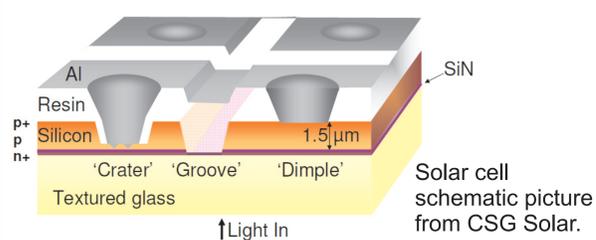


Light Trapping in Silicon Thin Films measured by Raman Spectroscopy

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Silicon thin films

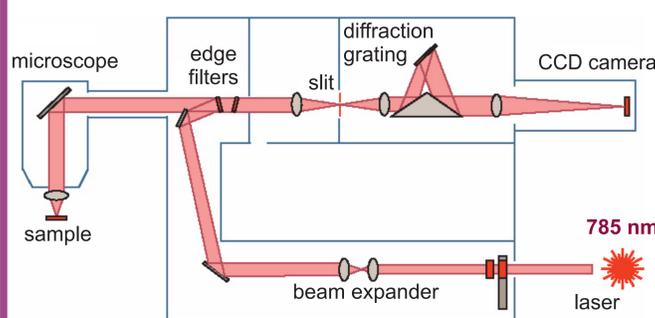


Crystalline silicon on glass [1]

- poly-crystalline silicon thin films
- 1 - 3 μm thick layers
- enhanced absorption in red and NIR needed - light-trapping
- looking for optimal substrate structuring

Raman intensity and light trapping

Experimental set-up



In-Via REFLEX Raman microscope
Renishaw

Raman intensity mapping

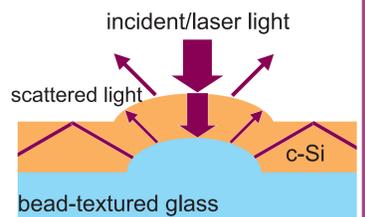
Raman intensity is proportional to the:

- photon path length in the layer [2]
- and therefore to the light trapping in the layer

Raman spectra were excited by weakly absorbed 785 nm laser (absorption depth 10 μm).

Microscopic

- local information and comparison with optical view
- feedback for light-trapping structure optimization



Macroscopic view

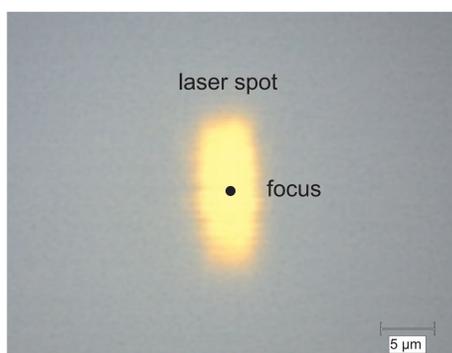
- comparison of light trapping for different substrates
- large scale inhomogeneities

Microscopic

Optical view

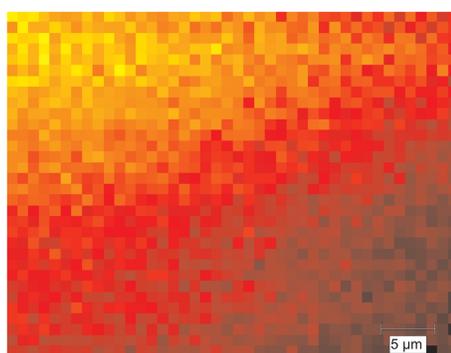
100x objective, laser spot defocused (5x10 μm), spectra collected from focus (~1 μm) - confocality

Planar substrate

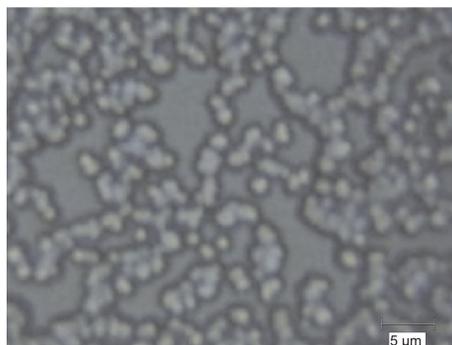


Raman mapping

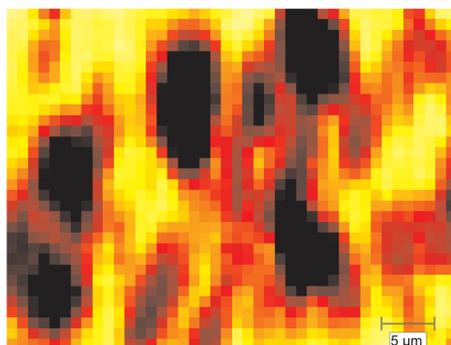
min Raman intensity max
min = 88 max = 92



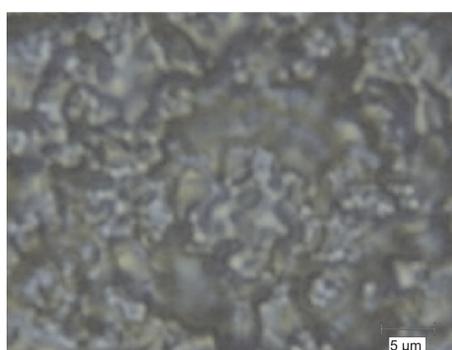
Substrate with beads



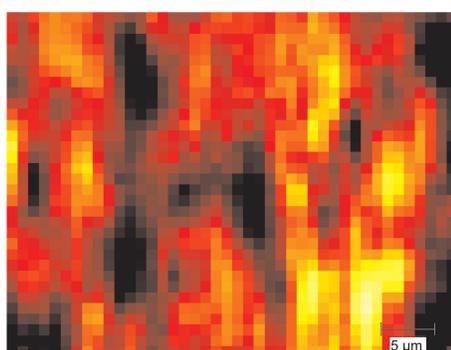
min = 1320 max = 1560



Abrasion etch substrate



min = 1230 max = 1640



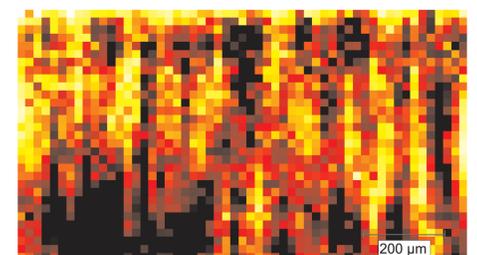
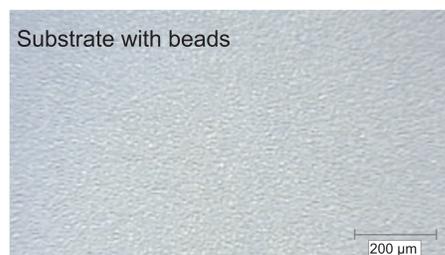
We can clearly see microscopical correlation of the local optical properties and Raman intensity. Area without beads - lower optical scattering and light trapping - lower Raman signal. Comparison of averaged Raman intensities is as follows:

Raman intensity ratio 1 (planar) : 16 (beads) : 16 (abrade)

Macroscopic

Experiment parameters

- 5x objective - conditions better simulate incident sun light
- focus diameter ~ 25 μm - averaged values
- sample was measured from glass side, without back-reflector and without contacts



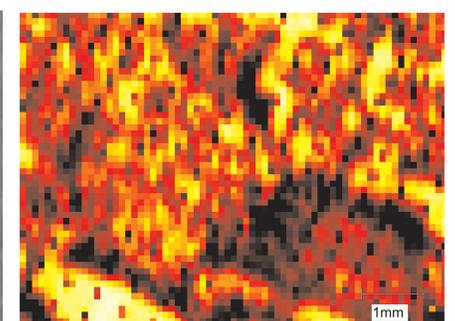
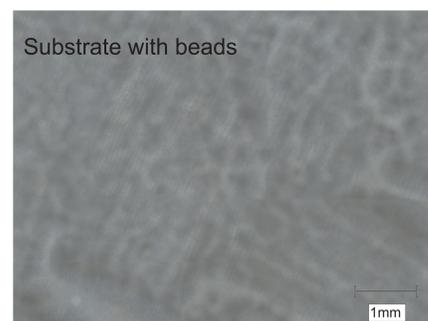
- smaller variance (see the max and min values) - values suitable for characterization
- observation of inhomogeneities on large scale

2600 Raman intensity 2700

Raman intensity ratio 1 (planar) : 15 (beads) : 15 (abrade)

Measurement on complete PV cells

- comparison with independence measurement - external Quantum efficiency
- basic difference - white paint back-reflector - increase of light scattering mainly for planar substrate



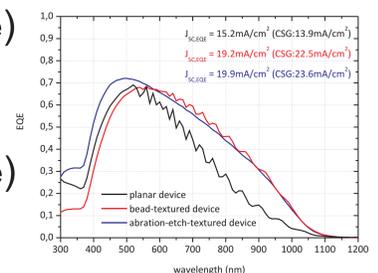
Raman intensity ratio

1 (planar) : 2.4 (beads) : 2.6 (abrade)

EQE ratio

1 (planar) : 1.7 (beads) : 1.7 (abrade)

Raman intensities ratios are well comparable with EQE results - Raman sees light trapping in the active layer.



Conclusions

- Micro-Raman mapping
 - provides information about local light-trapping properties
 - light-trapping structure characterization and optimization
 - averaged values agree with macro-Raman measurement
- Macro-Raman mapping
 - characterization of light trapping properties
 - Raman intensity ratios are well comparable with EQE data

References

- [1] M. J. Keevers, T. L. Young, U. Schubert and M. A. Green, 22nd European Photovoltaic Solar Energy Conference, 3-7 September 2007, Milan, Italy, paper 3DP.2.3
 [2] M. Ledinský, A. Vetushka, J. Stuchlík, T. Mates, A. Fejfar, J. Kočka and J. Štěpánek, J. Non-Cryst. Solids 354 (2008) 2253.

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