Grazing incidence X-ray fluorescence analysis of Pr doped Silicon Rich Silicon Oxide films

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Introduction – Si solar Cells

Best Research-Cell Efficiencies

- Multijunction Concentrators
  - Three-junction (2-terminal, monolithic)
  - Two-junction (2-terminal, monolithic)
- Single-Junction GaAs
  - Single crystal
  - Concentrator
  - Thin film
- Crystalline Si Cells
  - Single crystal
  - Multicrystalline
  - Thick Si film
  - Silicon Heterostructures (HIT)
- Thin-Film Technologies
  - Cu(In,Ga)Se_2
  - CdTe
  - Amorphous Si:H (stabilized)
  - Nano-, micro-, poly-Si
  - Multijunction polycrystalline
- Emerging PV
  - Dye-sensitized cells
  - Organic cells
    - (various technologies)
  - Inorganic cells
  - Quantum dot cells
- Spectrolab (metamorphic, 299x)
- Fraunhofer ISE (metamorphic, 454x)
- Boeing-Spectrolab (lattice matched, 364x)
- Spectrolab (lattice matched, 415x)
- Boeing-Spectrolab (metamorphic, 248x)
- Boeing-Spectrolab (metamorphic, 179x)
- Spectrolab (metamorphic, 117x)
- Sharp (MIM, 1-sun)

Efficiency (%)
Introduction – Si solar Cells

classical efficiency limit is currently estimated to be 29%

Introduction – Si solar Cells

Spectral modifications to increase efficiency


upconversion

downconversion
Nanostructures Intégrées pour la Microélectronique et la PHotonique (NIMPH) CIMAP, Caen, France

The NIMPH team develops thin films for photonics, semiconductor or conductive, doped with rare earth (and/without) nanostructured sensitisers.

Pr doped Silicon Rich Silicon Oxide
## Samples

<table>
<thead>
<tr>
<th>Sample name</th>
<th>Target type</th>
<th>Substrate Type</th>
<th>Treatment</th>
<th>Deposition condition</th>
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<tr>
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<td>Pr₆O₁₁ chips</td>
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<td>25</td>
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</tbody>
</table>
Characterisation

Functional Analysis: typically photo-luminescence

Structural / Elemental analysis?

- modelling uses the same formalism

GI-XRF is a further development

sensitive to electron density and its changes:
- material density
- film thickness
- optical constants
- roughness

reveals elemental surface concentrations:
- material composition
- in depth information
Experimental set-up

Panalytical X'Pert XRD

Problem: SD detector not integrated in the X'Pert system: synchronisation

Solution: XRR acquisition in continuous mode, angles calculated from time-stamp and live time
Experimental results

Sample D007 annealed at 900°C for 10'
Experimental results

Sample D022 – power 100W

Sample D023 – power 200W
Experimental results

Sample D022 – power 100W

annealed at 900°C for 10'

grazing incidence fluorescence for sample D022

grazing incidence fluorescence for sample D022R900

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Experimental results

Sample D048, 0 Pr$_6$O$_{11}$ chips, power 200W
Experimental results

Sample D050 – H2

0 Pr₆O₁₁ chips

Sample D054 – noH₂
Experimental results

Sample D071 – 10 sccm H2

11 Pr$_6$O$_{11}$ chips

Sample D072 – 20 sccm H2
Experimental results

Sample D080 – 10 sccm H2 0 Pr₆O₁₁ chips  Sample D082 –
Power 60W

grazing incidence fluorescence for sample D080

grazing incidence fluorescence for sample D082
Experimental results – chamber C2

A1182 sum

Cu elastic scatter (XRD)

counts per channel

energy / eV

grazing incidence fluorescence for sample A1182

SiKa x 1
CaKa x 10
FeKa x 10
PrLa x 10
PrLb x 10
SeKa x 10

fluorescence [a.u.]

angle [degrees]
Experimental results – chamber C2

grazing incidence fluorescence for sample A1182

- SiKa x 1
- CaKa x 10
- FeKa x 10
- PrLa x 10
- PrLb x 10
- SeKa x 10

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grazing incidence fluorescence for sample A1183

- SiKa x 1
- CaKa x 10
- FeKa x 10
- PrLa x 10
- PrLb x 10
- SeKa x 10

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X-Ray Tube Spectra

Horst Ebel
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X-ray tube spectra make an essential contribution to the quantitative description of experimental setups or for quantitative x-ray analysis. After an outline of the historical development of the description of tube spectra the approaches given by Wiederschwing, Ebel et al. Schossmann et al. and Pella et al. are treated in detail. Summarizing the theoretical treatment and the applications, it can be stated that both approaches give comparable results over a certain spectral range. Pella’s approach is restricted to electron incidence angles of 90° and application of Pella’s spectral responses in the lower keV range should be avoided. Copyright © 1999 John Wiley & Sons, Ltd.

\[
dN = \Omega i \cdot \text{const} \cdot Z \left( \frac{E_0}{E} - 1 \right)^x \frac{1 - e^{-\tau_{E,j} \cdot 2\rho Z \sin \phi/\sin \varepsilon}}{\tau_{E,j} \cdot 2\rho Z \sin \phi/\sin \varepsilon} dE
\]
X-Ray Tube spectra

Cu diffraction tube 40 kV - emission spectrum

- Bremsstrahlung
- Characteristic lines
- Excitation spectrum

spectral flux density [photons/(sr * s * mA * 0.1KeV)]

energy [keV]

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X-Ray Tube spectra

incident spectrum on sample

Transmission of absorbers between anode and sample

- 300 μm Be window
- 350 mm air path
- 12.5 μm Ni filter

spectral flux density [photons/(sr * s * mA * 0.1keV)]

energy [keV]

energy [keV]
Angle dependence
Polychromatic excitation
Angle dependence
Layered samples

**Glancing-incidence x-ray fluorescence of layered materials**

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*Philips Research Laboratories, P.O. Box 80000, 5600JA Eindhoven, The Netherlands*

(Received 2 January 1991)

X-ray fluorescence spectroscopy normally probes the first few micrometers of a material, but under conditions of glancing incidence the surface sensitivity is enlarged to the nanometer regime. In this paper, a formalism is given for the calculation of x-ray fluorescence intensities that is also valid at glancing incidence and includes absorption and enhancement effects. Calculations based on this theory for the angular dependence of glancing-incidence x-ray fluorescence (GIXF) intensities compare well with experimental data. Standing waves in thin layers are shown to be a sensitive probe for elements at various depths, an effect that can be exploited in GIXF for depth profiling in layered materials.

- interlayer and intralayer secondary fluorescence enhancement
Conclusions

- an easy solution for adding gi-xrf to xrr was shown
- qualitative GIXRF is quite “straight forward”
- detect possibly detrimental contamination
- get qualitative information on layer distribution

Future work and perspectives

- try to get quantitative
- combine XRR and GIXRF in a single fit
- carry out measurements at different wavelengths (e.g. MoKα and CuKα)
Acknowledgements

This research was partially carried out within the Xmat project ("Combination of X-Ray diffraction and X-Ray Fluorescence techniques in material science"), supported by the Provincia autonome di Trento and the European Union in the framework of the Marie Curie COFUND program - Call for proposals 4 - researcher 2009 – Outgoing.

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Thanks for your attention