The microscopic nature of gettering defects at $R_p/2$ in high-energy self-implanted silicon

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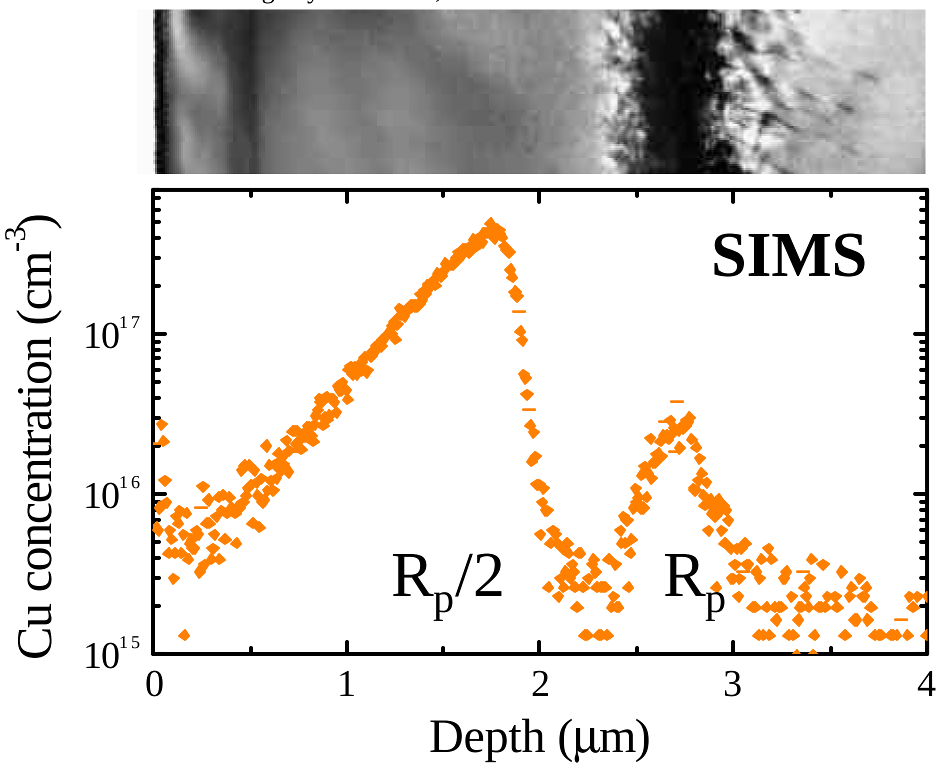
- Introduction: The $R_p/2$ effect in Si
- Study using depth-resolution-enhanced Positron Beams
- Conclusions

Defects in high-energy self-implanted Si ¾ The $R_p/2$ effect

- after high-energy (3.5 MeV) self-implantation of Si (5×10^{15} cm^{-2}) and RTA annealing (900°C, 30s): two new gettering zones appear at R_p and $R_p/2$ (R_p = projected range of Si^+)
- visible by SIMS profiling after intentional Cu contamination

TEM image by P. Werner, MPI Halle



- at R_p: gettering by interstitial-type dislocation loops (formed by excess interstitials during RTA)
- no defects visible by TEM at $R_p/2$
- **What type are these defects?**

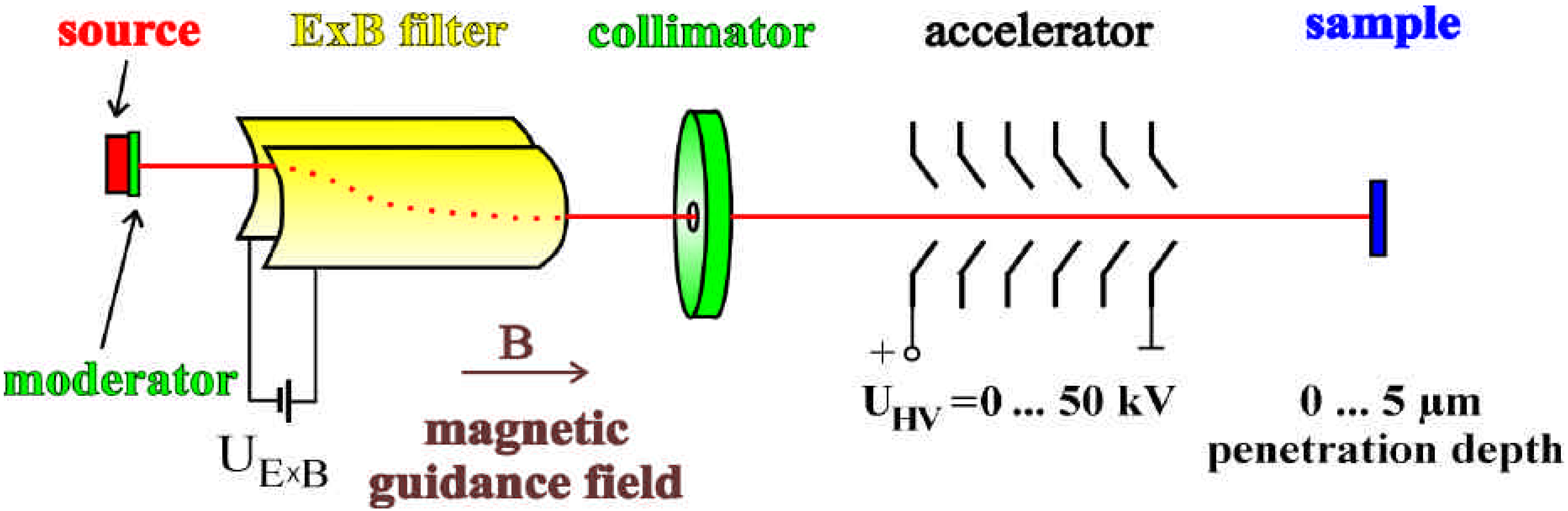
Interstitial type [3,4]

Vacancy type [1,2]

[1] R. A. Brown, et al., J. Appl. Phys. **84** (1998) 2459
[2] J. Xu, et al., Appl. Phys. Lett. **74** (1999) 997
[3] R. Kögler, et al., Appl. Phys. Lett. **75** (1999) 1279
[4] A. Peeva, et al., NIM B **161** (2000) 1090

Conventional positron beam technique

- positron annihilation successful in characterization of open-volume defects
- positron beam of mono-energetic positrons
- positrons are trapped at open-volume defects and change annihilation characteristics
- positron implantation depth varied by accelerating voltage (VEPAS)



magnetically guided positron beam system at Univ. Halle

Positron beam measurement with enhanced depth resolution

- mono-energetic positrons exhibit broad implantation profile
- the defect layers are expected in a depth of 1.7 µm and 2.8 µm corresponding to E_+= 18 and 25 keV
- implantation profile too broad to discriminate between the two zones

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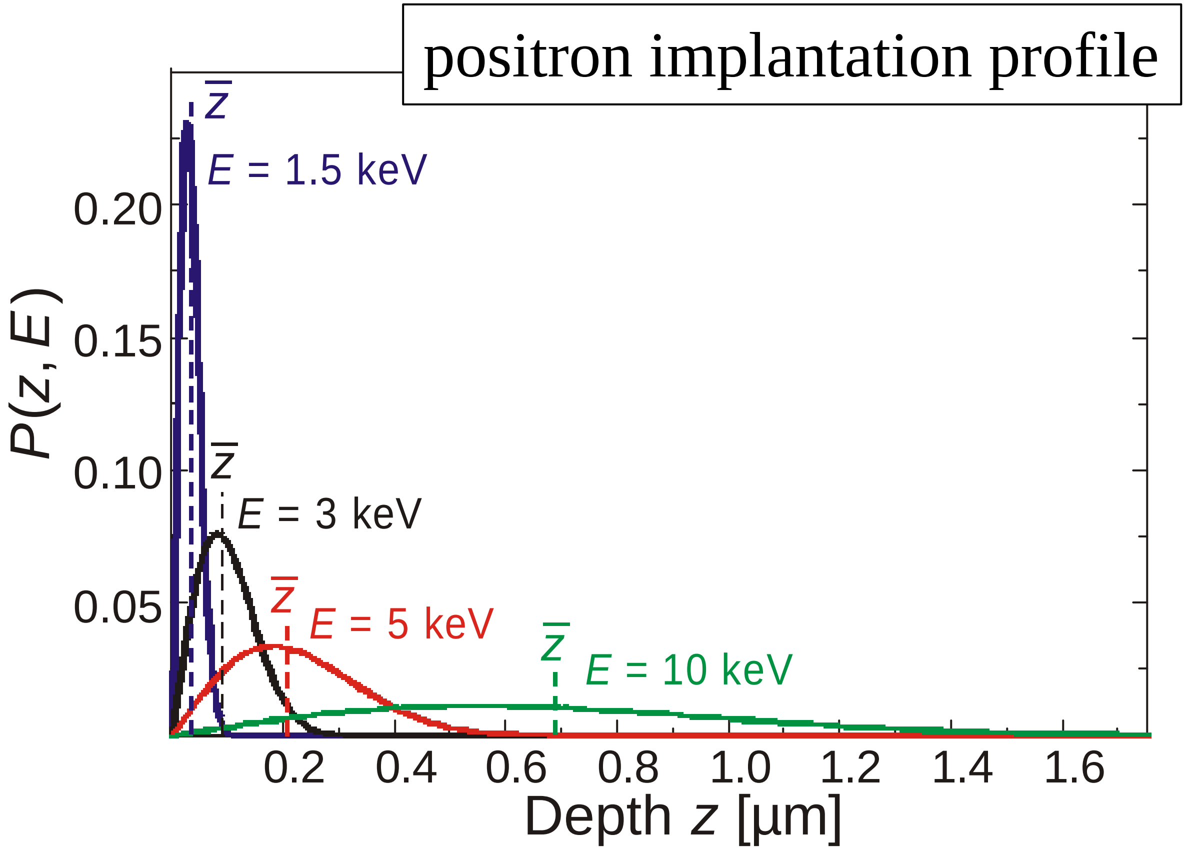
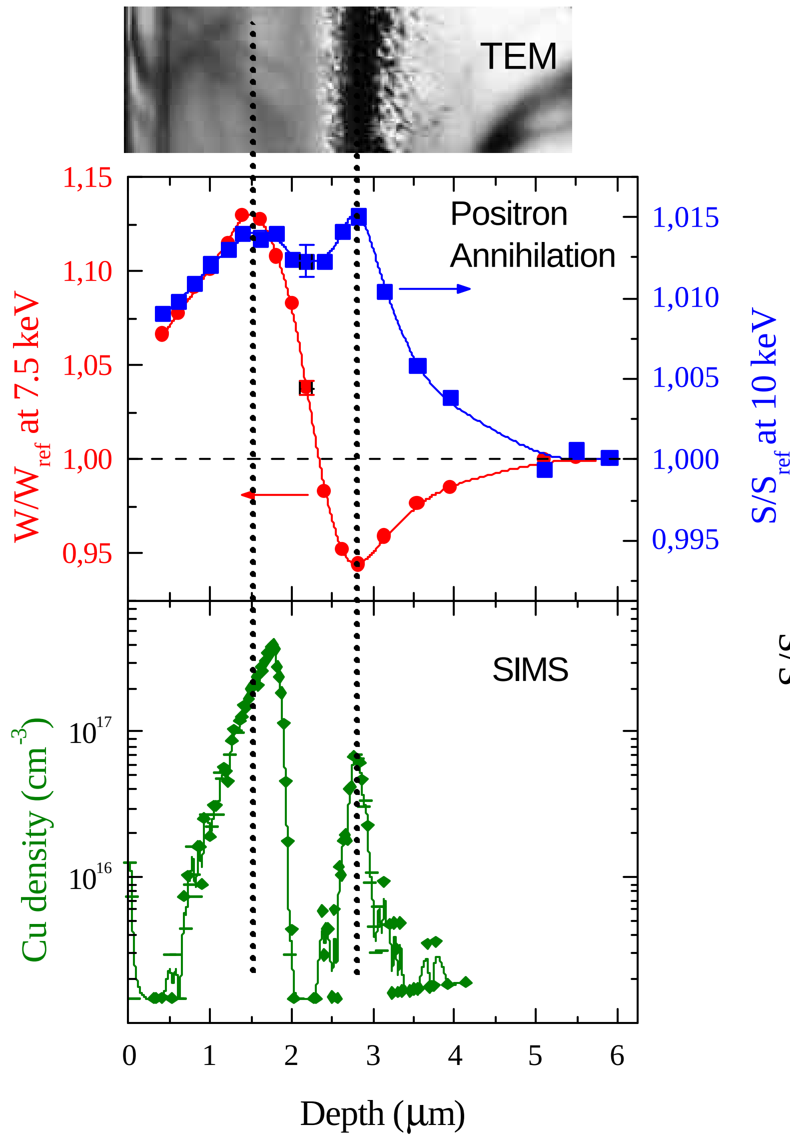
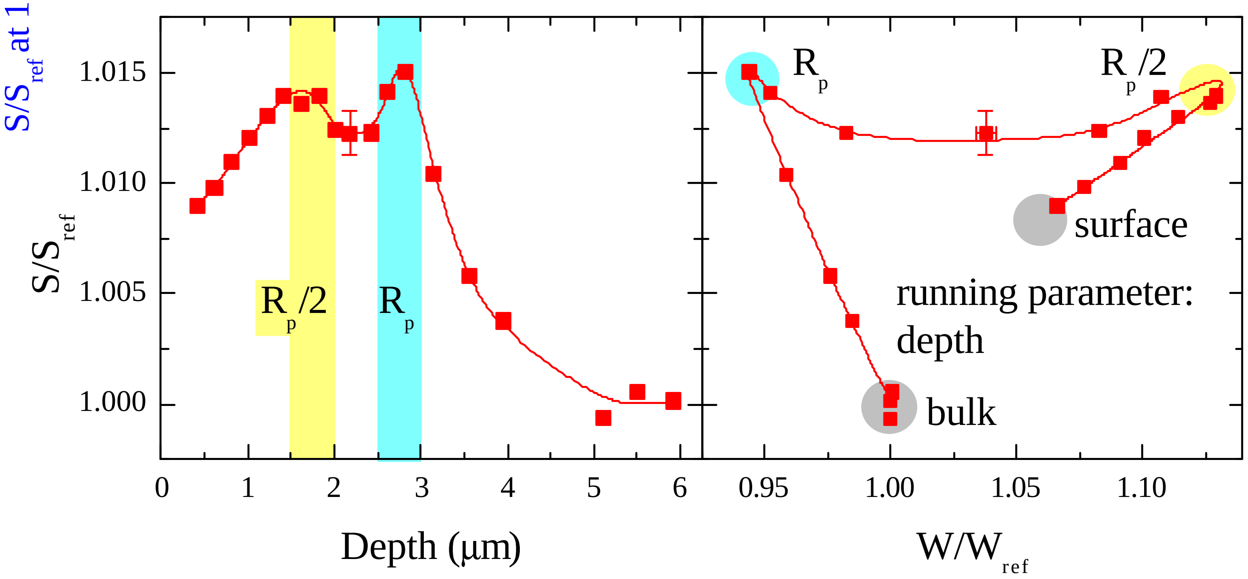
- step-by-step removal of sample surface by sputtering
- measurement at low e^+ energy with high depth resolution



Getter centers after high-energy self-implantation in Si

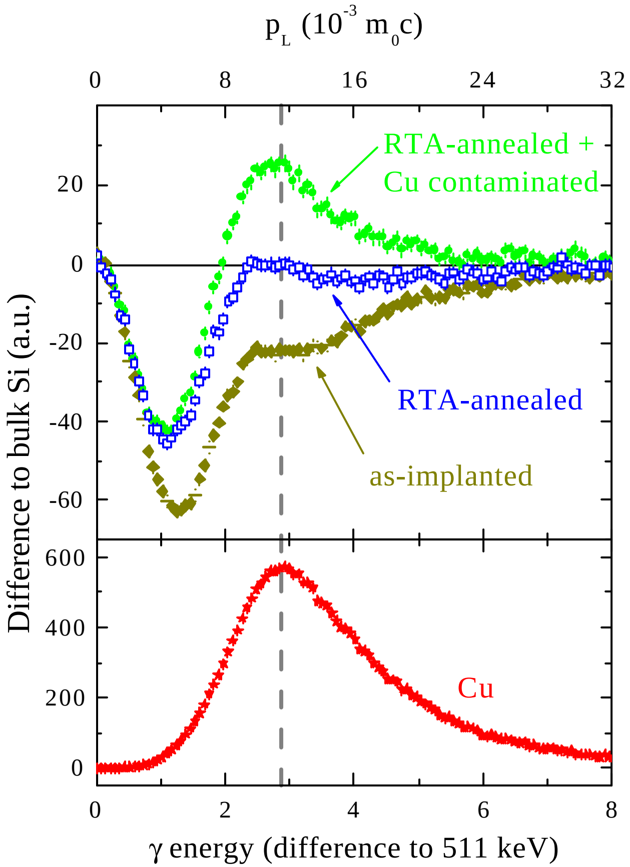


- VEPAS with improved depth resolution show clearly open-volume defects at $R_p/2$ and R_p
- they must be different (see S-W-plot)
- "normal" behavior of W parameter at R_p but high value at $R_p/2$: Cu decorates the vacancy-type defect

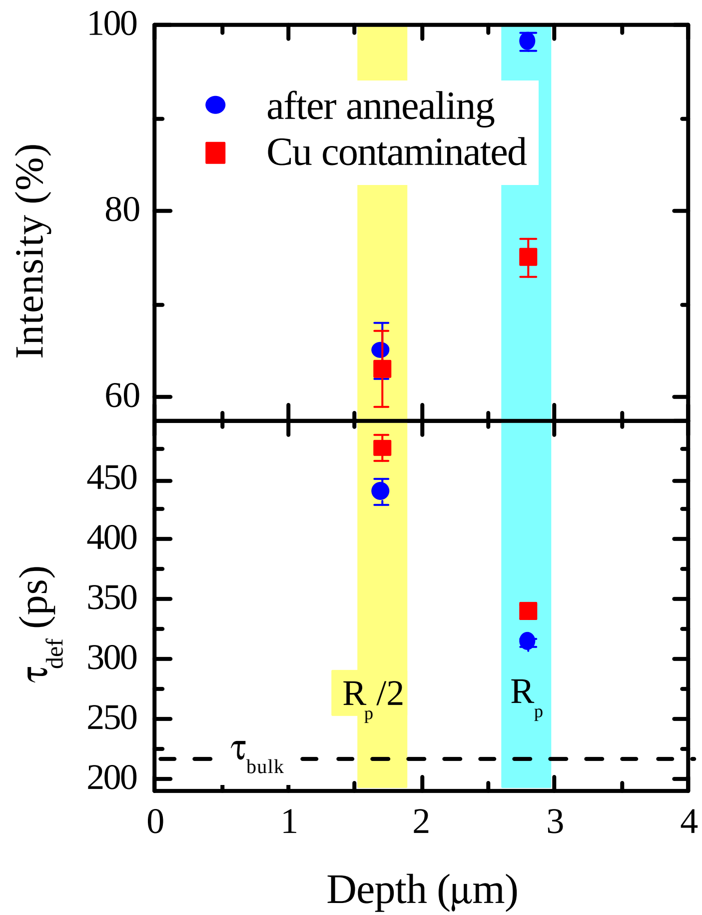


Doppler-coincidence and lifetime spectroscopy

- Doppler-coincidence spectroscopy shows the existence of Cu at the $R_p/2$ defect
- positron lifetime spectroscopy needed for determination of open volume size



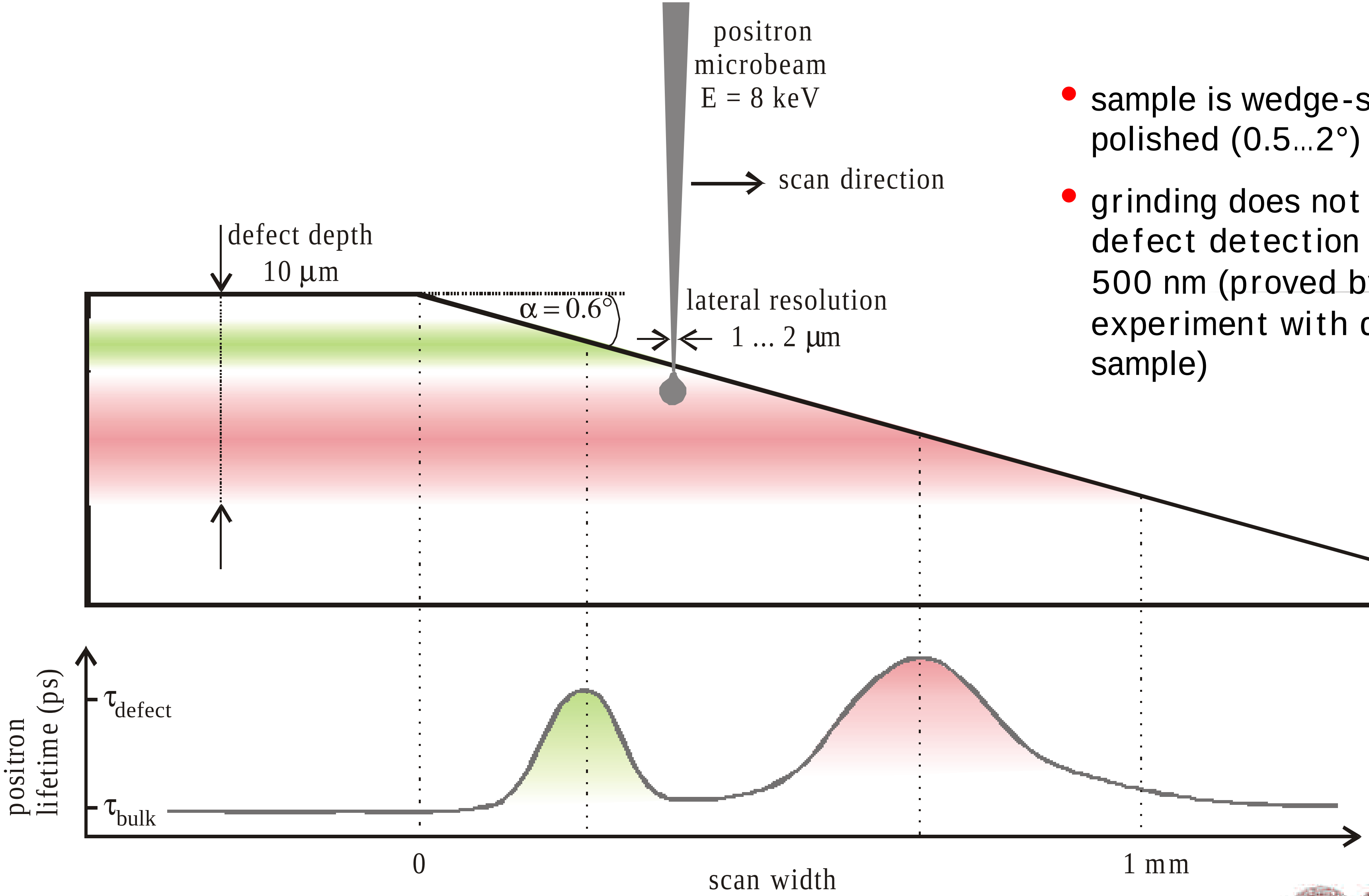
- samples were chemically etched and positron lifetime was measured at Munich Slow-Positron Lifetime Beam System
- at $R_p/2$: τ_d=450 ps (vacancy cluster, n > 10)
- at R_p: τ_d=320 ps (open volume = divacancy)



Conclusions

- **R_p/2:** small vacancy clusters are getter centers
- **R_p:** positrons are trapped by defects at dislocation loops

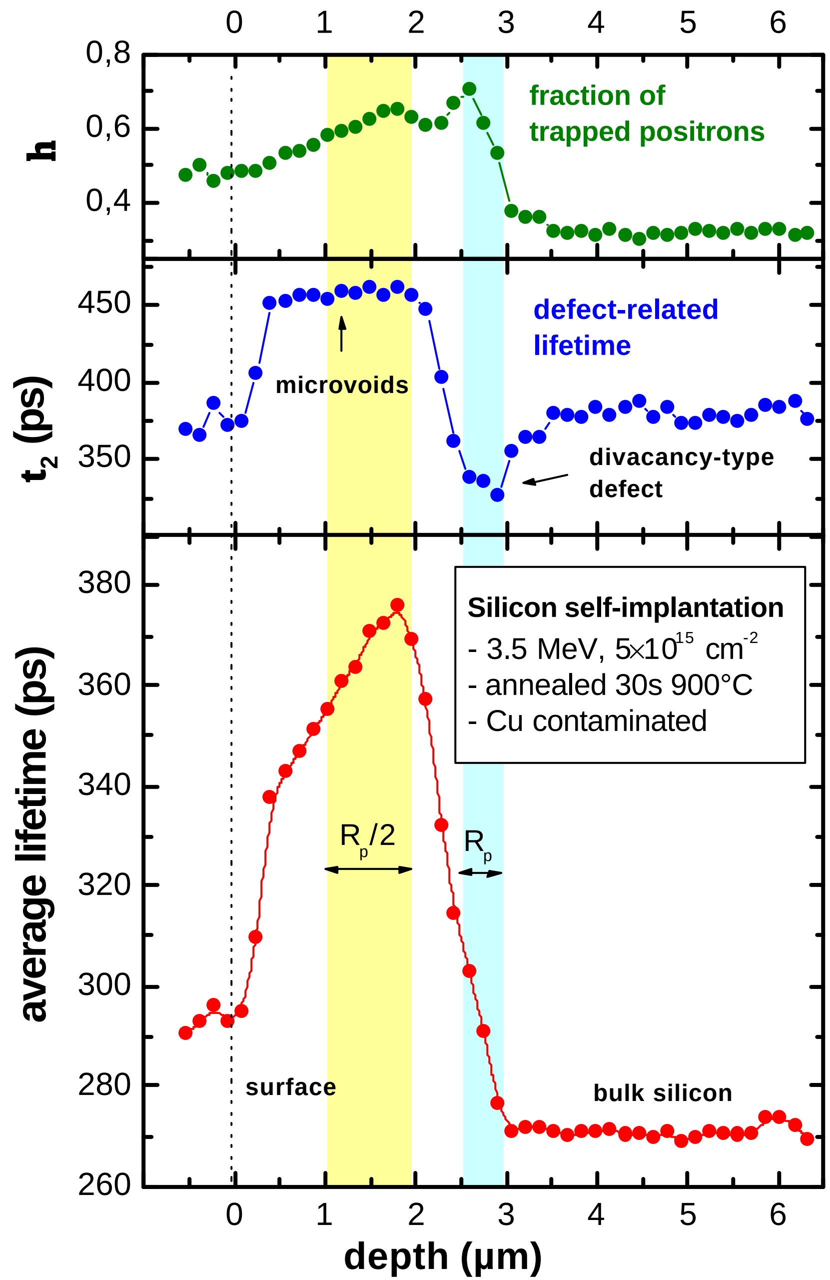
Enhanced depth resolution by using the Munich Scanning Positron Microscope

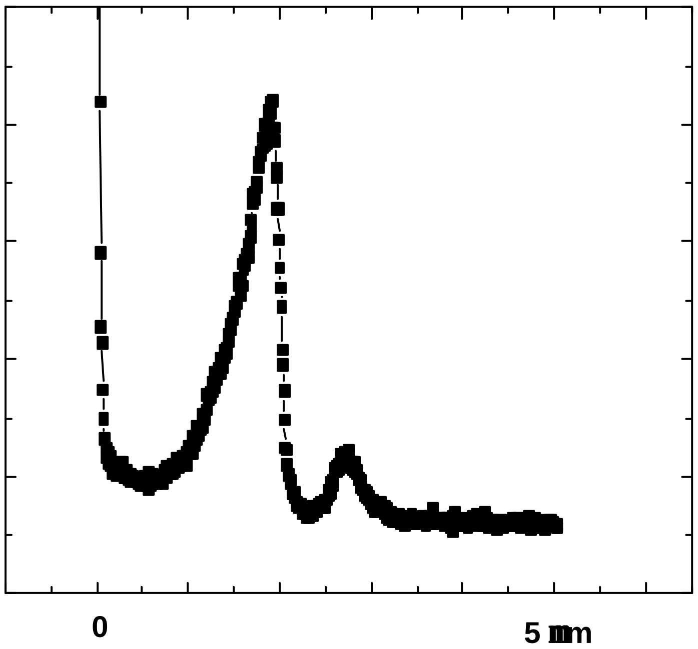


- sample is wedge-shaped polished (0.5...2°)
- grinding does not affect the defect detection in a depth of 500 nm (proved by reference experiment with defect-free sample)

First defect depth profile using Positron Microscopy

- 45 lifetime spectra: scan along wedge
- separation of 11 µm between two measurements corresponds to depth difference of 155 nm (α = 0.81°)
- beam energy of 8 keV ⇒ mean penetration depth is about 400 nm; represents optimum depth resolution
- no improvement possible due to positron diffusion: L_+(Si @ 300K) ≈ 230 nm
- both regions well visible:
  - vacancy clusters with increasing density down to 2 µm ($R_p/2$ region)
  - in R_p region: lifetime τ_2 = 330 ps; corresponds to open volume of a divacancy; must be stabilized or being part of interstitial-type dislocation loops





SIMS profile of Cu

Conclusions

- Vacancy agglomerates are the getter centers at $R_p/2$
- Depth profiling using positron microscope very promising

This presentation can be found as pdf-files on our Website:
http://www.ep3.uni-halle.de/positrons