Treffen deutscher Positronengruppen 2015, München:

Improvement of depth resolution of the positron beam spectroscopy by a sputtering technique

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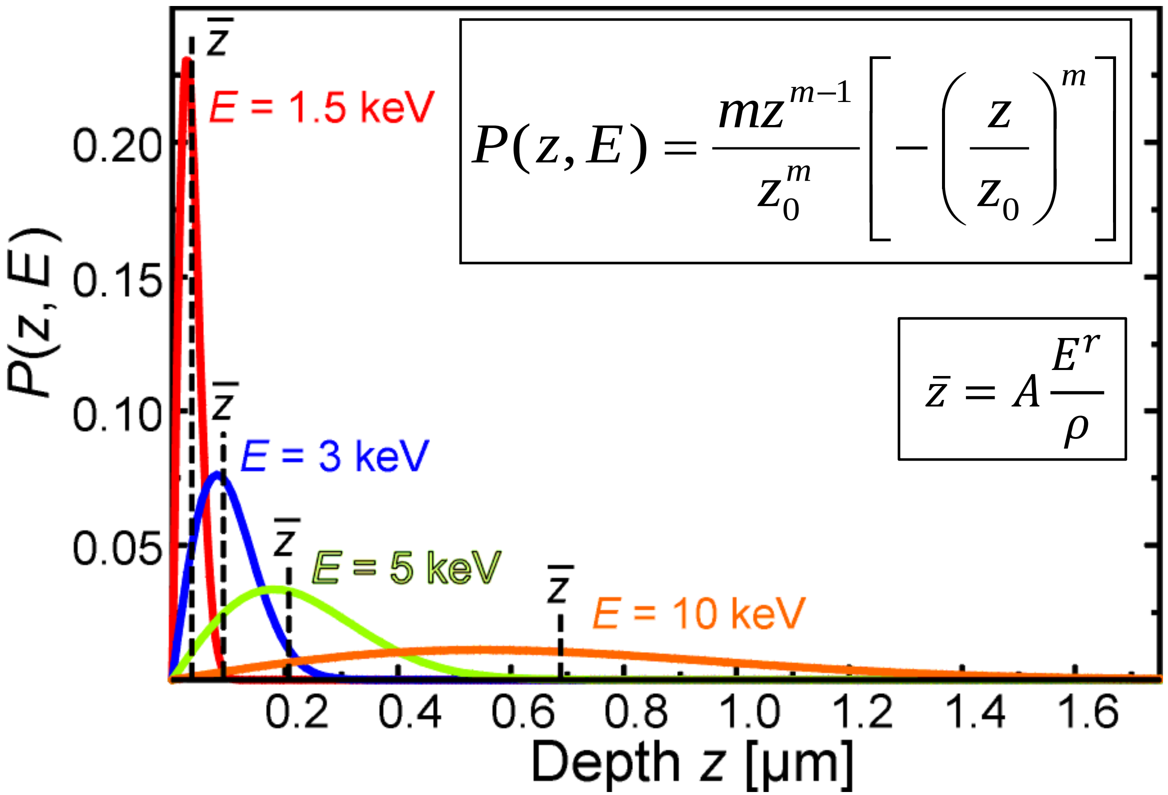
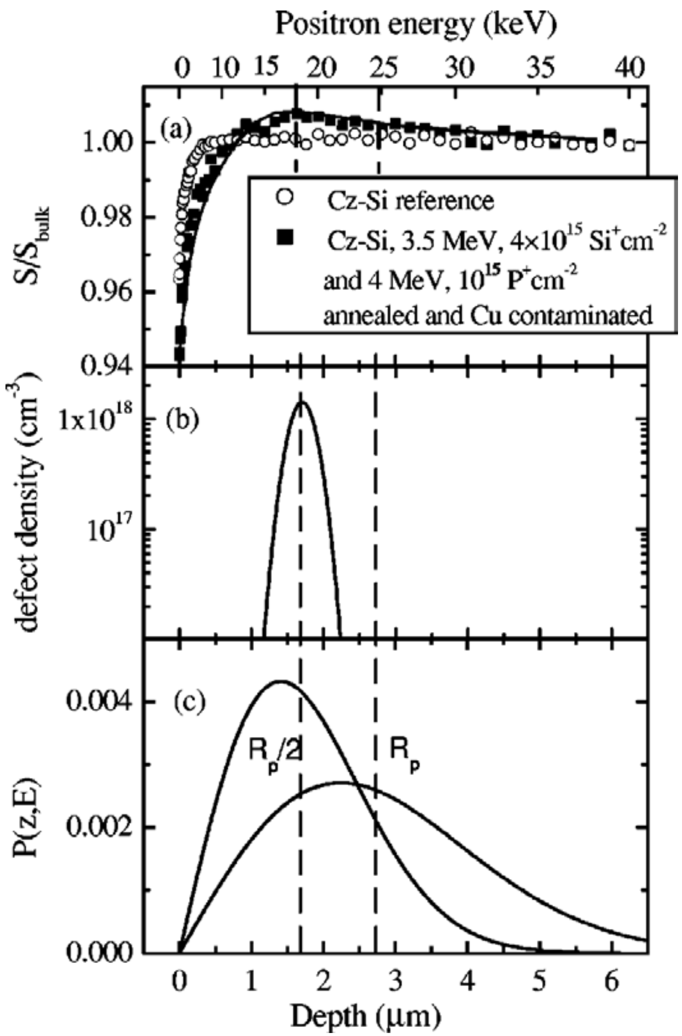
Implantation Profile

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



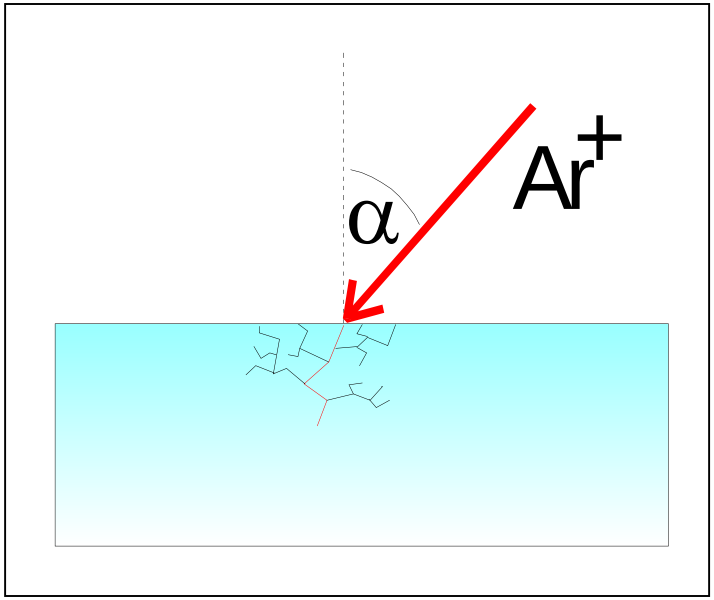
Example for limitation of depth profiling: Rp/2 effect in Si self-implantation



- after self-implantation of Si in Si @3.5 MeV – two defect-rich layers are found
- at Rp: Si self-interstitials form dislocation loops
- at Rp/2 (1.7 µm): ???
- the defect layers are 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

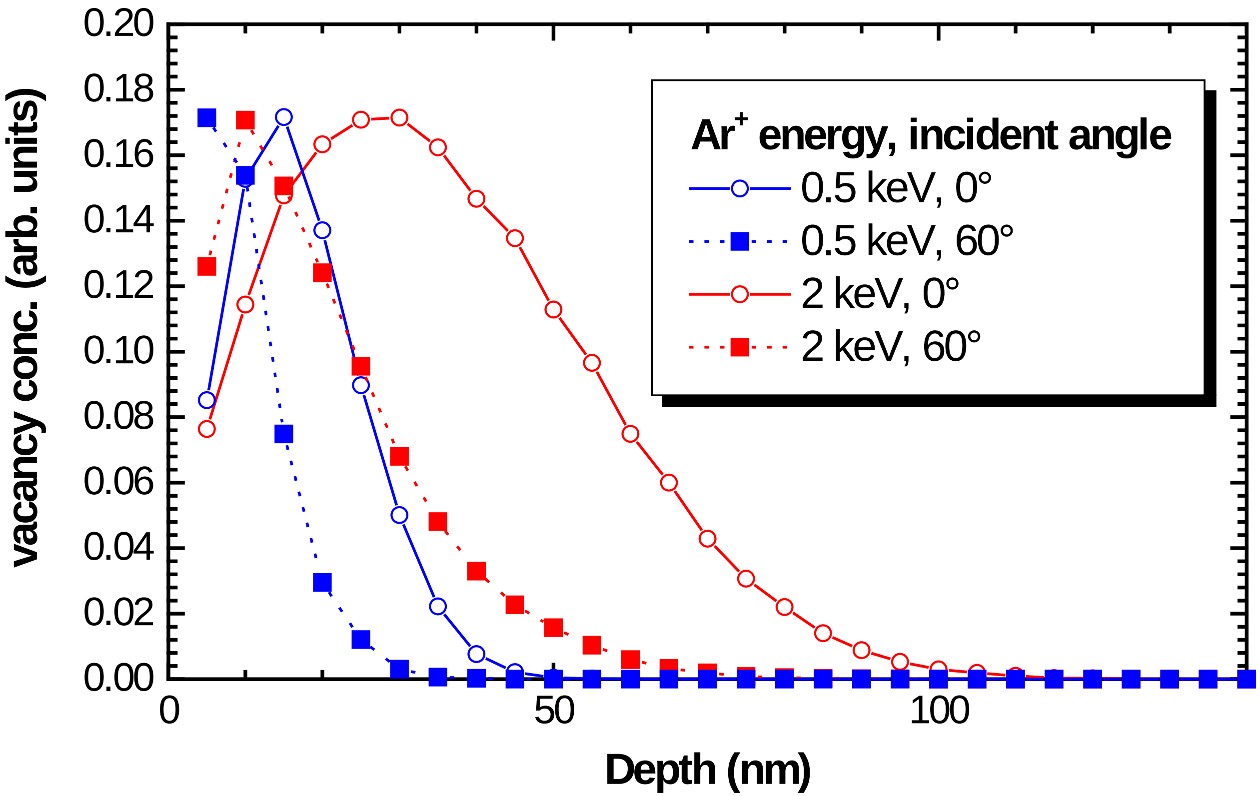
R. Krause-Rehberg, F. Börner, and F. Redmann; Applied Physics Letters **77**, 3932 (2000)

Surface removal by sputtering



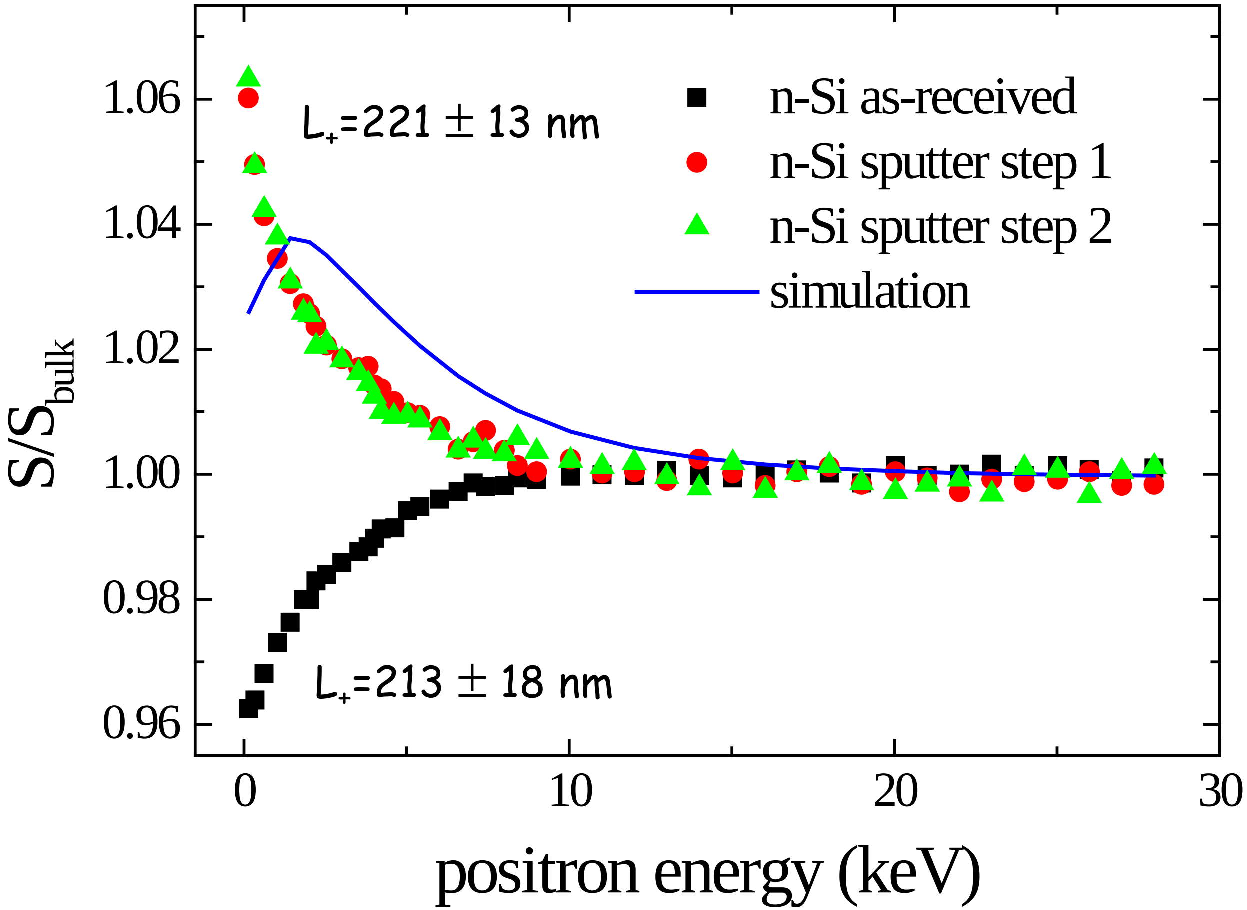
- Ar^+ Ions penetrate into surface
- create displacement cascades
- some cascades reach surface
- surface atoms are released

Simulated defect profiles created during sputtering



- in the moment: 1 keV @ 42° ⇒ defect depth ≈ 25 nm in Si
- only change of surface *S* parameter

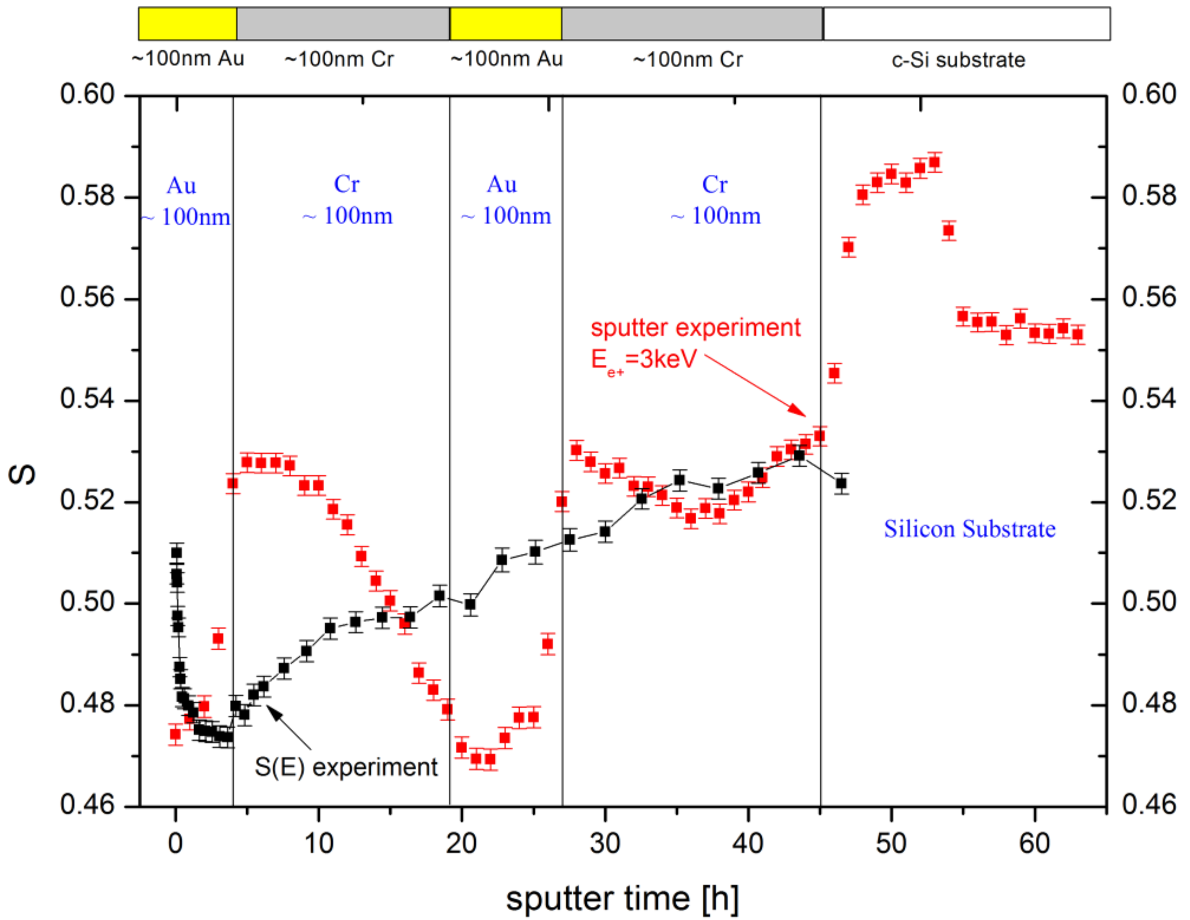
Sputter process changes surface parameter only



- 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 or diffusing defects

Results

Prove of principle with layer system Au/Cr/Au/Cr/Si

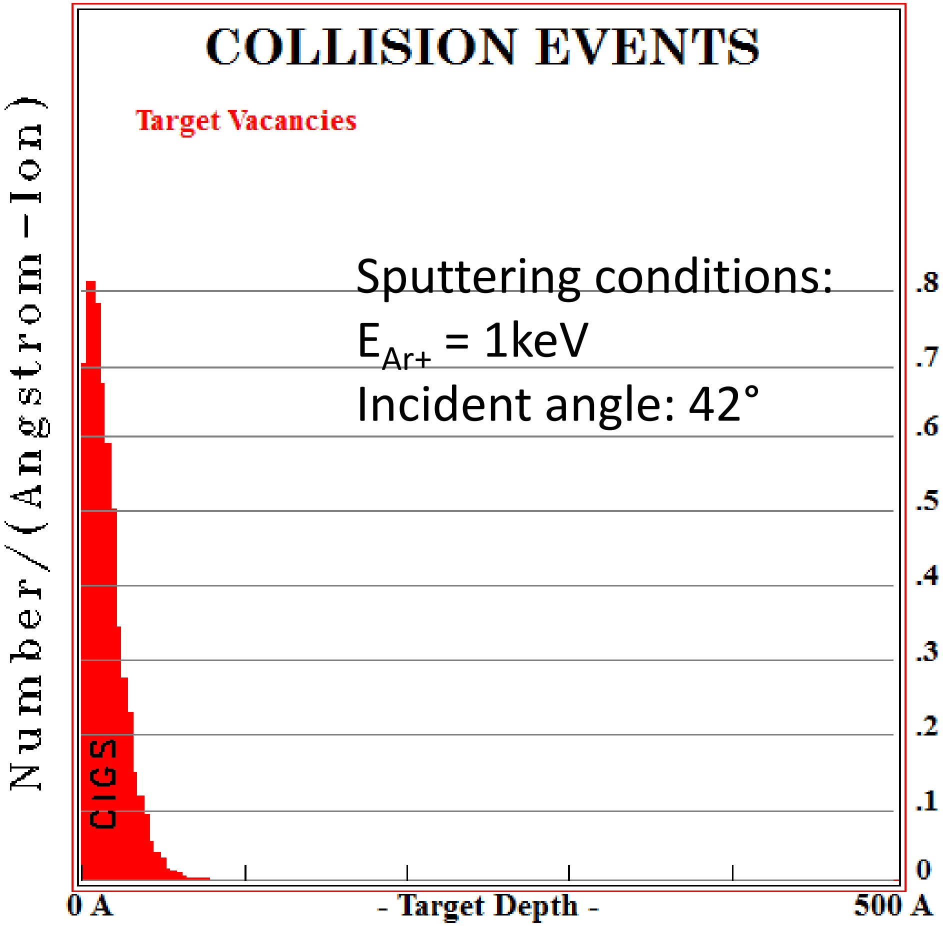


- with S(E) no defects measurable
- better depth resolution then S(E)-scan
- Interfaces sharply visible

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

Simulation of vacancy profile by Ar bombardment in CIGS

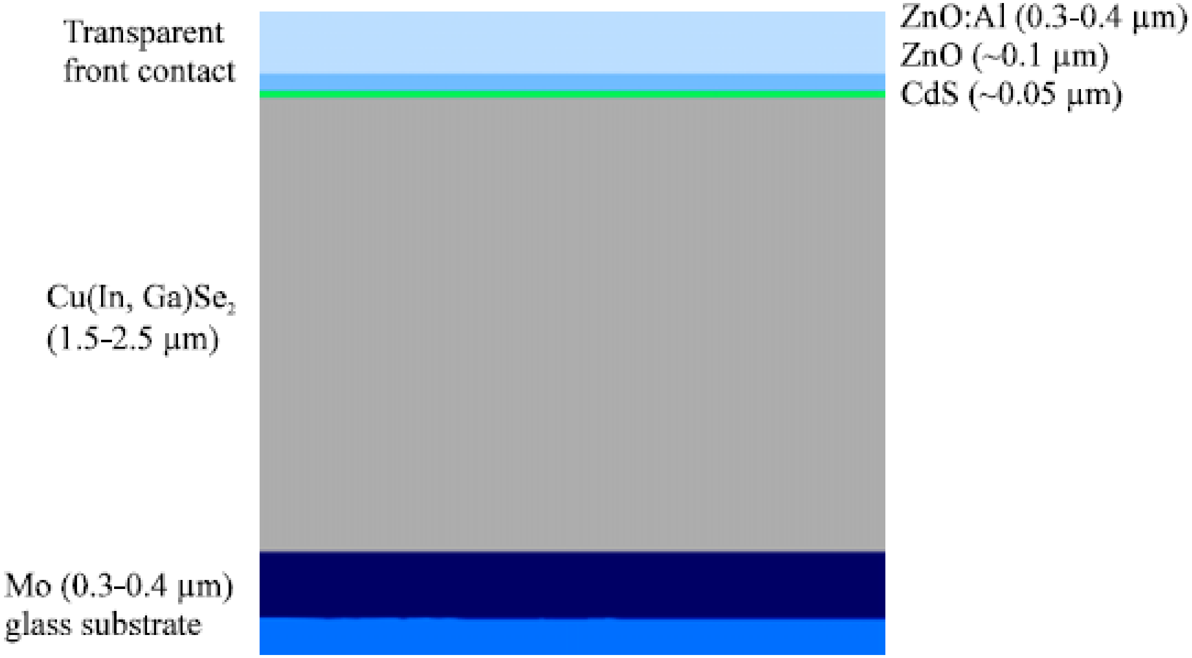
SRIM-Simulated defect profile for CIGS



- CIGS = $Cu(In,Ga)Se_2$ photovoltaic layer
- no vacancies beyond of 10 nm
- e^+ energy so that:
  - no influence of surface
  - still sharp e^+ implantation profile
- eventually several positrons energies at one sputter depth …

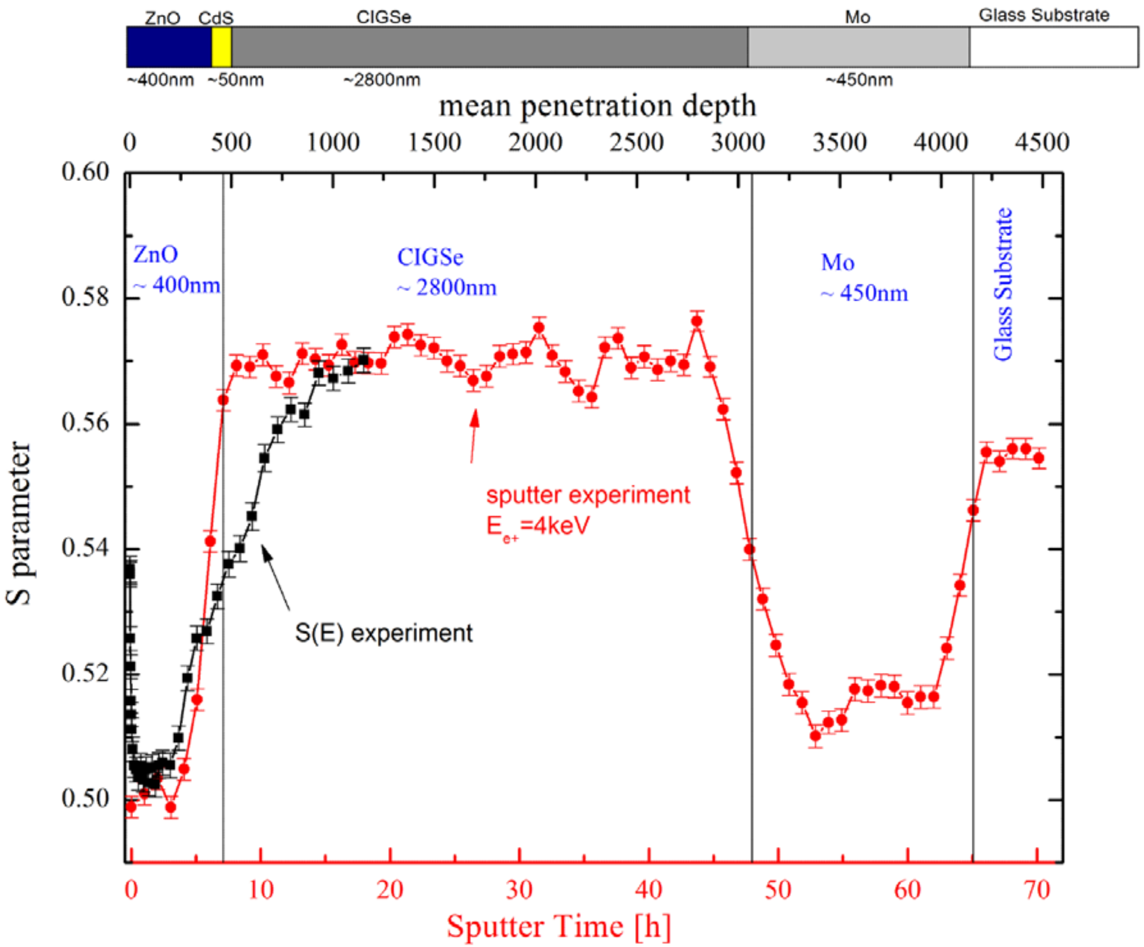
Results

Cu(In,Ga)Se_2 - (CIGSe)



- direct semiconductor
- E_g =1,04 eV – 1,67 eV
- used in thin film solar cells

Results



- Investigation of the whole solar cell, especially near the back contact

- In-situ sputtering

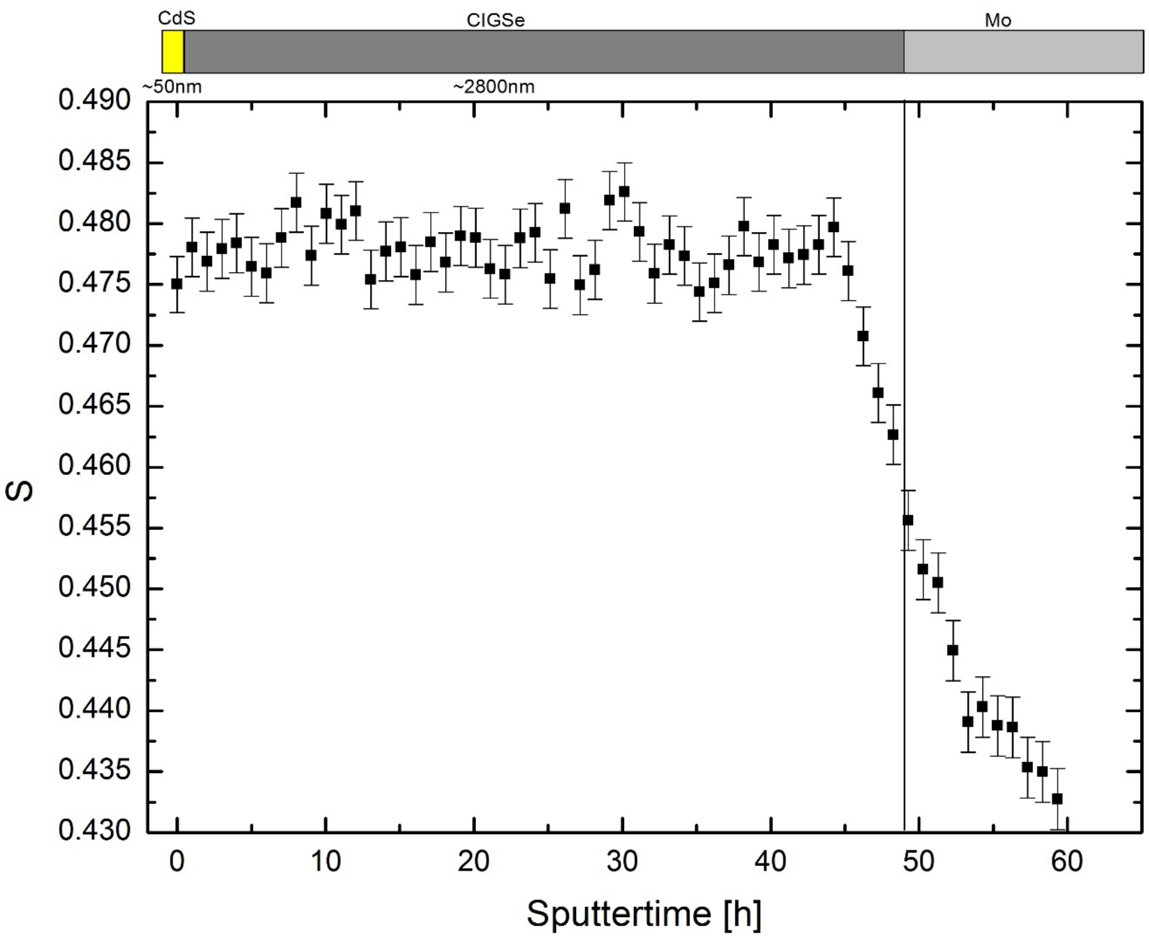
-> no air contact between the measurements

-> no degradation on the surface

-> shorter overall measurement time

Sputter parameters: I_B = 6 mA; U_B = 400 V

Results



- First sample of a CIGS series
- Result of today

Conclusions

- 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
- depth scan over 4 µm last about 40 h (100nm/h)

Acknoledgment

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