Stabilität von kristallinen,micromorphen und a-Si/c-Si heterojunction Silizium-Solarzellen unter Protonenbestrahlung

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Salerno University

One of the oldest universities in Europe

More than 40000 students

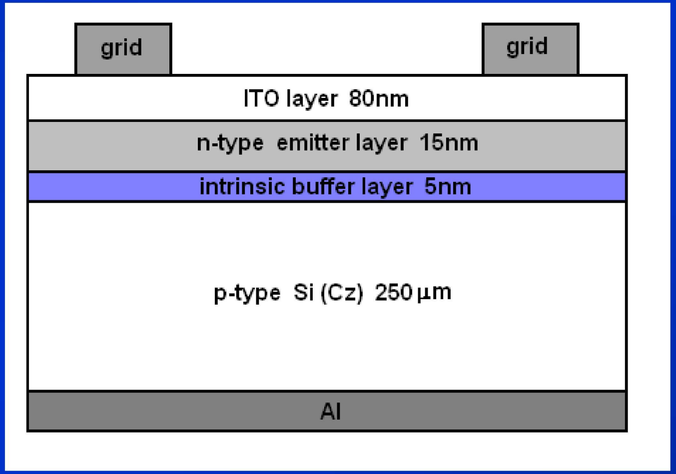
Large PV installation

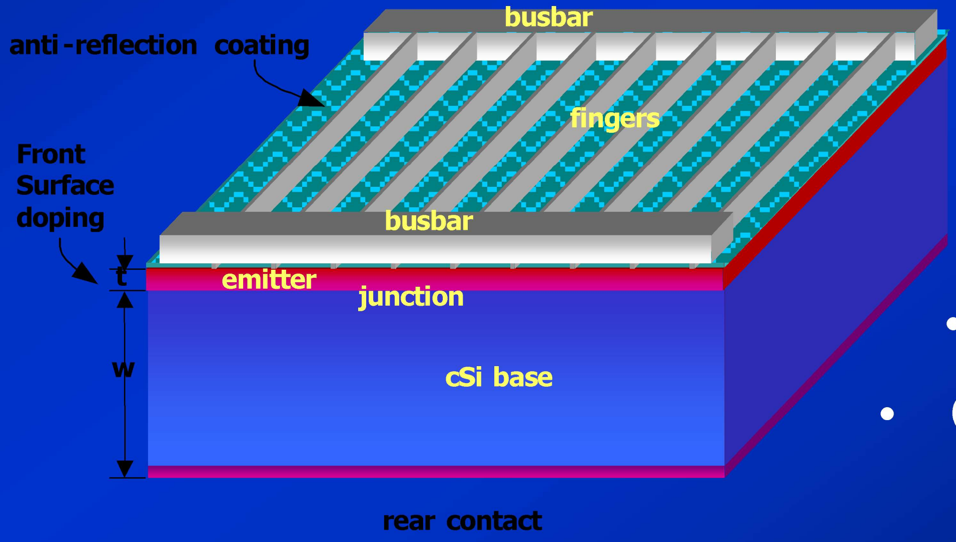
Outline

- Introduction
- Characterized devices
  - FZ and CZ p-cSi homojunctions,
  - a-Si/cSi heterojunctions
  - Micromorph TANDEM cells
- Non-invasive characterization techniques
  - Electroluminescence
  - Time Resolved Microwave Conductivity
- Proton irradiation of silicon solar cells measurement results
  - Technology comparison
  - Proton energy dependence
- Conclusions

Characterized devices (single junctions)

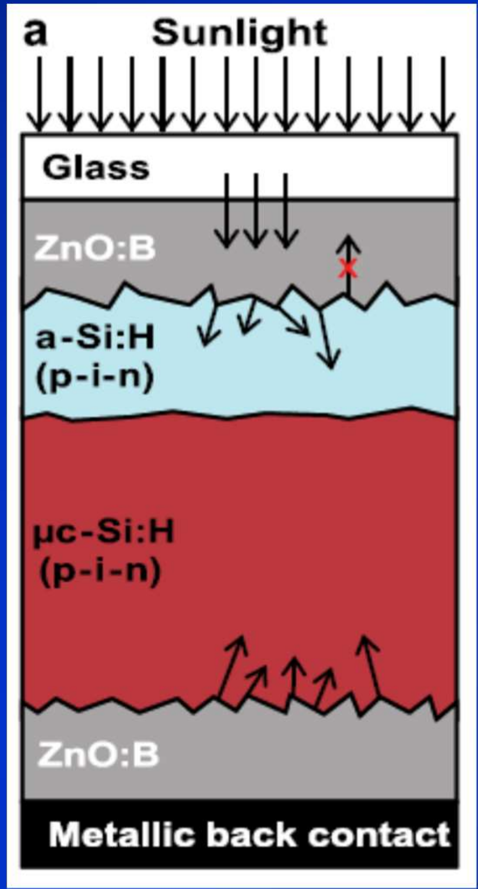
- n-aSi/i-aSi/p-cSi heterojunction (FERNUNI HAGEN)





- FZ cSi homojunction (ENEA)
- Cz cSi homojunction (SOLTEC)

Characterized devices (Tandem)



Theodorakos *et al.*

J. Appl. Phys. **115**, 043108 (2014)

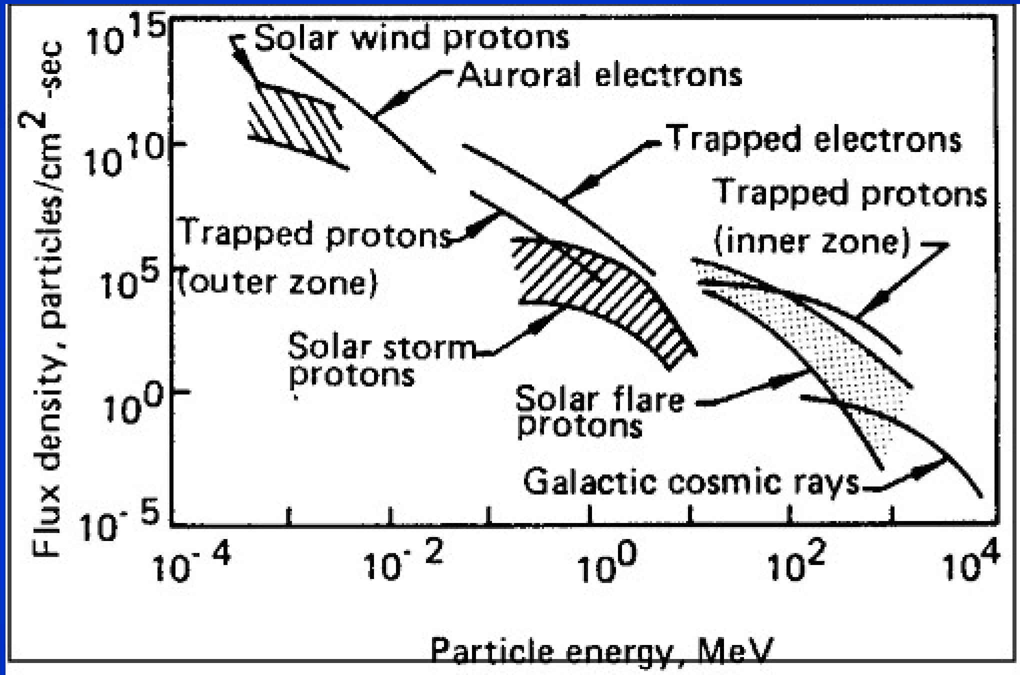
- Micromorph a-Si:H/microcrystalline Silicon Tandem solar cell (ENEA)

Space solar cell degradation

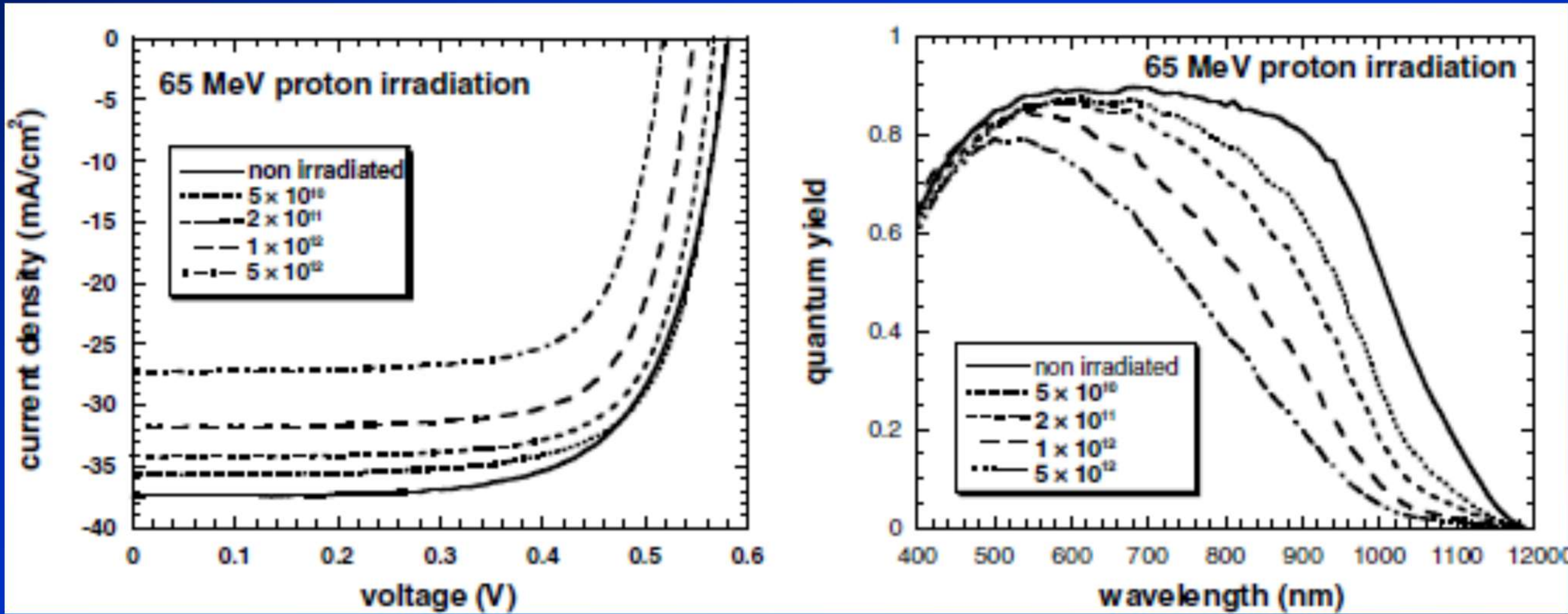
Main contribution to the solar cell degradation in space:

- High energy protons (from few keV to some TeV) cannot be completely shielded

- High energy electrons



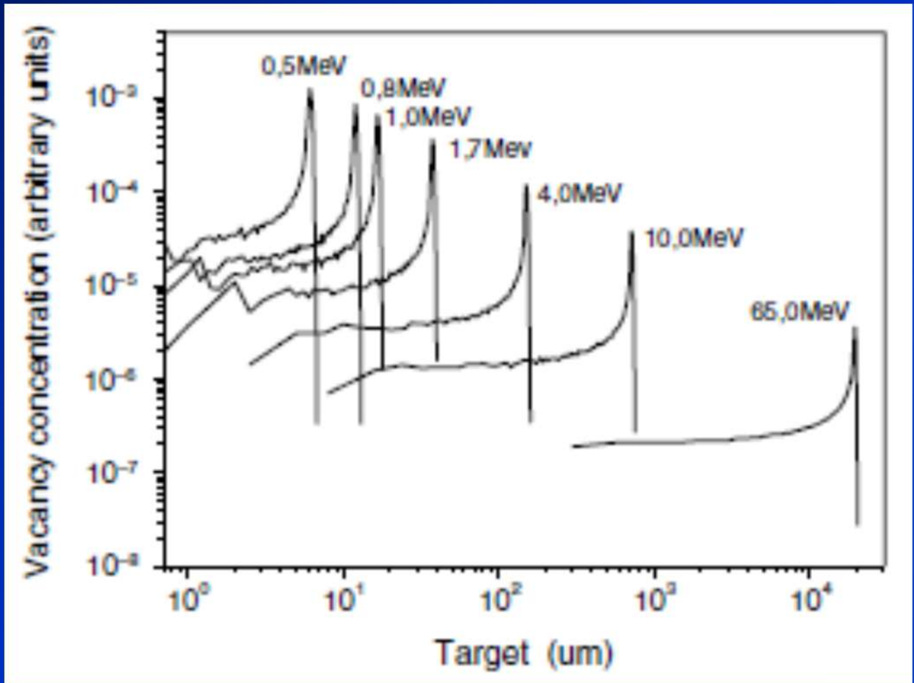
Proton induced damage in Cz-cSi solar cells, changing the IV-characteristics under AM1.5 illumination and the quantum yield spectra

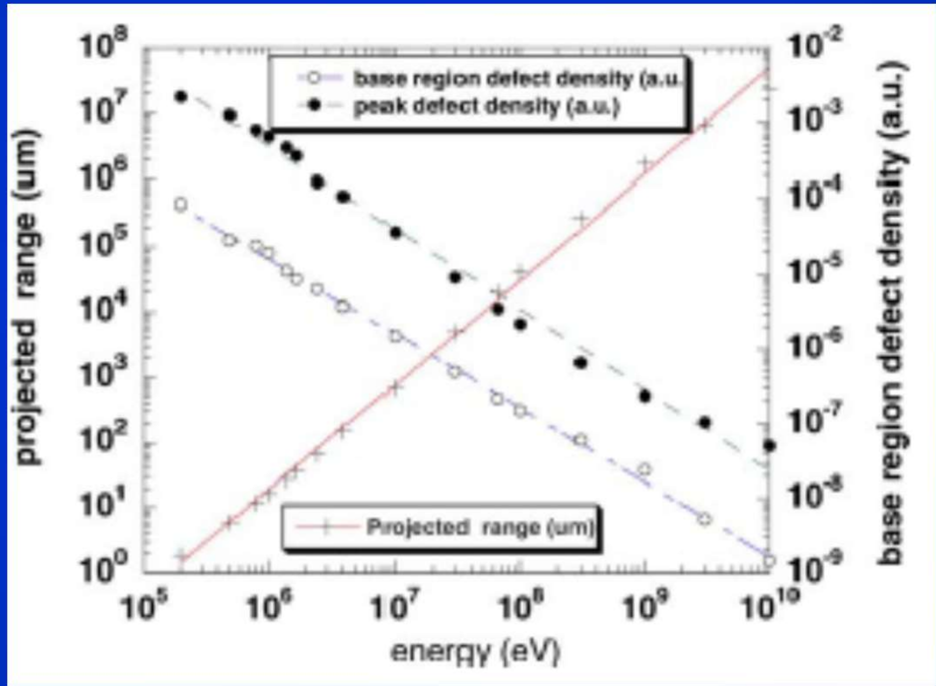


H.-C. Neitzert et al.: EL efficiency degradation of c-Si solar cells after irradiation with protons

phys. stat. sol. (b) **245**, No. 9, 1877–1883 (2008)

Proton induced depth profile of the radiation damage in crystalline Silicon, as simulated with SRIM





H.-C. Neitzert et al.: EL efficiency degradation of c-Si solar cells after irradiation with protons

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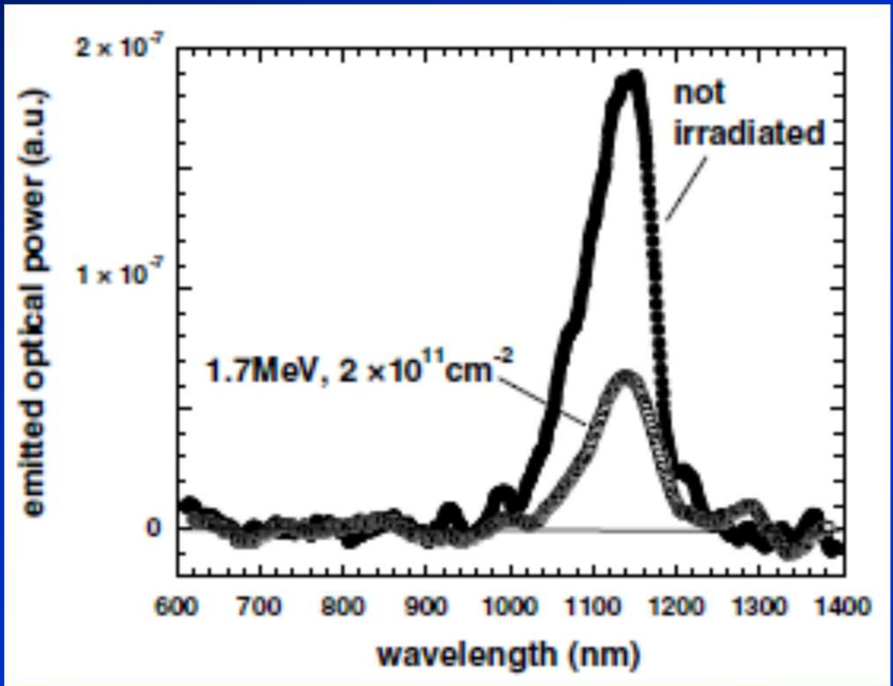
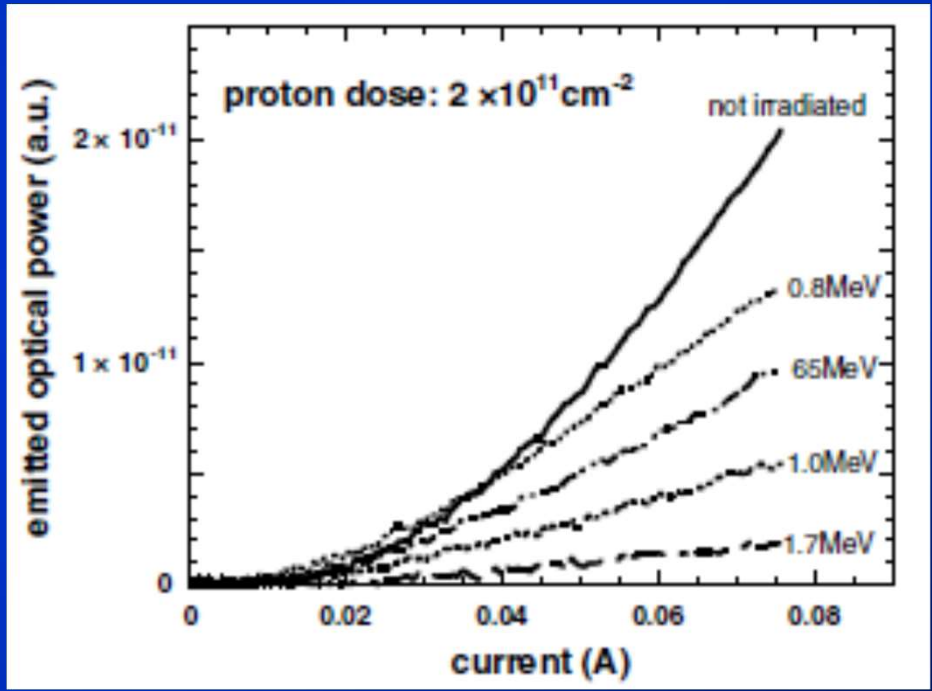
Energy dependence of proton induced change of electroluminescence in crystalline Silicon,





H.-C. Neitzert et al.: EL efficiency degradation of c-Si solar cells after irradiation with protons

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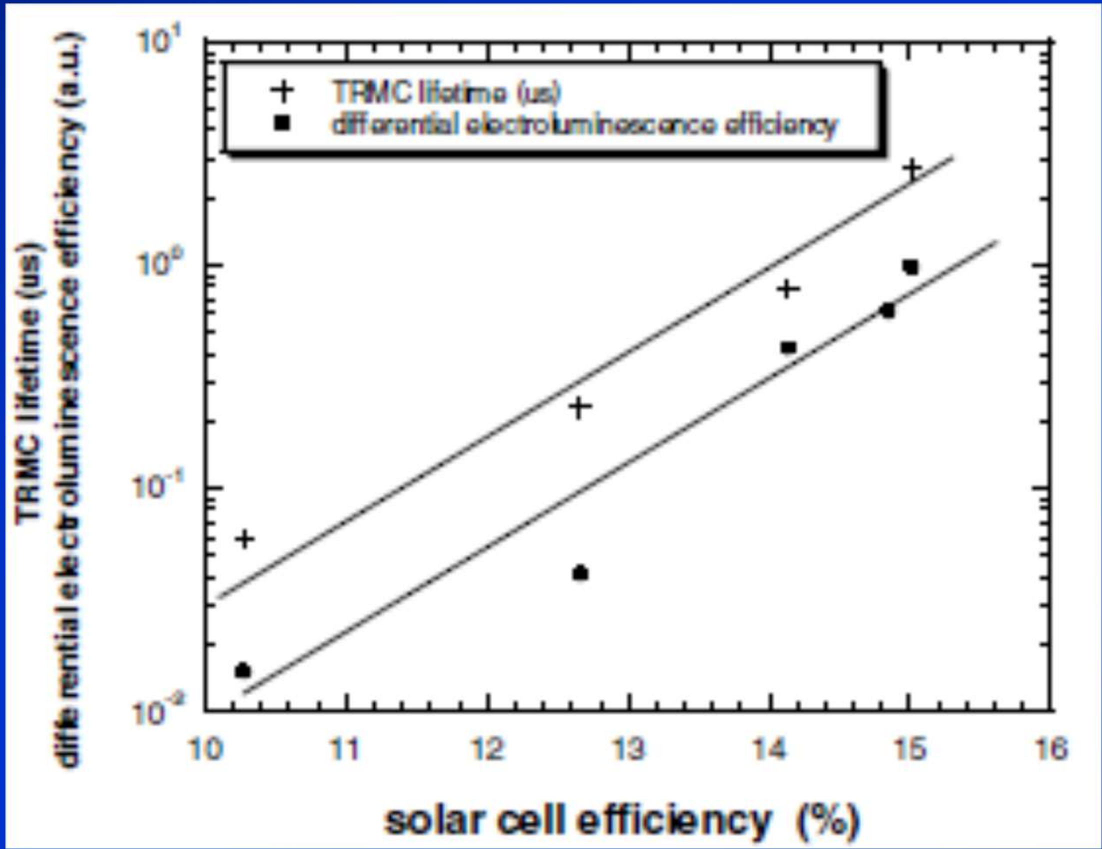
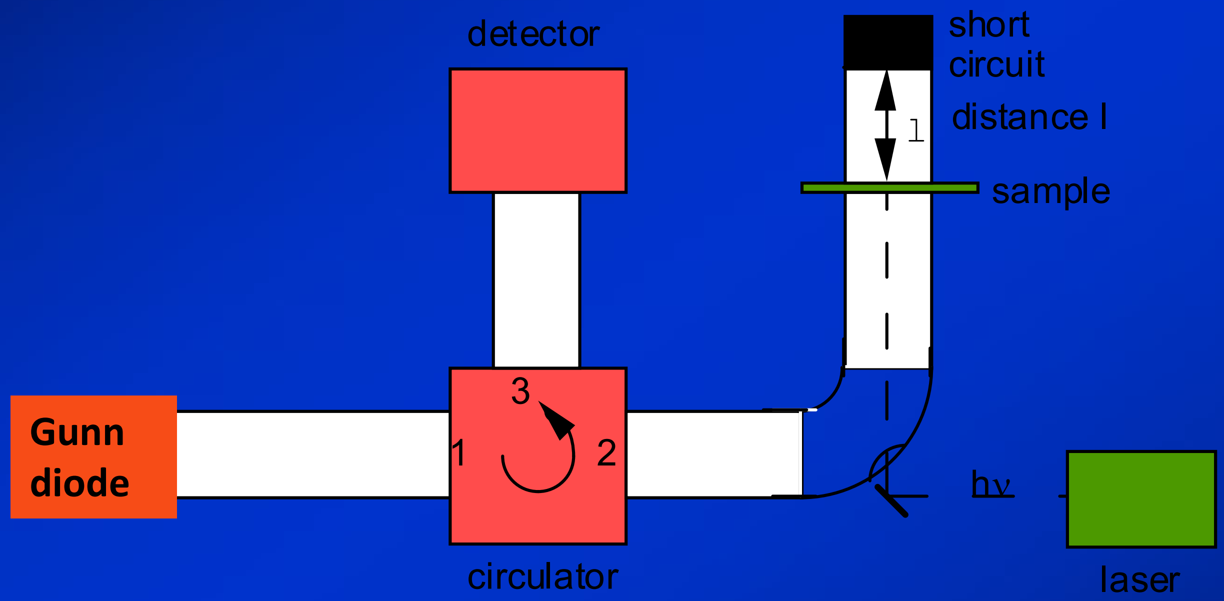
Correlation between Cz-crystalline Silicon cell efficiency and non destructive characterization parameters (TRMC and Electroluminescence)



H.-C. Neitzert et al.: EL efficiency degradation of c-Si solar cells after irradiation with protons

phys. stat. sol. (b) **245**, No. 9, 1877–1883 (2008)

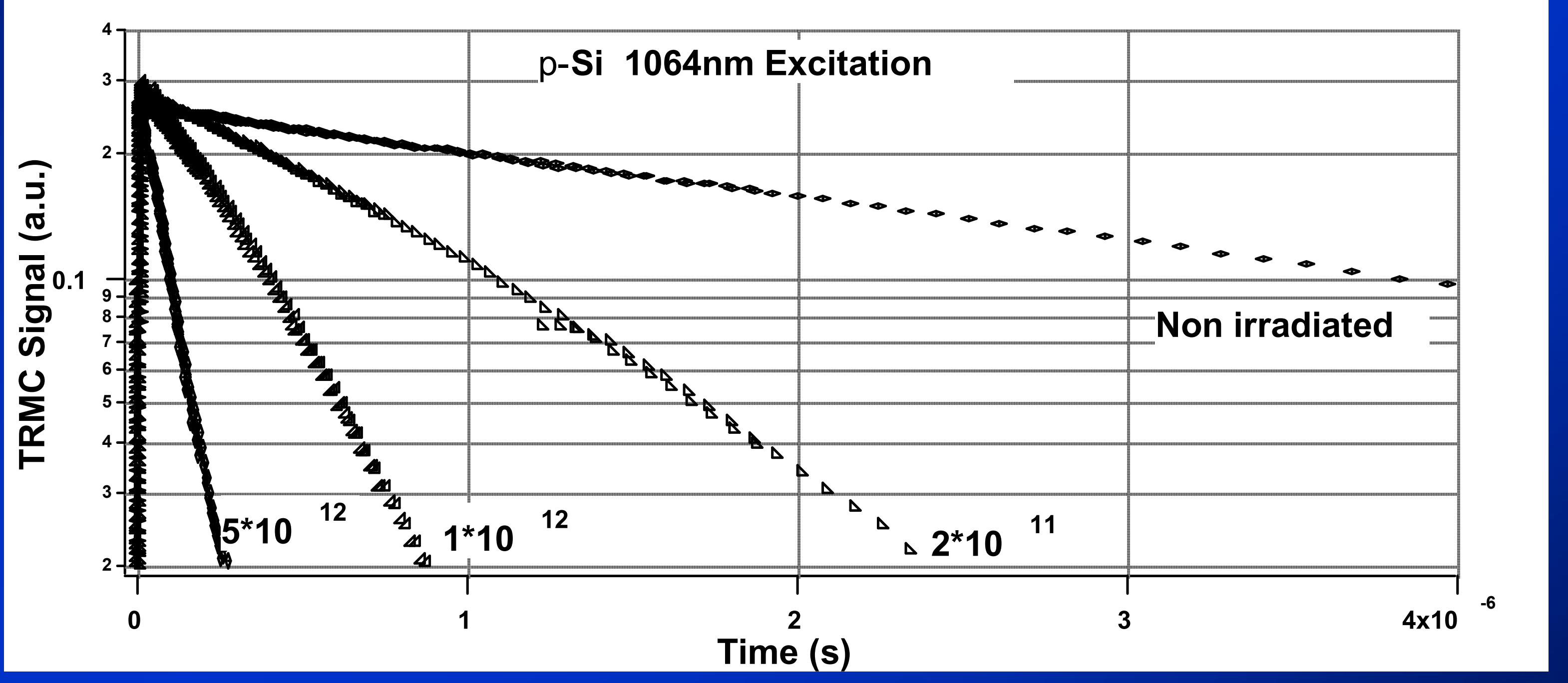
Time Resolved Microwave Conductivity (TRMC)



M. Kunst et al. / Thin Solid Films 450 (2004) 159–162

Photogenerated (using a Nd:YAG laser) free charge carriers in the sample change the reflected microwave power, that is directed by the circulator on to the fast point contact diode type microwave detector

Influence of proton irradiation at 65 MeV on the excess charge carrier lifetime in p-type Silicon, as determined by TRMC



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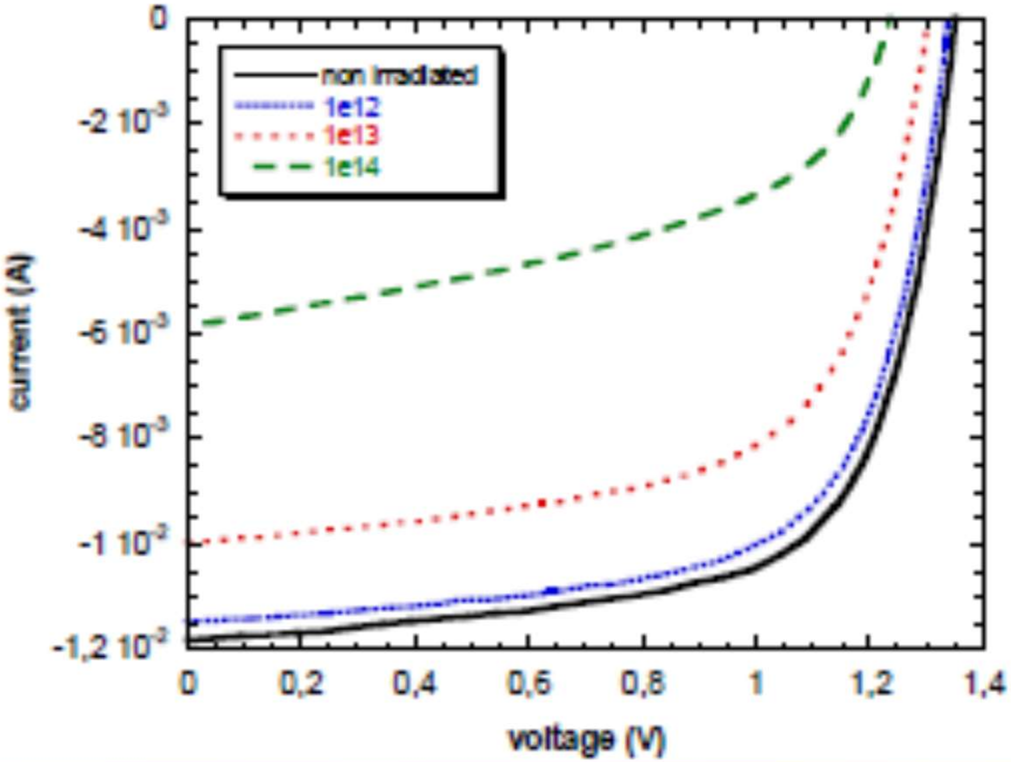
Degradation of Micromorph Tandem solar cells

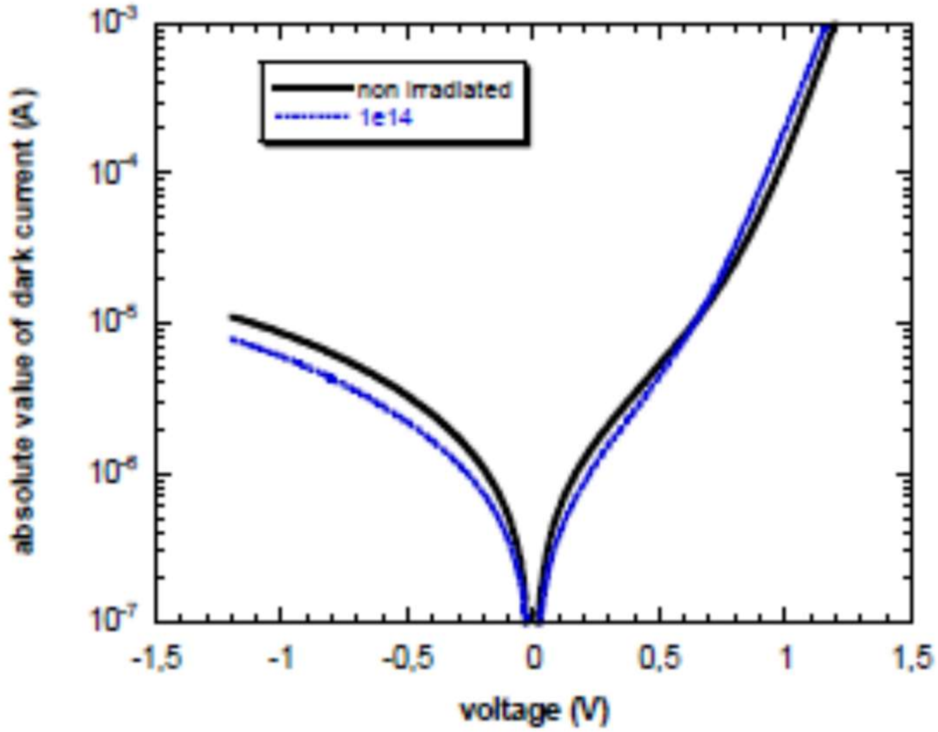
Fluence (p^+/cm^2)	Efficiency (%)	Voc (V)	Isc (mA/cm2)	FF. (%)
0	10.7	1.33	11.8	68.2
$1\cdot10^{12}$	10.3	1.31	11.5	67.9
$1\cdot10^{13}$	8.2	1.27	9.9	64.5
$1\cdot10^{14}$	4.3	1.18	5.8	50.4



H.-C. Neitzert et al.: Degradation of micromorph silicon solar cells
Phys. Status Solidi C 7, No. 3–4, 1065–1068 (2010)

Degradation of Micromorph Tandem solar cells

- Increase of saturation current after irradiation
  (g-r current increase)
- increase of shunt resistance after irradiation
  (improvement of lateral confinement)



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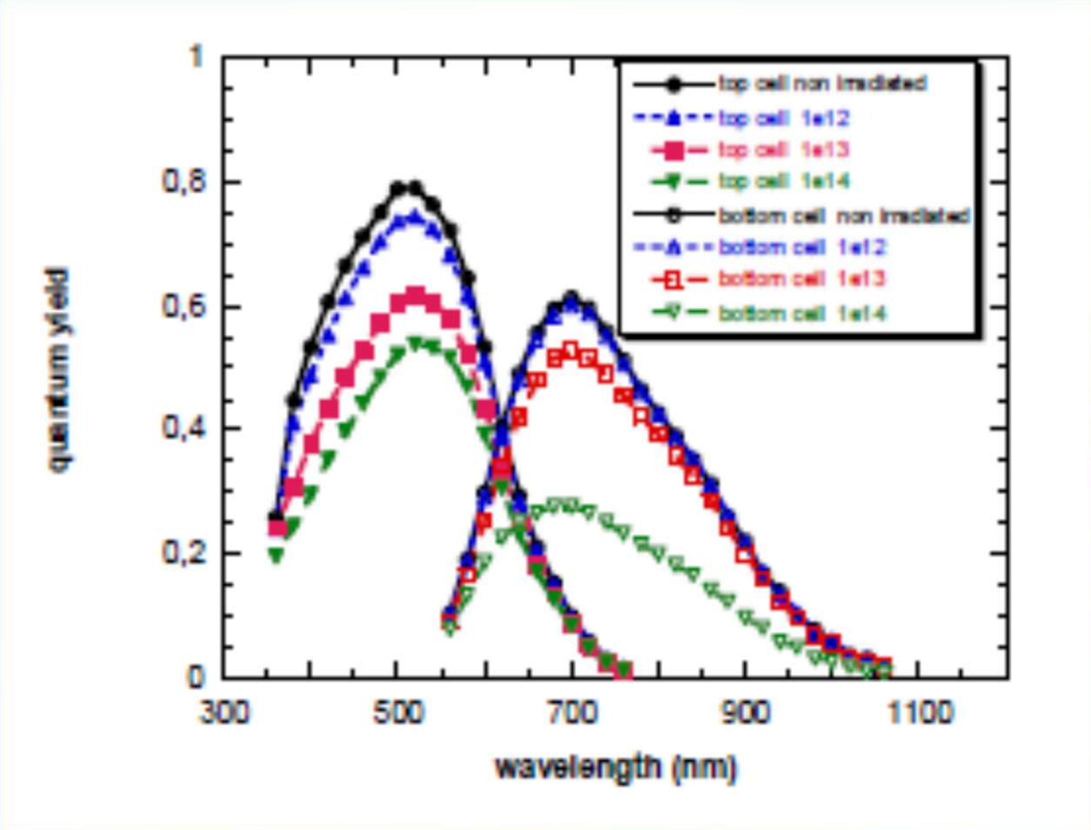
Phys. Status Solidi C 7, No. 3–4, 1065–1068 (2010)

Quantum yield spectra before and after irradiation at 65MeV with different proton fluences

Surprisingly we observe for low fluences only a a-Si:H top cell current decrease, despite the fact that the amorphous films should be more stable under irradiation than microcrystalline films



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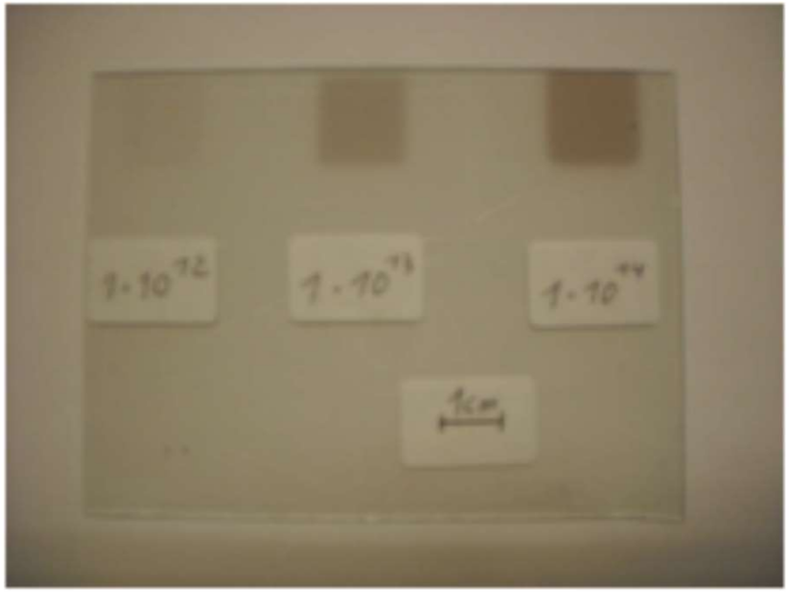
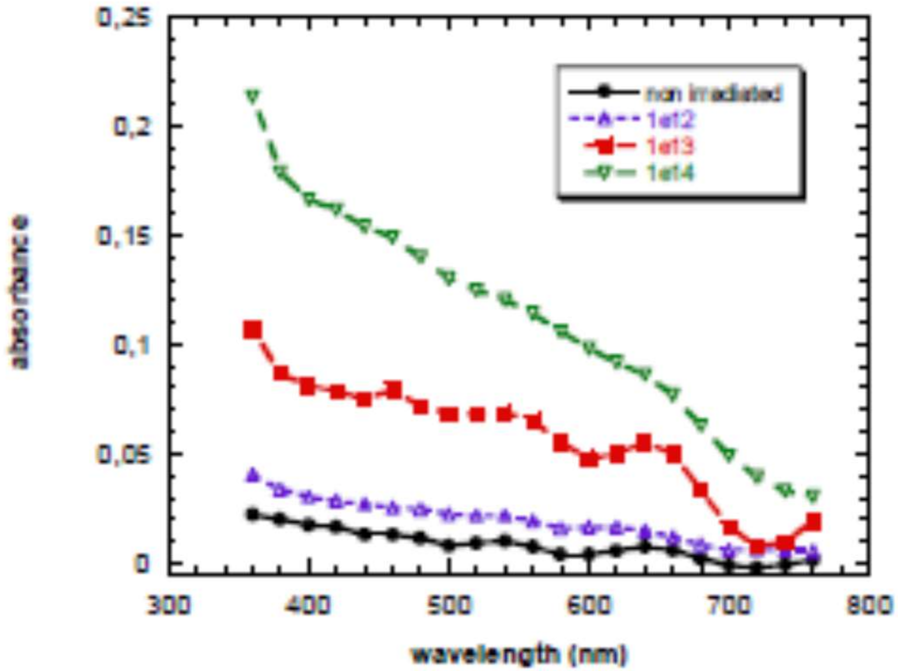
Solution: Change of substrate absorption has to be taken into account





Strong absorbance increase only in the visible spectral range affects mainly the performance of the top a-Si;H cell

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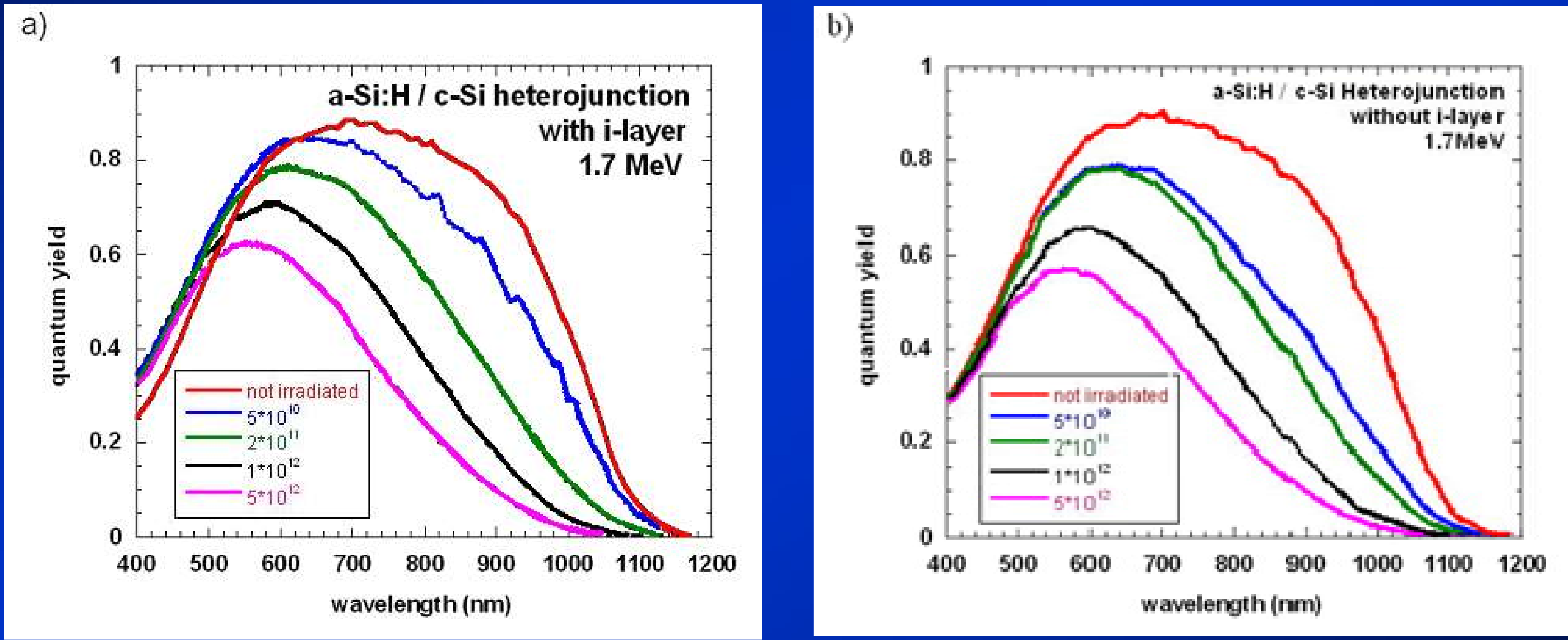
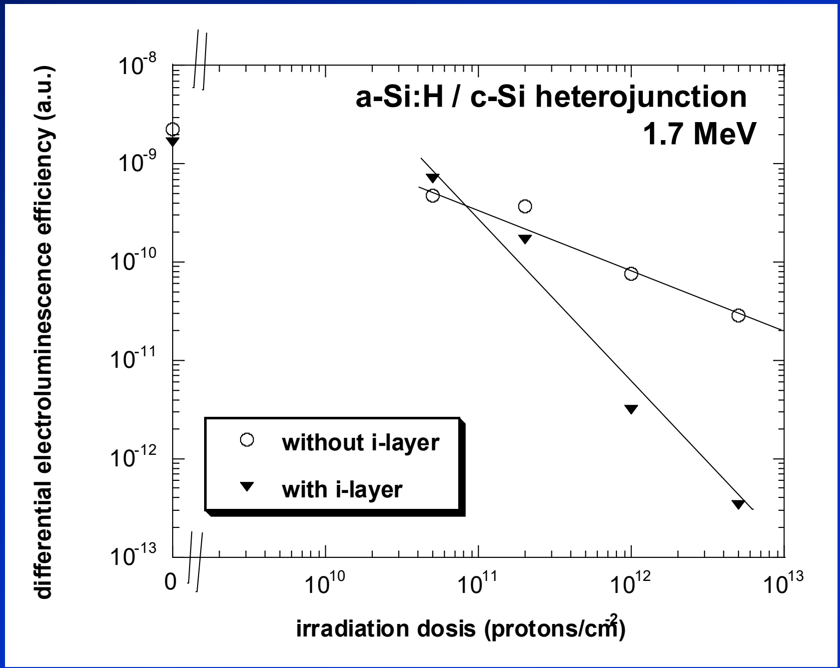
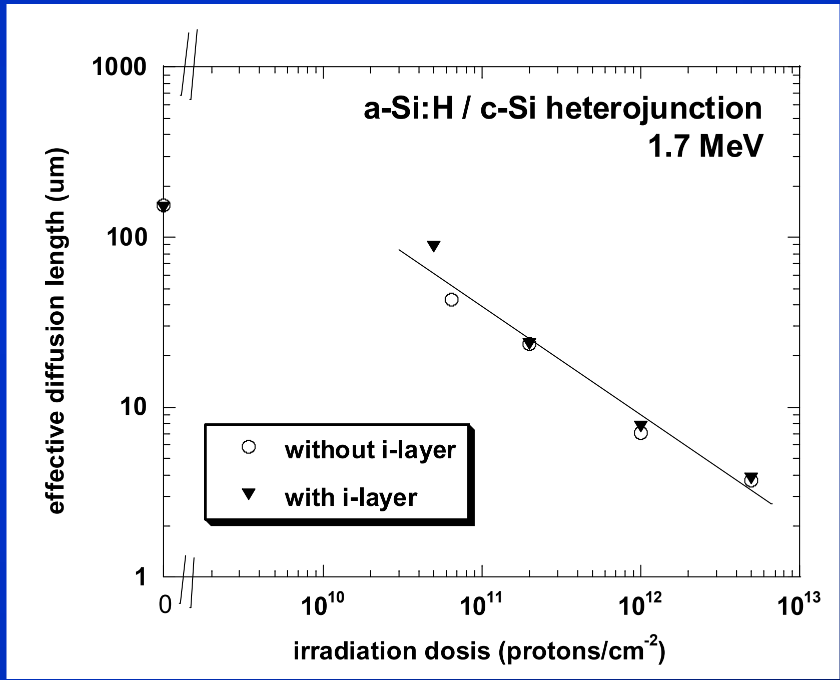
Quantum yield spectra of proton irradiated heterojunction solar cells with different interface structure



Proton irradiation can induce a short wavelength increase of the photocurrent in the case of the cells with intrinsic layer

Comparison of EL and QY results on irradiated aSi/cSi heterjunction solar cells

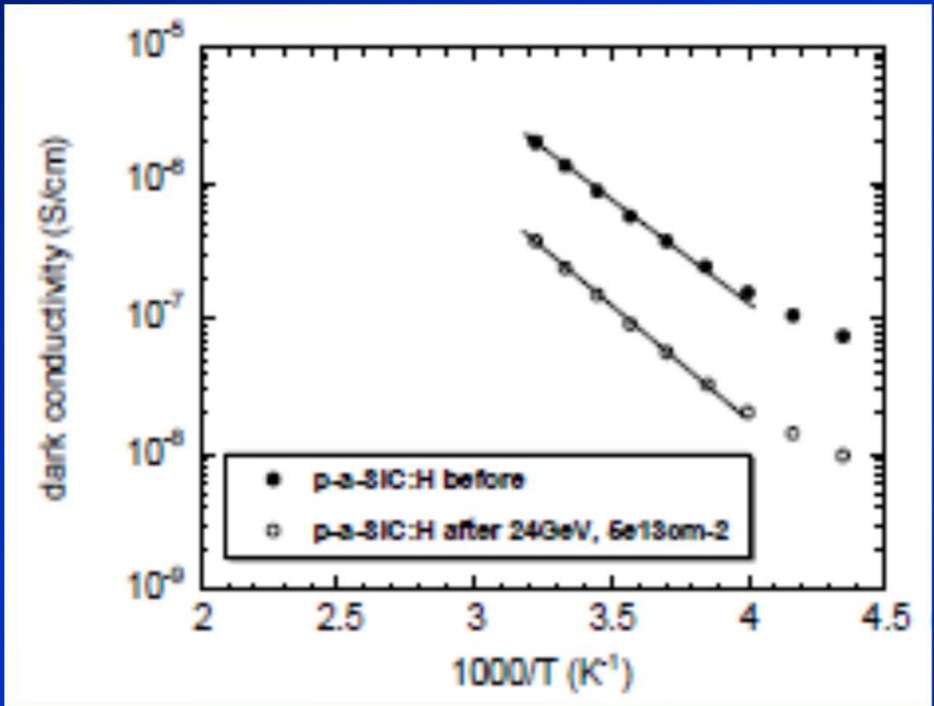




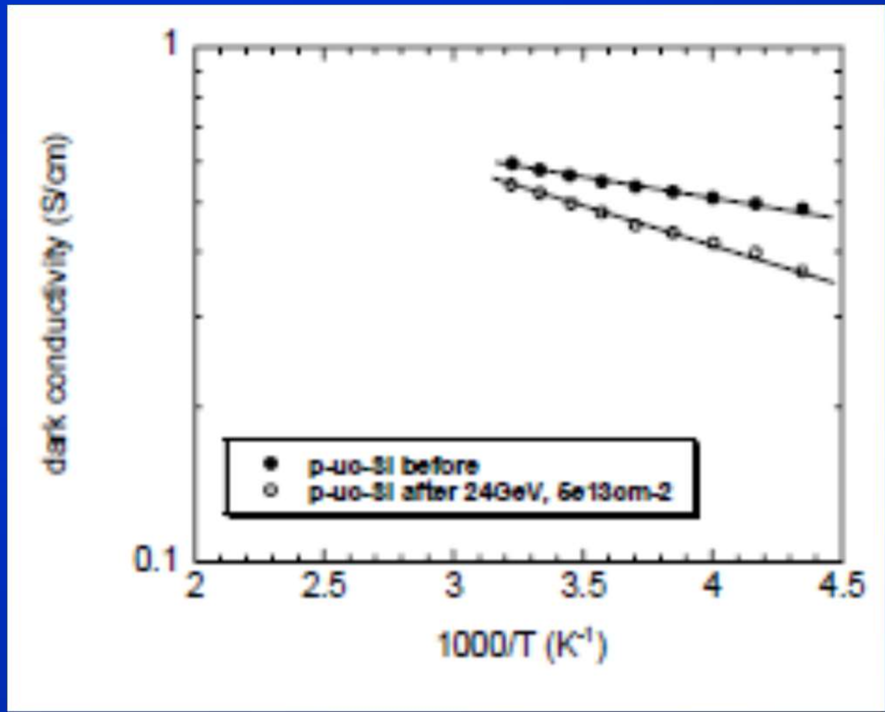
Insertion of thin intrinic layer has no influence on diffusion length but strong influence of electroluminescence degradation with proton irradiation

Extremely high energy (24 GeV) proton induced modification of amorphous silicon (a-Si:H) and microcrystalline silicon (μC-Si) films

Arrhenius-plots of the dark conductivities



amorphous



microcrystalline

H.C. Neitzert et al, Proc. of the 20th PVSEC, Barcelona (2005), p. 1627

Extremely high energy (24 GeV) proton induced modification of a-Si:H and μC-Si films

sample	dark cond. (at 300K) before (S/cm)	dark cond. (at 300K) irradiated (S/cm)	activation energy before (eV)	activation energy irradiated (eV)
n-type microcrystalline	11.8	0.493	0.0064	0.0134
p-type microcrystalline	0.57	0.49	0.0156	0.0286
p-type amorphous	1.3e-6	1.5e-7	0.256	0.286
intrinsic amorphous	7.4e-11	2.4e-9	0.89	0.83

H.C. Neitzert et al, Proc. of the 20th PVSEC, Barcelona (2005), p. 1627

Extremely high energy (24 GeV) proton induced degradation of thin film silicon

Even at an extremely high proton beam energy of 24 GeV
(irradiation at the CERN (Geneve))
we observed a degradation of thin film silicon

The degradation is more pronounced for microcrystalline
films than for amorphous films

Conclusions

- New measurement techniques have been applied for the characterization of radiation induced degradation of solar cells, in particular: contactless time resoved microwave reflection (TRMC) measurements and electroluminescence spectroscopy.

- The energy dependence of the solar cell degradation has been determined and compared to SRIM simulation results.

- The lower the initial silicon defect density, the faster is the proton induced degradation.

- Amorphous silicon is more stable than micro-crystalline silicon, which is more stable than Cz-monocrystalline silicon, which is more stable than FZ-monocrystalline Silicon.

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