Improvement of depth resolution of the positron beam spectroscopy by a sputtering technique to study photovoltaics CIGSe layers

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AG Positron annihilation
Setup for Doppler broadening spectroscopy

M. Elsayed, „The appearance of vacancies during Cu and Zn diffusion in III-V compound semiconductors“. Dissertation, Martin-Luther-Universität Halle-Wittenberg, 2010

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Improvement of depth resolution of the positron beam spectroscopy by a sputtering technique to study photovoltaic CIGS layers

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• implantation profile often approximated as Makhov profile

• extreme broad distribution of implanted positrons at \( E > 3 \text{ keV} \)

\[
P(z, E) = \frac{m z^{m-1}}{z_0^m} \left[ - \left( \frac{z}{z_0} \right)^m \right]
\]

\[
\bar{z} = A \frac{E^r}{\rho}
\]
the defect layers are expected in a depth of 1.7 µm and 2.8 µm corresponding to $E_+ = 18$ keV and 25 keV

implantation profile too broad to discriminate between the two zones

simulation of $S(E)$ curve gives the same result for assumed defect profile
Surface removal by sputtering

- Ar$^+$ ions penetrate into surface
- create displacement cascades
- some cascades reach surface
- surface atoms are released

*Krause-Rehberg: PSSD 99*
Simulated defect profiles created during sputtering

Krause-Rehberg: PSSD 99
Sputter process changes surface parameter only

- sputter conditions: 2 keV, 60°
- no change of positron diffusion length due to sputtering
- depth resolution is limited by e+ diffusion, not by implantation profile

**Krause-Rehberg: PSSD 99**

**Graph:**
- $S/S_{\text{bulk}}$ vs. positron energy (keV)
- $L_+ = 221 \pm 13 \text{ nm}$
- $L_+ = 213 \pm 18 \text{ nm}$

**Legend:**
- n-Si as-received
- n-Si sputter step 1
- n-Si sputter step 2
- simulation
**Cu(In,Ga)Se$_2$ - (CIGSe)**

- direct semiconductor
- $E_g = 1.04$ eV – 1.67 eV
- fabricated by 3 steps co-evaporation process
- used in thin film solar cells
Results

Simulated defect profile for CIGS

- No vacancies from a depth of 10 nm
- $e^+$ energy chosen so that:
  - must be no influence of surface
  - still sharp $e^+$ implantation profile

Sputtering conditions:
- $E_{Ar^+} = 1$ keV
- Incident angle: 42°
Results

Prove of principle with layer system

- with $S(E)$ no defects measurable
- better depth resolution then $S(E)$-scan
- Interfaces sharply visible

Sputter parameters: $I_B = 4$ mA; $U_B = 400$ V
Results

- Investigation of the whole solar cell, especially near the back contact
- In-situ sputtering
  -> no air contact between the measurements
  -> no degradation on the surface
  -> shorter overall measurement time

Sputter parameters: $I_B = 6 \text{ mA}; U_B = 400 \text{ V}$
• distinctly better depth resolution is possible by sputtering
  -> real defect profiling
• interfaces become sharply visible
• depth resolution is no more limited by positron implantation profile but only by effective positron diffusion length (fundamental barrier)
• chemical information independent of defects by surface annihilation parameters
• disadvantage: not nondestructive
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