Progress in Hot Carrier Solar Cells

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Selective Energy Contacts

Carriers must be collected over narrow energy range:
- In conduction band for e- and valence band for h+;
- Prevents loss of energy to cold carriers in contacts;
- Minimises increase in entropy;
- Replenishment of extracted energy by carrier-carrier scattering in hot carrier population.

Concept of Hot Carrier cell (1.2)

Absorption of all solar photons with energies greater than the absorber threshold energy. Collect carriers before they thermalise with lattice.

Selective energy contacts

Hot Carrier cooling

Electrons carry most energy
- Cool predominantly via small wavevector optical phonon emission - timescale of ps
- Relaxed energy - phonon bottleneck effect

Hot Optical phonon population "phonon bottleneck effect"
- Slows further carrier cooling

Sample structure

AI contact pads

n+ c-Si wafer (500 µm)

- Layers deposited by RF-sputtering
- On annealing at 1100°C- The Si rich layer (middle layer) crystallises to Si QD in a matrix of SiO2

NDR at 300K- indicates SEC
- Energy gap normalised to max. acoustic phonon energy.

I-V [3]

5 nm SiO2
7 nm Si QD array
5 nm SiO2

NDR using resonant tunnelling for SEC

Phononic band gaps in nanostructures

Phononic band gap ratios for binary compounds:
- Energy gap between acoustic and optical modes;
- Energy dispersion of optical modes;
- Normalised to max. acoustic phonon energy.

Conductive AFM [4]

ESM showing the Si QD layer

LA phonon decay - selection rules

Acoustic phonon dispersion for 1D periodic structure (Linear chain model)
- Bi-layer periodicity of two.
- Ratio of acoustic impedances of seven.
- Shows a folded dispersion with mini-gaps in all directions in real and reciprocal space.

DOS for a 3D structure with the phonon dispersion shown in (a).

Optically assisted I-V [5]

Light I-V gives larger current carriers excited to SEC level
- Tentative evidence for resonance at ~ 3.5V for dark and ~ 2.1V under illumination - collection of hot carriers at lower bias with optical assistance.

Thermal characterisation

Heat probe

At contact pads

Thermalelectric voltage generation- evidence of tunnelling through QD structure

Interface modes

References:
2. M.A. Green, Third Generation Photovoltaics (Springer-Verlag, 2000).

Conclusions

- Carrier collection over narrow energy range
- We are using resonant tunnelling through confined levels in Si QDs for this;
- I-V data at room temperature, indicates energy selective NDR type behaviour;
- I-V of small areas under AFM gives tentative evidence for steps in current;
- Small resonance in the dark increases in magnitude but at lower bias in light;
- Further indication of creation of a non-equilibrium 'hot' carrier population;
- Further work will improve this resolution and combine C-AFM with optical I-V.

Interface modes

Dispersions curves of acoustic phonons with:
- a) Intermediate; b) very soft;
- c) Very stiff; interface modes

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Energy (eV)

Wave vector x 109