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Woods Energy Seminar, 28 May 2008

Third Generation Photovoltaics

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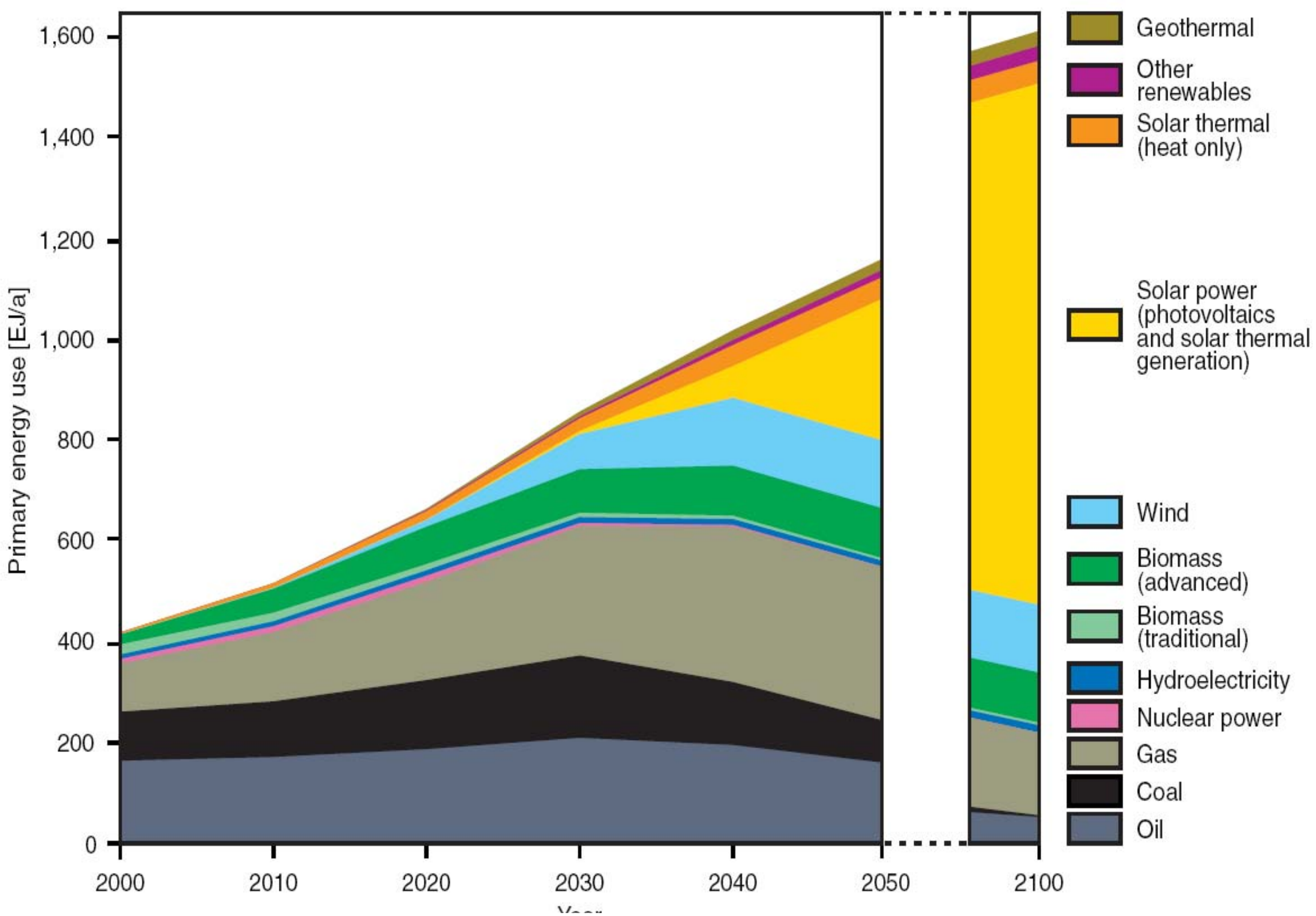
Photovoltaics Centre of Excellence supported by the Australian Research Council, the Global Climate and Energy Project and Toyota CRDL

Meeting the IPCC target of 60% reduction in GHG emission by 2050

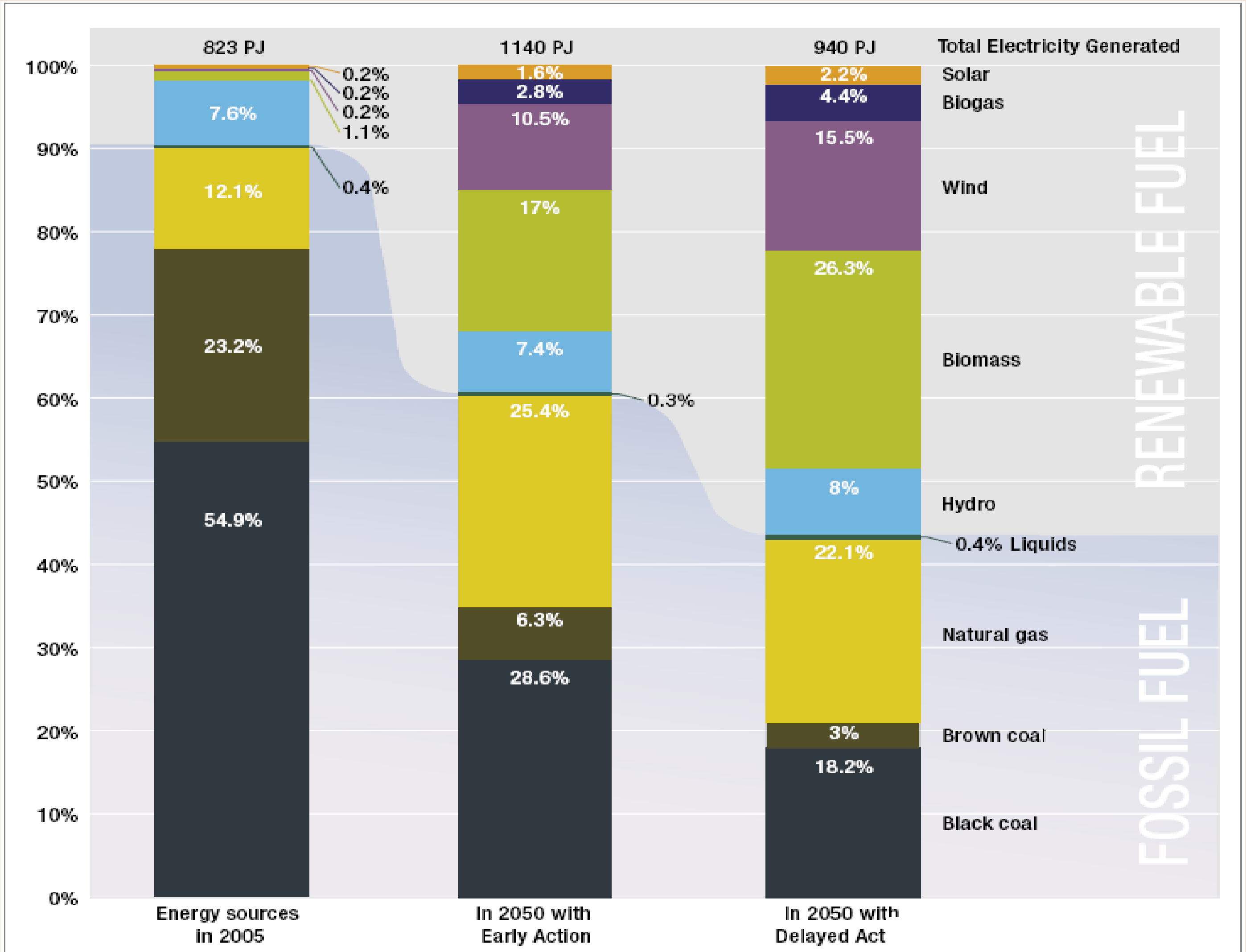


WBGU

GERMAN ADVISORY COUNCIL ON GLOBAL CHANGE

– appointed for a term of four years by the federal cabinet (Bundeskabinett)

The business case for early action
60% reduction in GHG emission by 2050

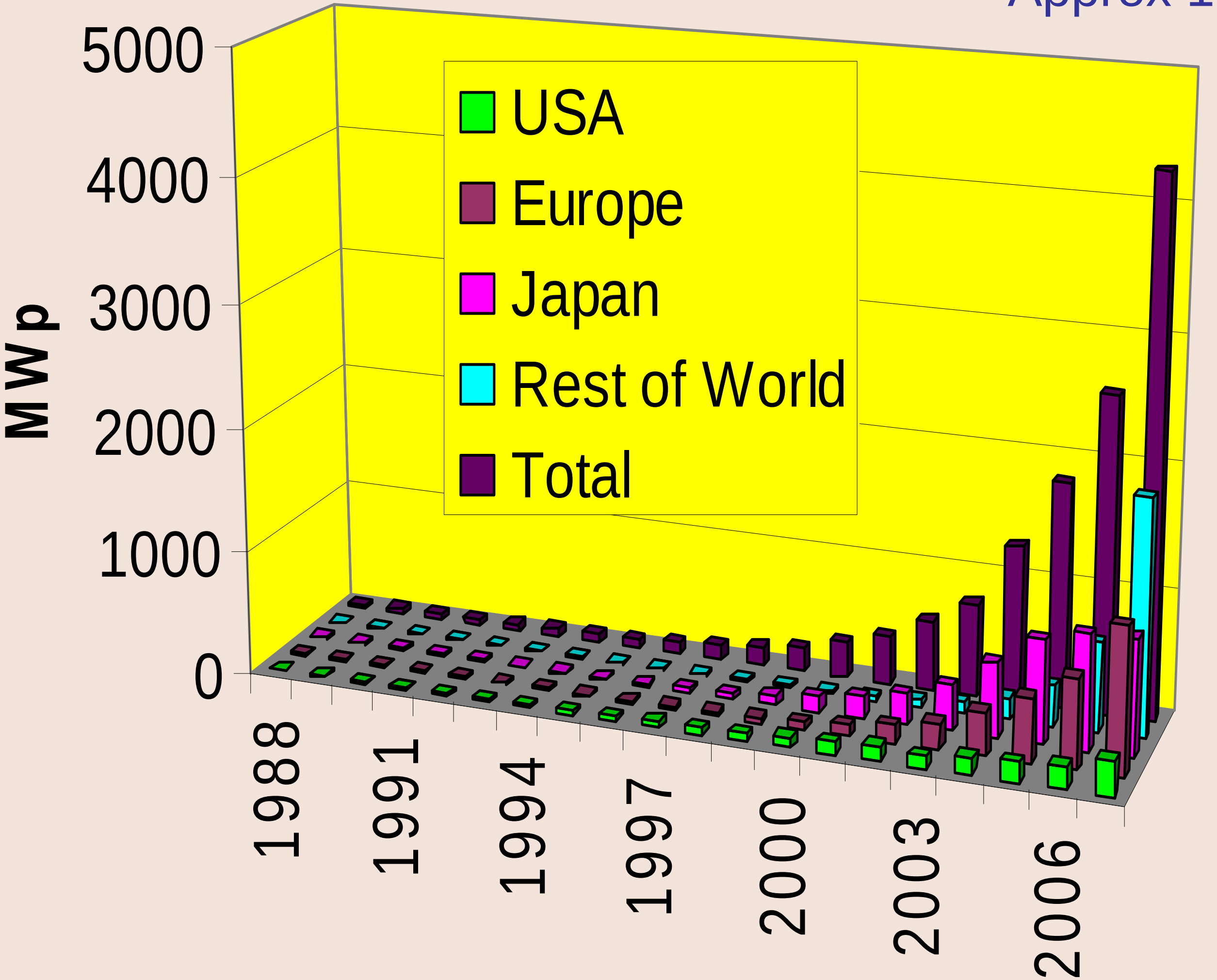


Outline

- The importance of Photovoltaics
- Three generations of Photovoltaics
- The main losses in photovoltaic cells
- Third Generation approaches
    - Silicon nanostructure tandem cells
        - Band gap engineering – quantum confinement
        - Fabrication of materials / devices
    - Hot Carrier cells
        - Contacts – energy filtering
        - Hot Carrier cooling – energy loss to phonons
- Summary

Booming Photovoltaics

Market growth at 35%/yr for last 10 years, 60%+ in 2007
Approx 1 million jobs in PV by 2020
Approx 1 million jobs in RE by 2010



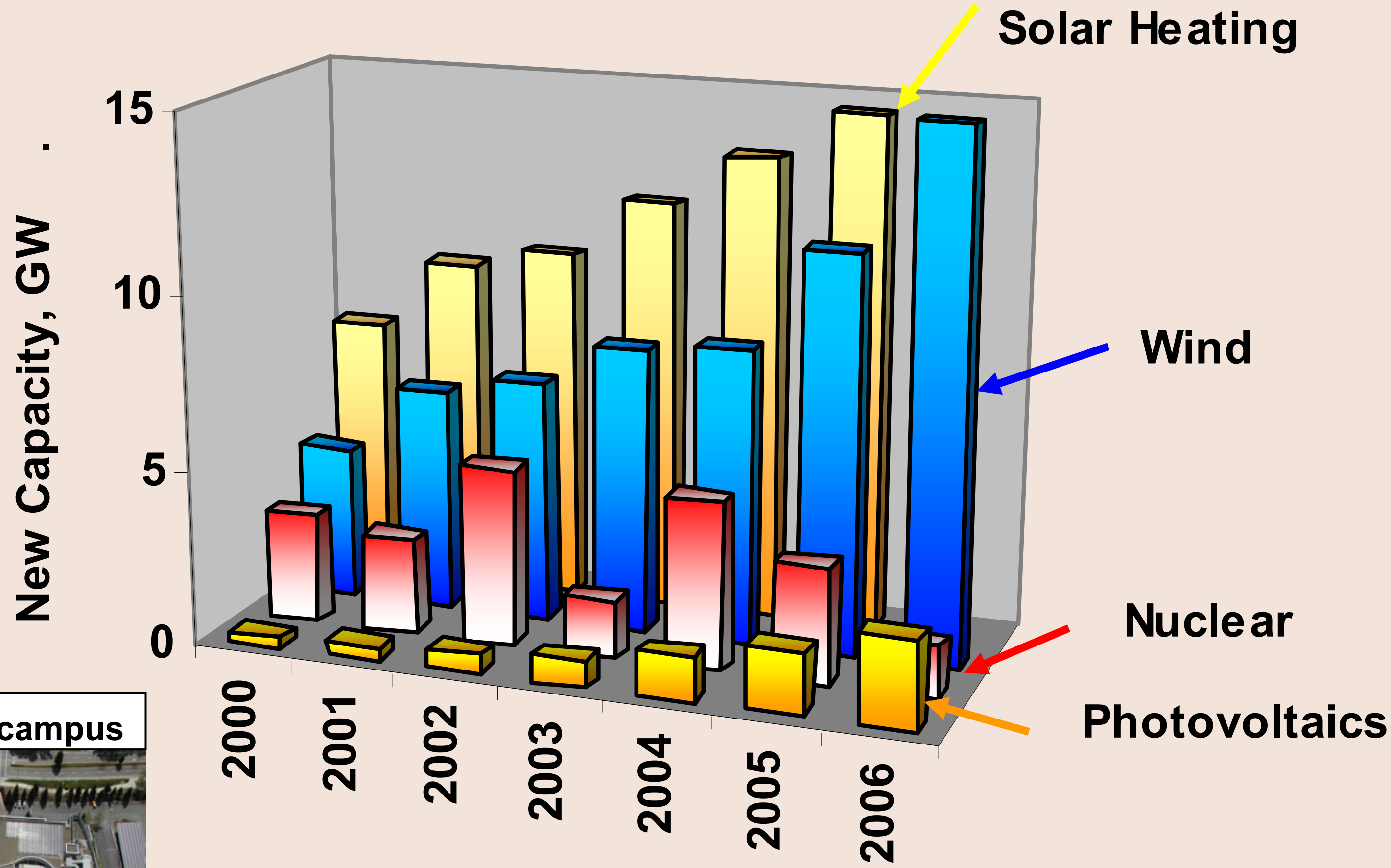
Global PV market
US$6.5 billion in 2006
→ $16.4 billion in 2012

Driven by rebates/tariffs:
Japan, Germany
Now other Euro. Countries
and S Australia

USA: Power purchase agreements

Japan: market is stable with reducing rebates

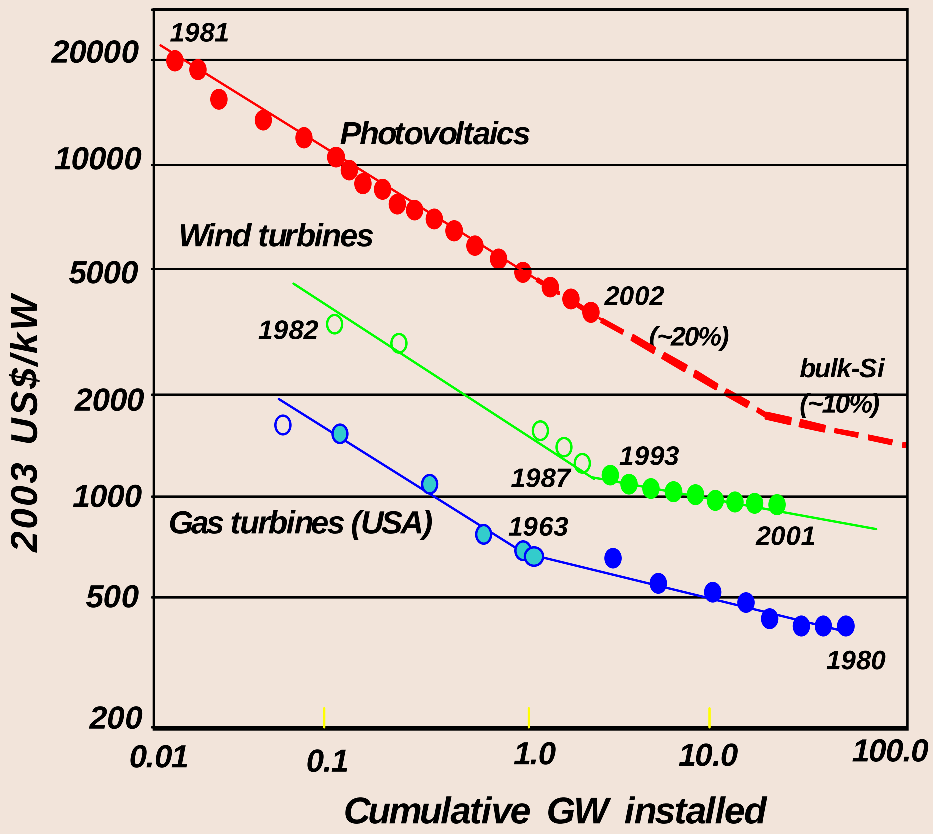
Annual capacity increase

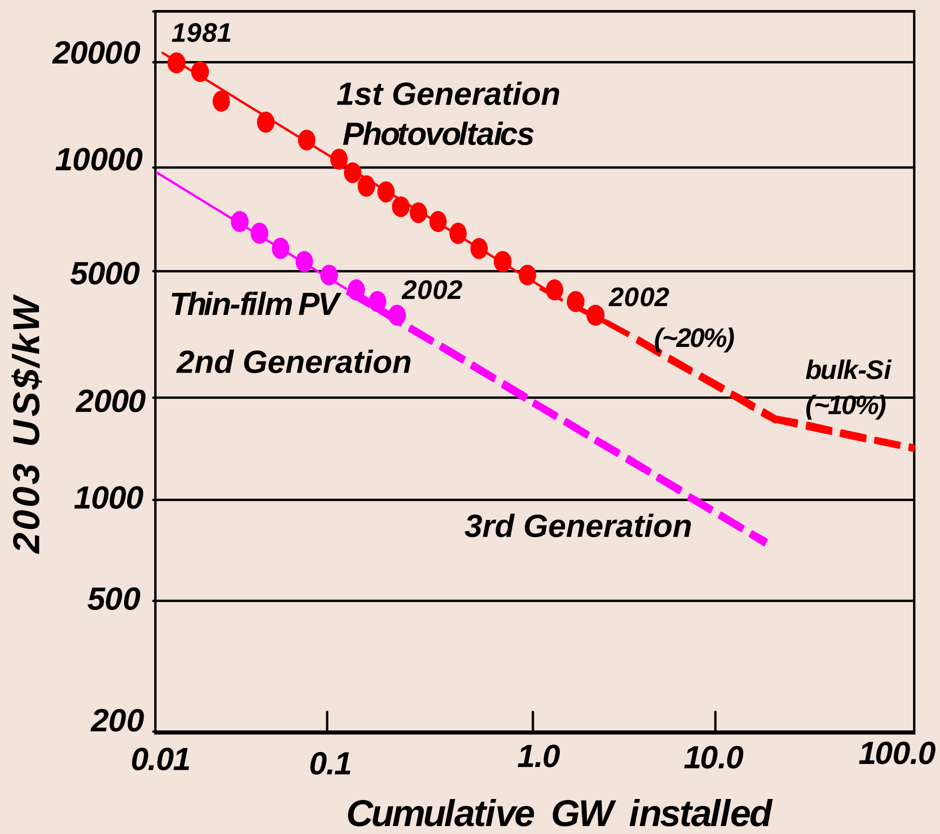


Google's Mountain View campus

Sources: Photon International, WNA, WWEA, IEA

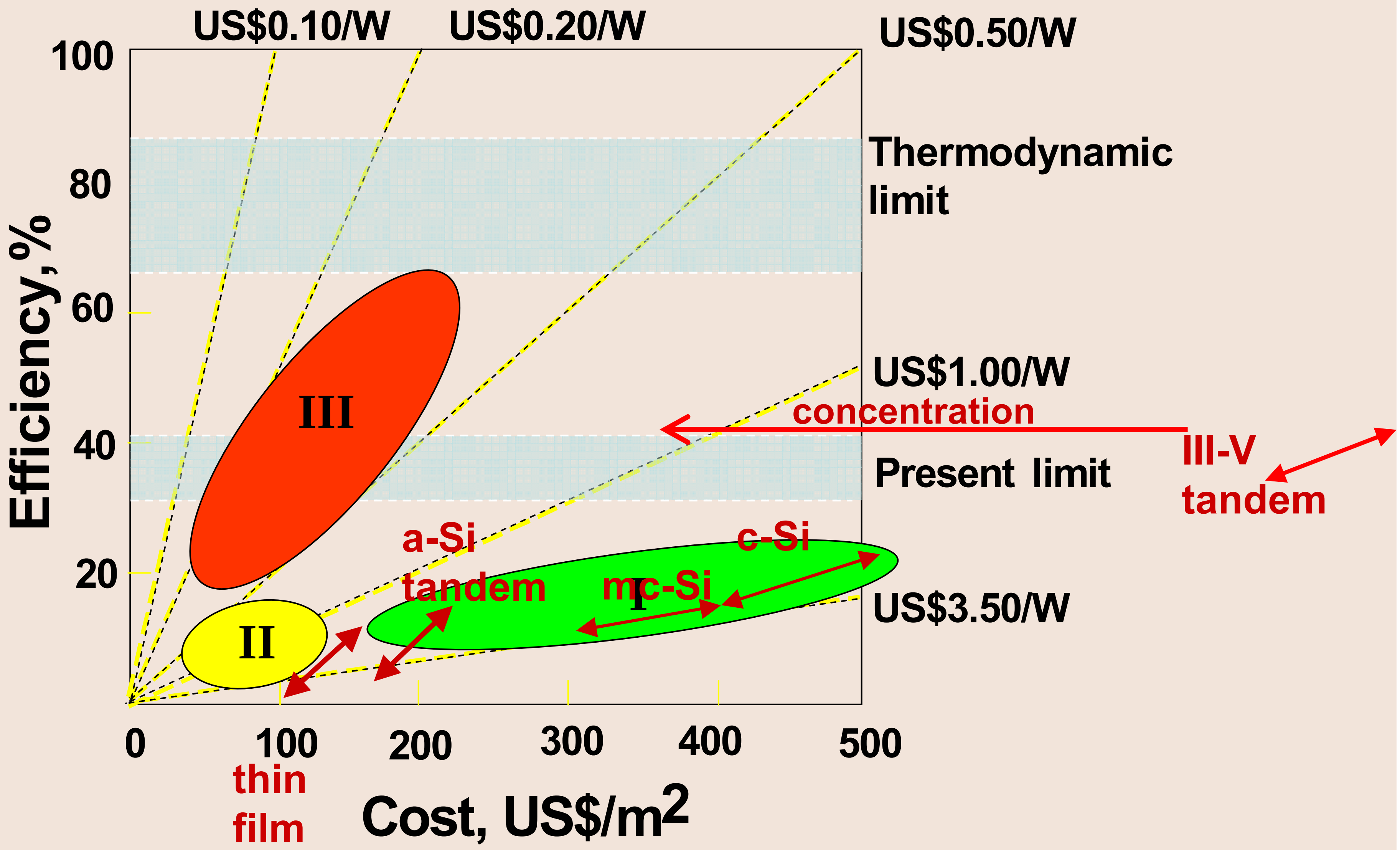
Learning curves





. more potential for learning
. lower cost at smaller volumes

Photovoltaics: Three Generations



Efficiency Loss Mechanisms

1. Sub bandgap losses

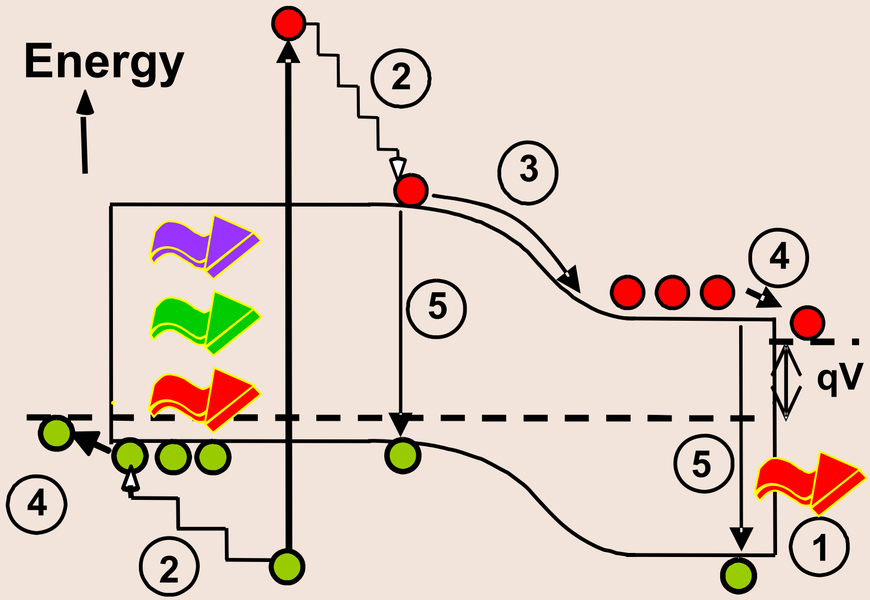
2. Lattice thermalisation

Two major losses – 50%

Also: *3. Junction loss*

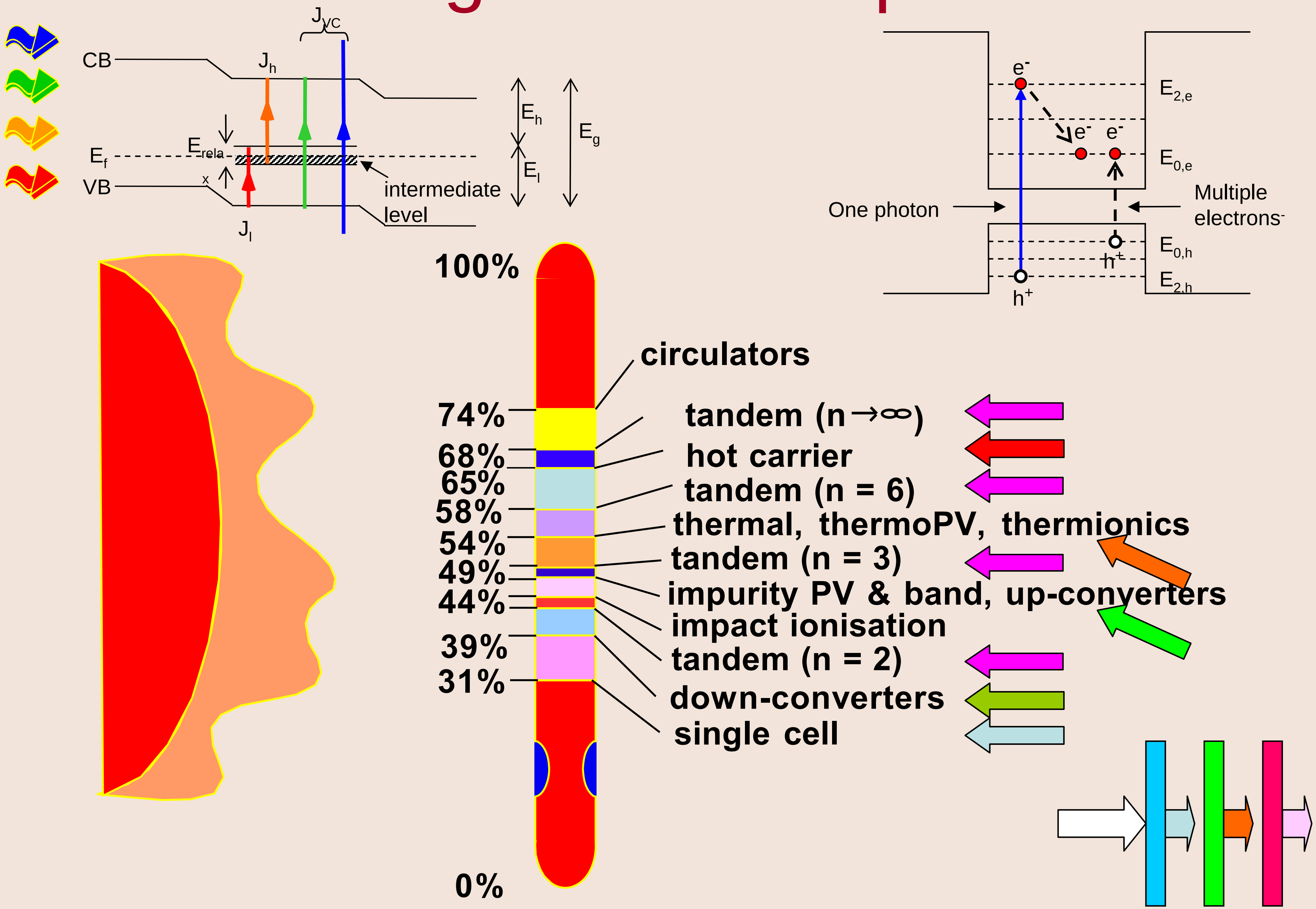
4. Contact loss

5. Recombination



Limiting efficiencies	**1 sun**	**Max concn.**
Single p-n junction:	31%	40.8%
Multiple threshold:	68.2%	86.8%

Third generation options



Silicon based Tandem Cell

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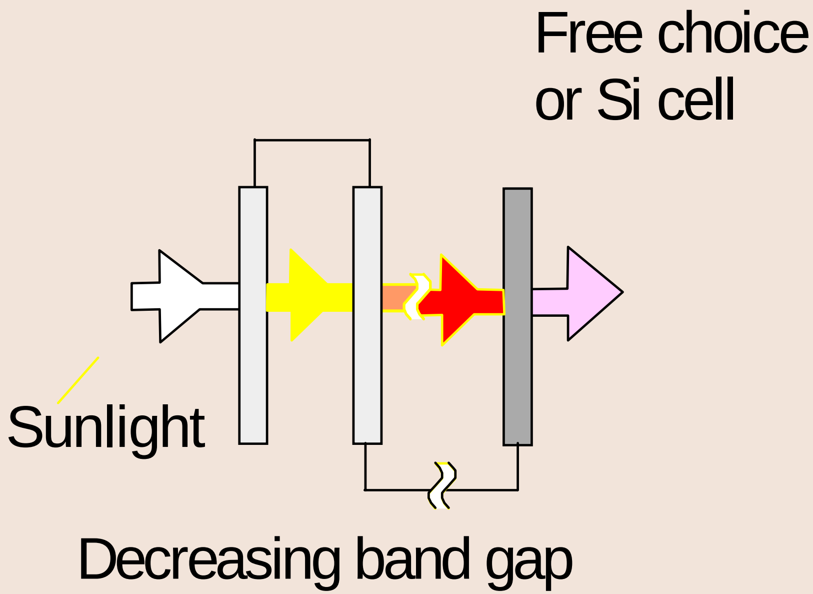
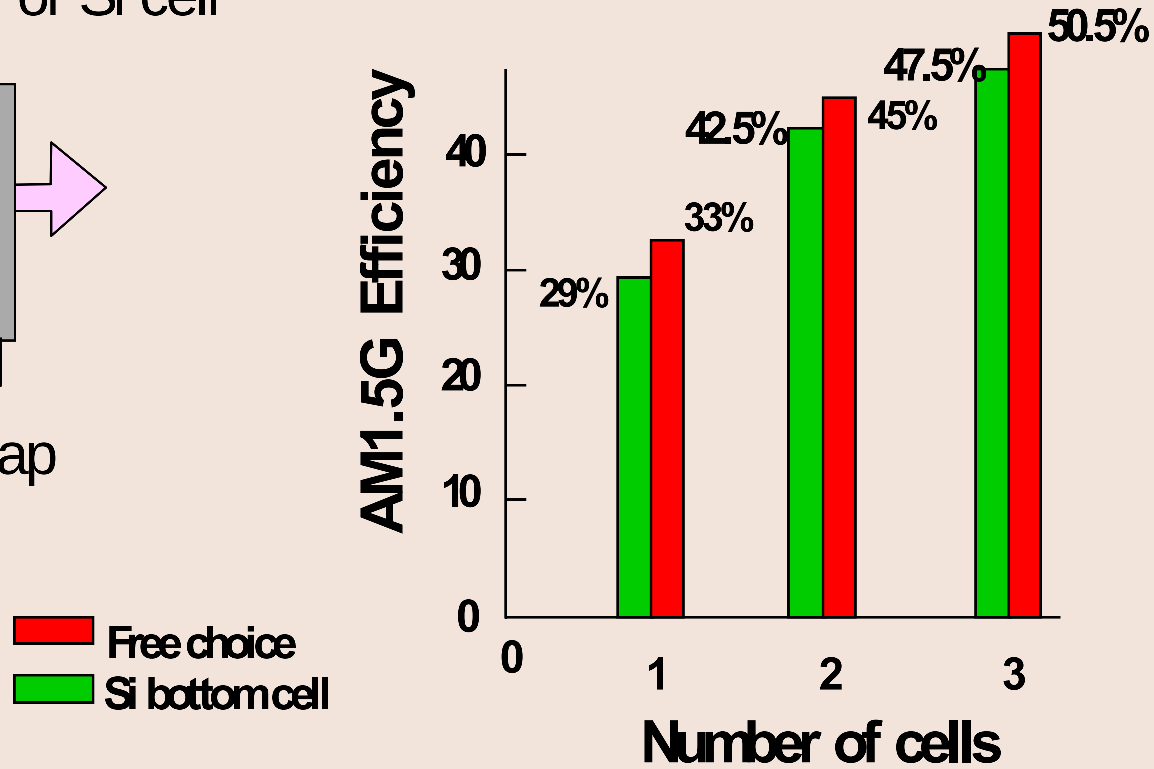
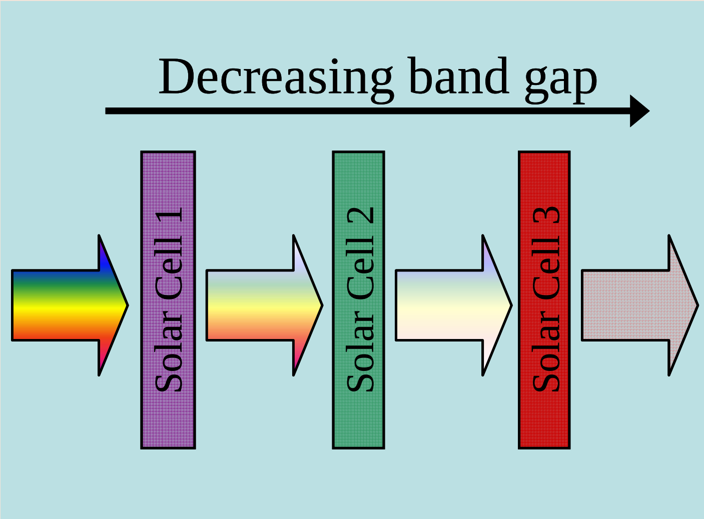


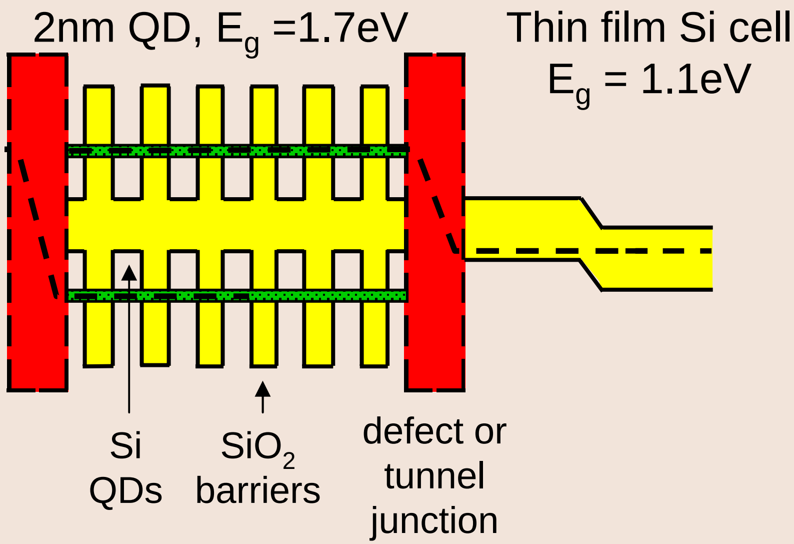


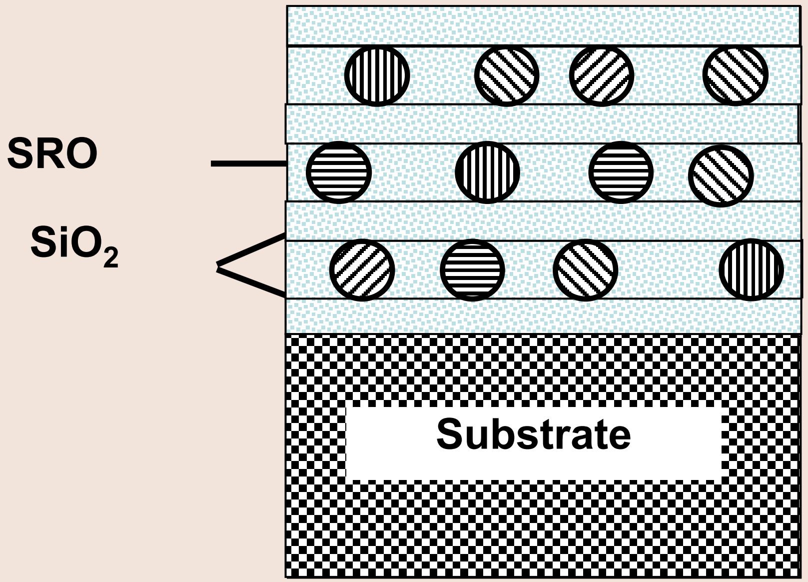
Intrinsic radiative and Auger losses included

Silicon based Tandem Cell



Engineer a wider band gap – Si QDs



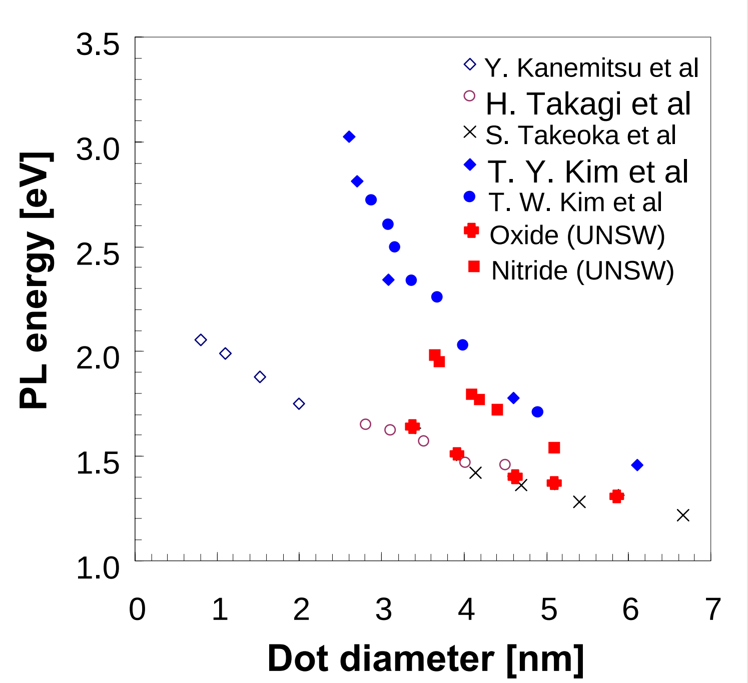


Anneal 1100°C
– Si precipitation

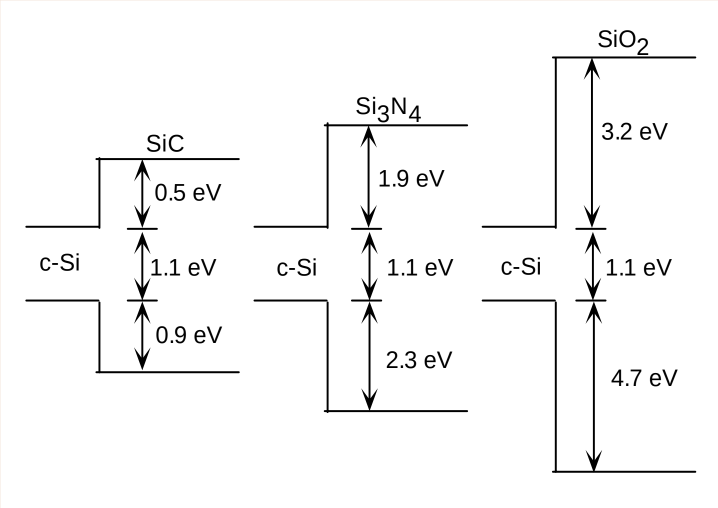
$$SiO_x \rightarrow \frac{x}{2} SiO_2 + \left(1 - \frac{x}{2}\right) \cdot Si$$

Si nanostructure tandem cell

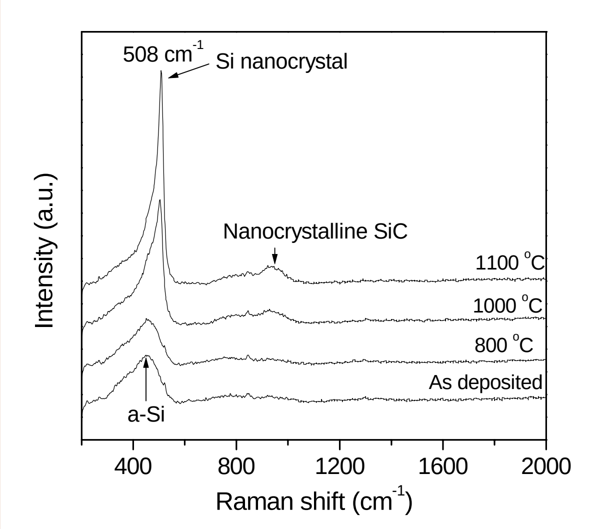
Si QDs in oxide/nitride

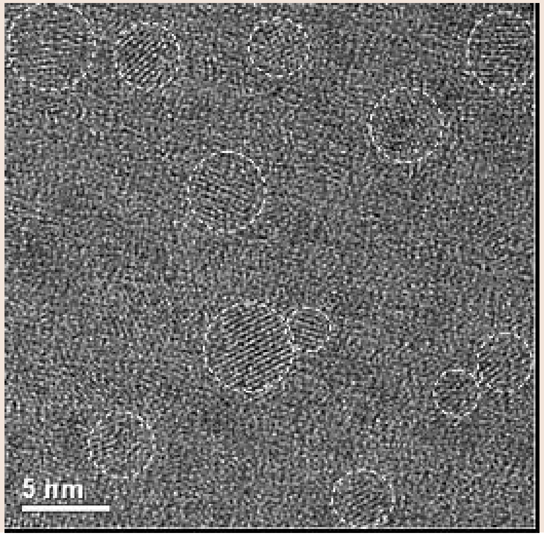


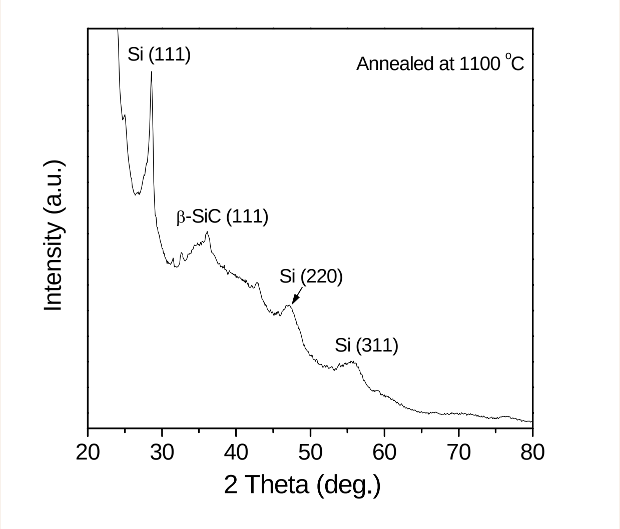
Alternate matrices

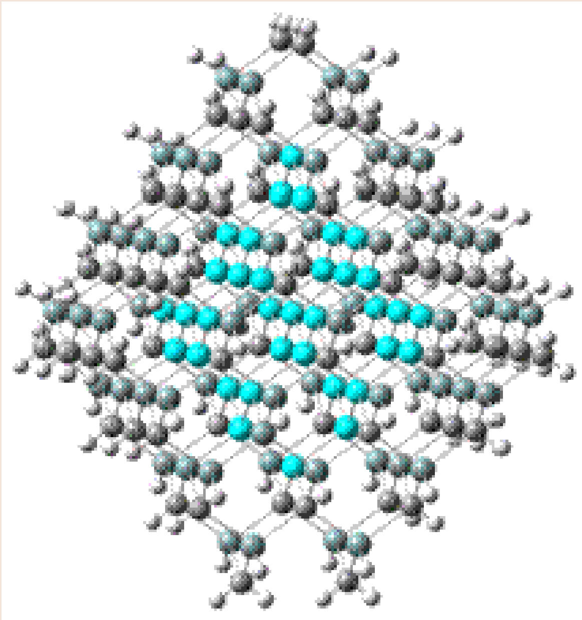


Si QDs in SiC

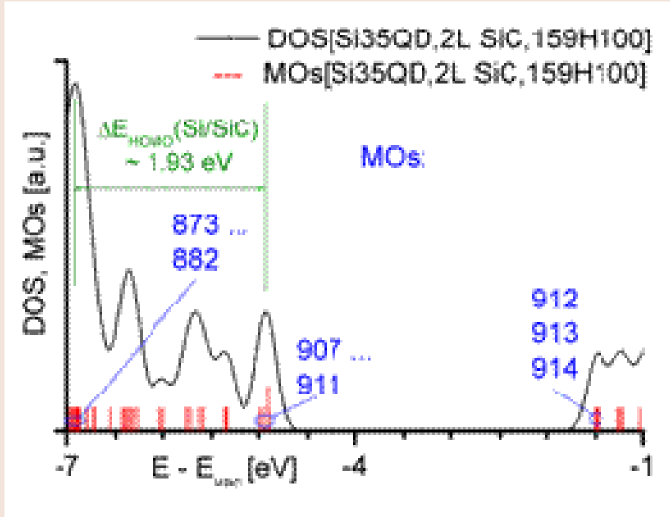








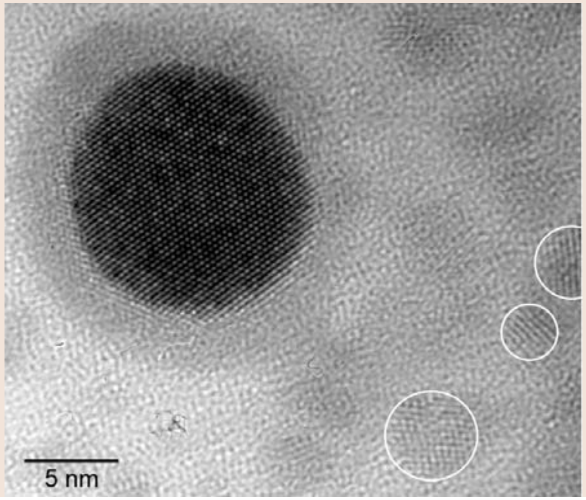
Gaussian modelling of Si QD in SiC

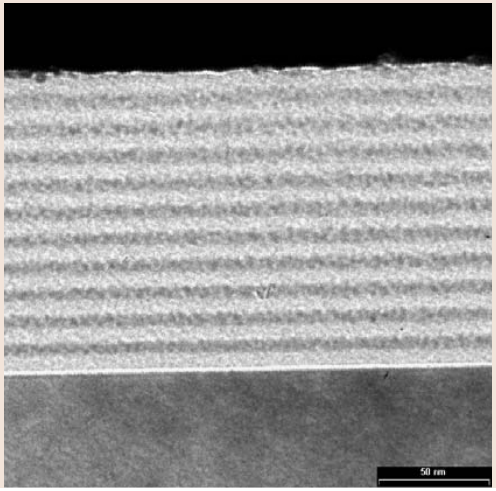


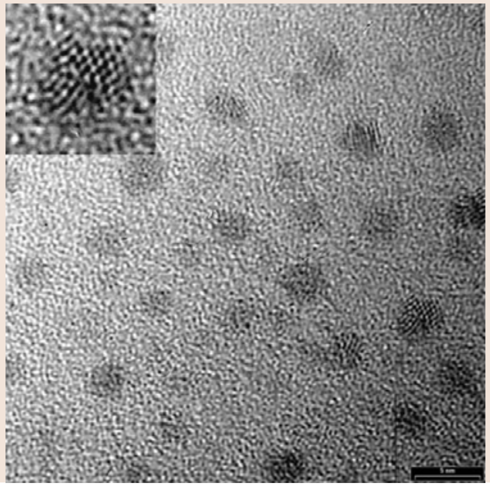
Alternate QDs

Tin QDs in SiO_2

Ge QDs in SiO_2







Various material combinations

Quantum Dot / Matrix combinations and current status of investigations

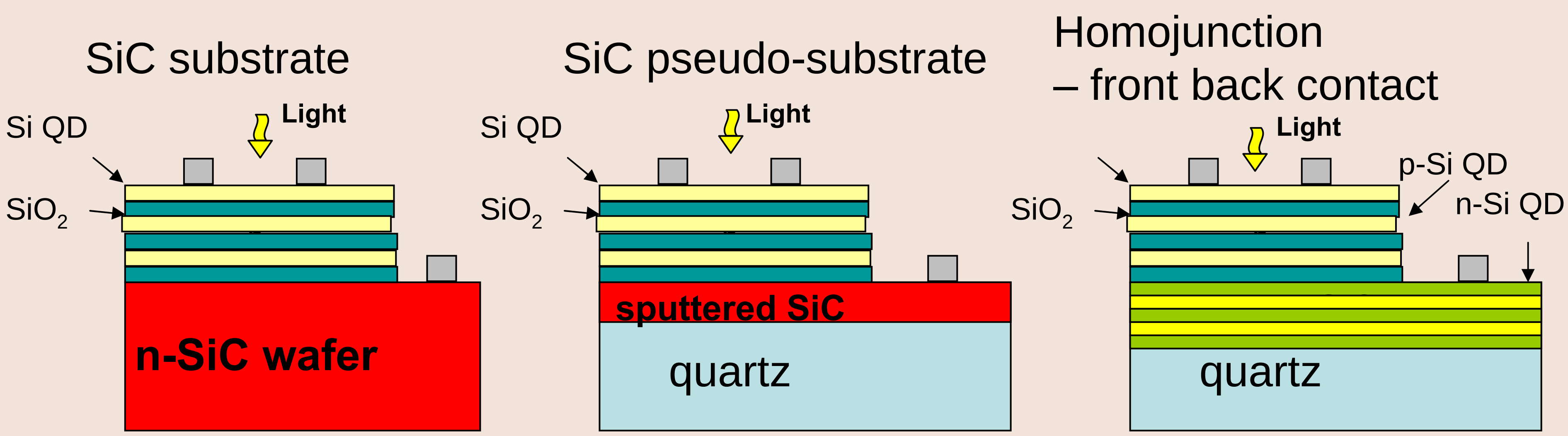
Increasing conductivity →

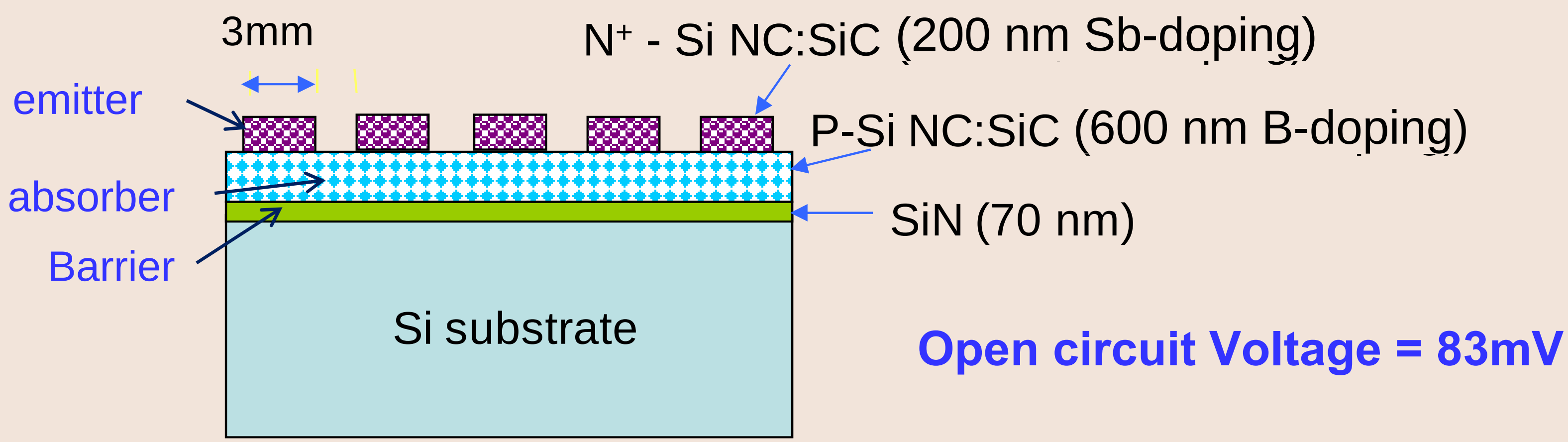
Decreasing processing temperature ↓

	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)

Si substrate - problem – Can't be sure absorption is not in Si
Hence – transparent substrate or pseudo-substrate





Hot Carrier cell

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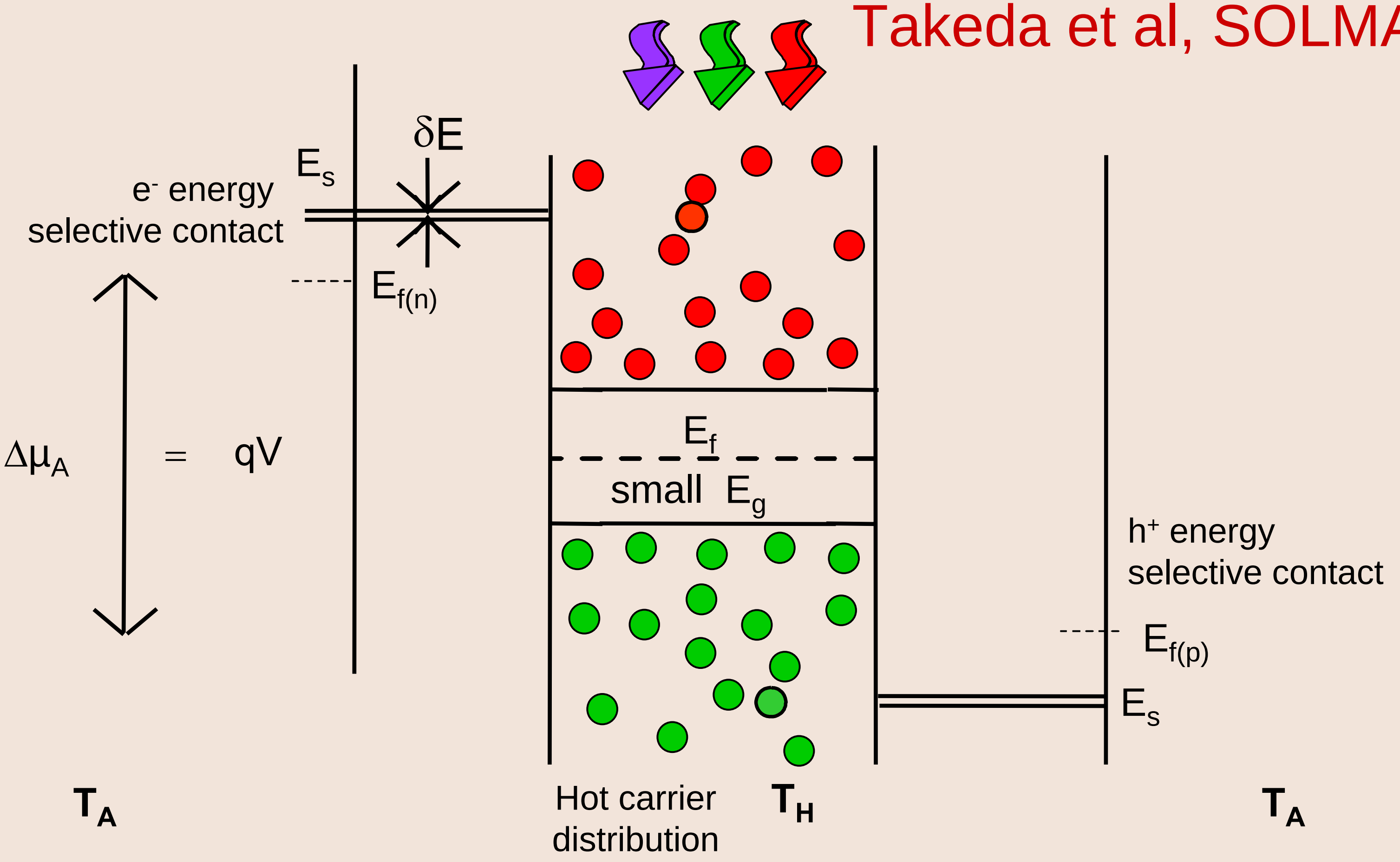
Extract hot carriers before they can thermalise:

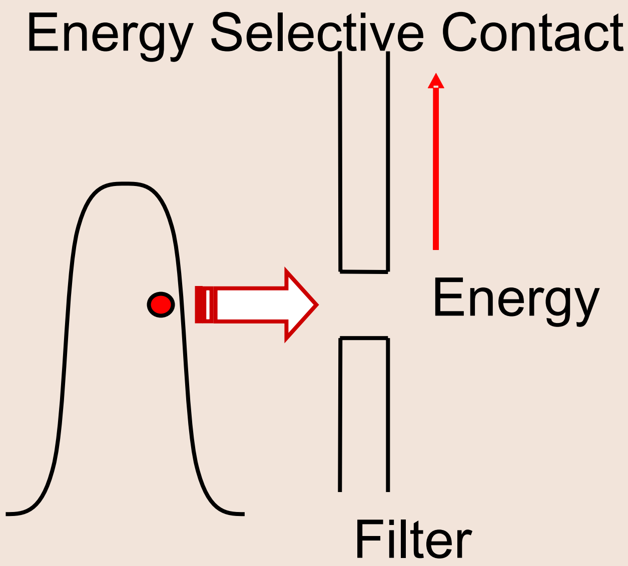
- Need to slow carrier cooling
- Collect carriers over narrow range of energies

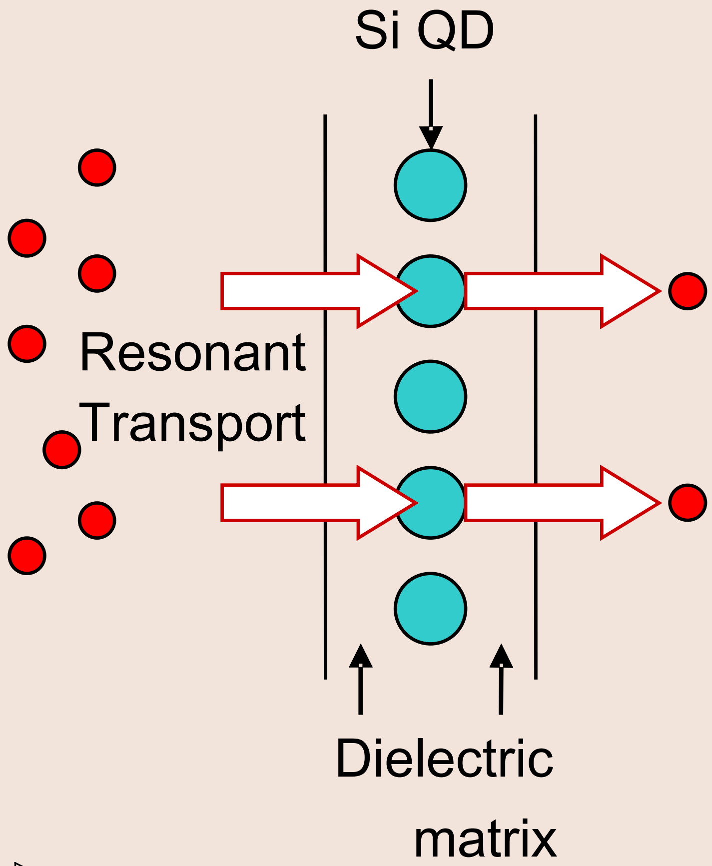
Ross & Nozik, JAP, 53 (1982) 3813
Würfel, SOLMAT, 46 (1997) 43 1995
Green, 3rd Gen PV (S-Verlag) 2003
Würfel, PIP, 13 (2005) 277

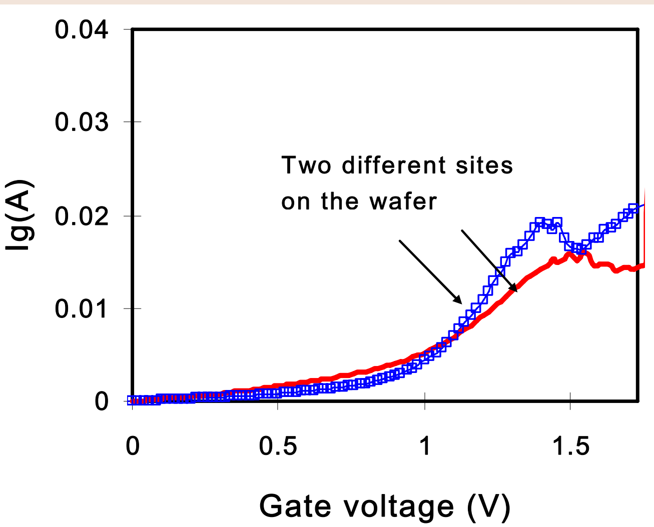
Green, 2003
Würfel, 2005
Takeda et al, SOLMAT, 08



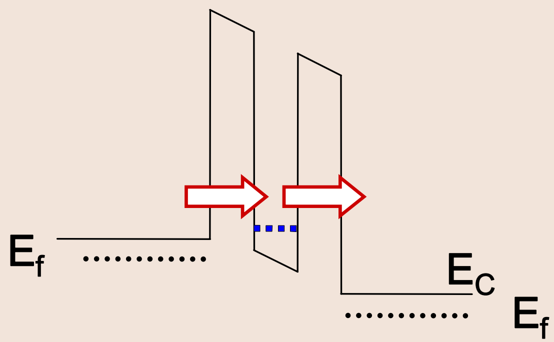
Resonant Tunneling Transport

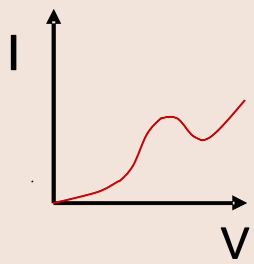




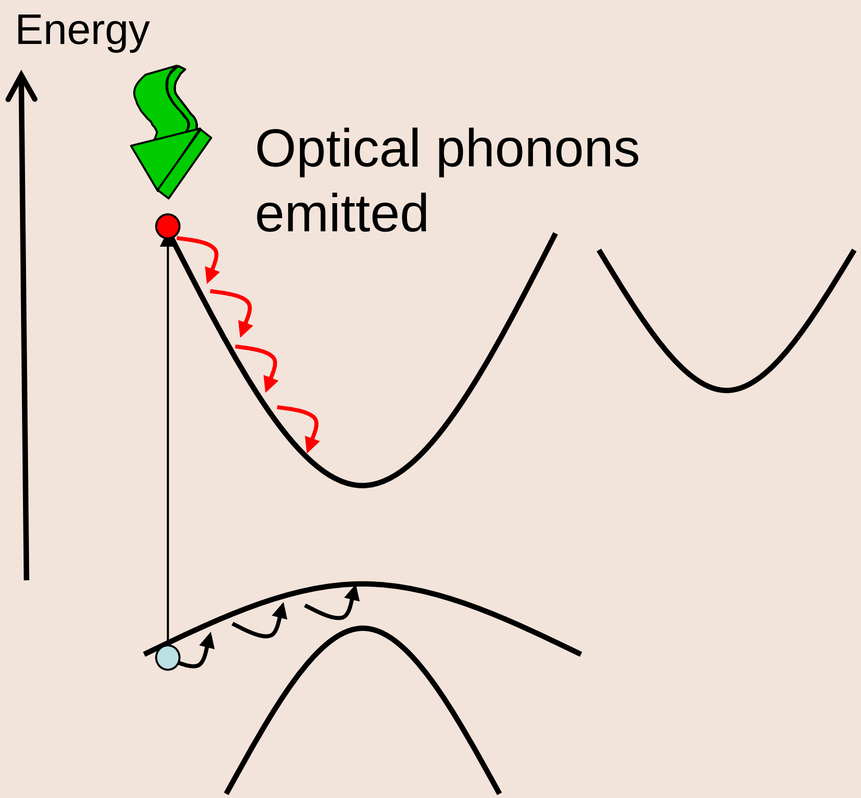


NDR at 300K - Repeatable





Hot Carrier cooling



Electrons carry most energy

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

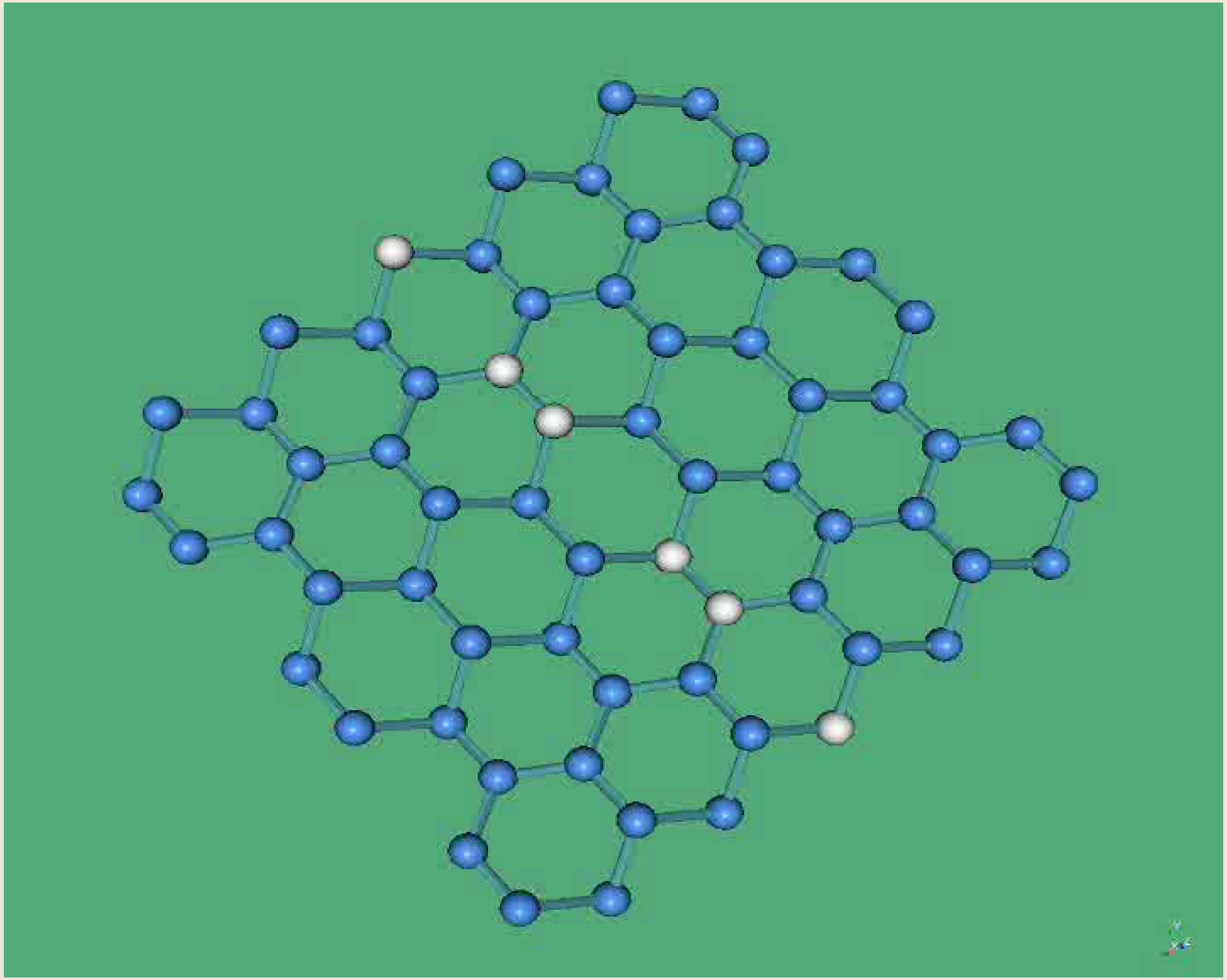
↓

Hot Optical phonon population "phonon bottleneck effect"

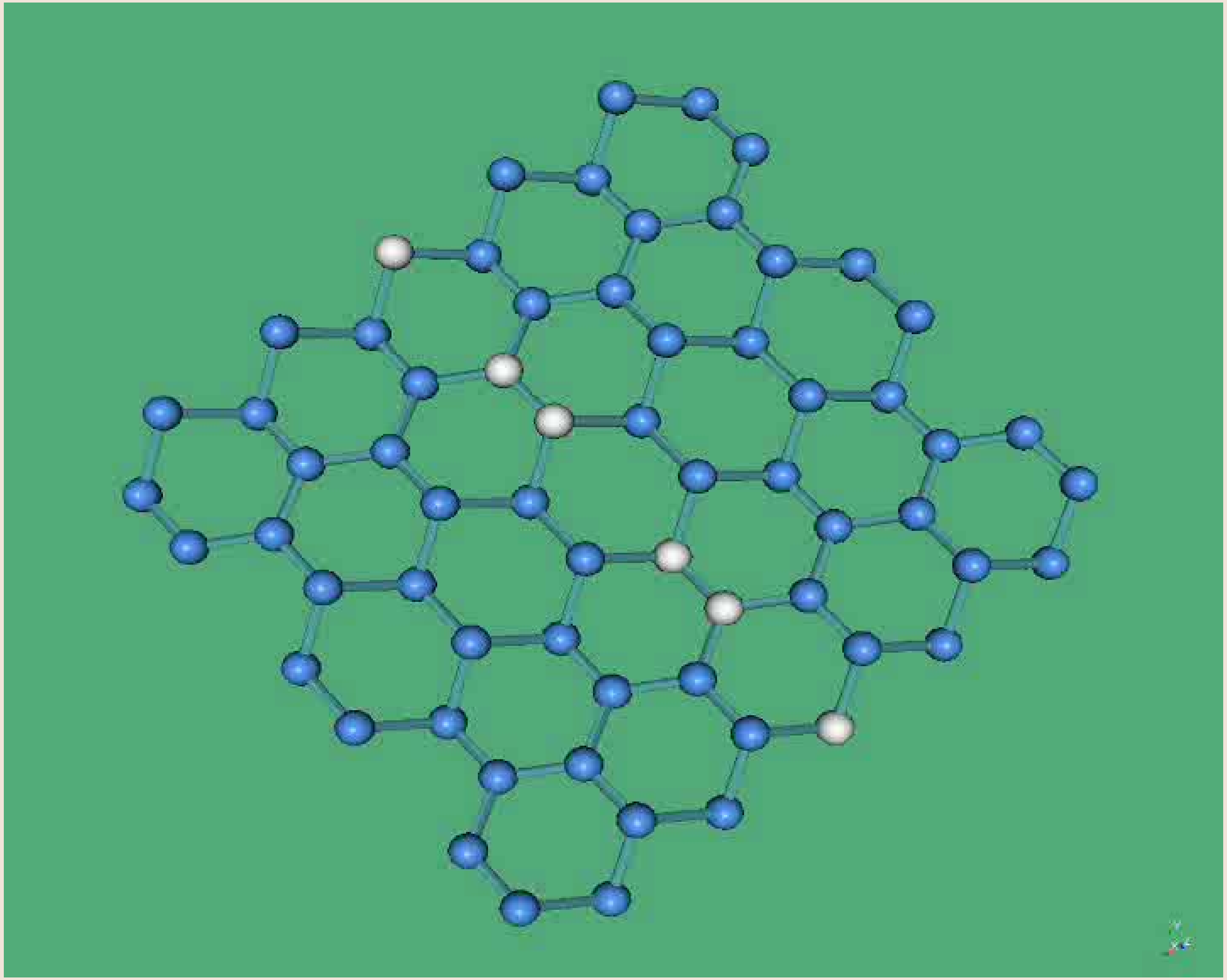
Decay of Optical phonons to Acoustic is critical

Slows further carrier cooling

Optical phonon decay

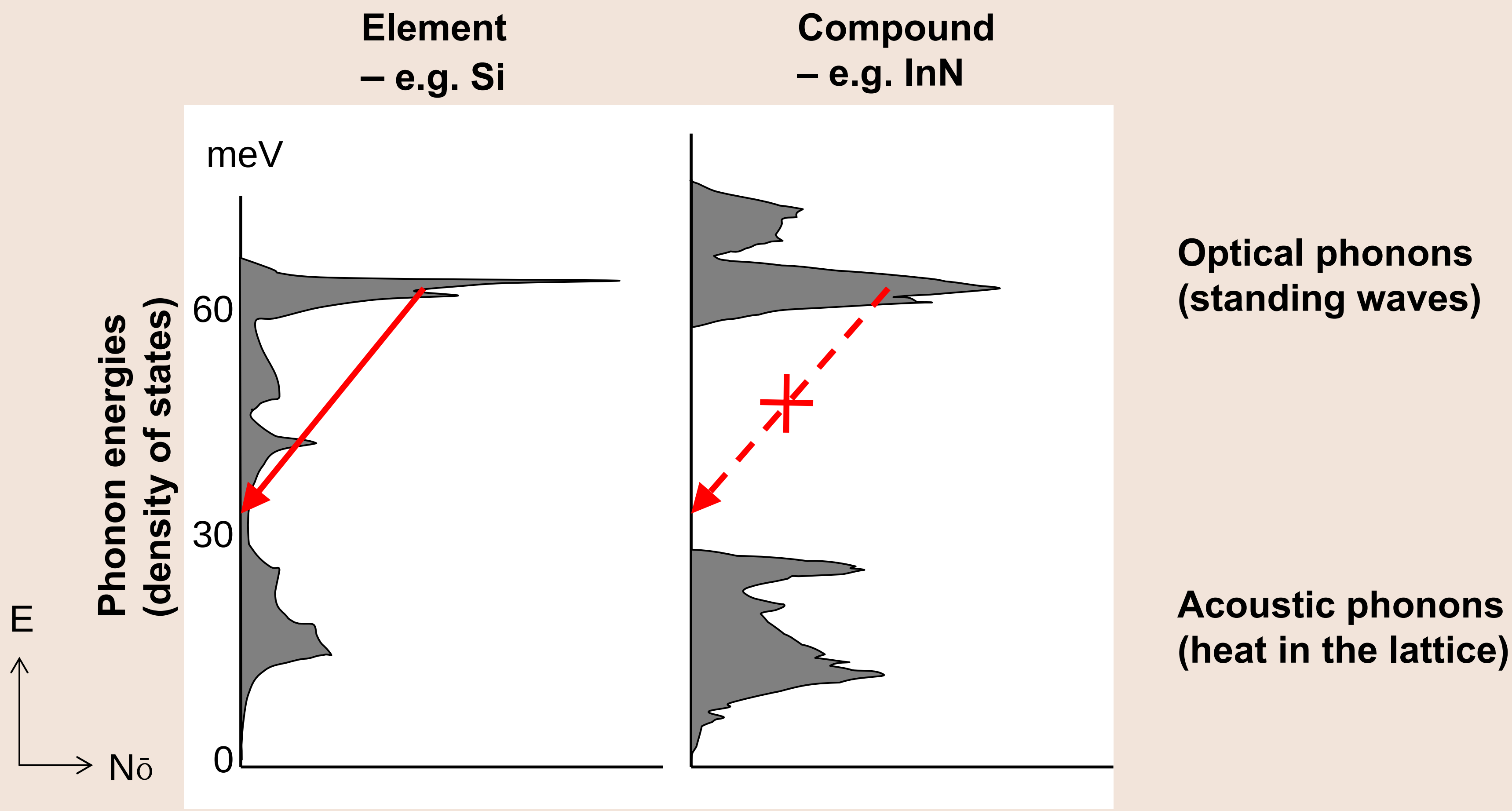


Optical phonon decay



O → LA + LA (Anharmonicity or Klemens mechanism)

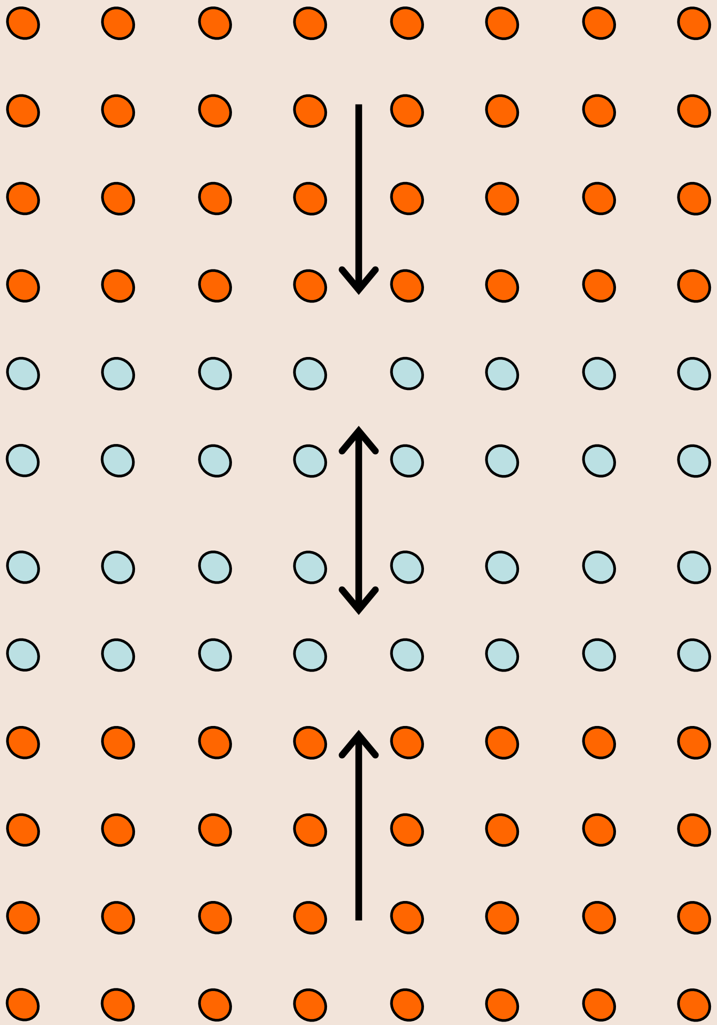
Allowed phonon energies

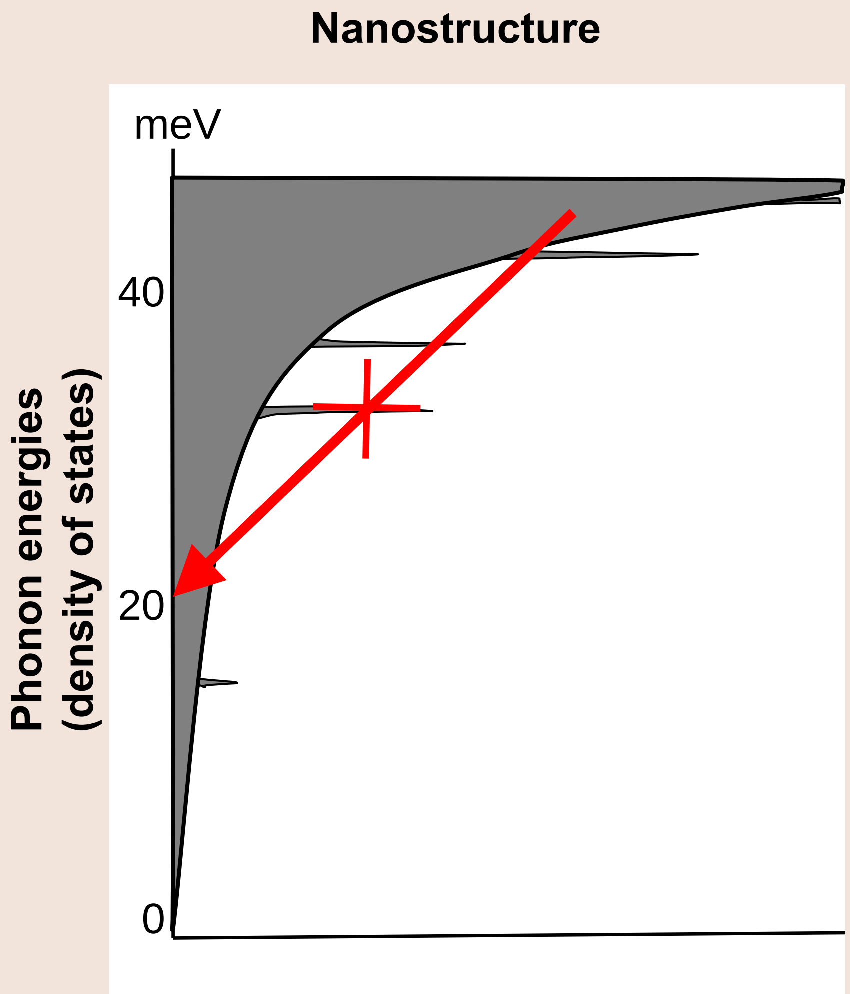


Some evidence for slowed carrier cooling in InN: Chen & Cartwright, APL, 83 (2003) 4984

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

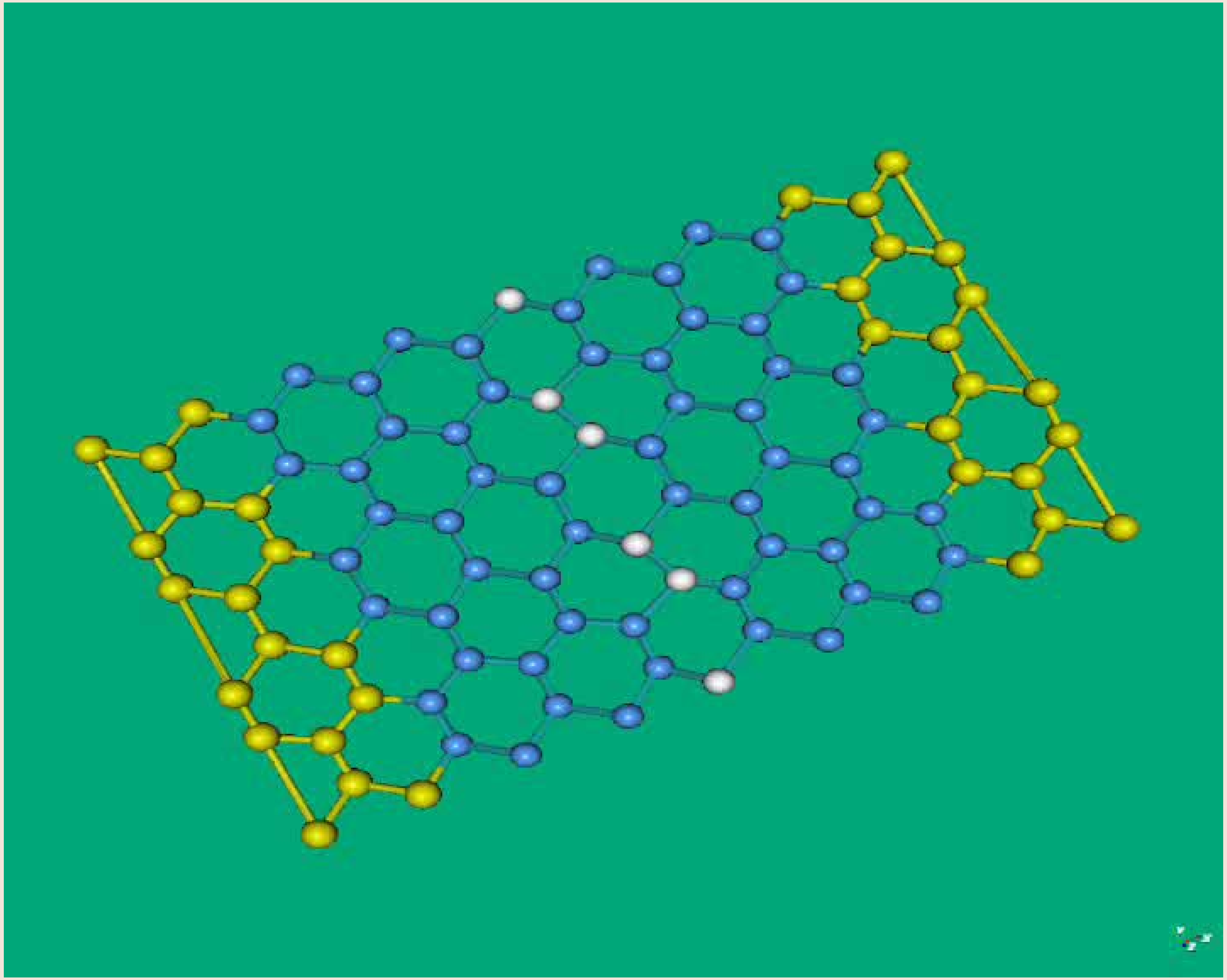
Phononic gaps in nanostructures





Linear force constant model: $l = 4a_1 + 4a_2$
– mass ratio = 2; force constant ratio = 5

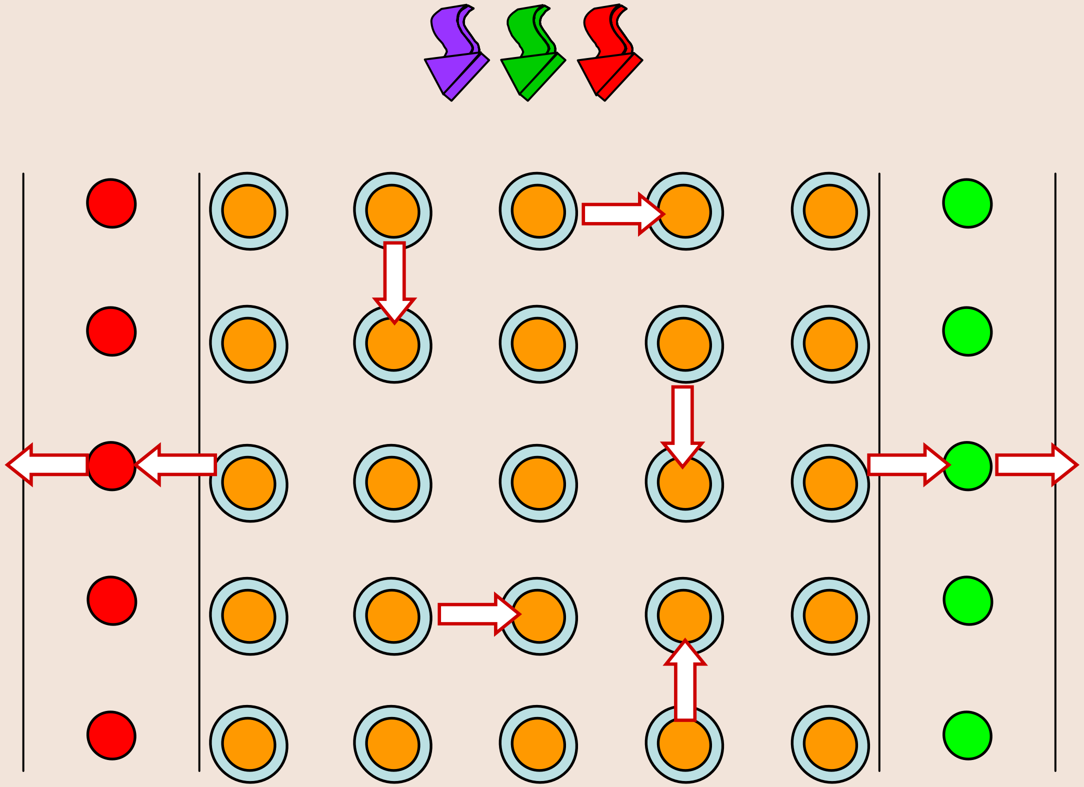
Phonon propagation in nanostructure



Acoustic phonon reflected from zone edges → standing wave

Towards a complete cell

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



Summary

- Relevance and growth of Photovoltaics
- Three PV Generations
- Main energy losses
- Third Generation approaches
- Si nanostructure tandem cells
    - Band gap eng.
    - Range of QD materials
    - Early devices
- 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

Third Generation Strand (2008)

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