Improvement of depth resolution in slow-positron defect profiling

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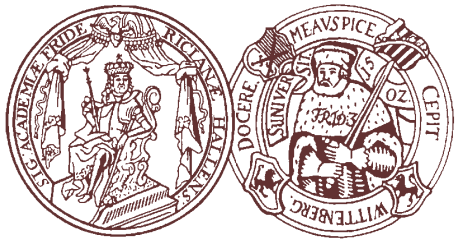
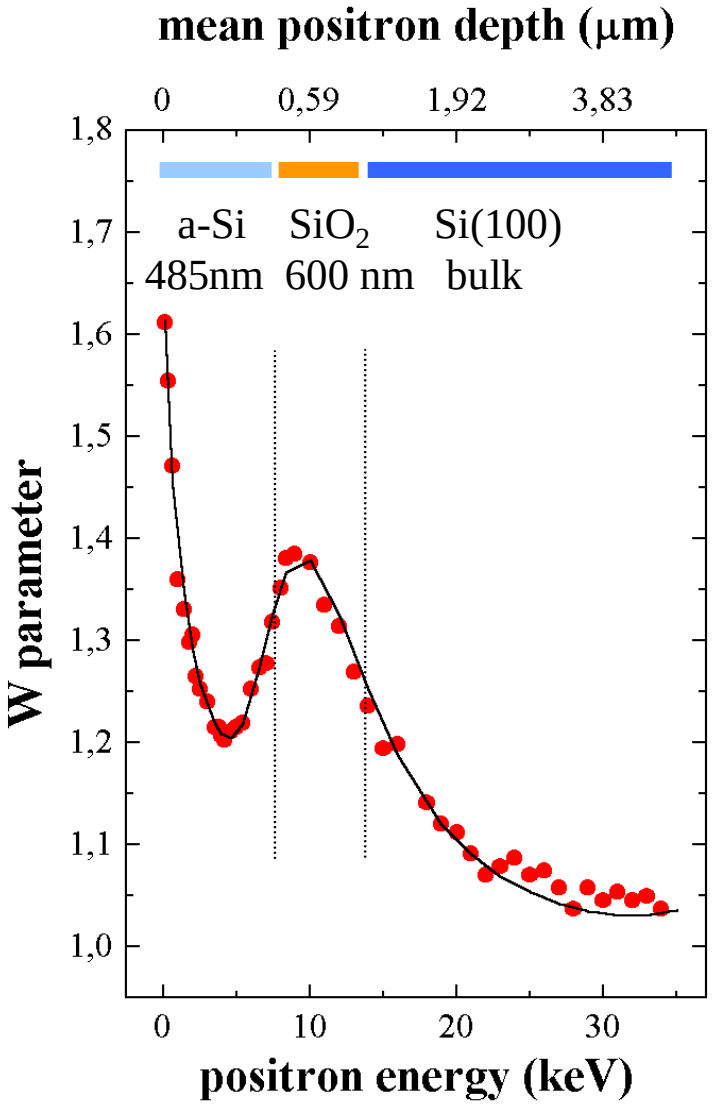
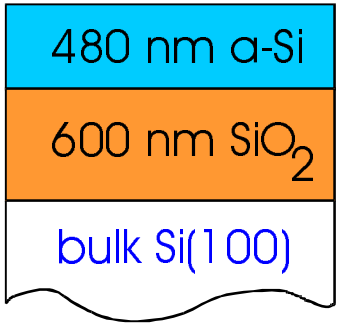


- the present dilemma: defect profiles cannot be reconstructed
- long-range defect profile (> 3 μm) : chemical etching
- a real improvement for a depth < 1μm: sputtering of the surface
  - ⇨ investigation of the structure: a-Si/a-SiO_2/Si(100)
  - ⇨ defect profiles after ion-implantation

The present dilemma: no real defect profiling



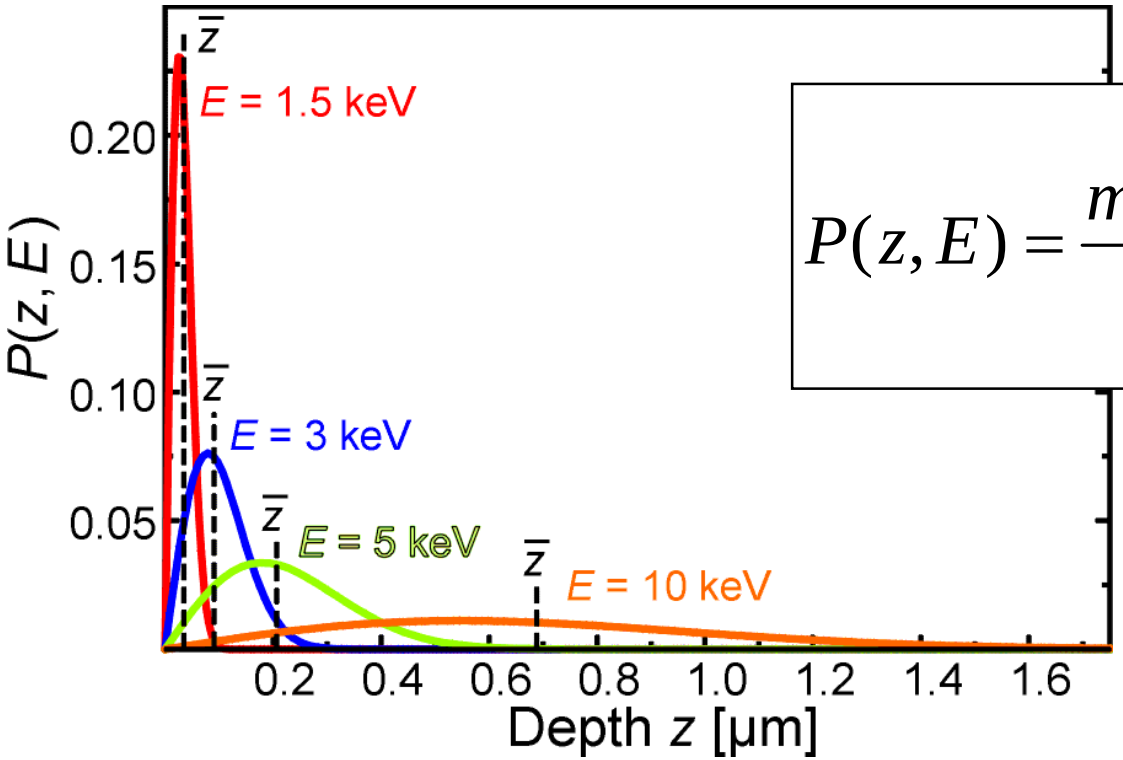
layer structure



- depth resolution mostly not restricted by positron diffusion
- mainly due to positron implantation profile of monoenergetic positrons
- in practice: defect distribution often approximated as block profile
- not possible to extract the actual defect profile
- problem: defects at interfaces or δ layers can easily be overlooked

Positron implantation profile

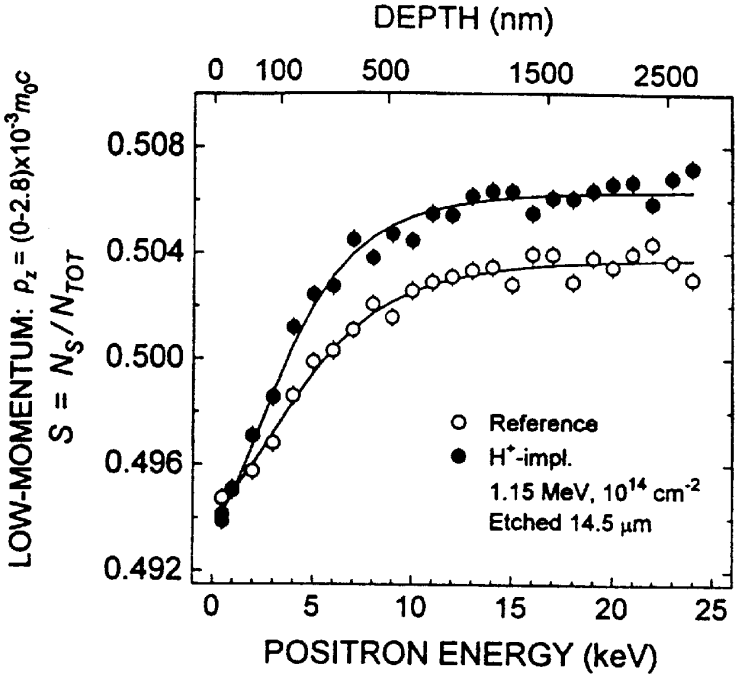
- implantation profile often approximated as Makhov profile
- better description: by Monte Carlo simulations
- extreme broad distribution of implanted positrons at E > 3 keV

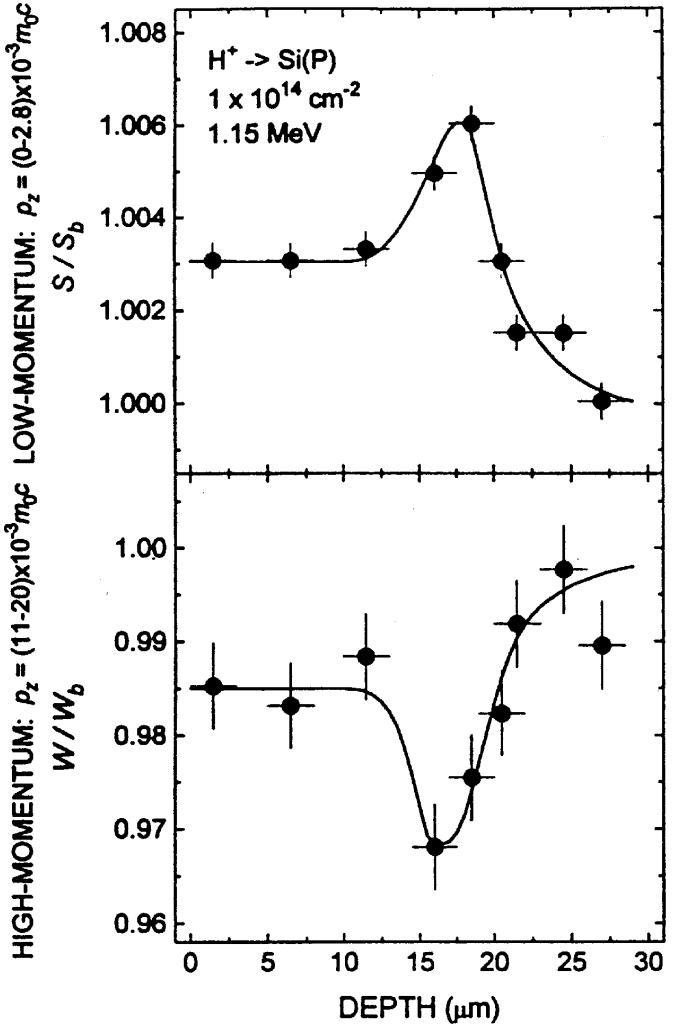


$$P(z,E) = \frac{m z^{m-1}}{z_0^m}\left[-\left(\frac{z}{z_0}\right)^m\right]$$

Defect profiling by chemical etching

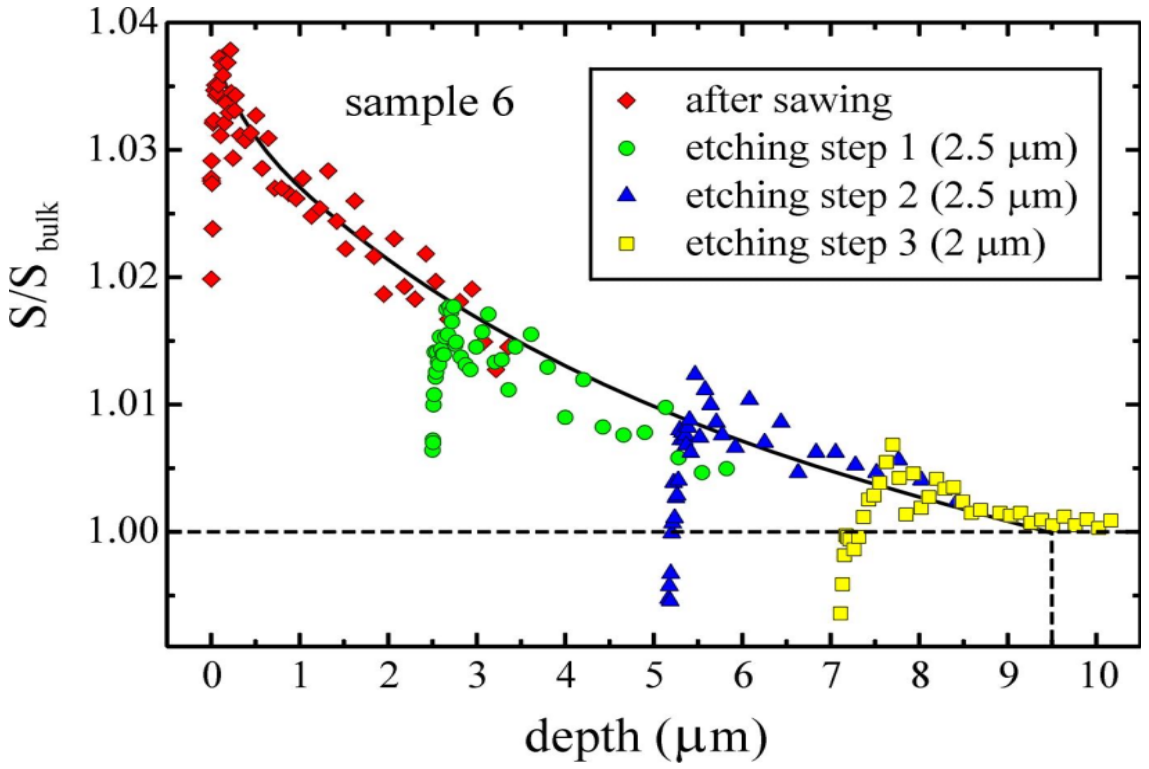
- high-energy proton irradiation
- defects too deep to be seen by S(E) scans
- way out: chemical etching





H. Kauppinen et. al: Phys. Rev. B **55** (1997) 9598

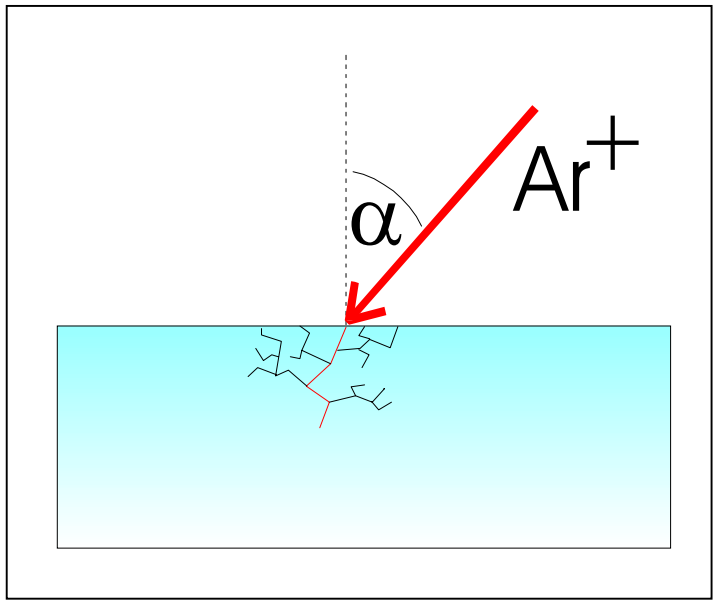
Defect profiling by chemical etching

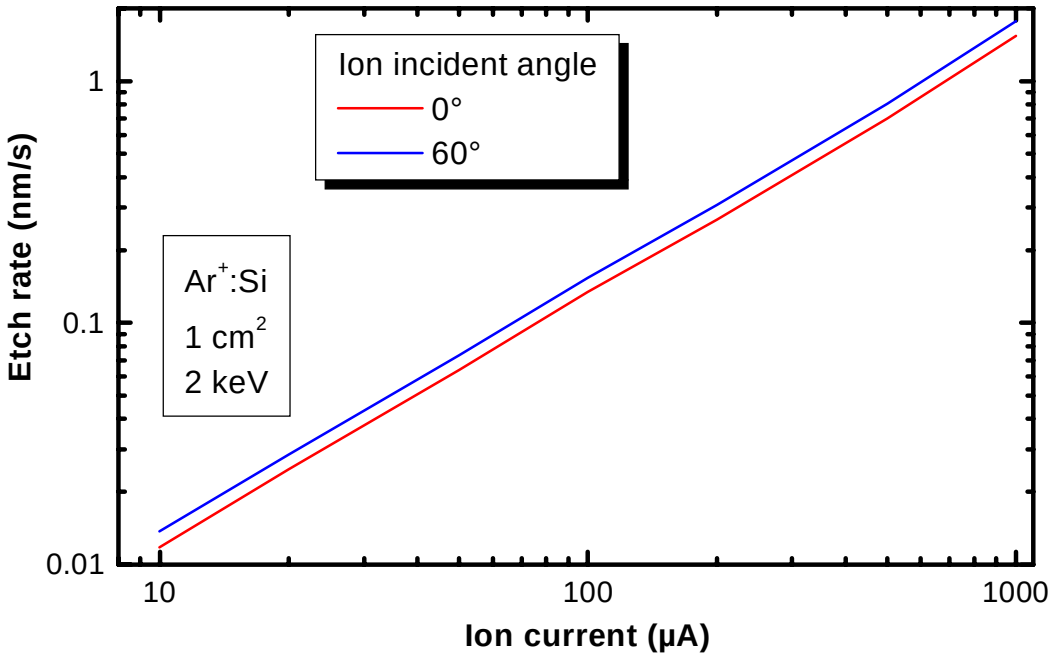


F. Börner et al.: J. Appl. Phys. 84 (4), 2255-2262 (1998)

- Sawing of GaAs wafers by a diamond wheel saw creates defectprofile
- Depth: several µm
- Profile becomes visible by chemical etching and repeated slow positron measurement
- etching difficult to control (homogeneity, depth)
- can only be used for rather thick defect layers
- etching in nm scale: ion sputtering

Surface removal by sputtering



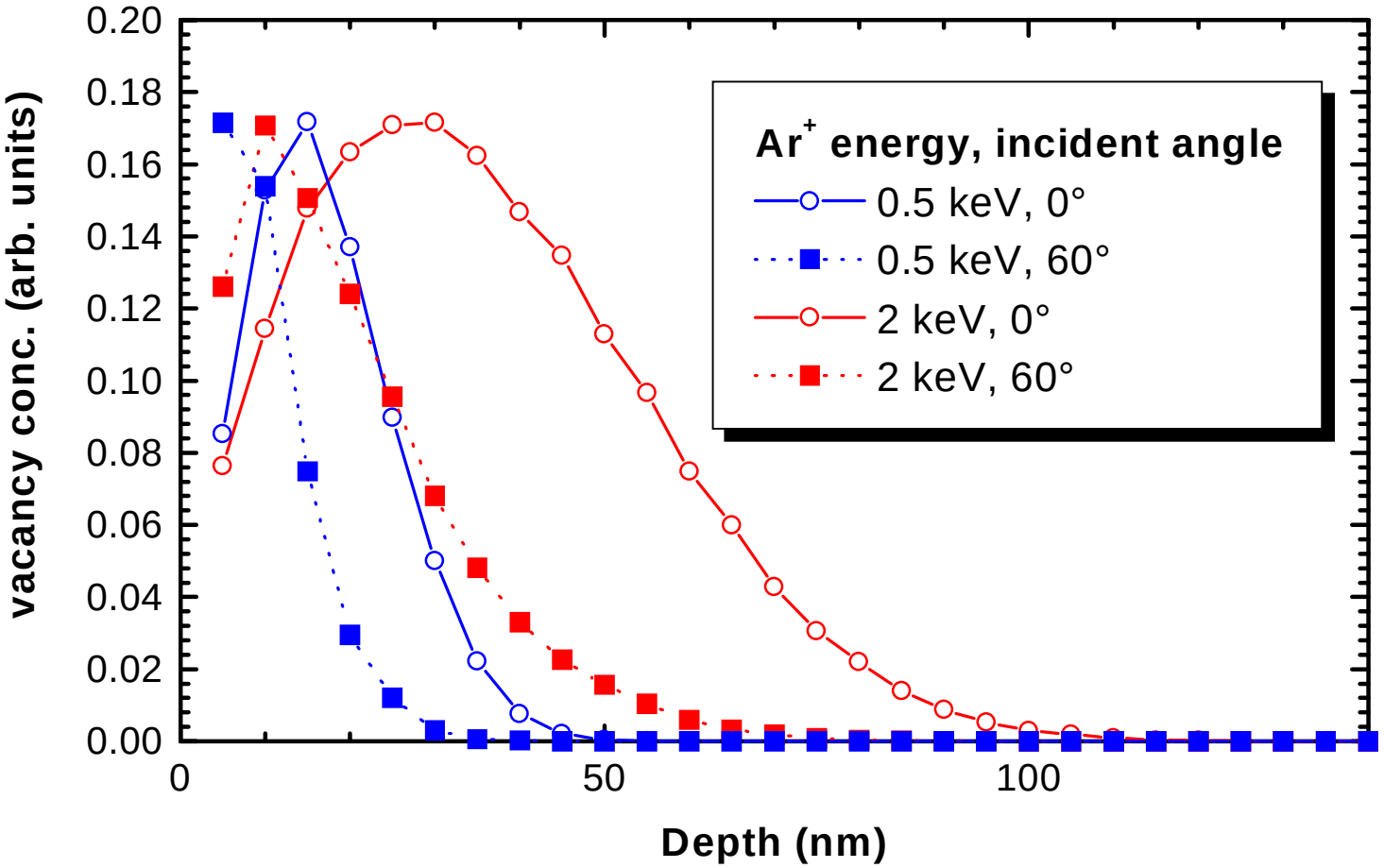


- Ar^+ Ions penetrate into surface
- create displacement cascades
- some cascades reach surface
- surface atoms are released

- Ion current is a function of Ar pressure
- our conditions: 10^{-6} Torr
- sputtering is performed by a sputter gun
- available for about $ 10,000 (standard) and $ 22.000 (scanning ion beam)

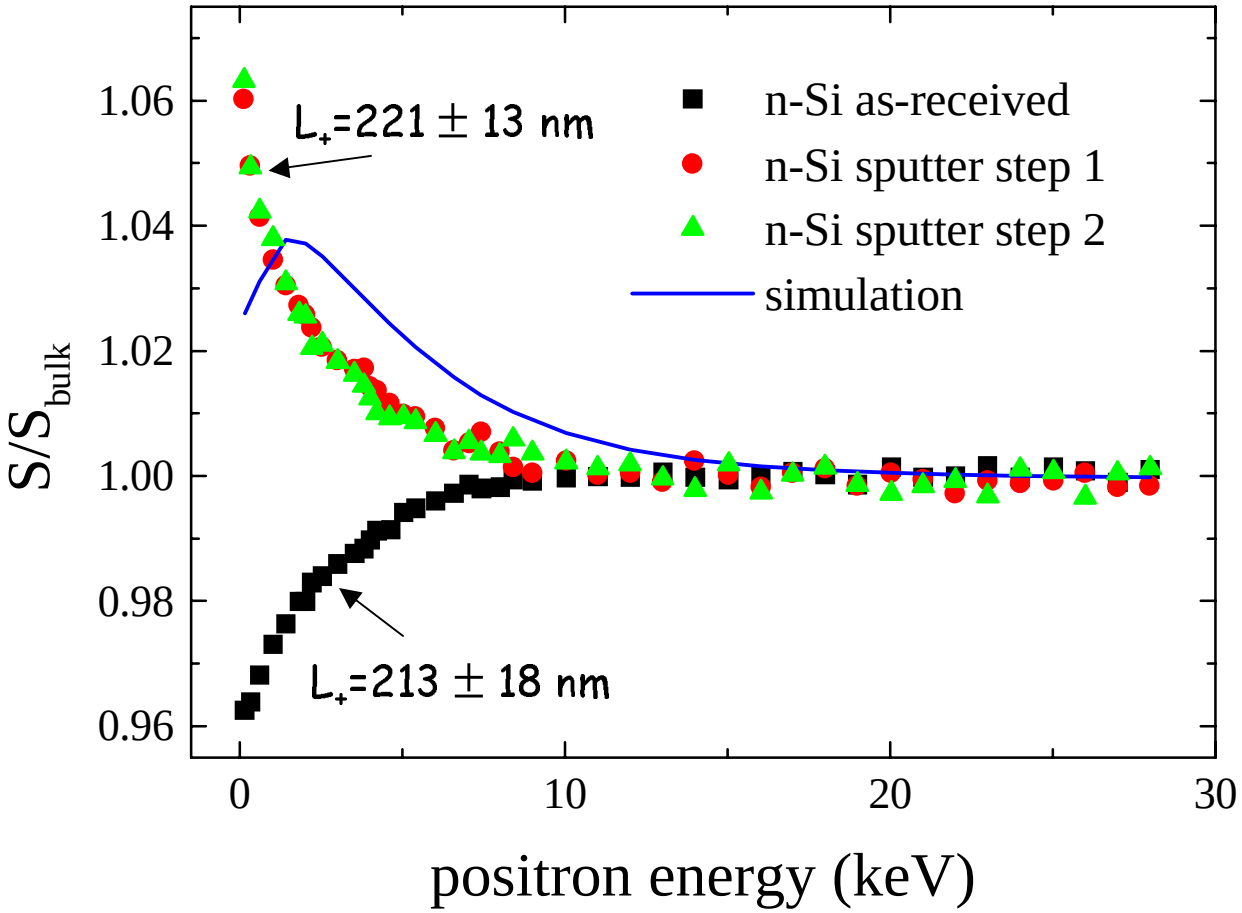
Defect profiles created during sputtering

TRIM simulations: do not consider removal of surface → calculated profiles too deep



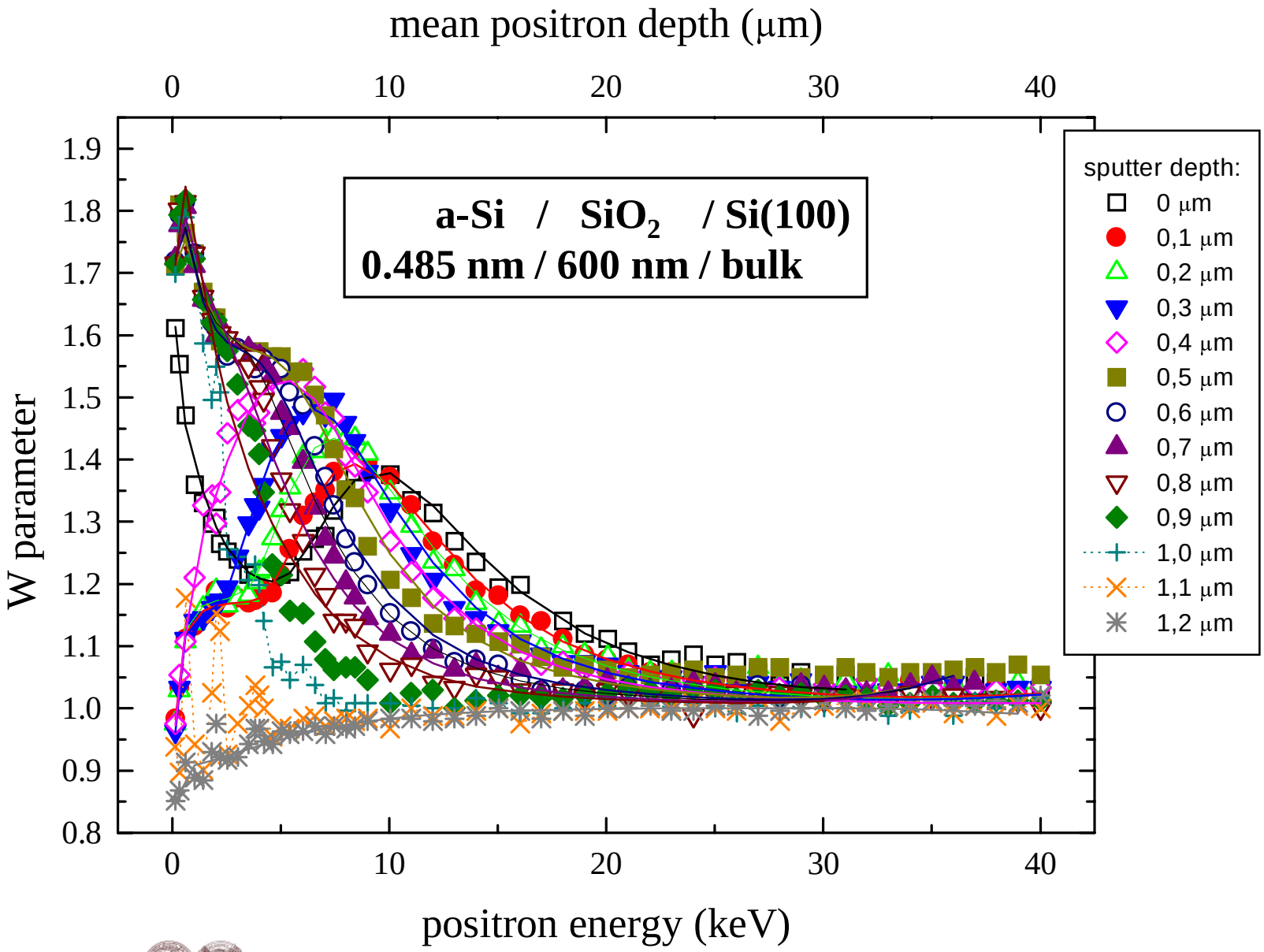
best conditions for us: low energy, large angle

Sputter process changes surface parameters only

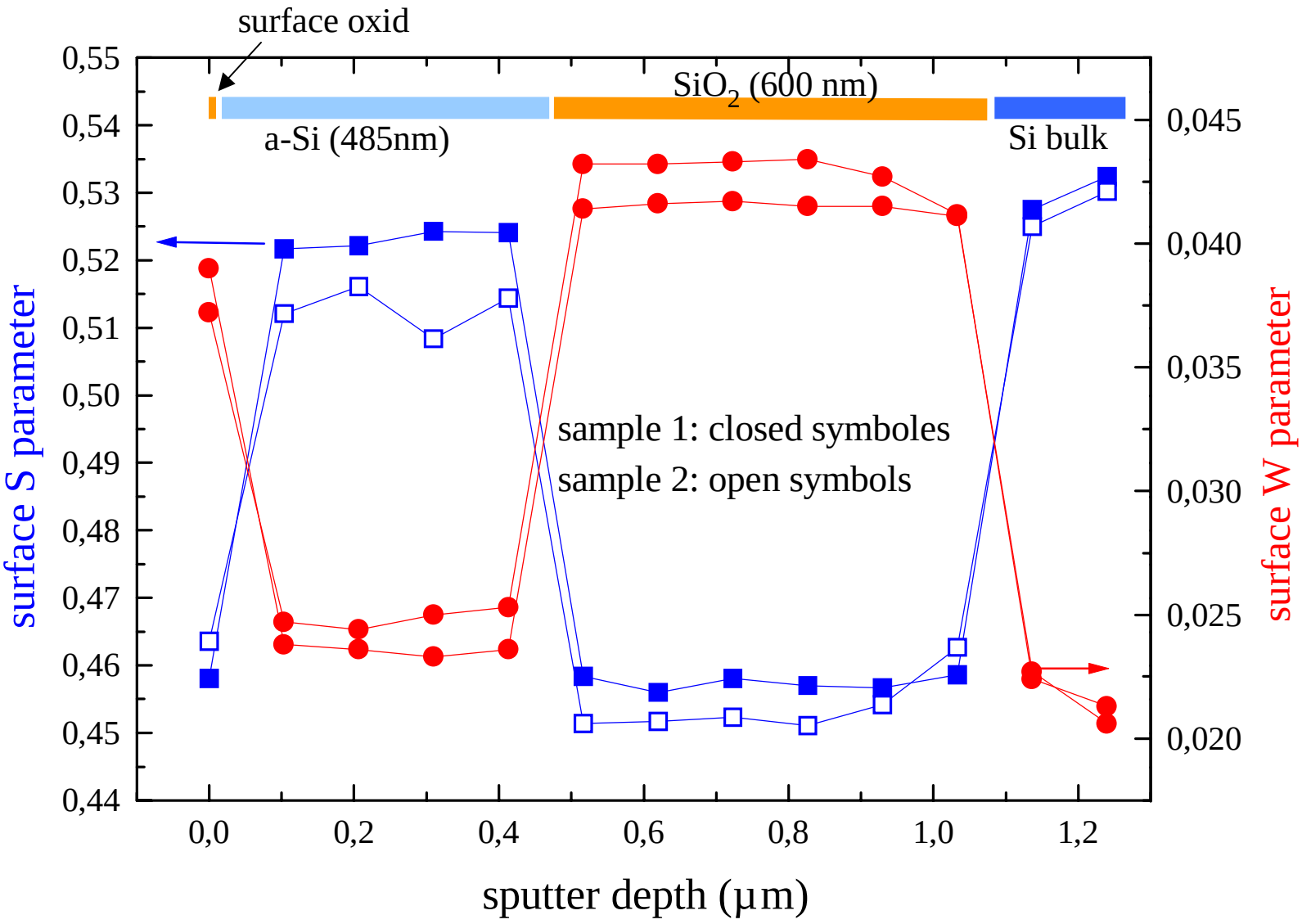


- sputter conditions: 2 keV, 60°
- no change of positron diffusion length due to sputtering

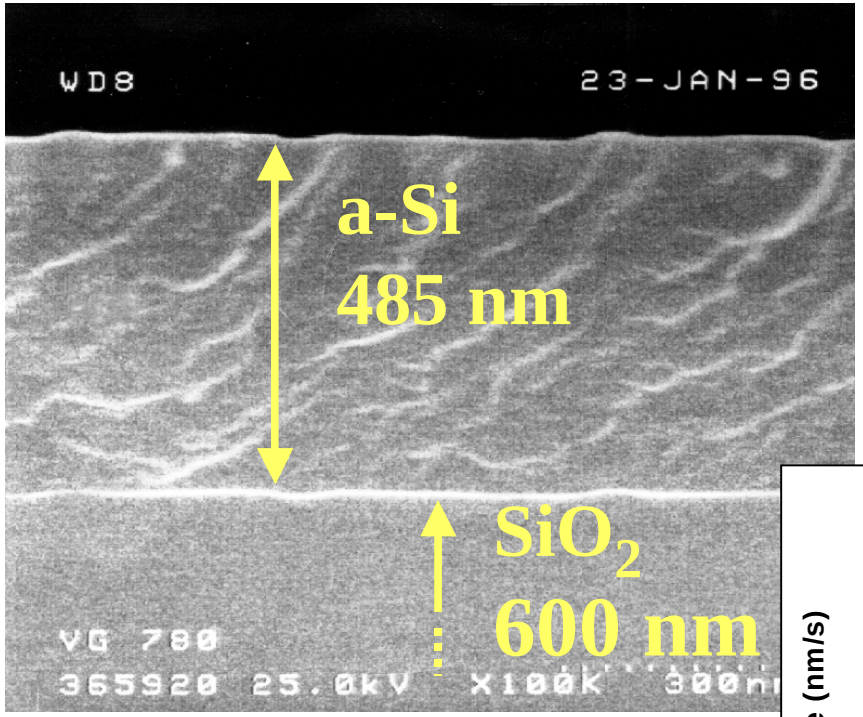
Full energy scans as function of sputter depth



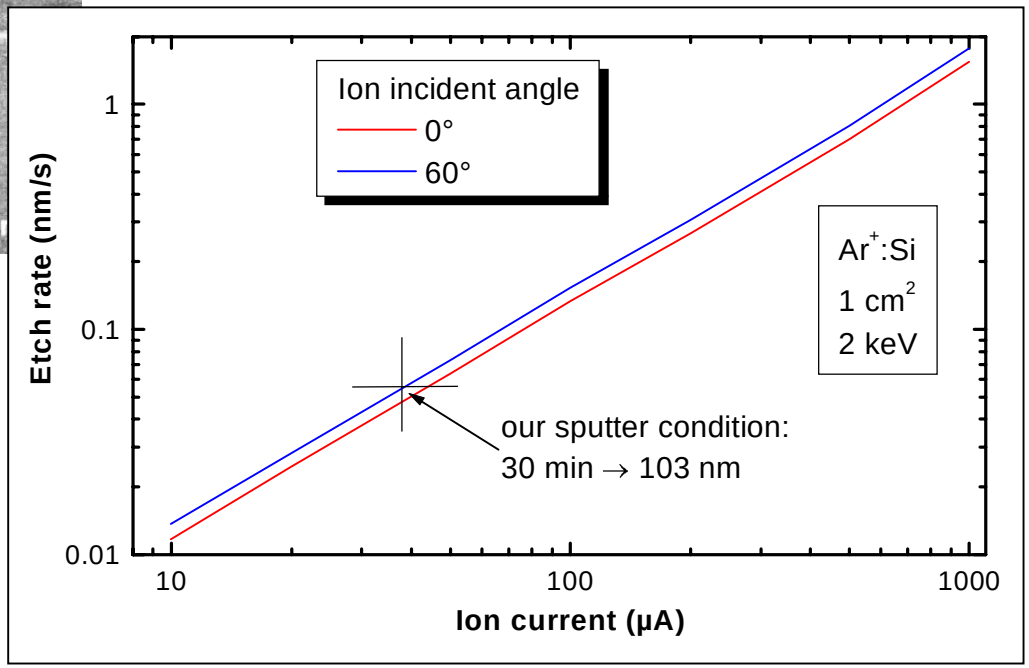
Surface annihilation parameters



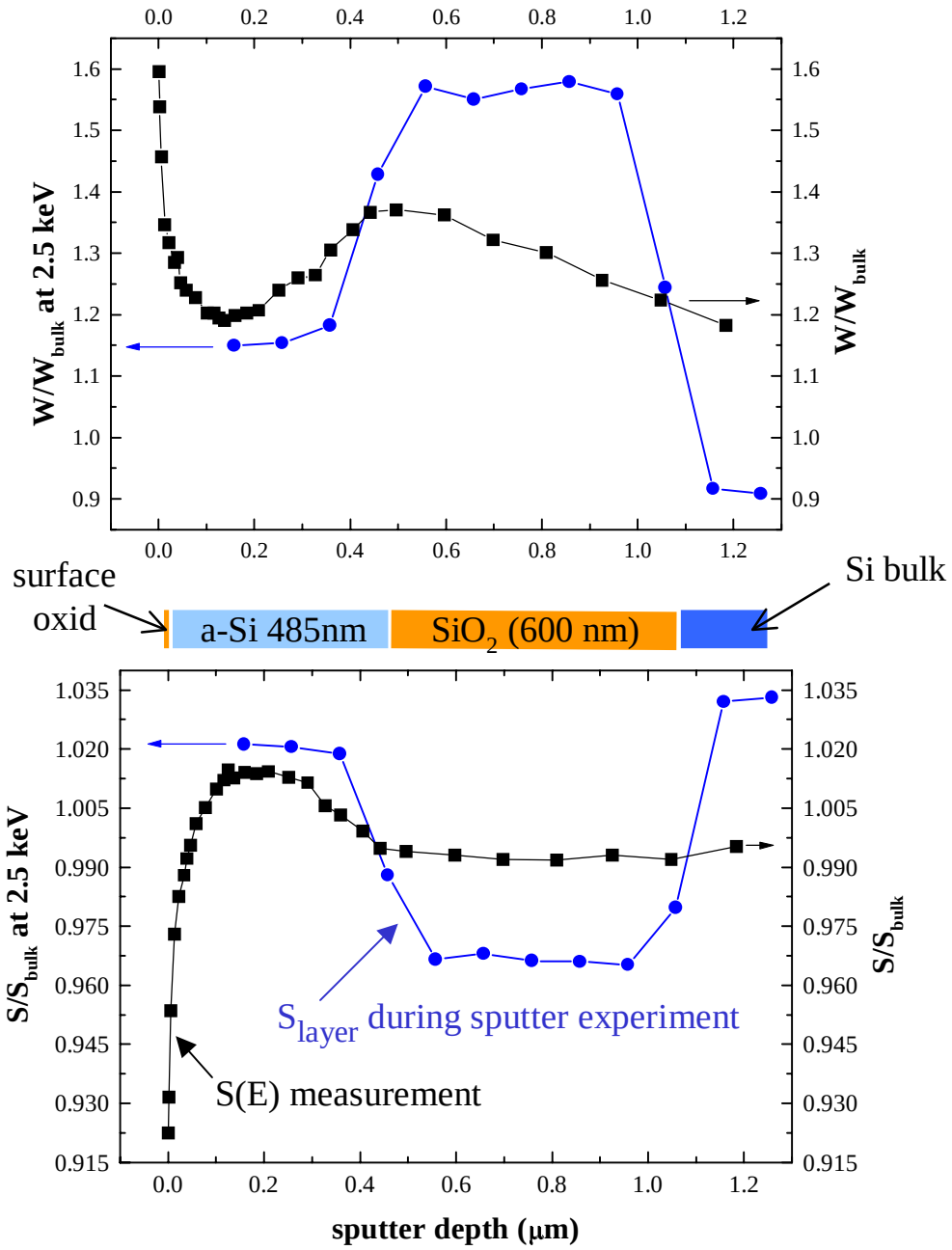
Calibration of sputter etch rate



- thickness was determined by cross-sectional scanning electron microscopy
- sputtering at an Ar pressure of 10^{-6} Torr for 30 min takes ≈ 100 nm away



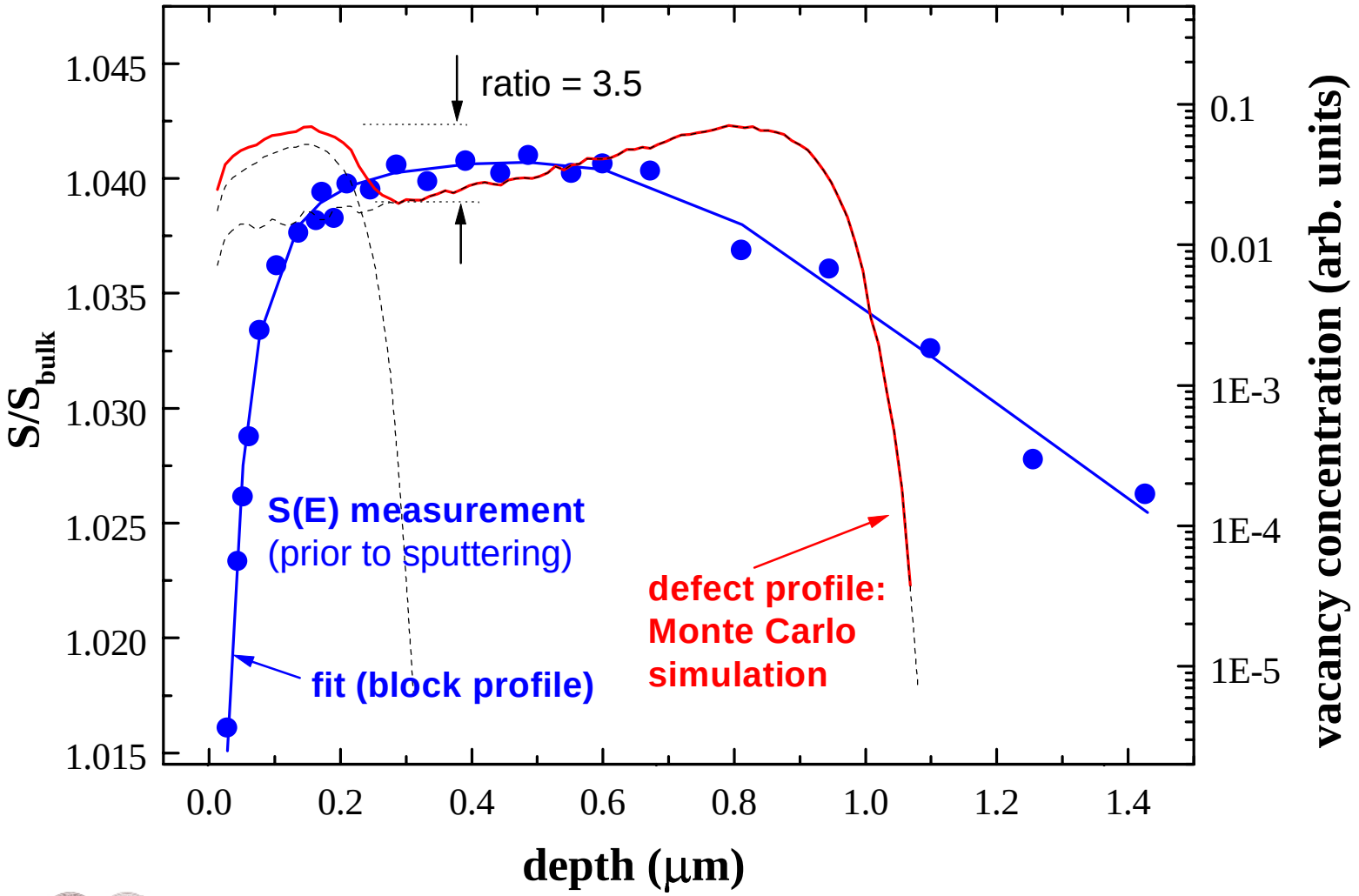
Annihilation parameters as function of depth



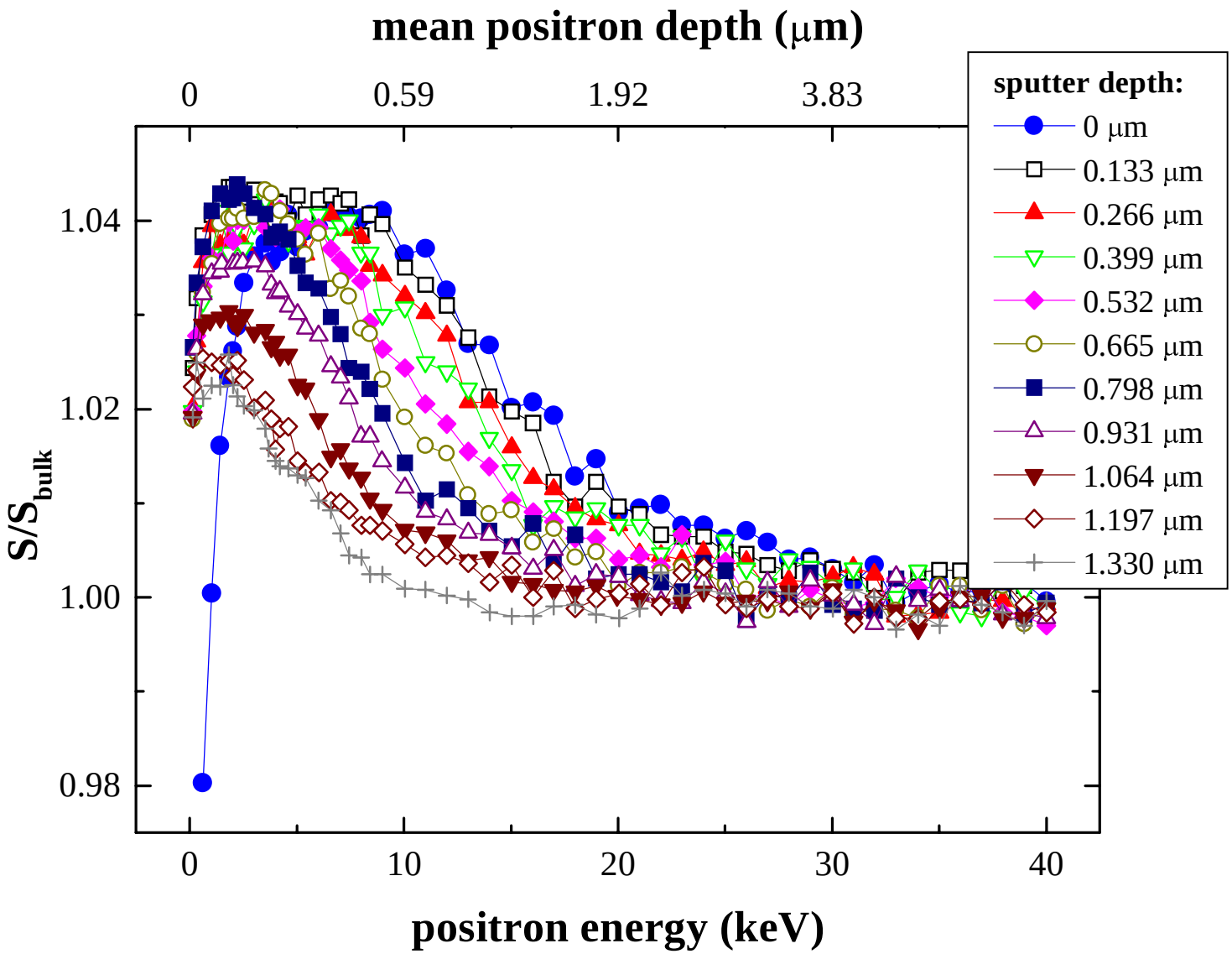
- annihilation parameters are taken in a suitable depth after each sputtering step
- e^+ energy choosen so that:
  - must be no influence of surface
  - still sharp e^+ implantation profile
- annihilation parameters of all layers are precisely obtained
- important especially for deep layers
- depth resolution is limited by e^+ diffusion, not by implantation profile

Defect profile after ion implantation

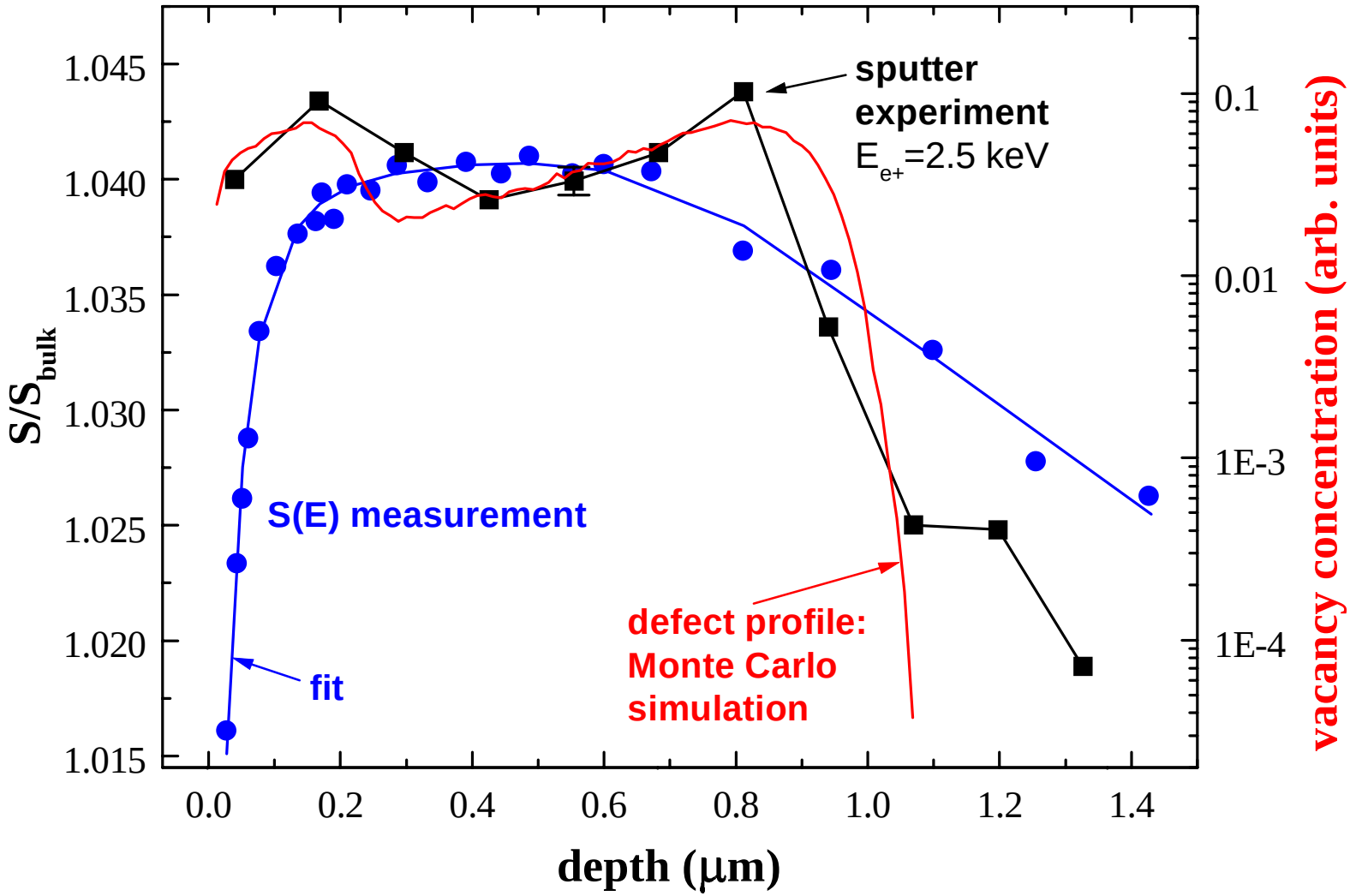
twofold implantation: B:Si 50 keV (2.5×10^{15} cm^{-2}) and 300 keV (5×10^{15} cm^{-2})



Sputter experiment after twofold ion implantation



Full energy scans as function of sputter depth



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)
- typical layer parameters can be measured directly instead of fitting them
- chemical information independent of defects by surface annihilation parameters
- disadvantage: not nondestructive

Acknowledgement

We would like to thank:

- Mr. G. Lenk (Univ. Jena) for ion implantation
- Dr. P. Zeindl for supplying the a-Si/SiO_2/Si sample
- Positron annihilators in Halle and Dr. S. Eichler for fruitful discussions

This presentation can be found as slide show at the "Positrons in Halle" Webpage:

http://www.ep3.uni-halle.de/positrons

Announcement

Workshop: Positron Source at DESY in Hamburg

Time: 1.-3. September 1999

Location: DESY, Hamburg, Germany

Information and registration: http://www.ep3.uni-halle.de/positrons/POST

Aims:

- discussion whether such a project makes sense (FRM-II, ELBE)
- convincing DESY authorities that a) positrons are useful and b) that there are enough potential users
- discussion of technical problems
- to establish a group of people who are willing to further support this project

In case you are interested in such a positron source, but you are unable to come to the workshop: Please contact me anyway!