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Third Generation Photovoltaics: Silicon nanostructure & Hot Carrier solar cells

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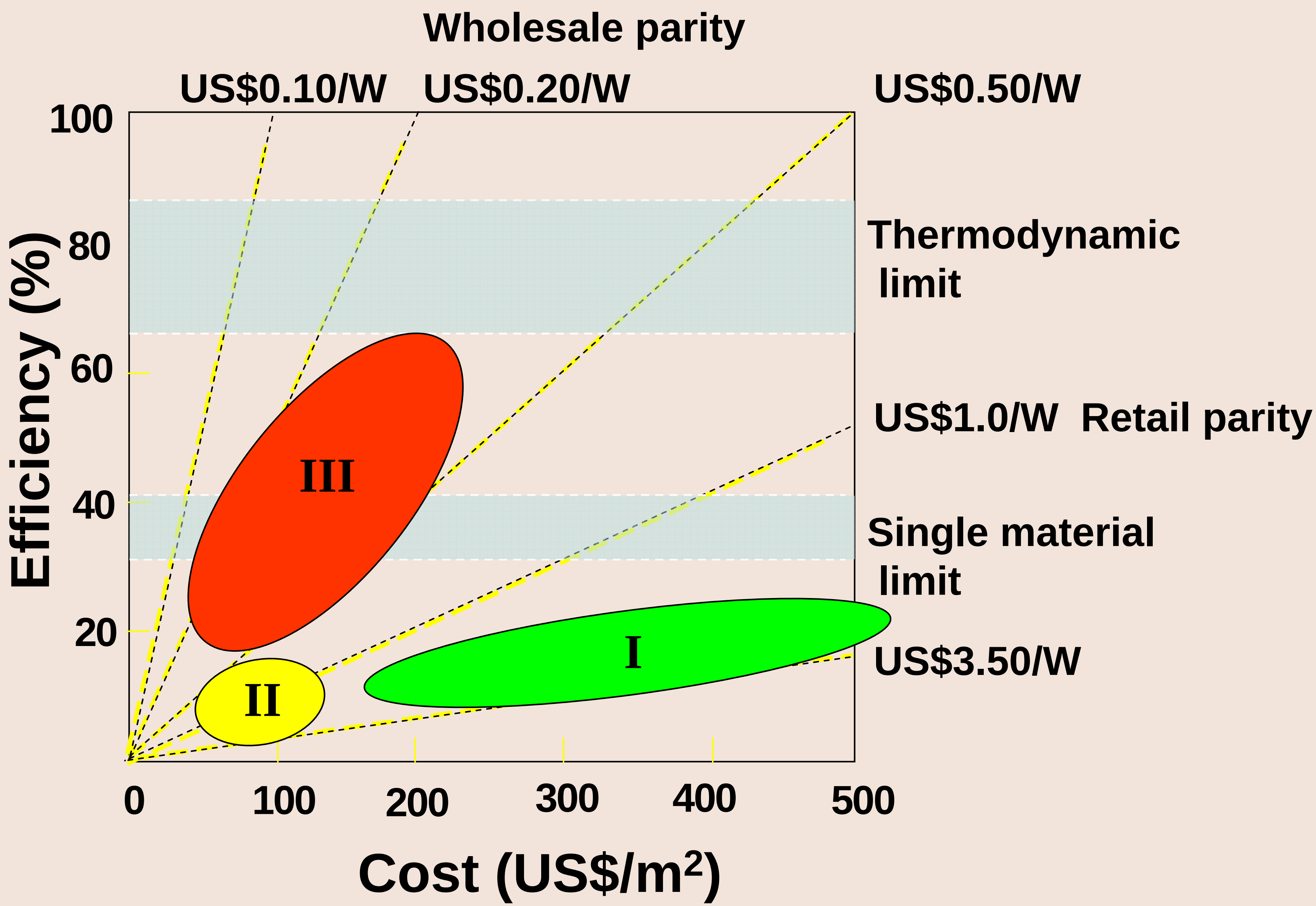
Photovoltaics Centre of Excellence supported by the Australian Research Council

Outline

- The main losses in photovoltaic cells
- Third Generation approaches
  - Silicon nanostructure tandem cells
    - Band gap engineering – quantum confinement
    - Materials and devices
  - Hot Carrier cells
    - Hot Carrier cooling
    - Interrupting energy loss to phonons
- Summary

Photovoltaics: Three Generations



Efficiency Loss Mechanisms

1. Sub bandgap losses

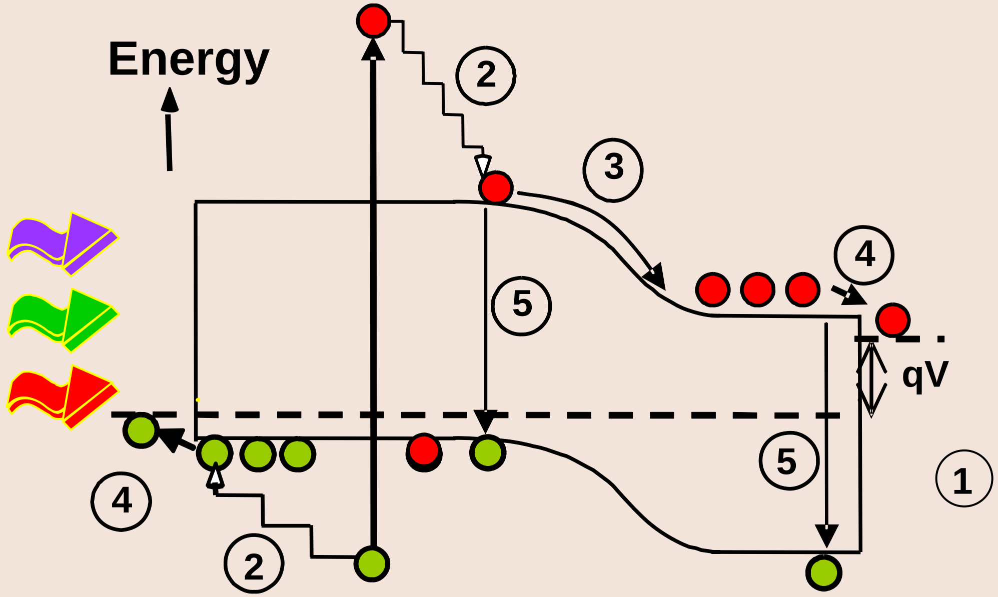
2. Lattice thermalisation

Two major losses – 50%

Also: *3. Junction loss*

4. Contact loss

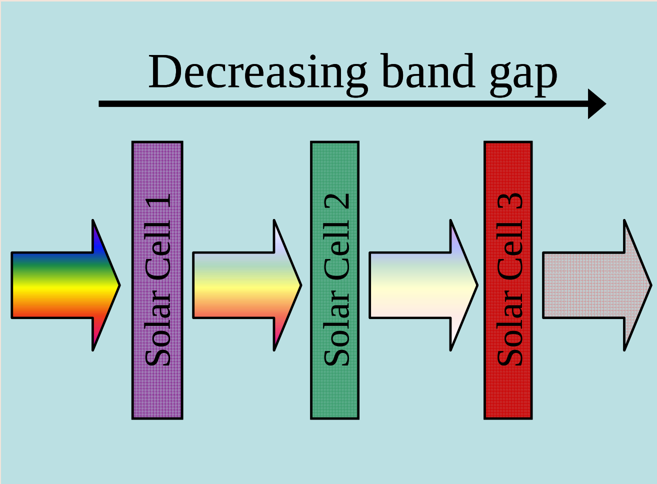
5. Recombination

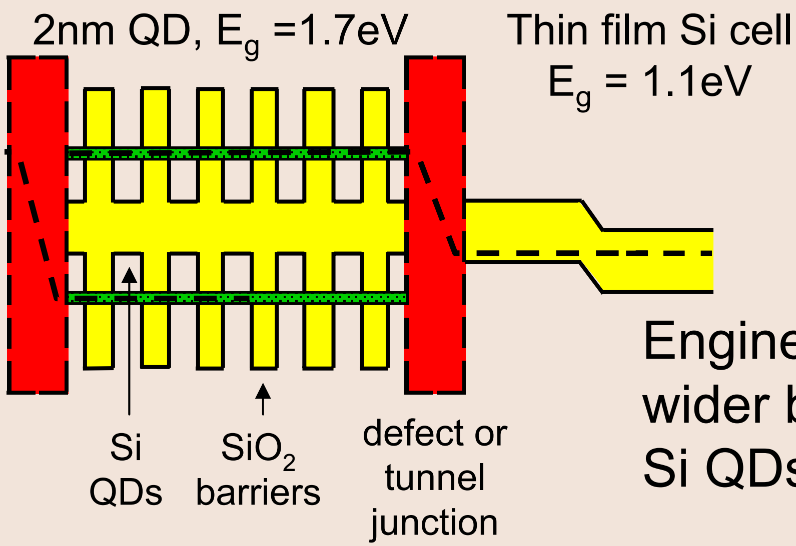


Limiting efficiencies	**1 sun**
Single p-n junction:	31%
Multiple threshold:	68.2%

Silicon based Tandem Cell

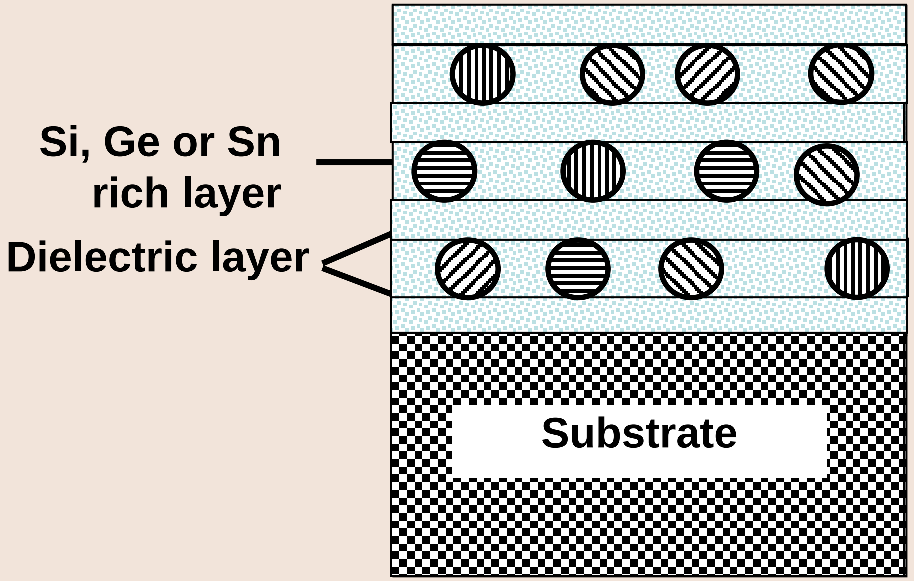
Martin Green, Gavin Conibeer, Dirk König, Eunchel Cho, Tom Puzzer, Yidan Huang, Shujuan Huang, Dengyuan Song, Angus Gentle, Ivan Perez-Wufl, Chris Flynn, Jeana Hao, Sangwook Park, Yong So, Bo Zhang





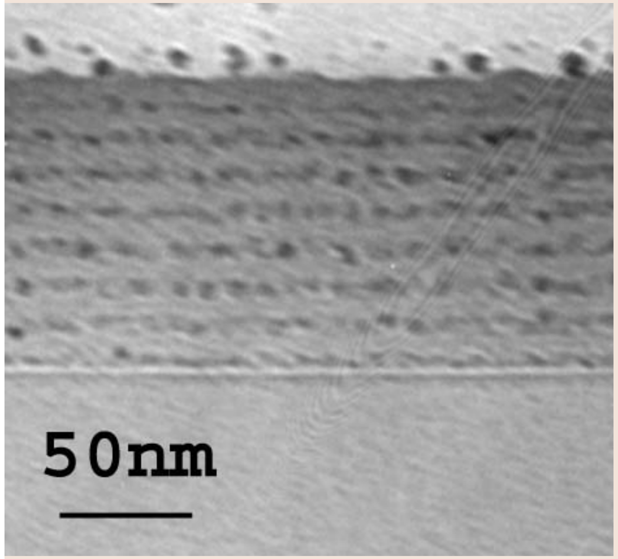
Engineer
wider band gap
Si QDs

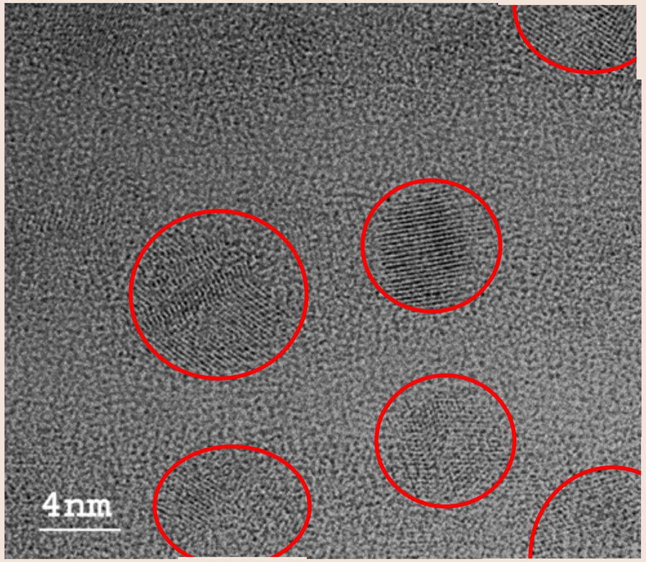
Anneal 1100°C
– Si precipitation

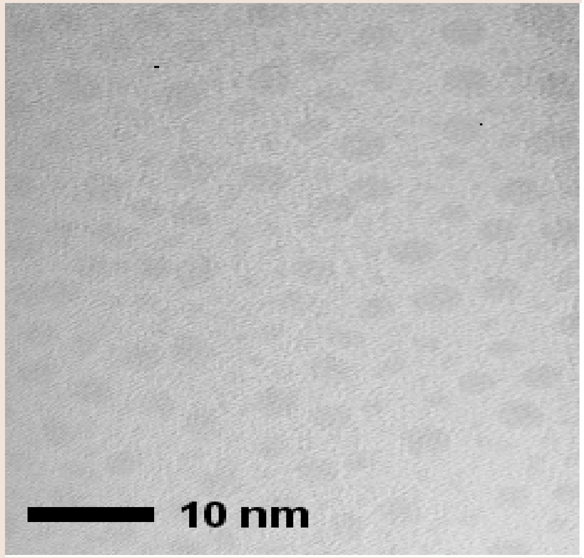


Zacharias, 2000

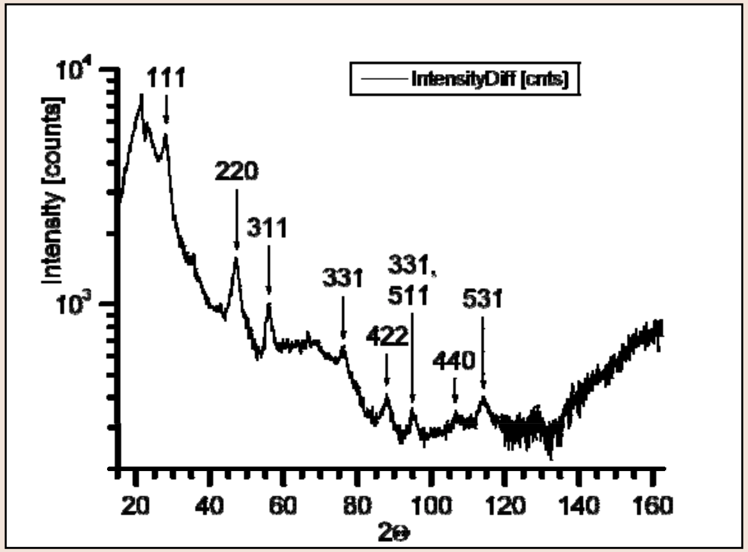
Si QD characterisation



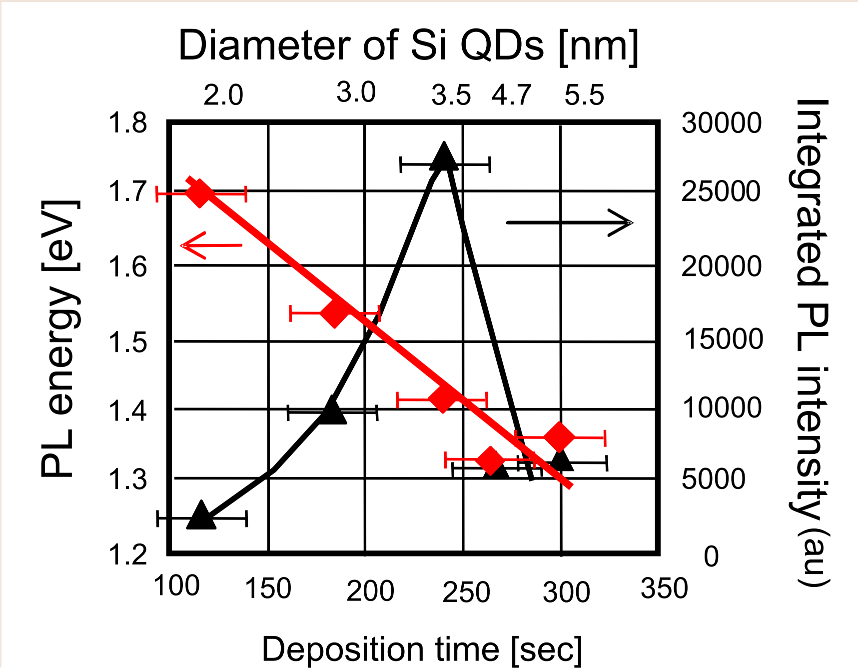




XRD Si QDs in **oxide** d_{QD} 4.5nm

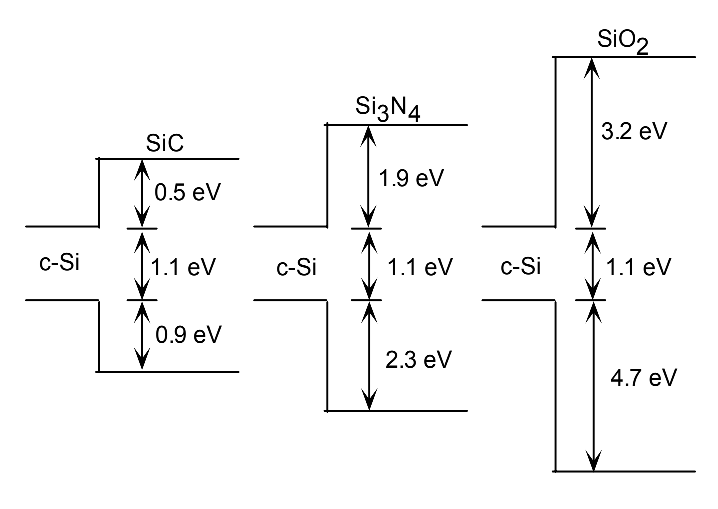


PL optical energy levels

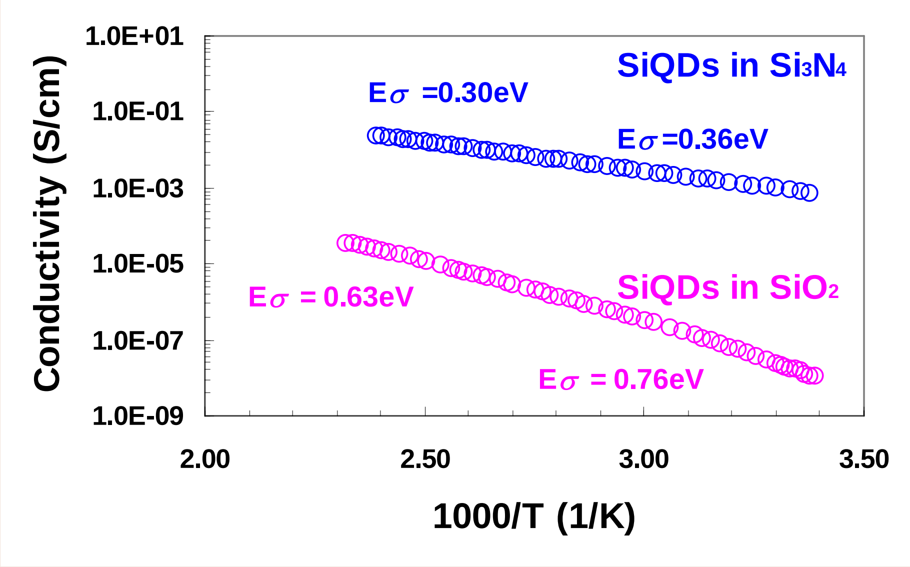


Range of QD materials

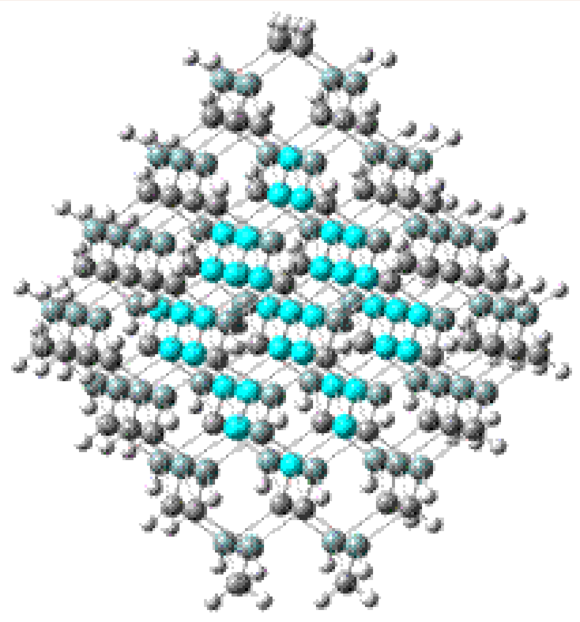
Alternative matrices

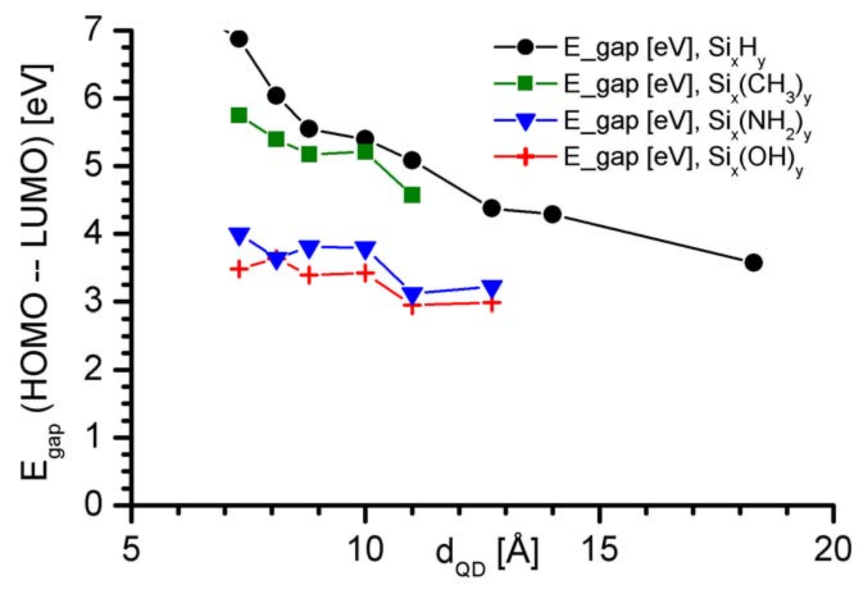


Greater σ for Si_3N_4 but also lower E_{act}



DFT model -ling





Various material combinations

Quantum Dot / Matrix combinations and current status of investigations

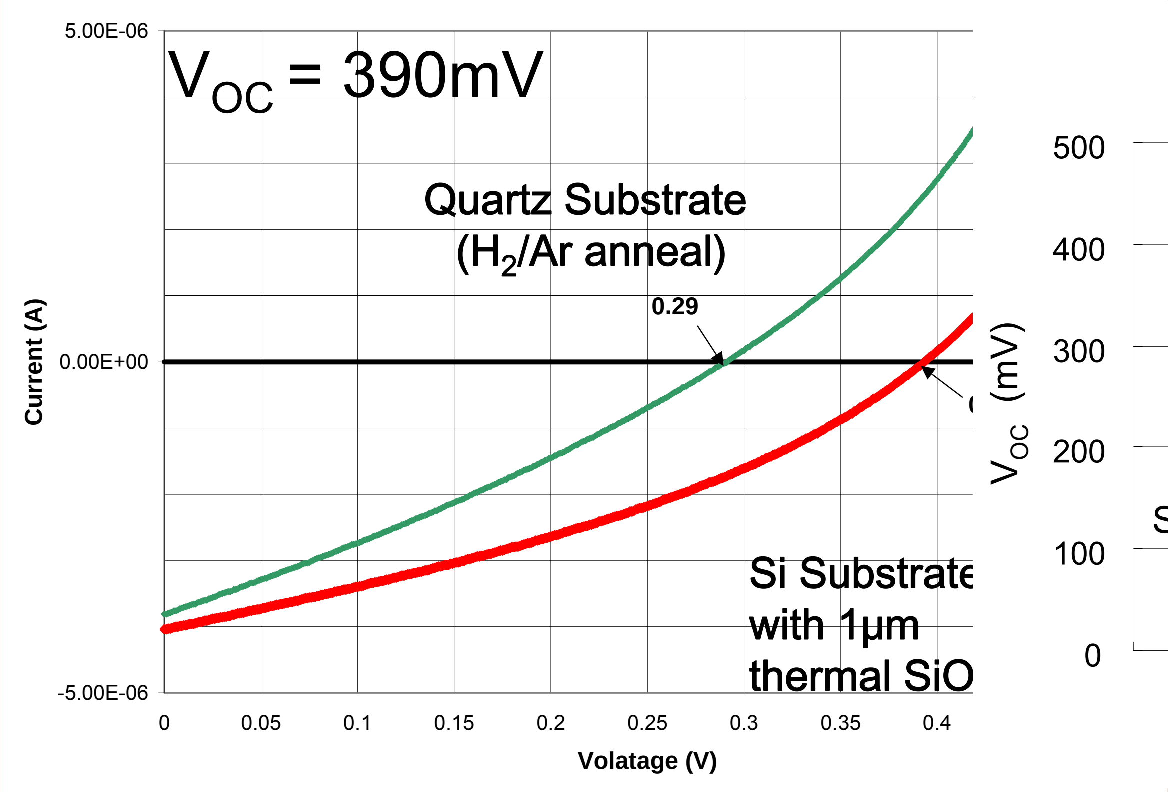
Increasing conductivity →

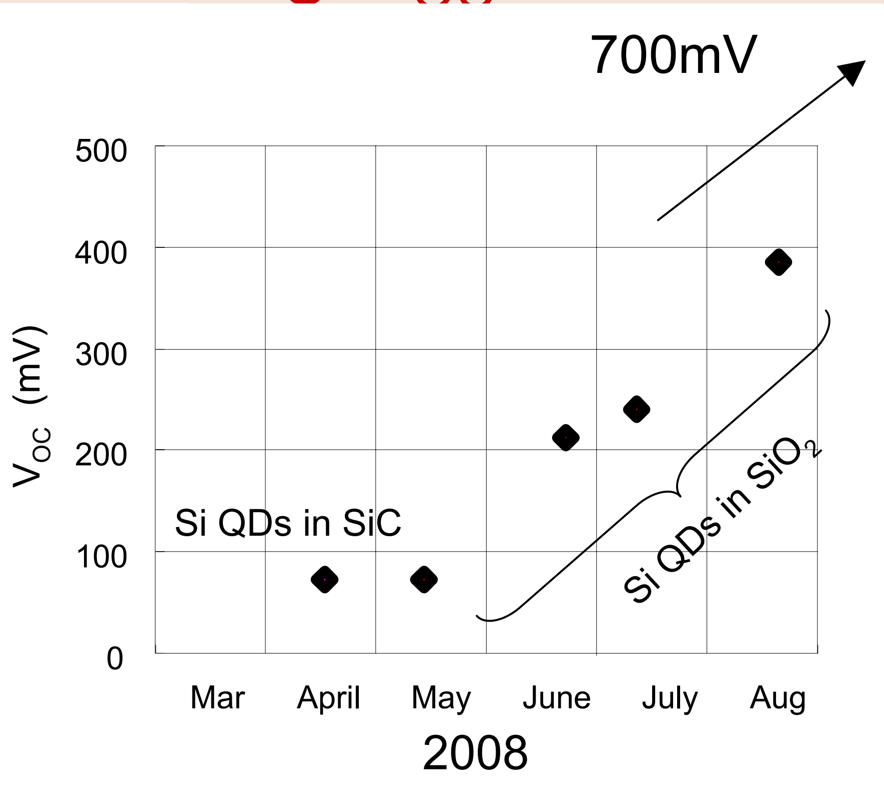
Decreasing processing temperature ↓

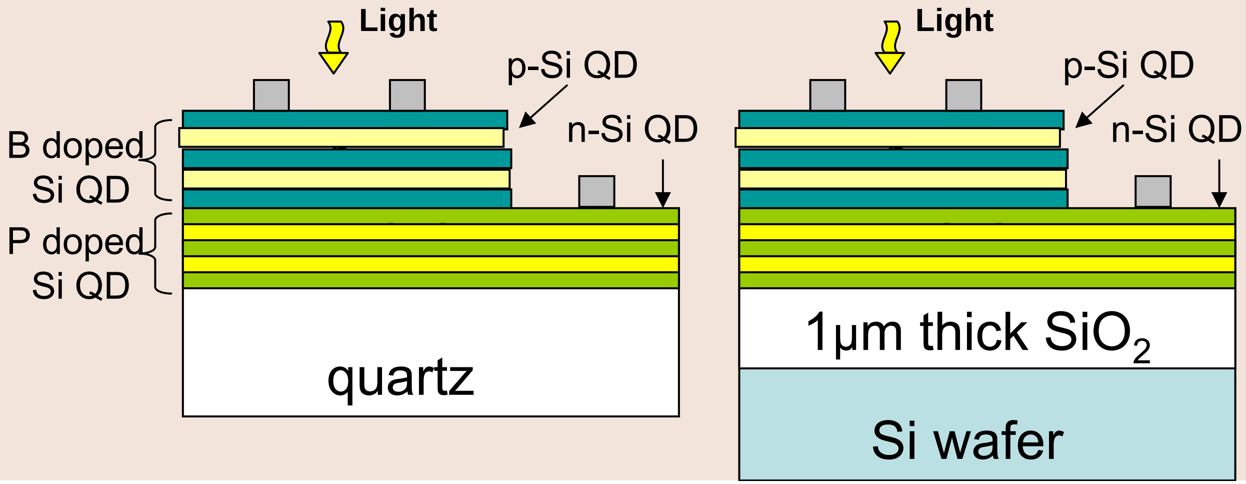
	SiO_2	Si_3N_4	SiC
Si	SPOED	SPOED	SPOD
Ge	SP	-	-
Sn	SPO	PO	-

S = Simulation (ab-initio modelling - DFT)
P = Physical (electron microscopy, X-ray difraction)
O = Optical (photoluminescence, absorptance)
E = Electronic (conductivity, conductivity with Temp.)
D = Devices (Diodes, Cells)

PV devices with increasing V_{OC}







Continuing Work

- Quality of dielectrics
- Passivate QD interfaces
- Improved device design
- Increase absorption

Hot Carrier solar cell

GCEP
Global Climate & Energy Project
STANFORD UNIVERSITY

Started September 2008

University of New South Wales, Sydney:

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Inst. Research Development Energie Photovoltaic / CNRS, Paris:

Jean Francois Guillemoles, Lunmei Huang

University of Sydney:

Timothy Schmidt, Raphael Clady, Murad Tayebjee

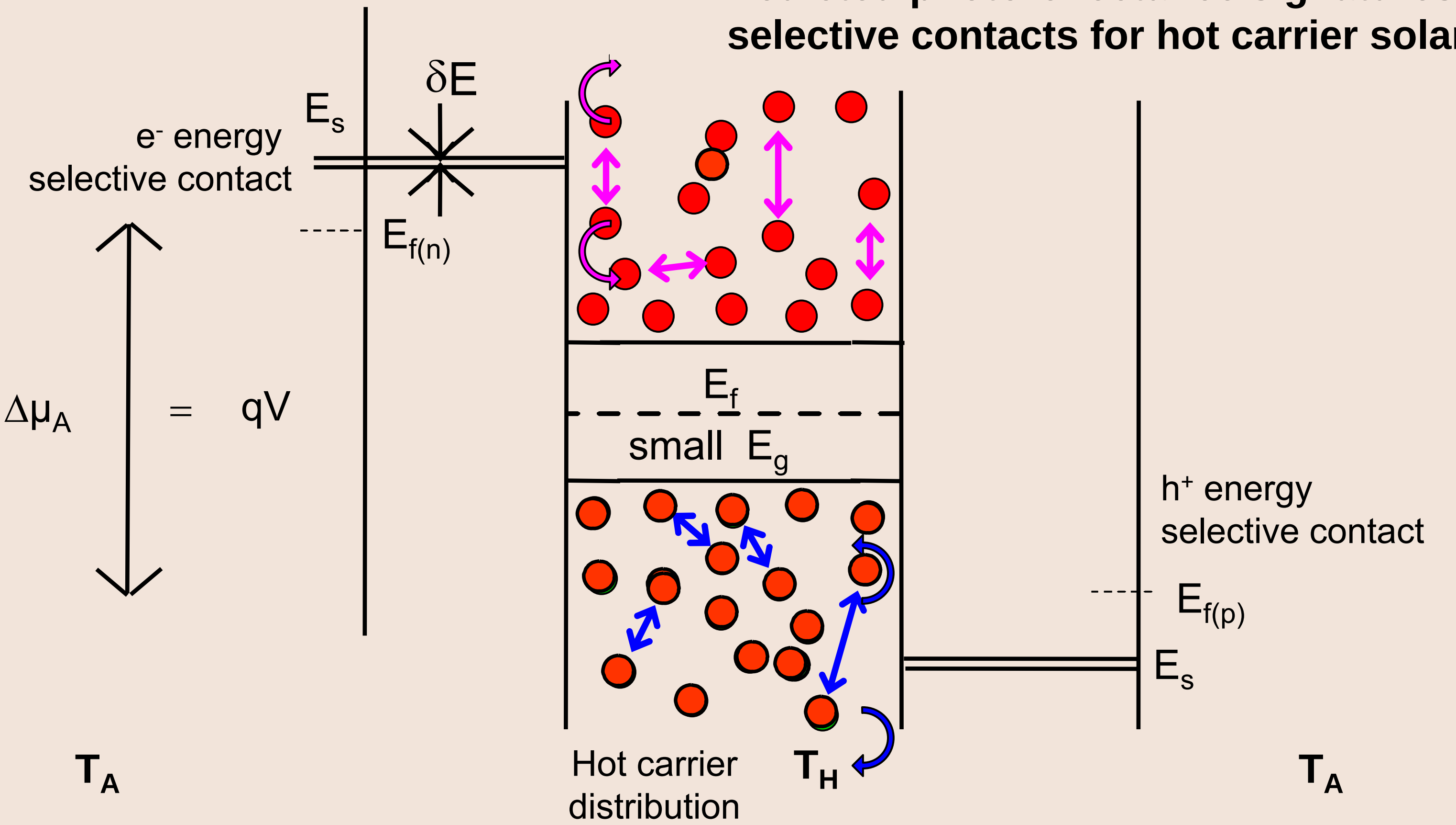
Hot Carrier solar cell: Concept

Extract hot carriers before they can thermalise:

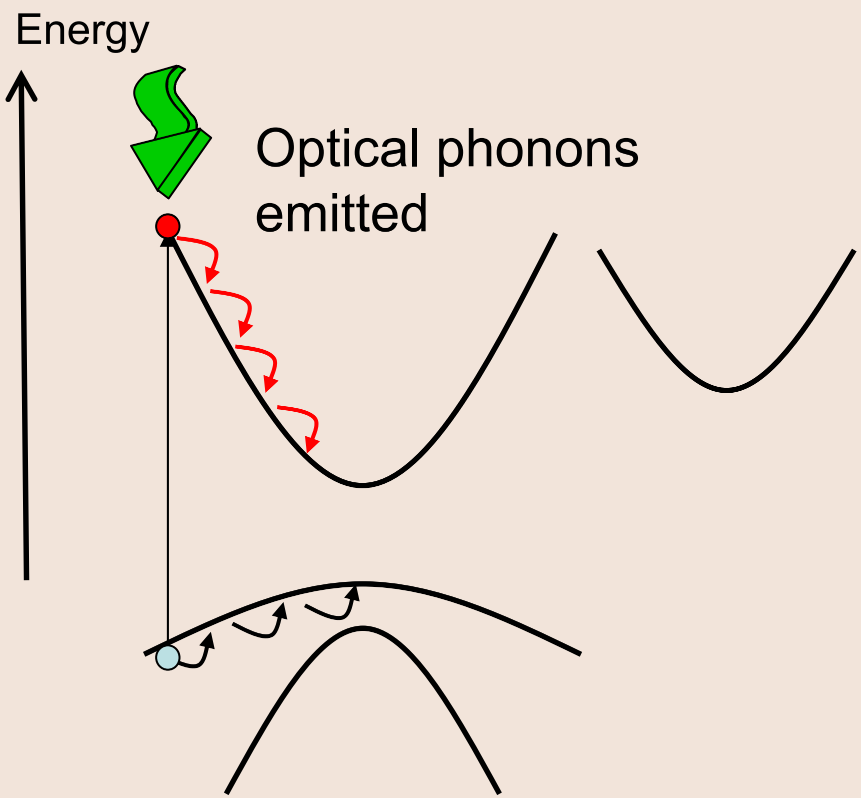
- Need to slow carrier cooling
- Collect carriers over narrow range of energies
- Renormalisation of electron (hole) energies

Ross & Nozik, JAP, 53 (1982) 3813
Würfel, SOLMAT, 46 (1997) 43 1995
Green, 3rd Gen PV (S-Verlag) 2003
Würfel, PIP, 13 (2005) 277
Conibeer, TSF, 516(2008) 6948

Enrique Canovas et al: Poster session: "Predicted photoreflectance signatures on QD selective contacts for hot carrier solar cells"



Hot Carrier cooling



Electrons carry most energy

Cool predominantly via
small wave vector **optical** phonon
emission - timescale of ps
inelastic – energy relaxation

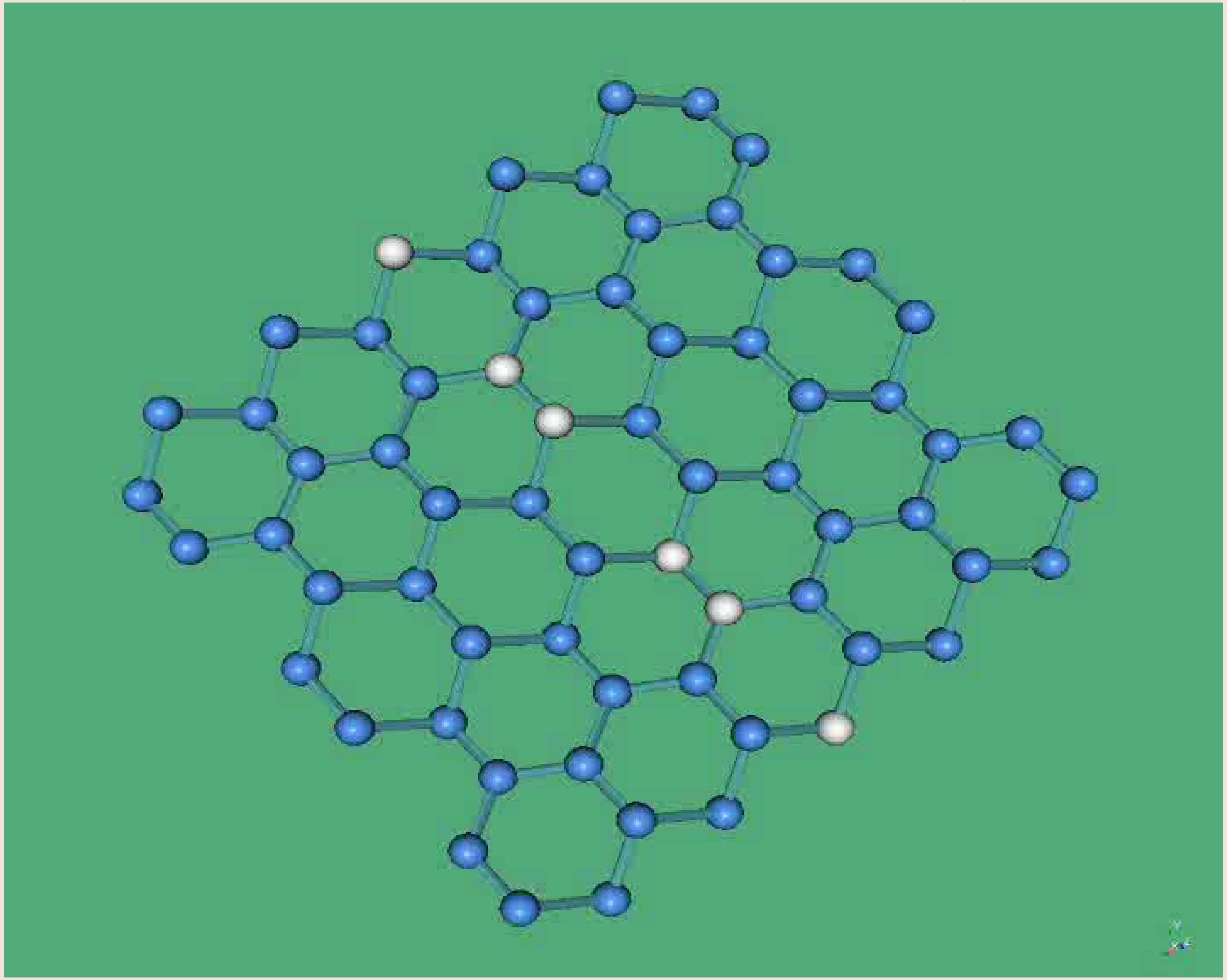
↓

Hot Optical phonon population
“phonon bottleneck effect”

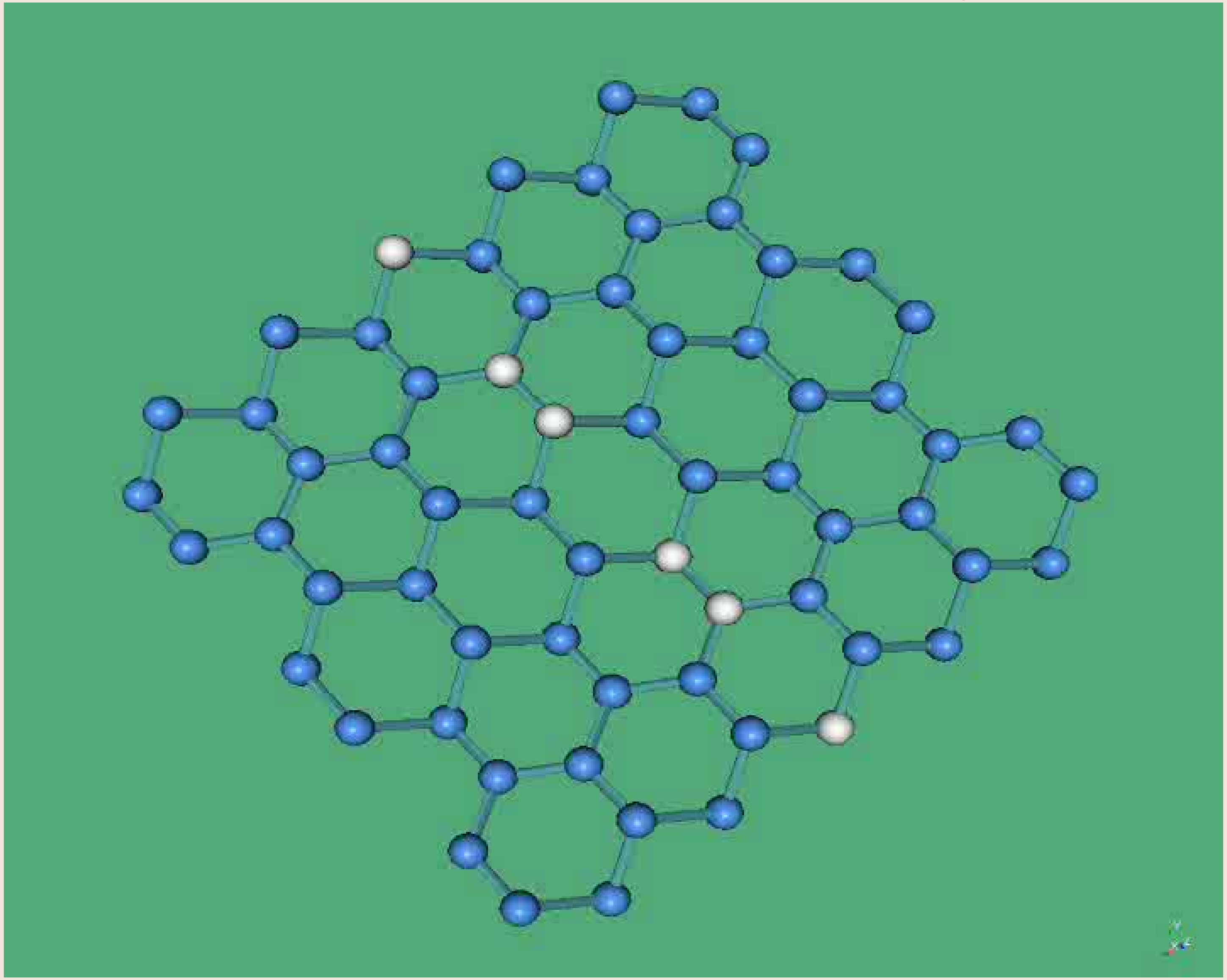
Decay of Optical phonons to Acoustic is critical

Slows further carrier cooling

Optical phonon decay

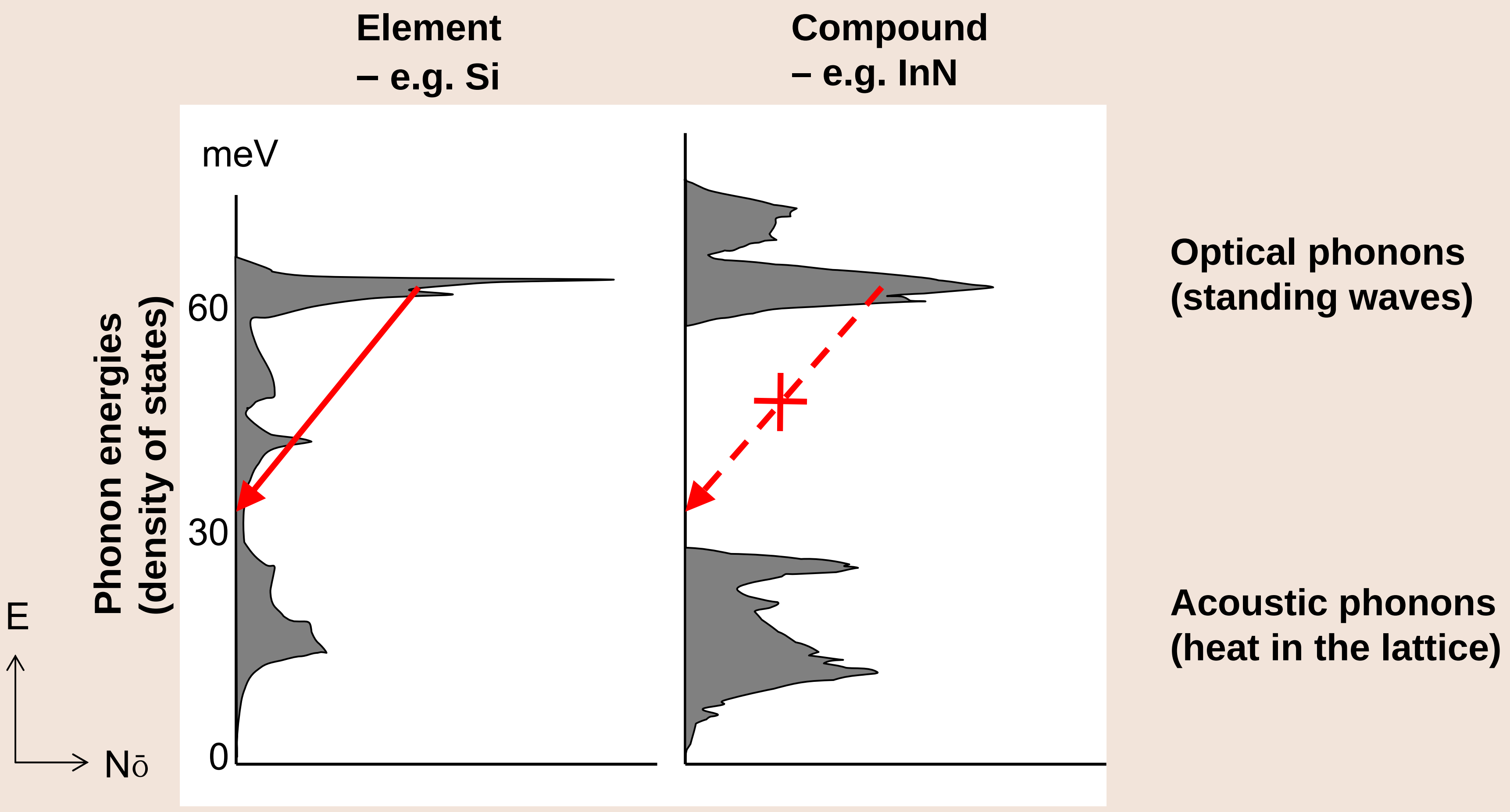


Optical phonon decay



O → LA + LA (Anharmonicity or Klemens mechanism)

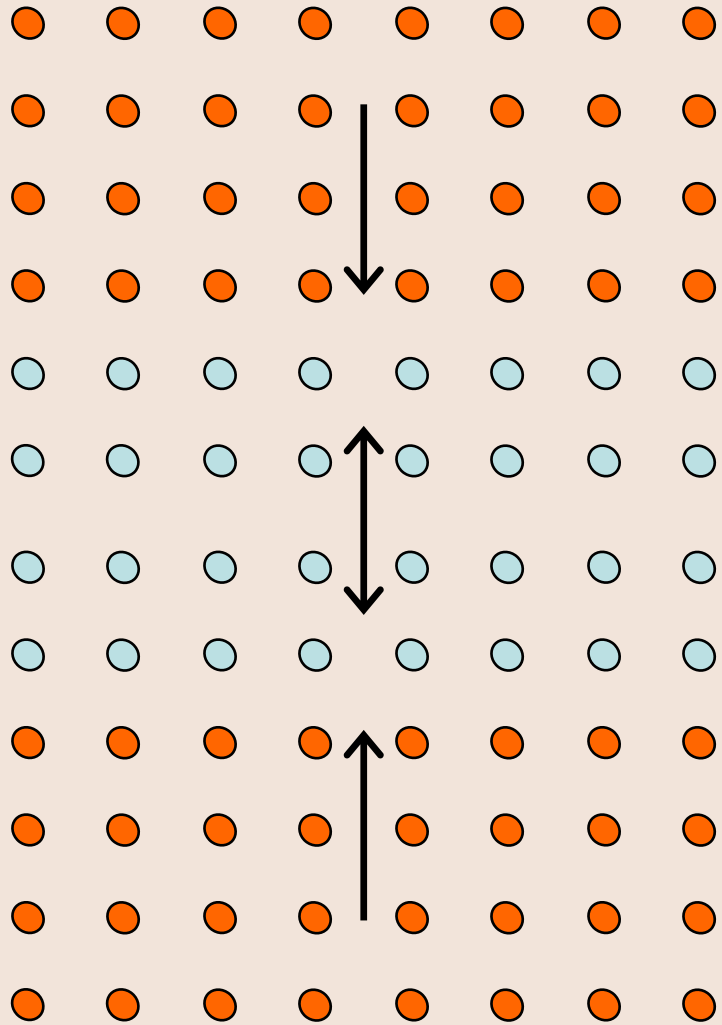
Allowed phonon energies



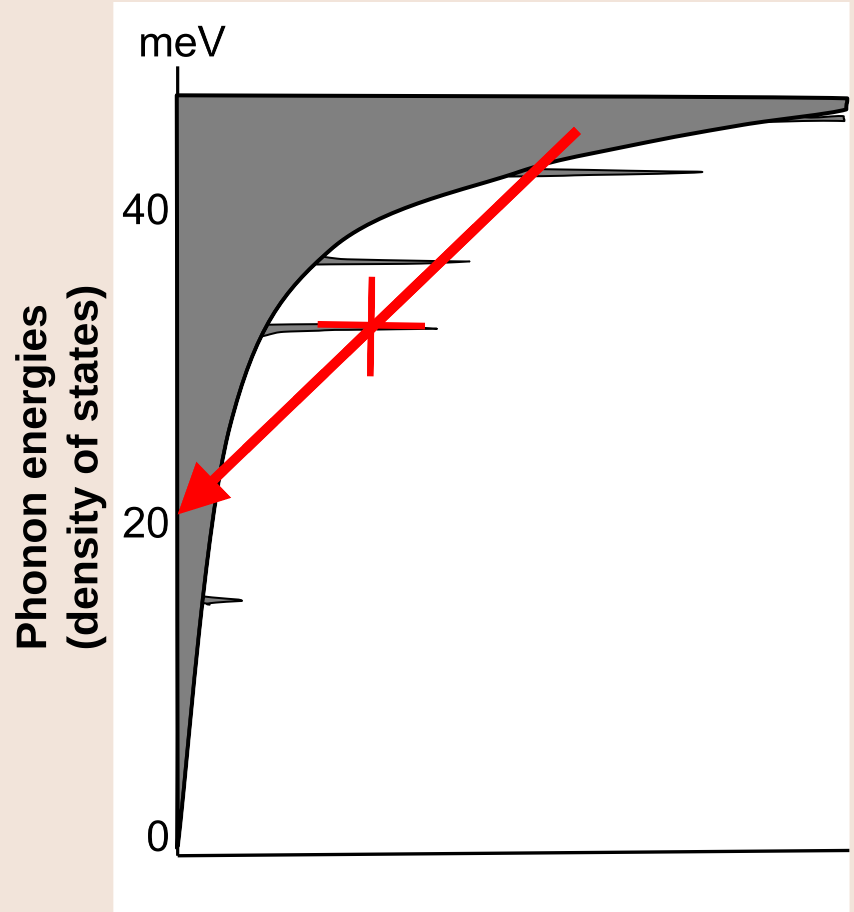
Some evidence for slowed carrier cooling in InN: Chen & Cartwright, APL, 83 (2003) 4984

And for longer phonon lifetimes in GaN, AlSb, InP – all of which have large phonon gaps

Phononic gaps in nanostructures

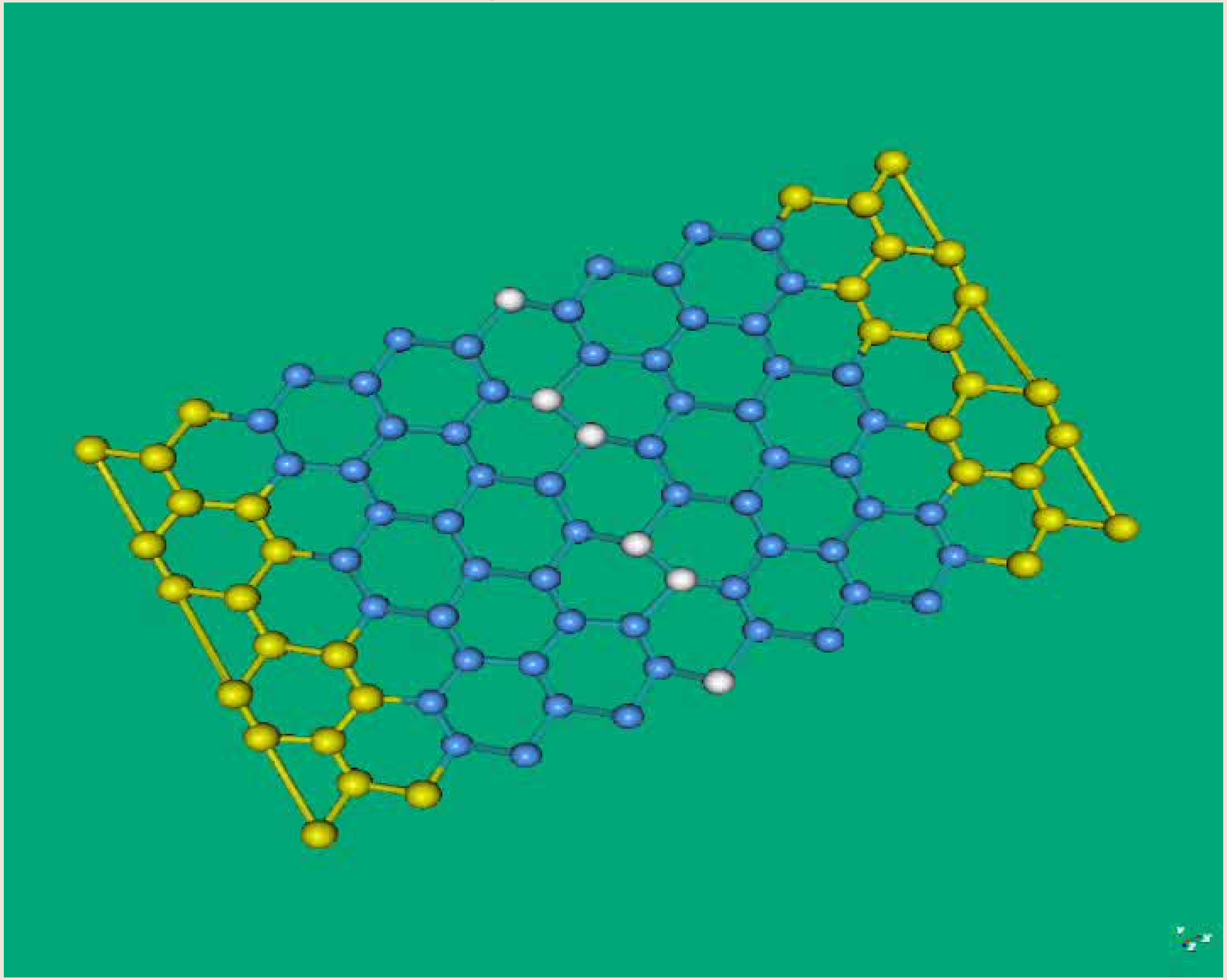


Linear force constant model:
mass ratio = 2; force constant ratio = 5



'Phononic band gaps' – modulate acoustic impedance
analogy to Photonic band gap – modulate refractive index

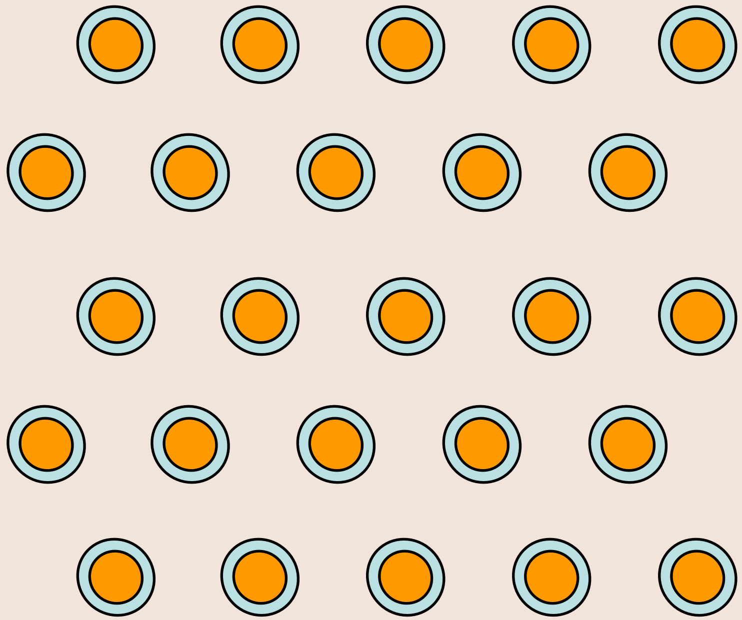
Phonon propagation in nanostructure



Acoustic phonon reflected from zone edges → standing wave

1D to 3D modelling

Uniform 3D periodic QD array

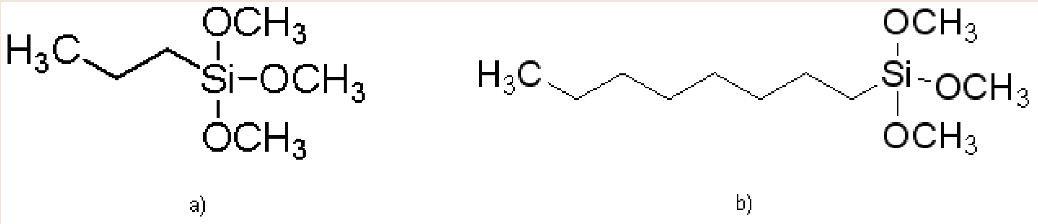


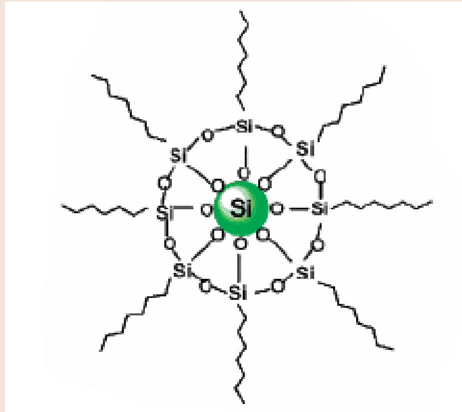
- Coherent interference
- Periodic QD array – probably fcc – probably core shell QDs
- 1D modelling to 3D – Lunmei Huang
- Long range / short range defects – Andy Hsieh, Binesh PV

Colloidal dispersion of nanoparticles

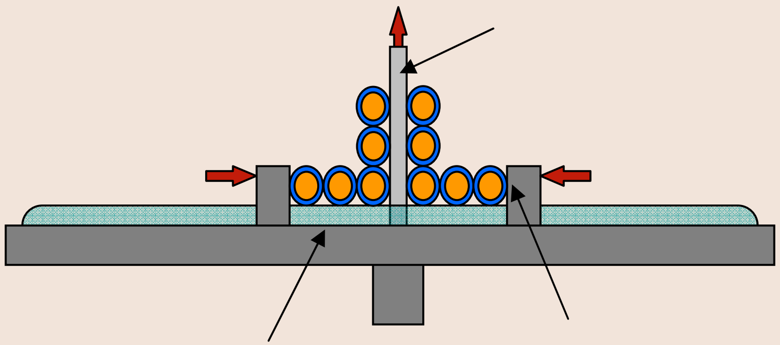
- Colloidal dispersion of Si or other nanocrystals
– want uniform spacing and mono-disperse size

- Core shell nanocrystals – hetero-interface
– Guillemoles, IRDEP, Paris





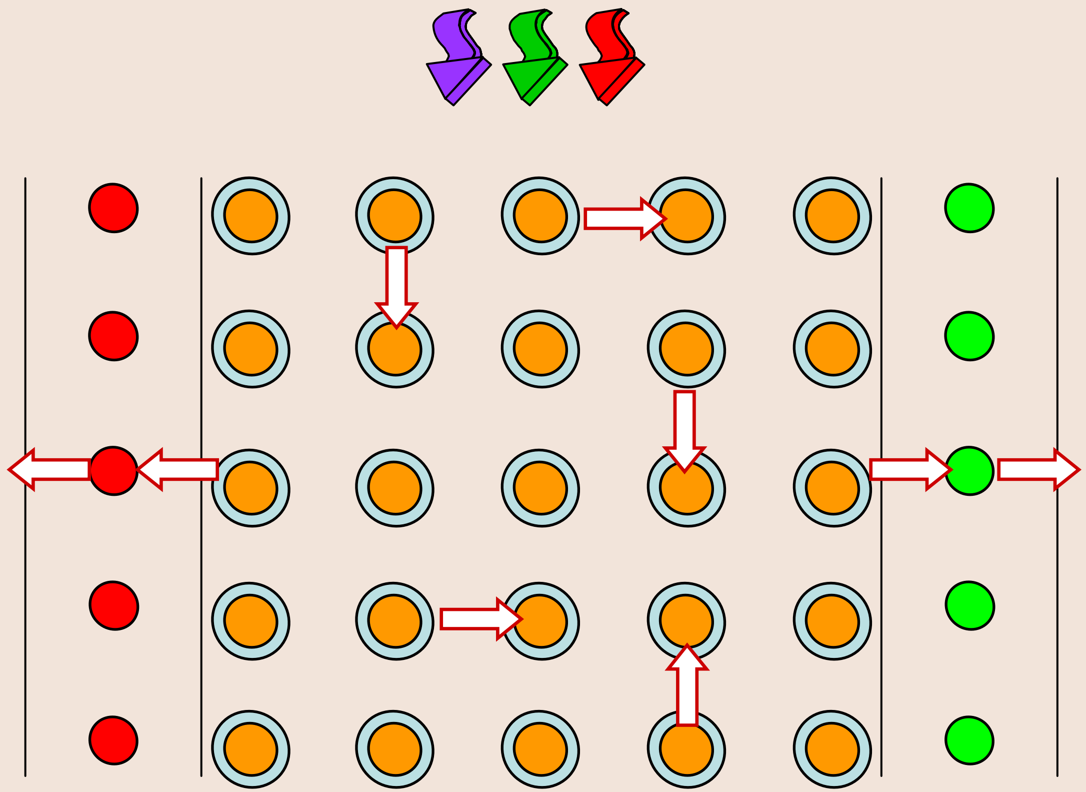
Organosilanes of varying alkyl chain lengths – a)Trimethoxy(propyl)silane, b) Trimethoxy(octyl)silane



Langmuir-Blodgett deposition of monolayers build up multiple mono-layers

Towards a complete cell

- Fabrication of slowed cooling absorber
- Transport and Renormalisation of carrier energies
- Energy Selective Contacts



Summary

- Principal energy losses
- Si nanostructure tandem cells
  - Band gap engineering
  - Range of QD materials
  - Devices now up to 390mV V_{OC}
- Hot Carrier cells
  - Energy filter contacts
  - Phonon bottleneck
  - Nanostructures - QD based cell
- Third generation multi-energy level devices
  - tend to involve QD nanostructures
  - enable tailoring of material properties

Thank you for your attention

Research Staff:

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