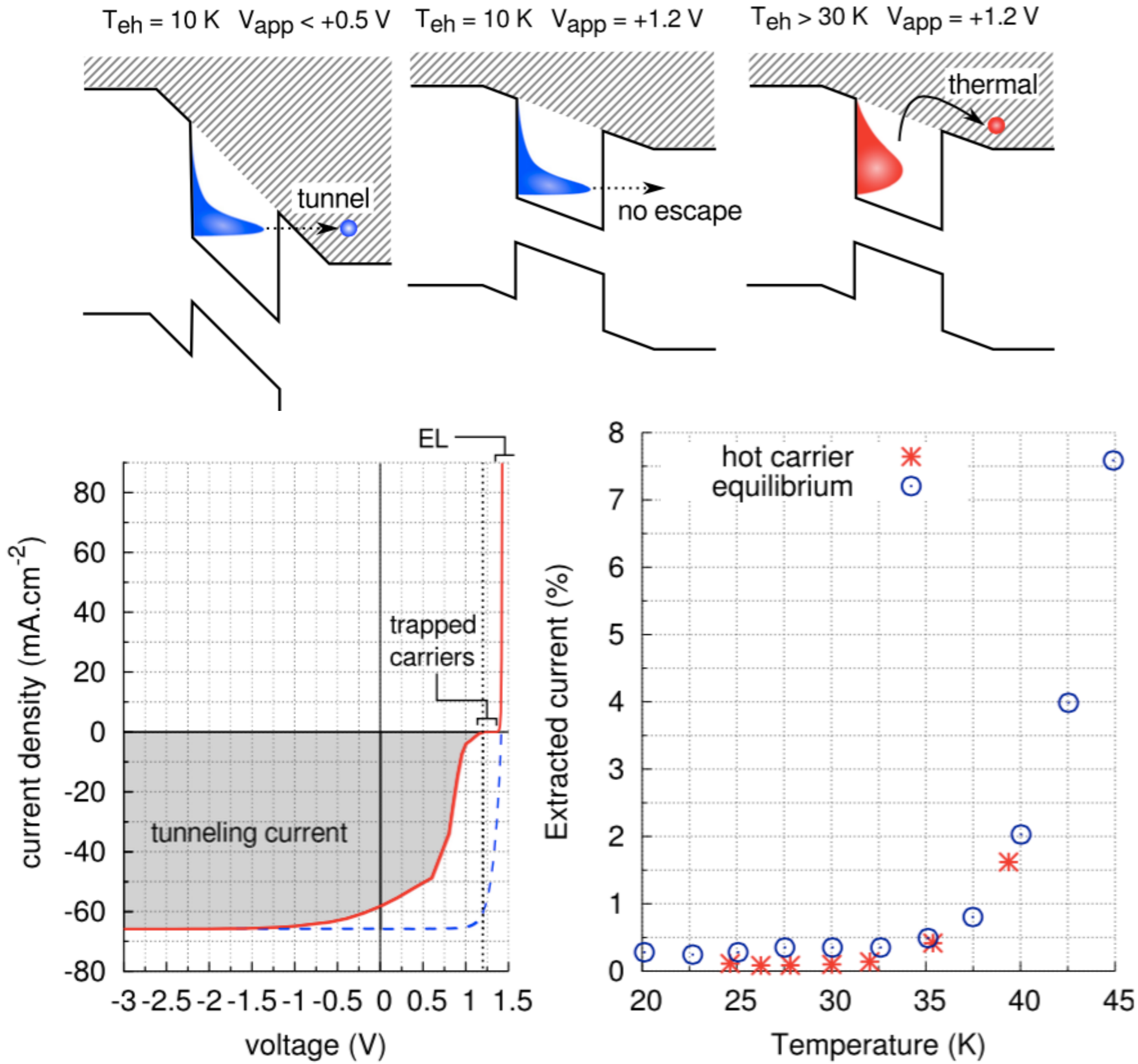
Barman, S. & Srivastava, G., 2004.
Long-wavelength nonequilibrium optical phonon dynamics in cubic and hexagonal semiconductors.
Physical Review B, 69(23), p.235208.

QW Hot-Carrier PV Cell



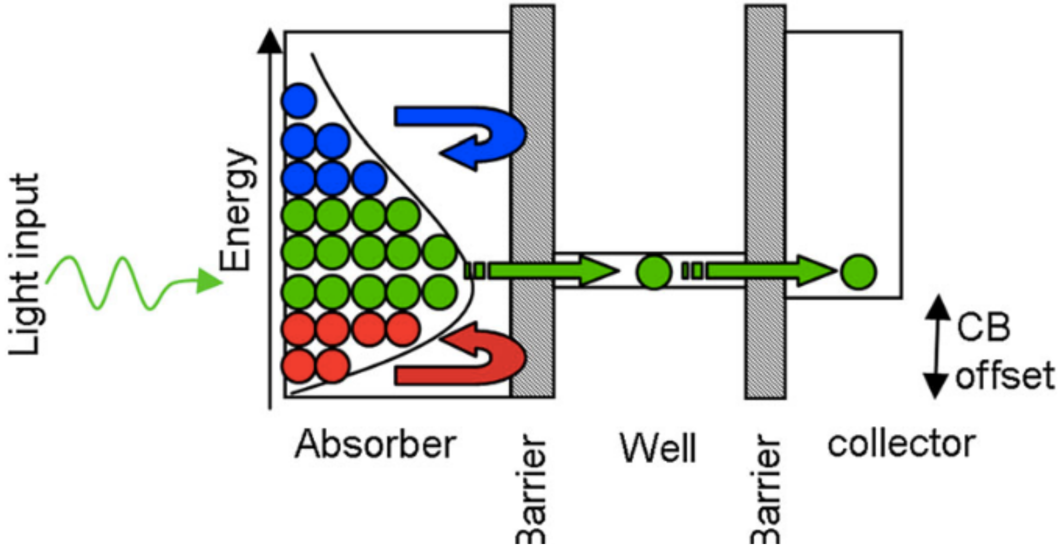
Hirst, L.C. et al. *Applied Physics Letters*, 104(23), p.231115. (2014)

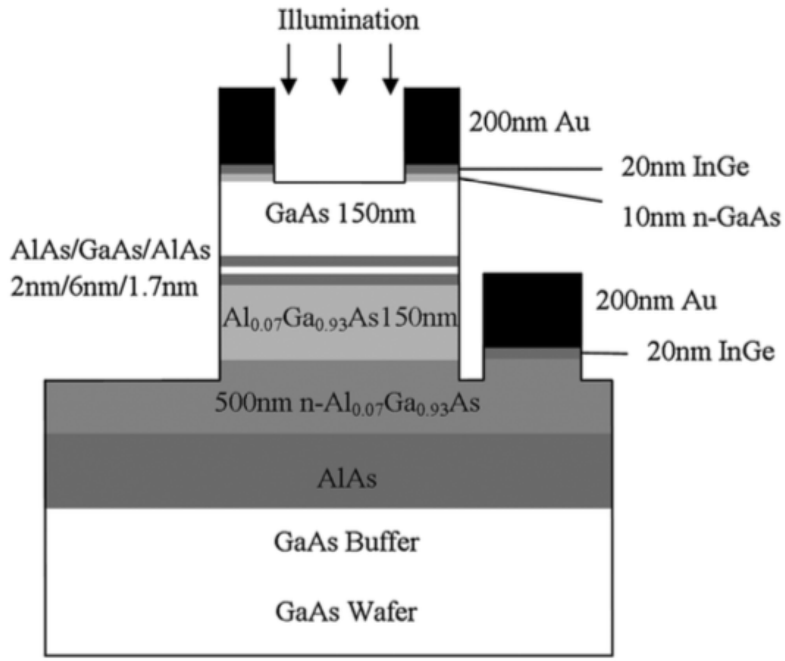
QW Hot-Carrier PV Cell

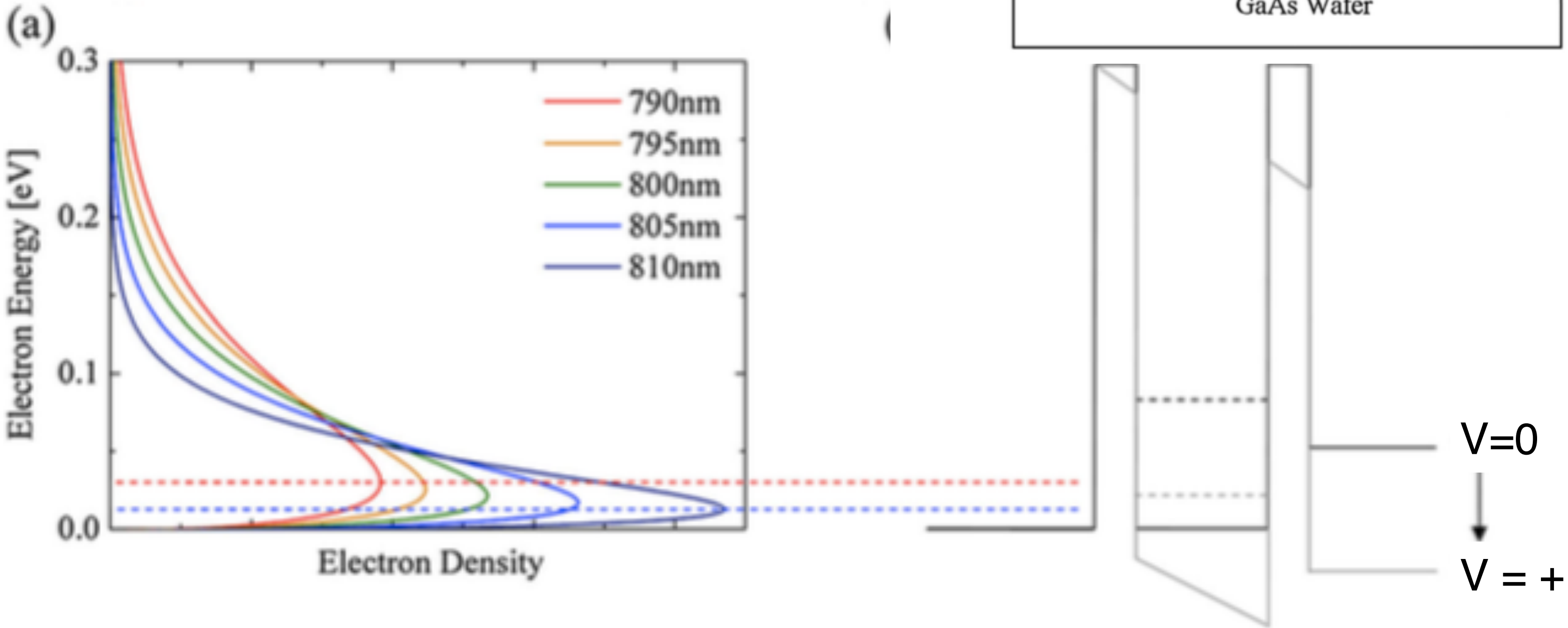


Hirst, L.C. et al. *Applied Physics Letters*, 104(23), p.231115. (2014)

Resonant Tunnel Hot Carrier Solar Cell



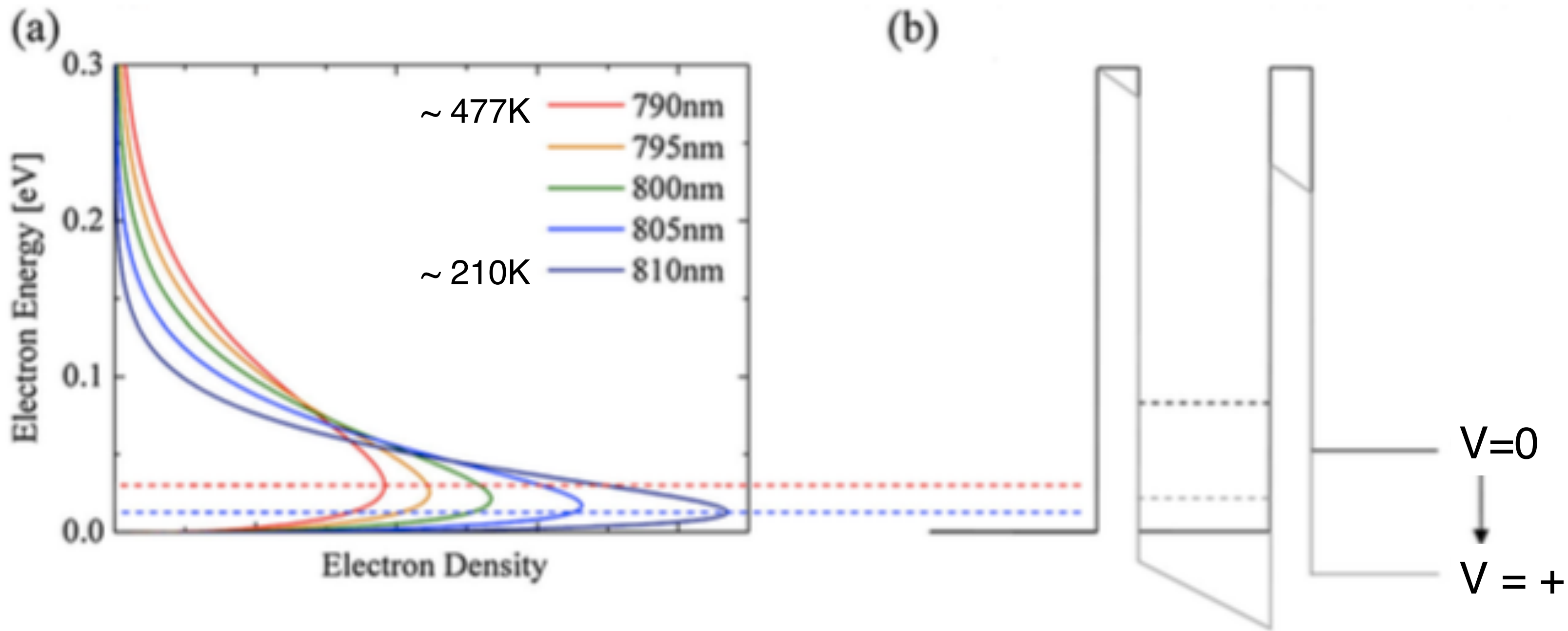




Dimmock, J.A.R. et al., *Progress In Photovoltaics*, 22(2), pp.151–160 (2014).

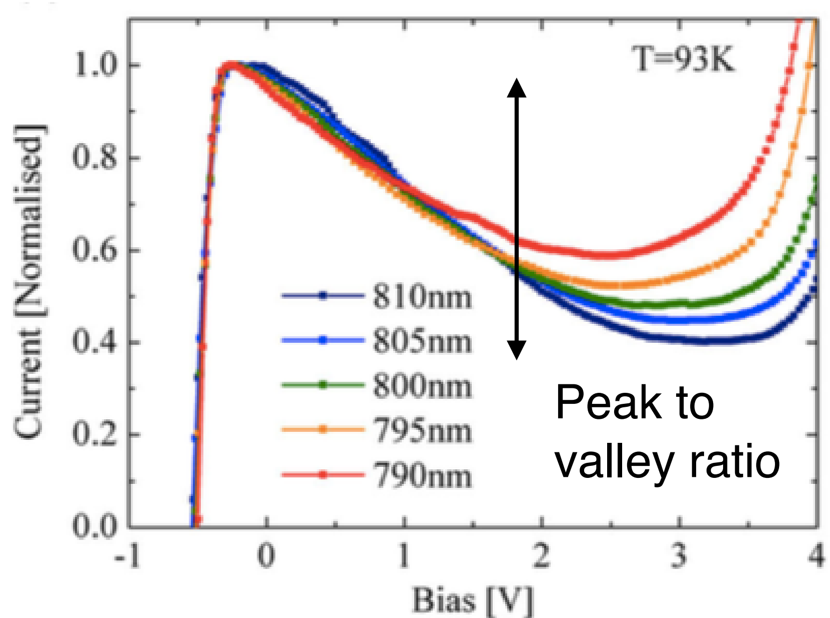
SPIE OPTO., pp. 935810–8 (2015)

Evidence for hot carriers : Peak to valley ratio



- GaAs carrier distribution warms with increasing laser intensity.
- Carrier distribution becomes energetically broader

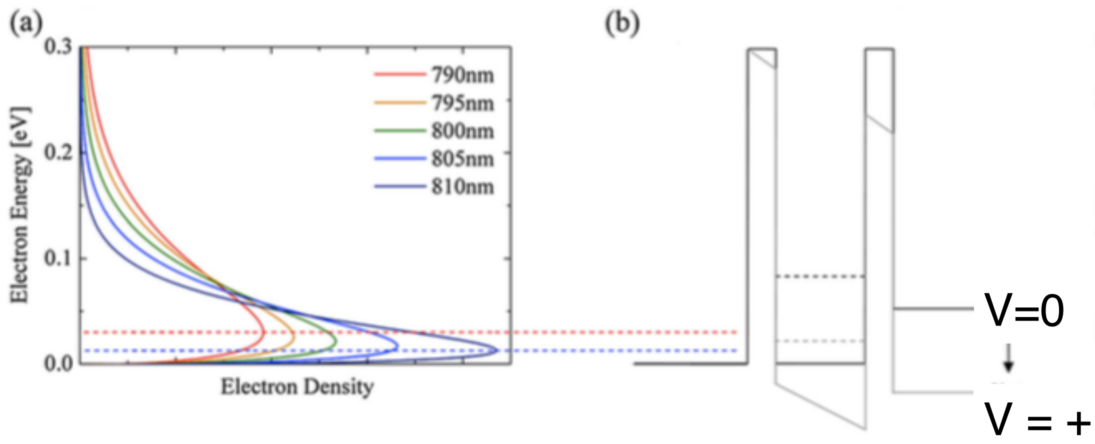
> PVR decreases.

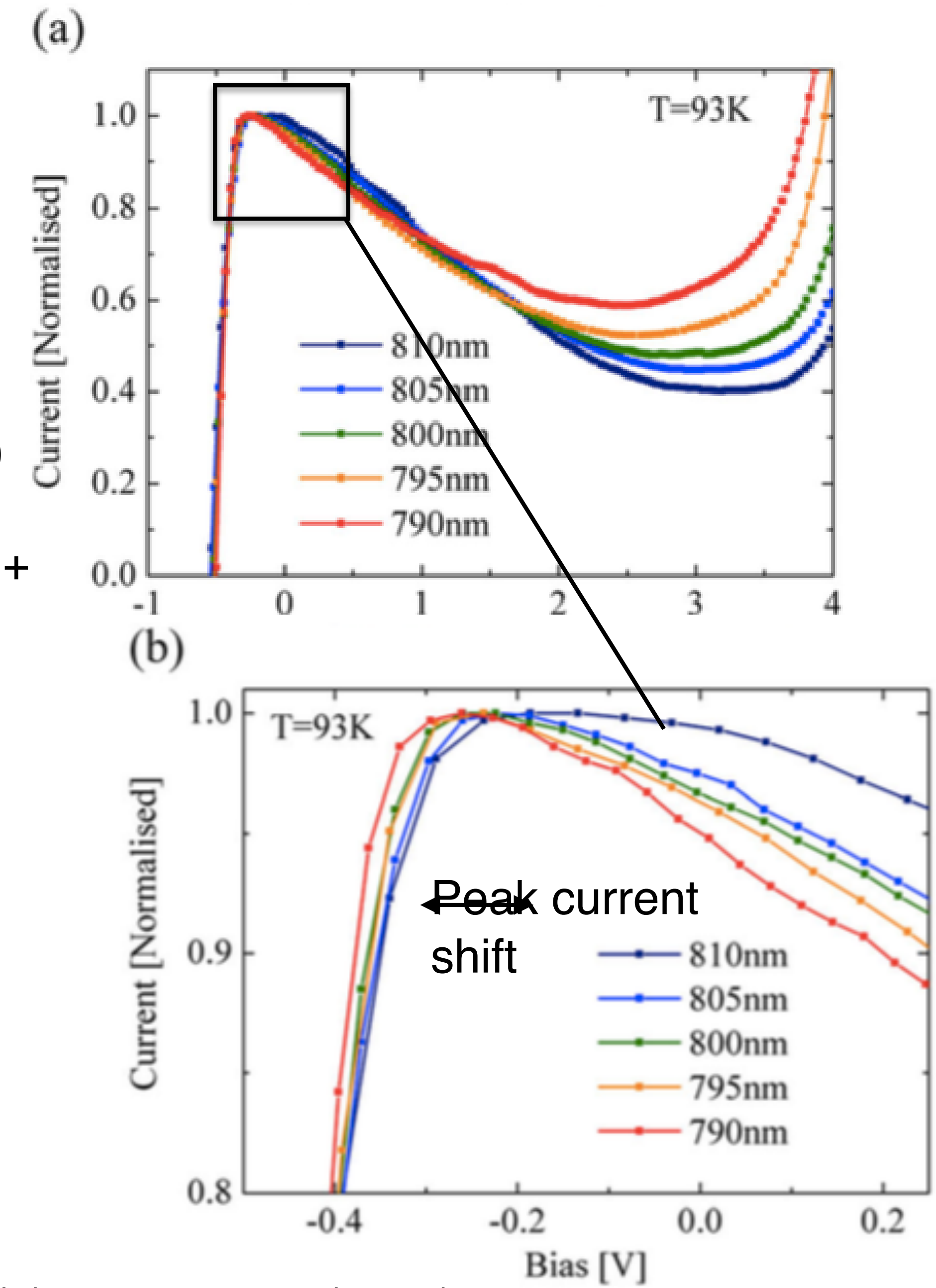


Dimmock, J.A.R. et al., *Progress In Photovoltaics*, 22(2), pp.151–160 (2014).

SPIE OPTO., pp. 935810–8 (2015)

Evidence for hot carriers : Peak tunnel current





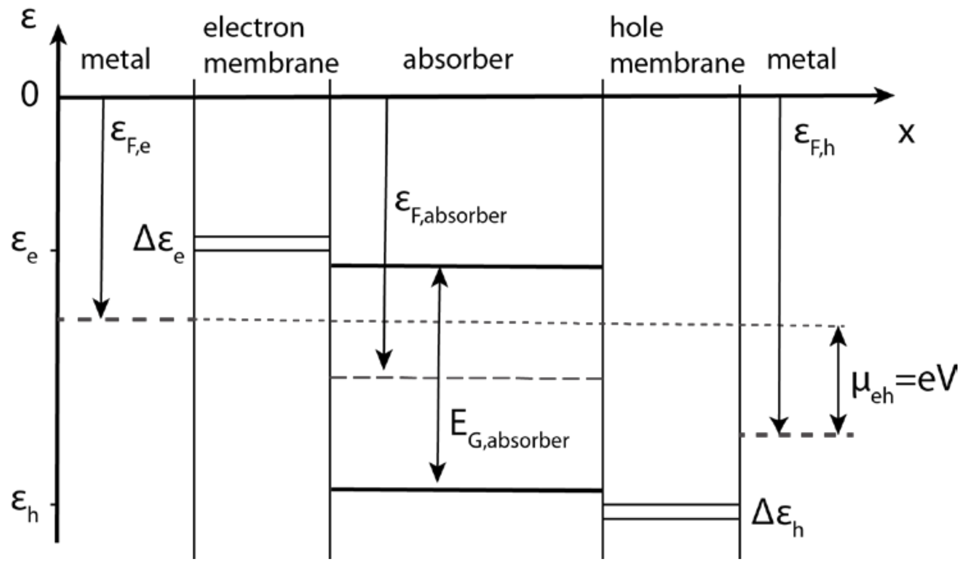
- GaAs carrier distribution warms with increasing laser intensity.
- Peak carrier density shifts to higher energy

> Peak tunnel current shifts to lower biases

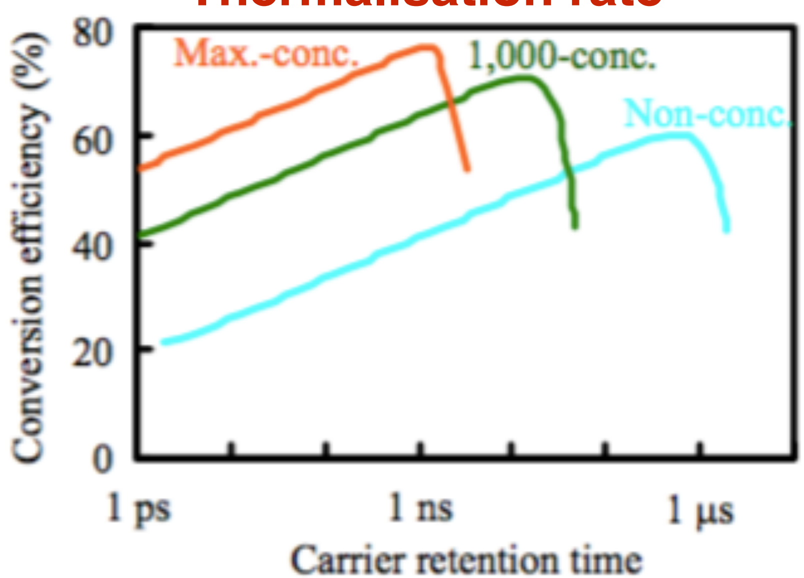
Dimmock, J.A.R. et al., *Progress In Photovoltaics*, 22(2), pp.151–160 (2014).

SPIE OPTO., pp. 935810–8 (2015)

Challenges for the hot carrier solar cell

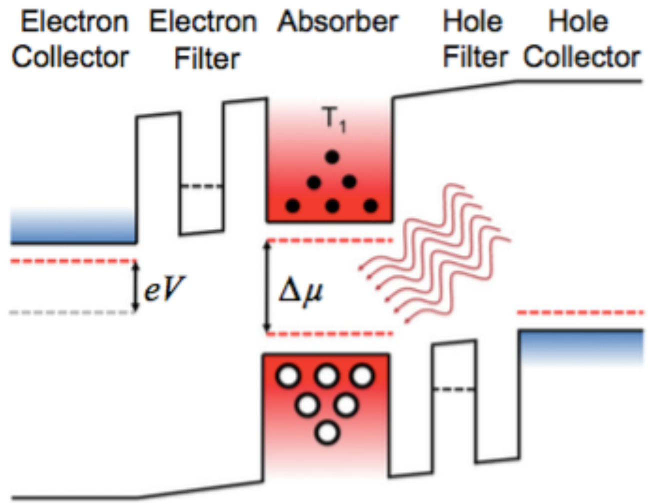


Thermalisation rate



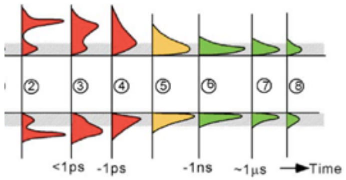
Takeda, Y. et al., Appl.Phys.Lett. 105(7), p. 074905. (2009)

Bandwidth of membranes

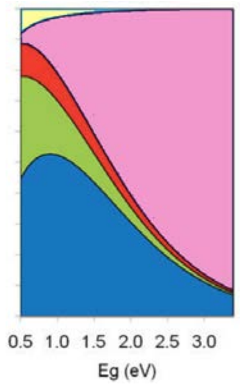


Limpert, S., et al., New Journal Of Physics, 17(9), p.095004 (2015)

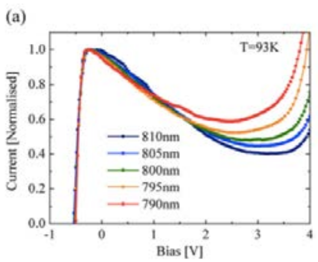
Conclusions



Carrier thermalisation is a major source of energy loss in conventional solar cells.



Hot carrier solar cell can, in principle achieve solar power conversion efficiencies of 50% in a relatively simple structure.



Hot carrier solar cells have been recently demonstrated, under intense, monochromatic illumination at cryogenic temperatures.

! Remarkably slow carrier thermalisation will be required to rival present solar power conversion efficiencies.