

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

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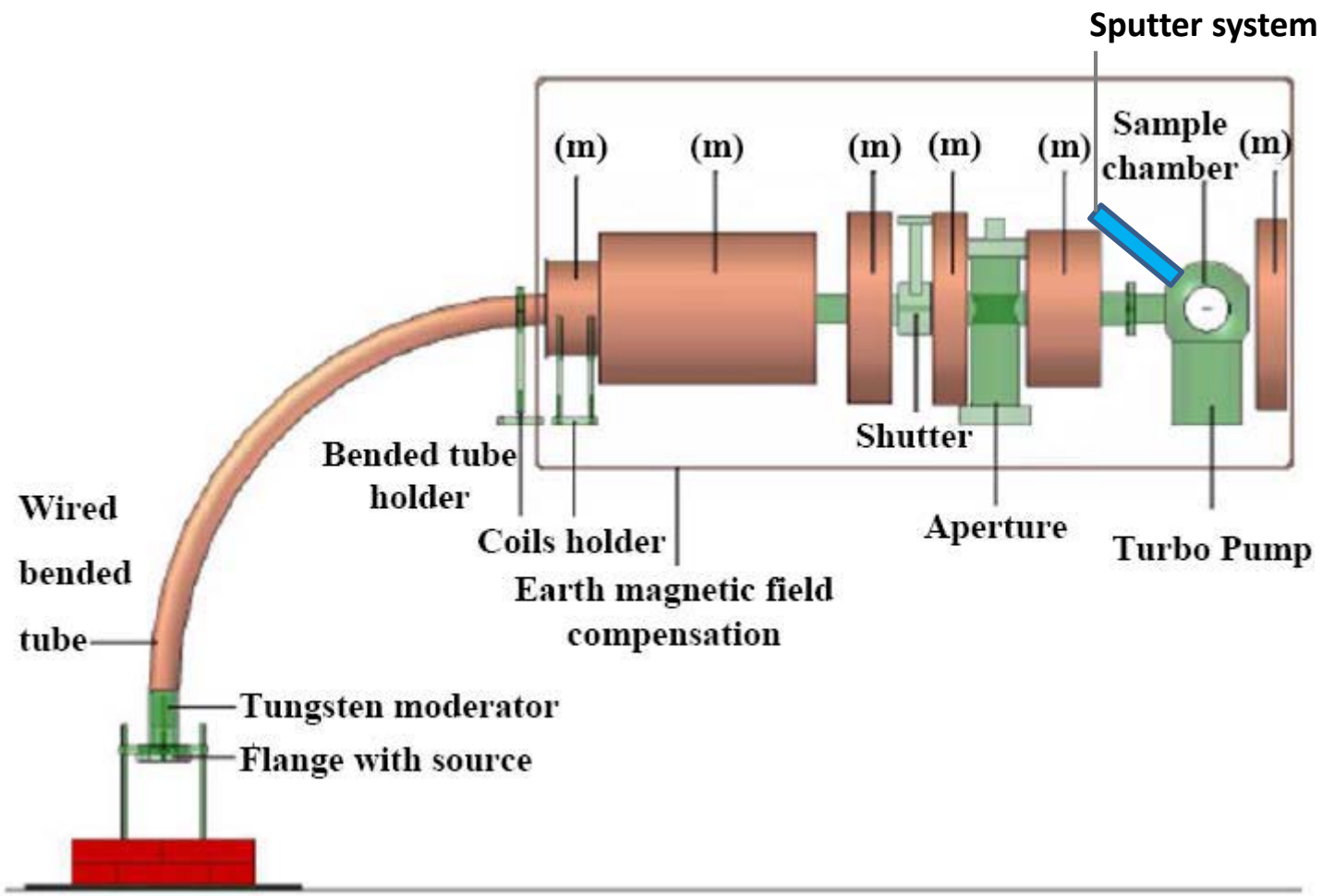
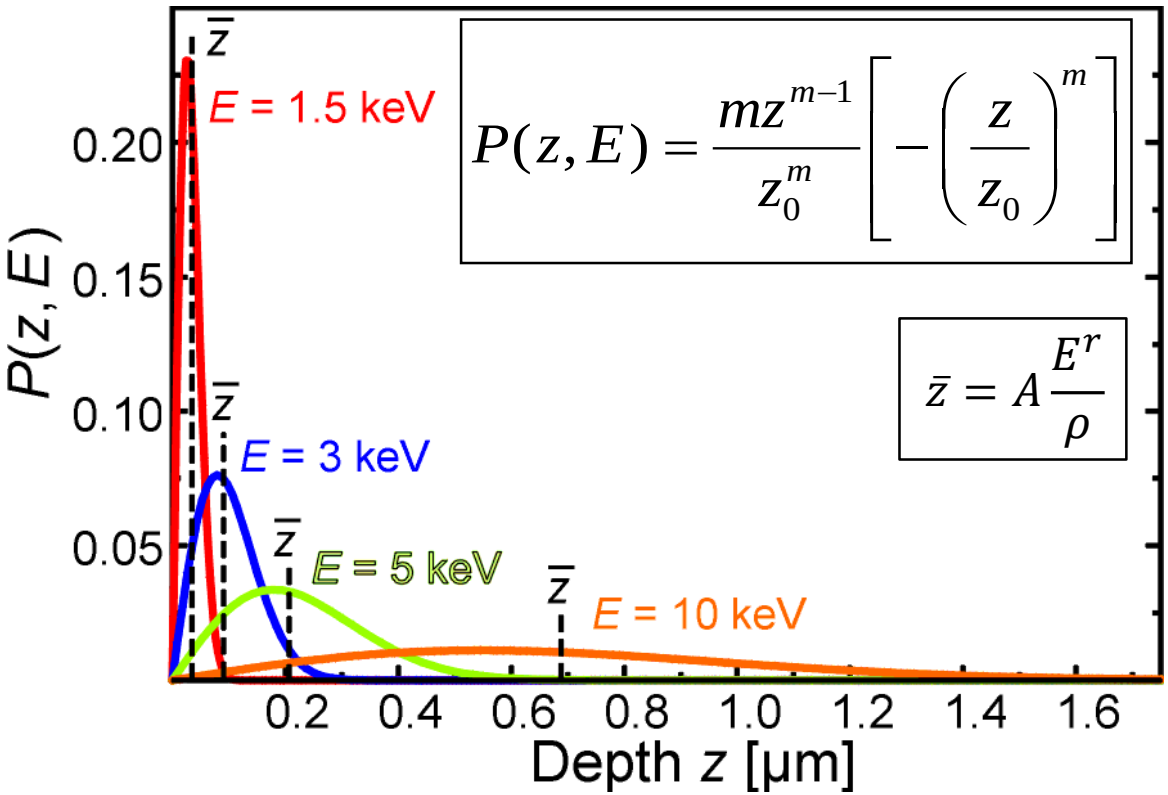
AG Positron annihilation

Setup for Doppler broadening spectroscopy



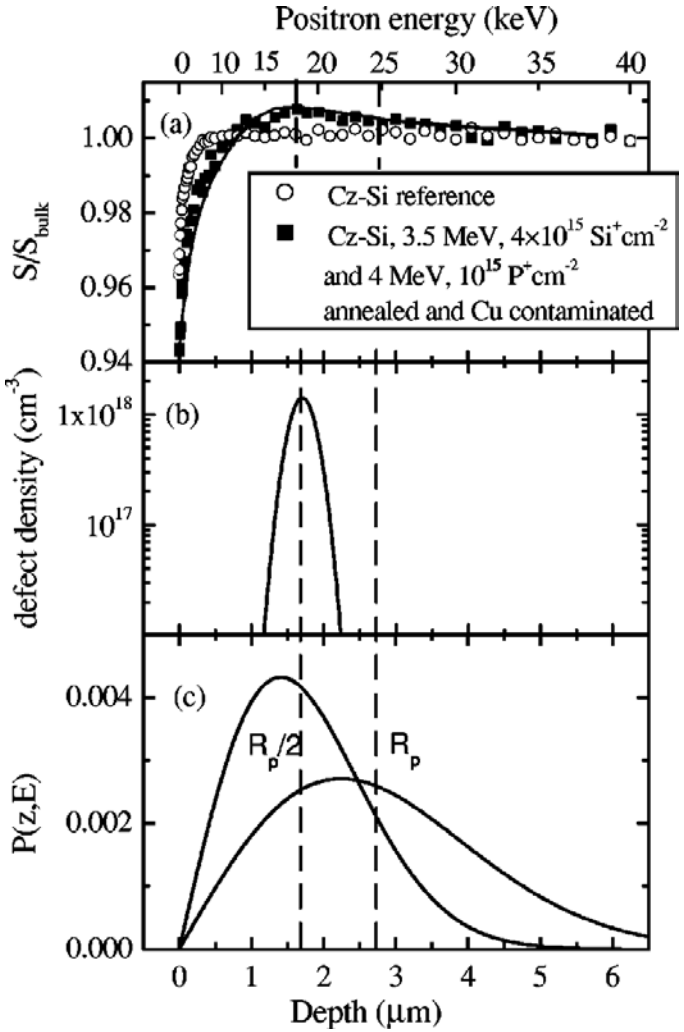
M. Elsayed, „The appearance of vacancies during Cu and Zn diffusion in III-V compound semiconductors“. Dissertation, Martin-Luther-Universität Halle-Wittenberg, 2010

- implantation profile often approximated as Makhov profile
- extreme broad distribution of implanted positrons at E > 3 keV



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

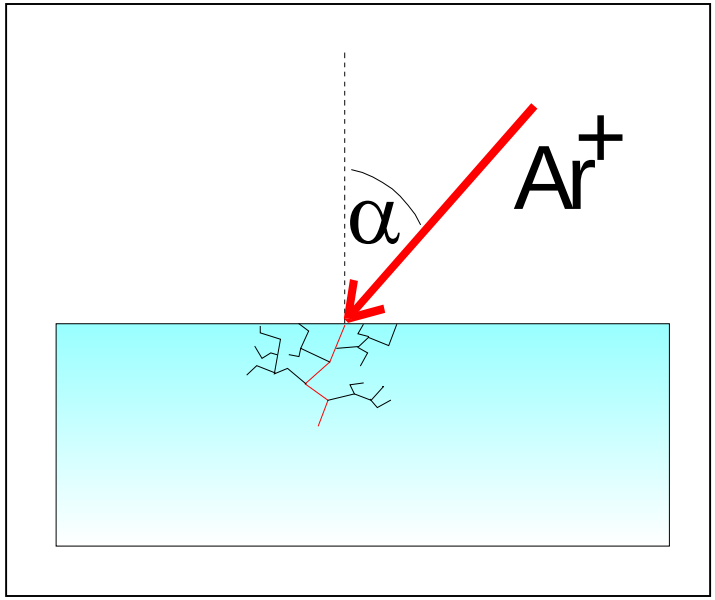
$$\bar{z} = A\frac{E^r}{\rho}$$



R. Krause-Rehberg, F. Börner, and F. Redmann; Applied Physics Letters **77**, 3932 (2000)

- 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

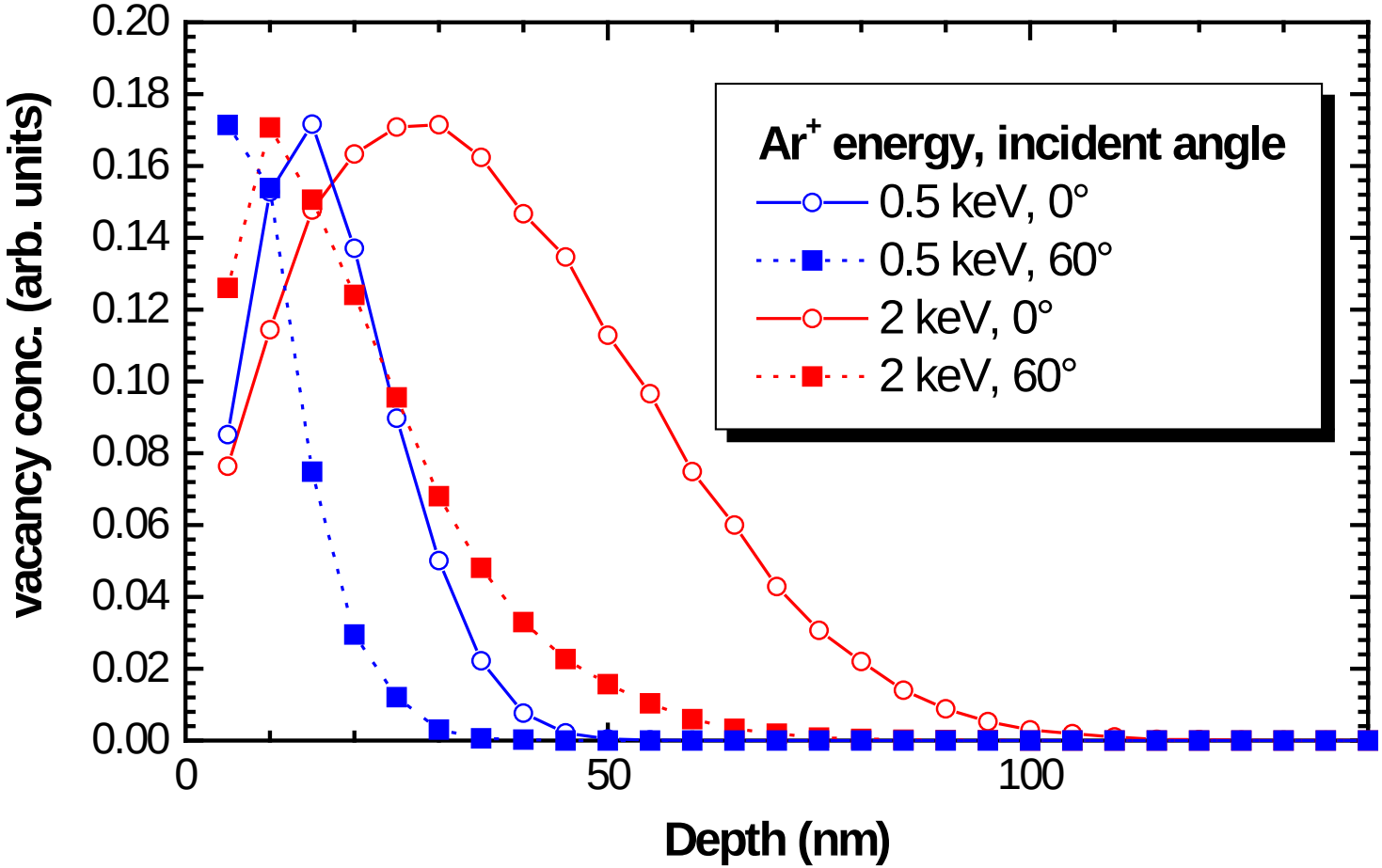
Surface removal by sputtering



Krause-Rehberg: PSSD 99

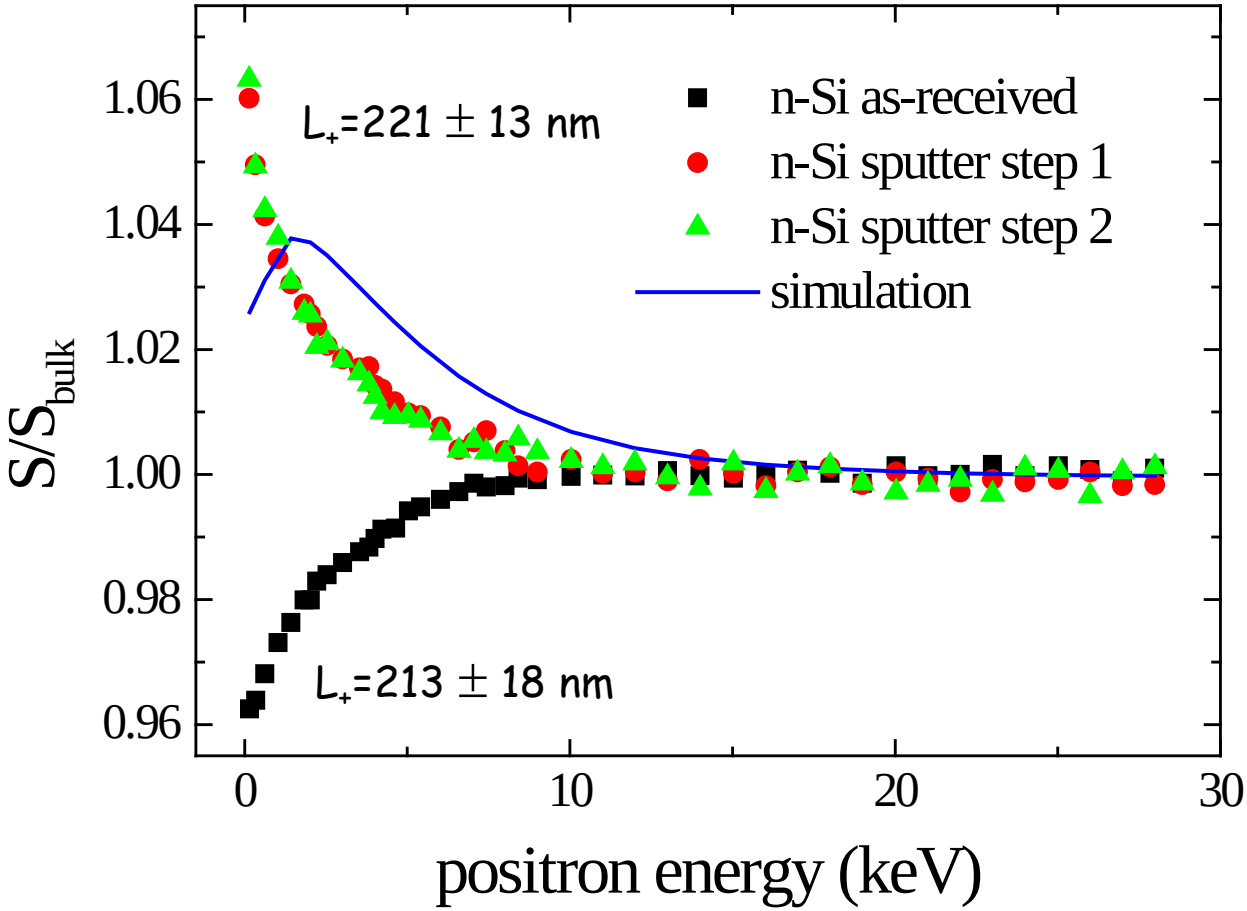
- Ar^+ Ions penetrate into surface
- create displacement cascades
- some cascades reach surface
- surface atoms are released

Simulated defect profiles created during sputtering



Krause-Rehberg: PSSD 99

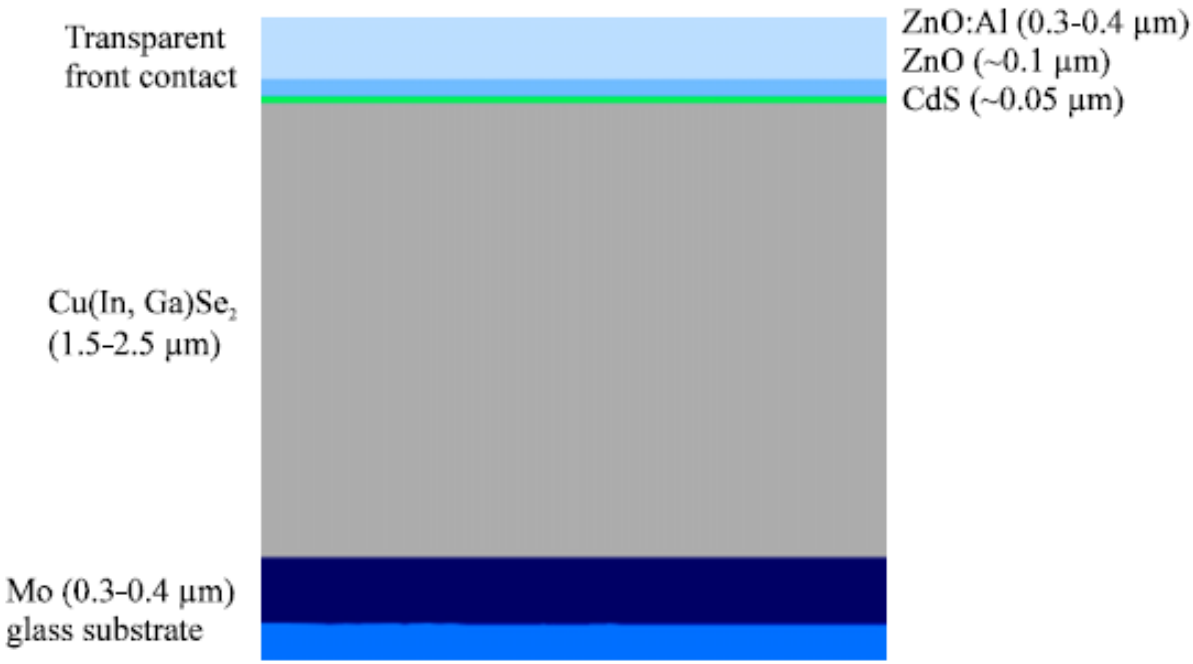
Sputter process changes surface parameter only



Krause-Rehberg: PSSD 99

- 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

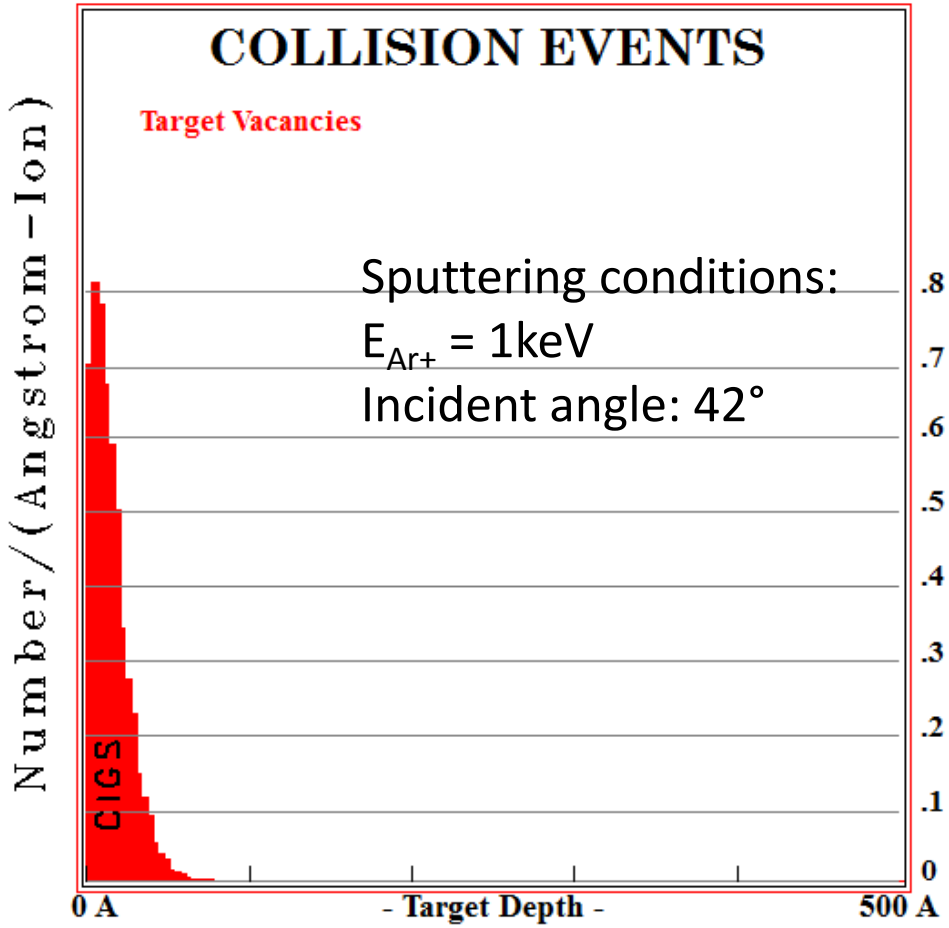
$Cu(In,Ga)Se_2$ - (CIGSe)



- direct semiconductor
- E_g =1,04 eV – 1,67 eV
- fabricated by 3 steps co-evaporation process
- used in thin film solar cells

Results

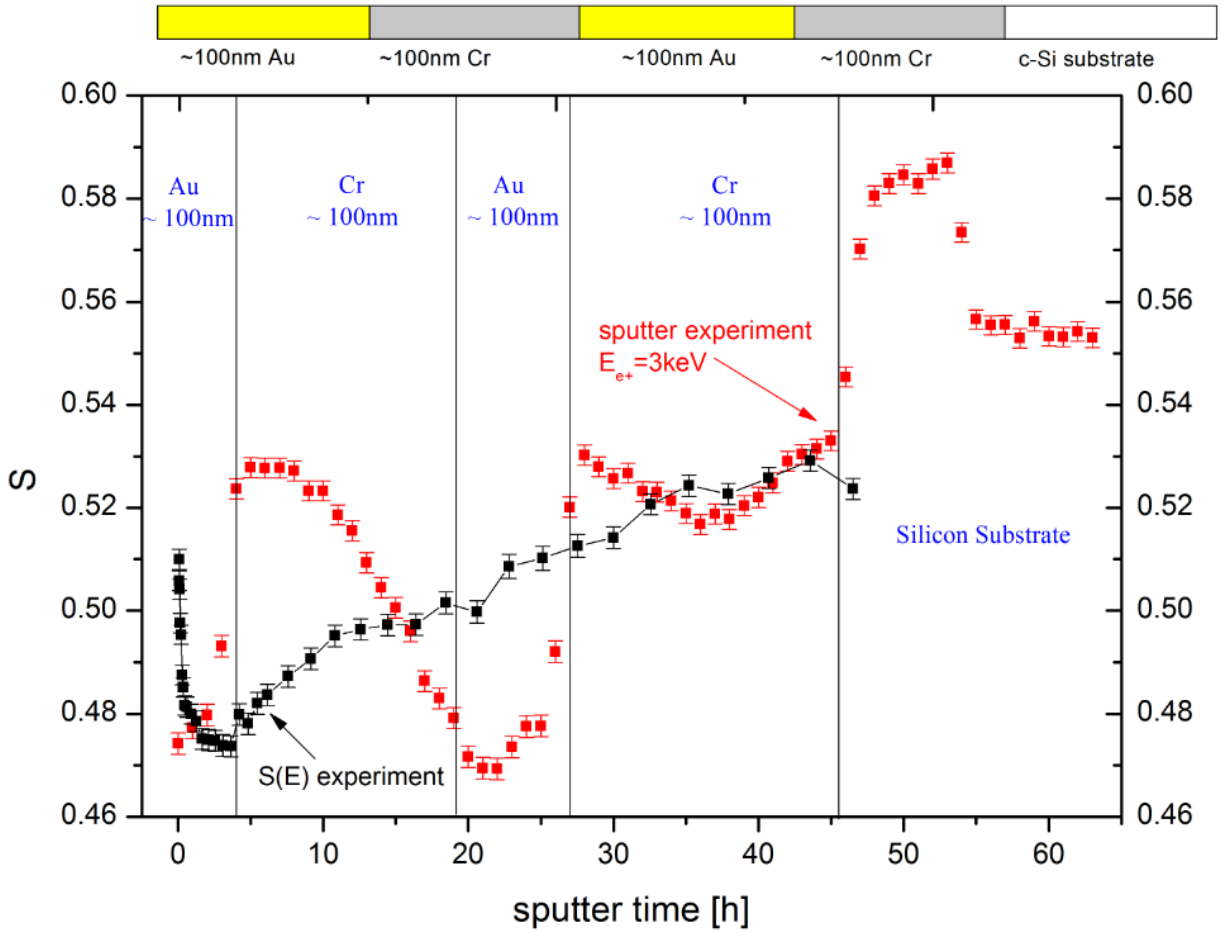
Simulated defect profile for CIGS



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

Results

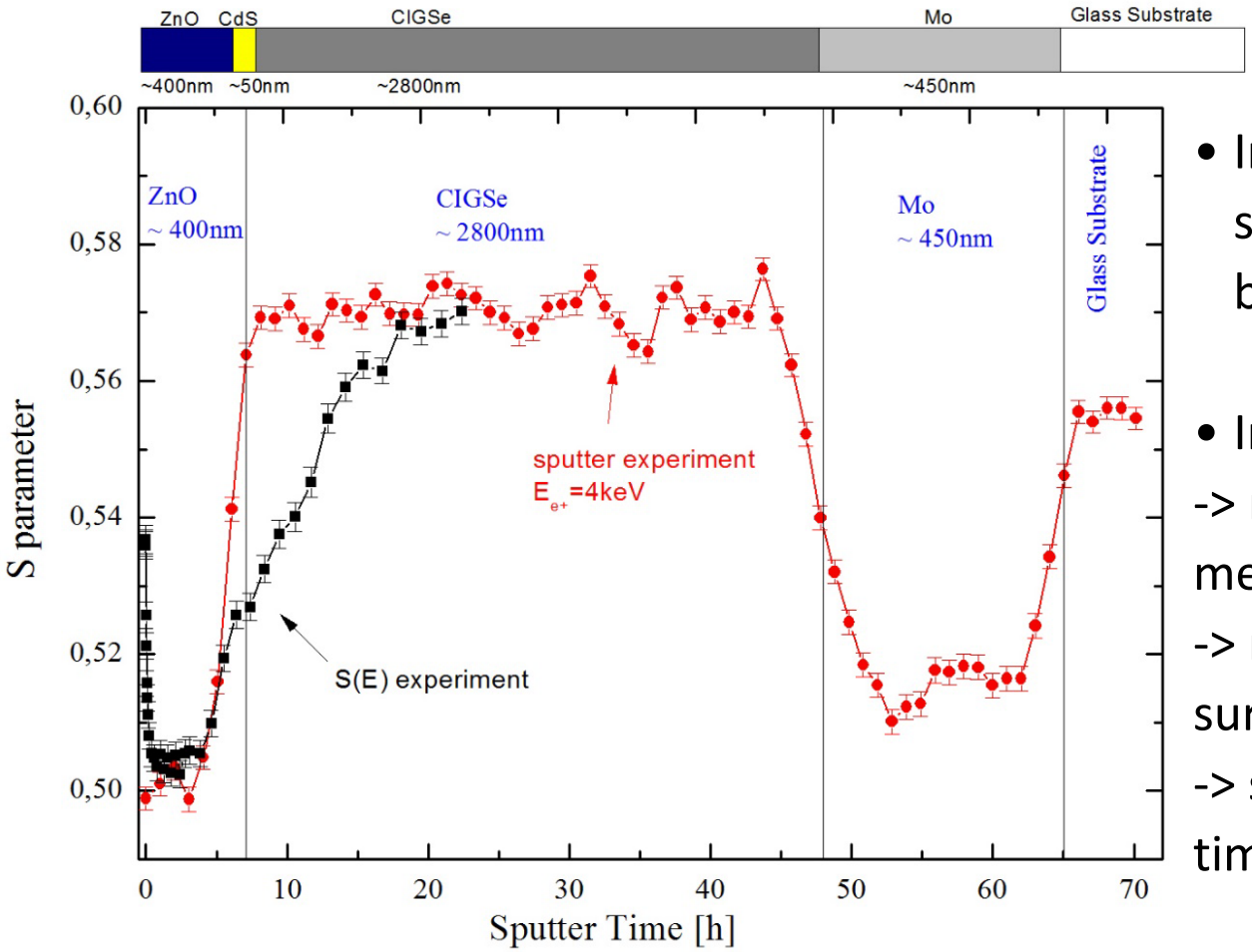
Prove of principle with layer system



- 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 mA; U_B = 400 V

Conclusion

- 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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