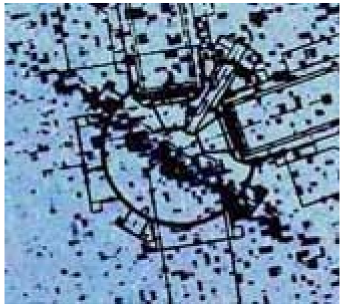
Study of lattice defects in solids by positron annihilation


MPS2000

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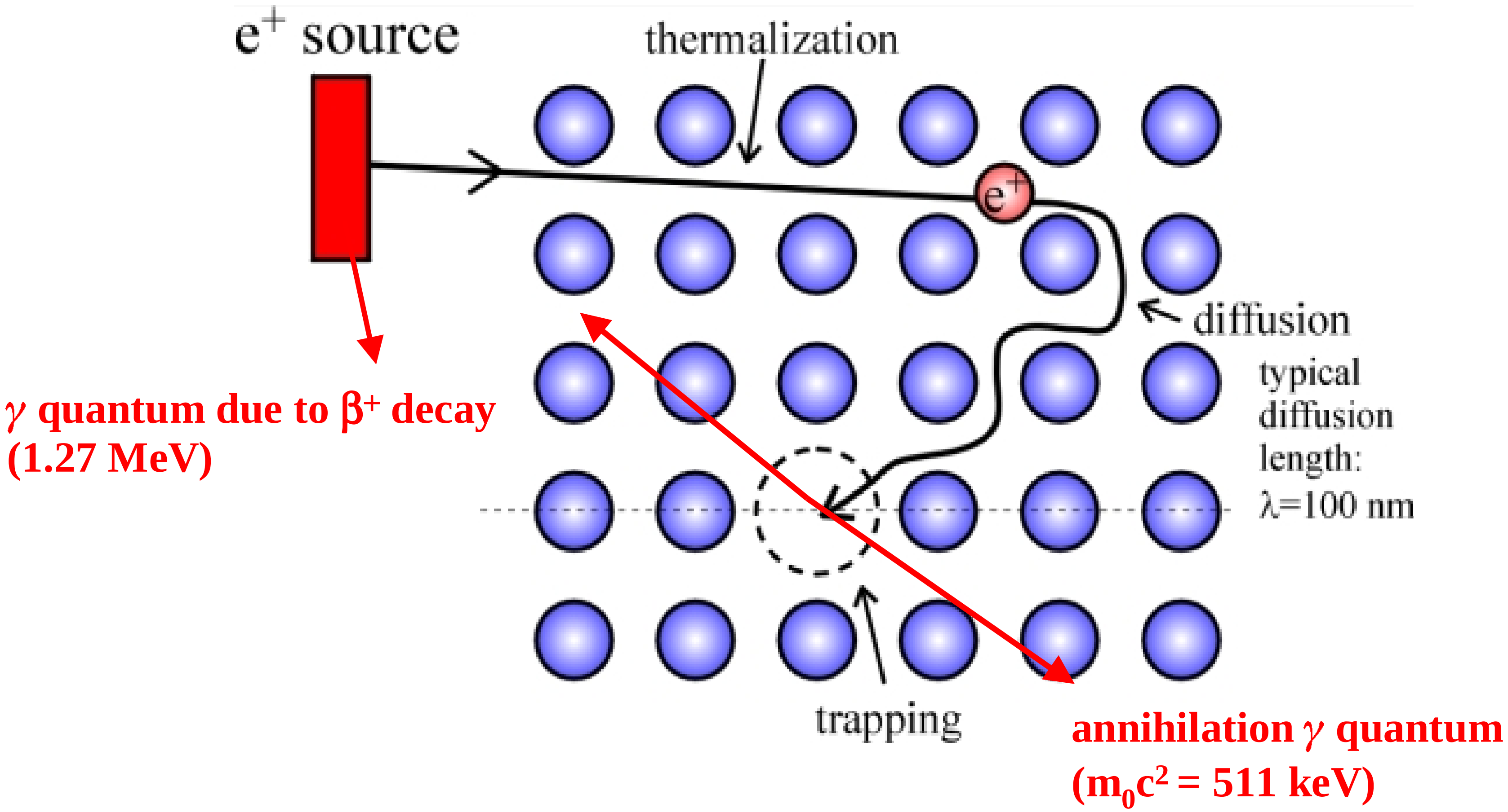
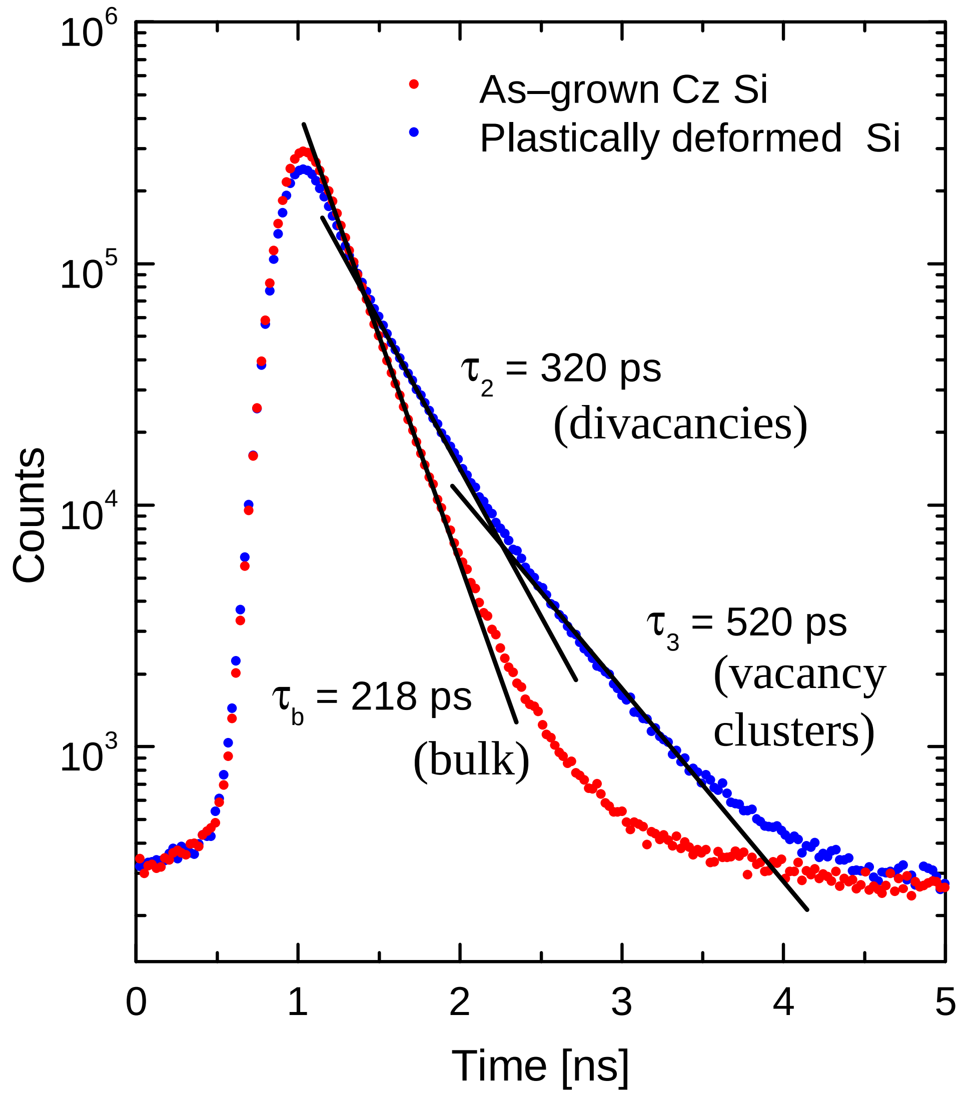
- Introduction: How positrons “see” lattice defects
- Techniques of Positron Annihilation
- Examples:
  - electron-irradiation-induced defects in Ge
  - ion implantation in Si
  - non-destructive testing of steel

Positron trapping at crystal lattice defects



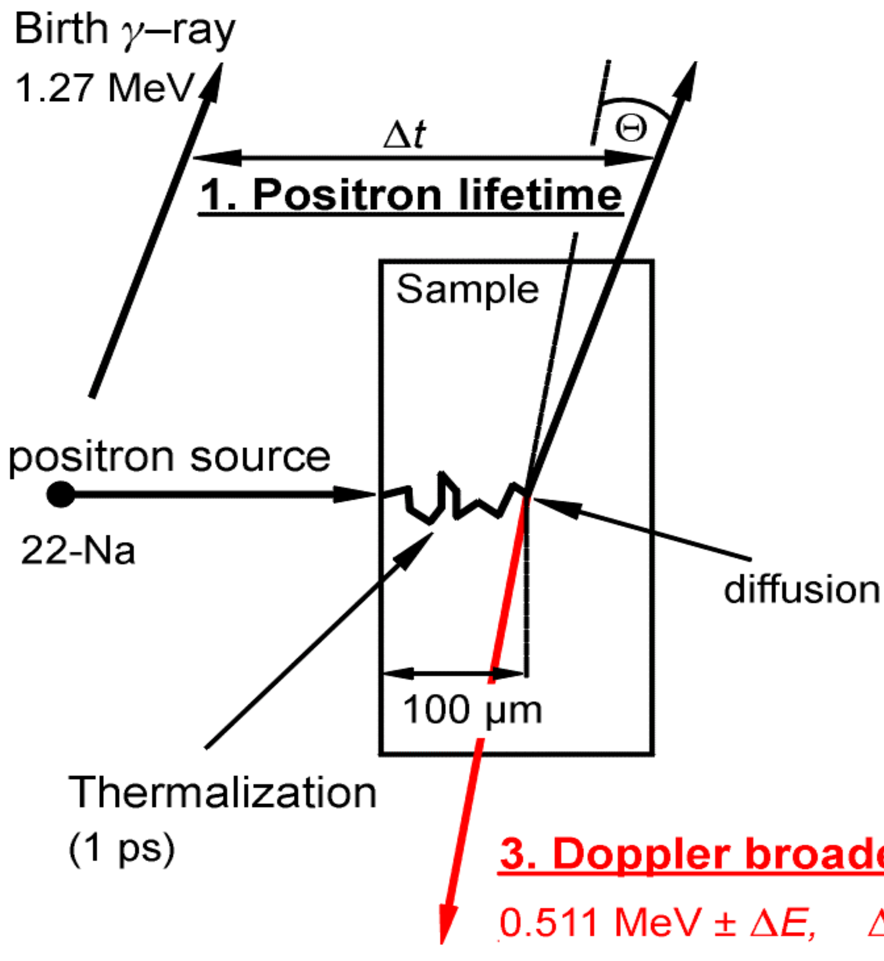
- positron wave-function can be localized in the attractive potential of a defect
- annihilation parameters change in the localized state (e.g. positron lifetime)
- defects can be detected (identification and quantification)

Positron lifetime spectroscopy



- positron lifetime spectra consist of exponential decay components
- positron trapping in open-volume defects leads to long-lived components
- longer lifetime due to lower electron density
- analysis by non-linear fitting: lifetimes τ_i and intensities I_i
- positron lifetime spectrum: $$N(t) = \sum_{i=1}^{k+1} \frac{I_i}{\tau_i} \exp\left(-\frac{t}{\tau_i}\right)$$
- trapping coefficient
  $$\boxed{\kappa_d = \mu C_d} = \frac{I_2}{I_1}\left(\frac{1}{\tau_b} - \frac{1}{\tau_d}\right)$$
  trapping rate
  defect concentration

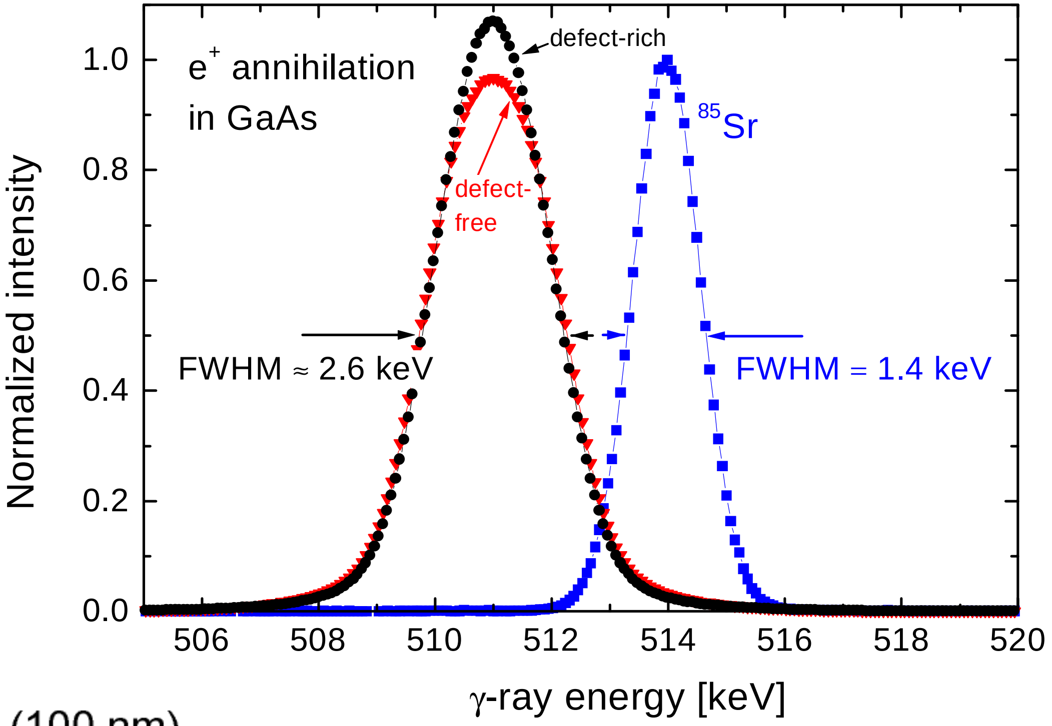
Doppler broadening of the annihilation line



diffusion (100 nm)

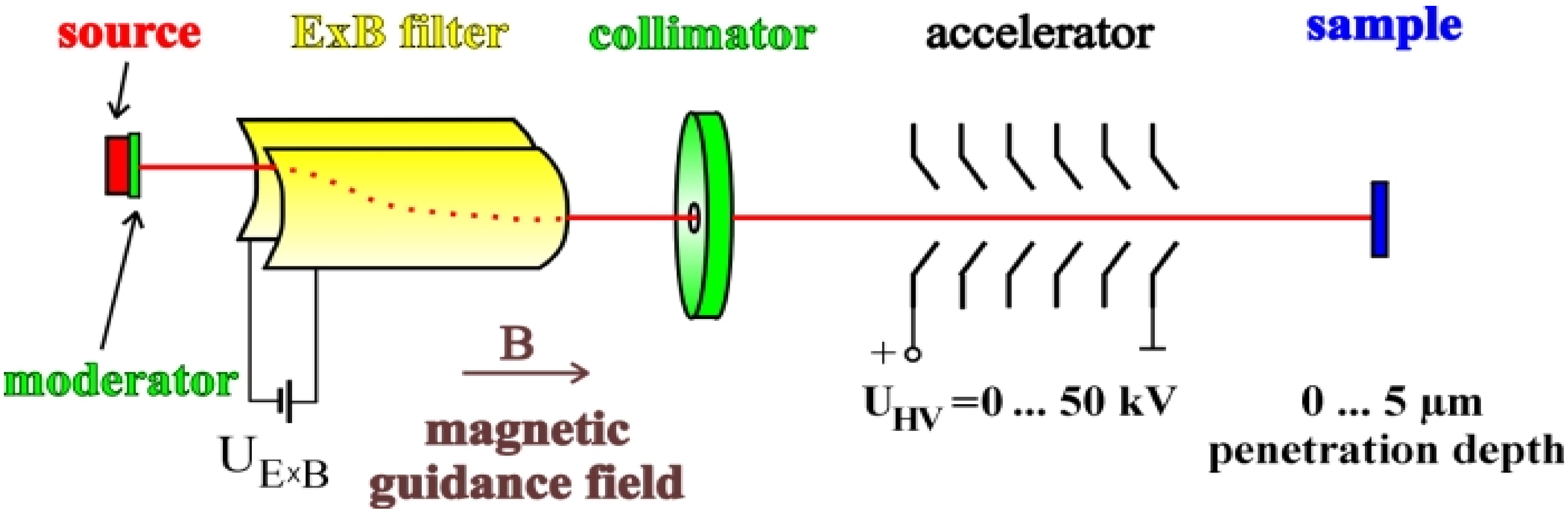
3. Doppler broadening

0.511 MeV ± ΔE, $\Delta E = p_z c/2$



- broadening of 511-keV annihilation γ-line due to electron momentum
- core electrons cause stronger broadening due to high momenta
- in vacancies: fraction of annihilating core electrons is reduced

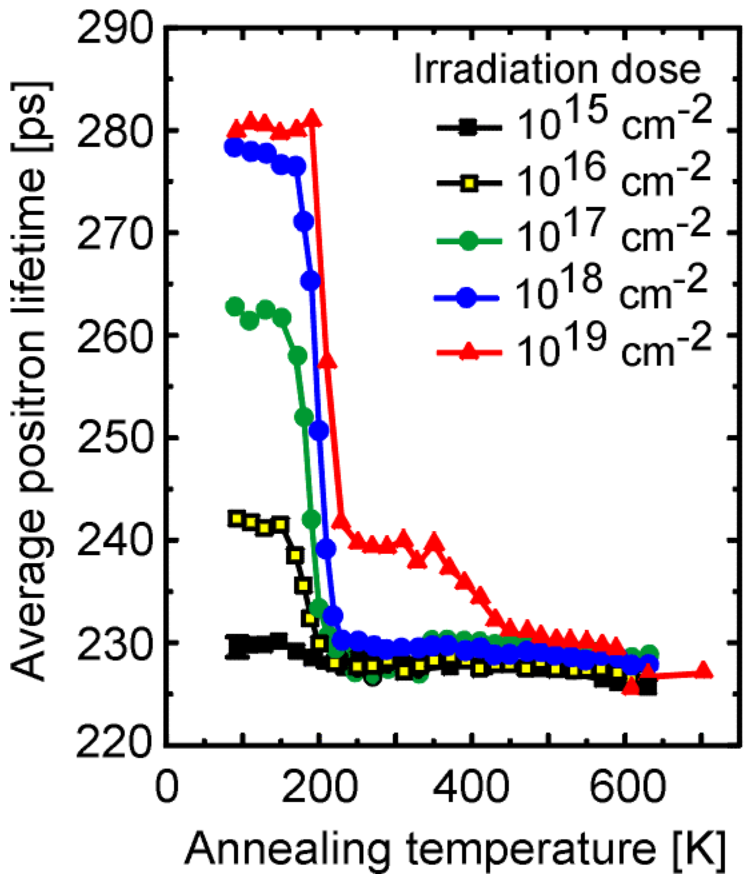
Monoenergetic positron beam for defect profiling near surfaces

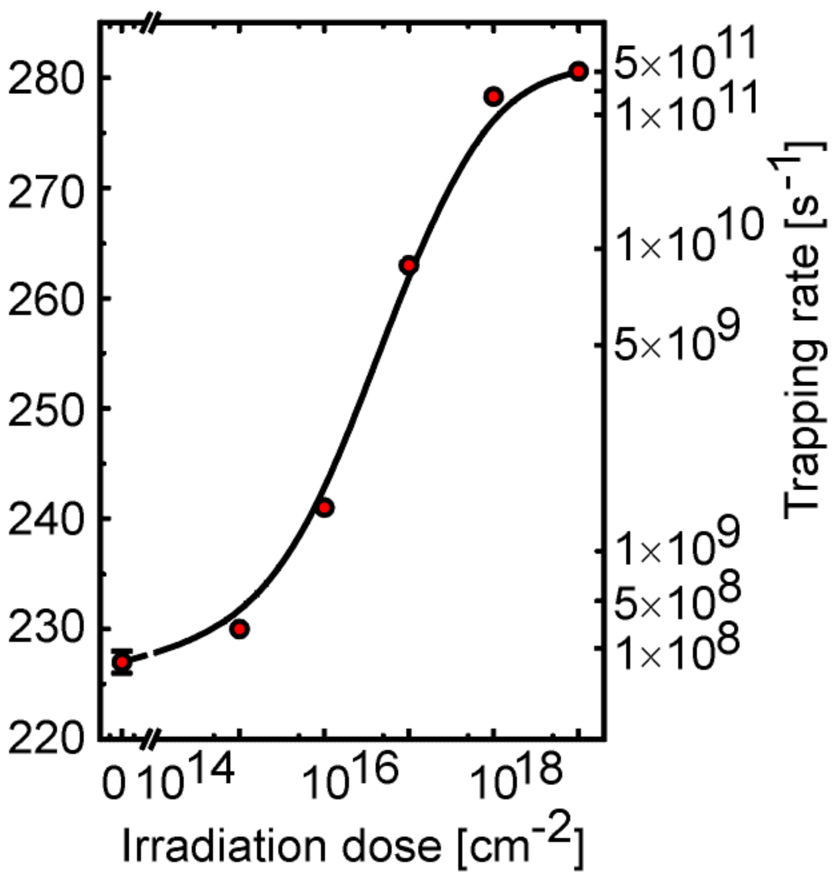


- monoenergetic positrons created by moderation ($E_+ = 3$ eV)
- energy can be tuned by acceleration stage: defect profiling

Electron-irradiated Ge

- electron irradiation generates Frenkel pairs
- vacancy annealing and defect reactions may be studied by positrons

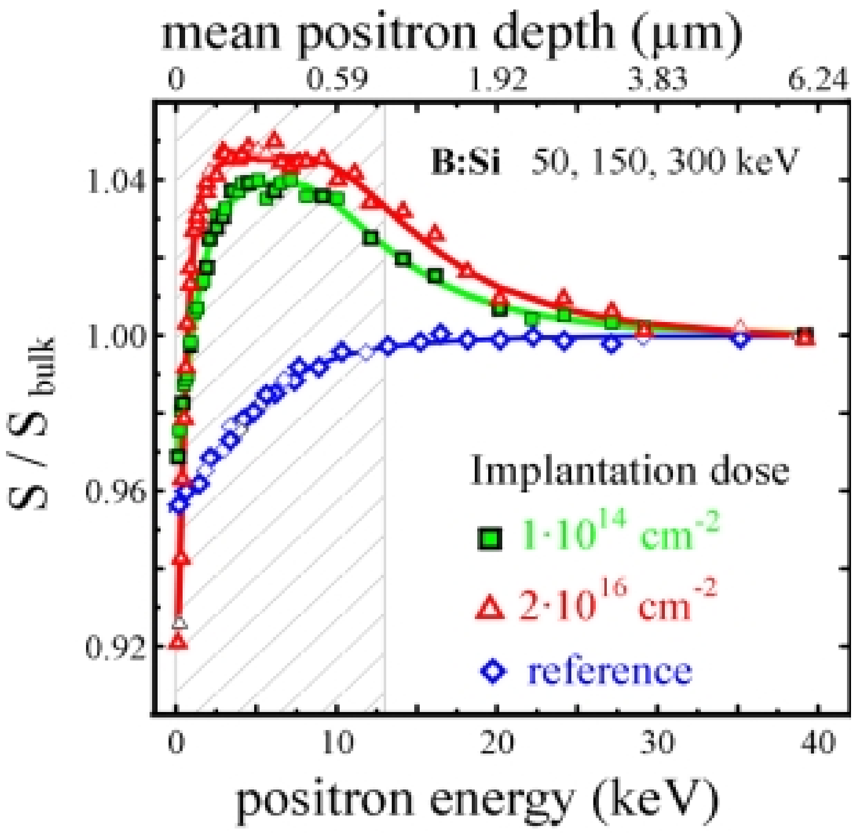


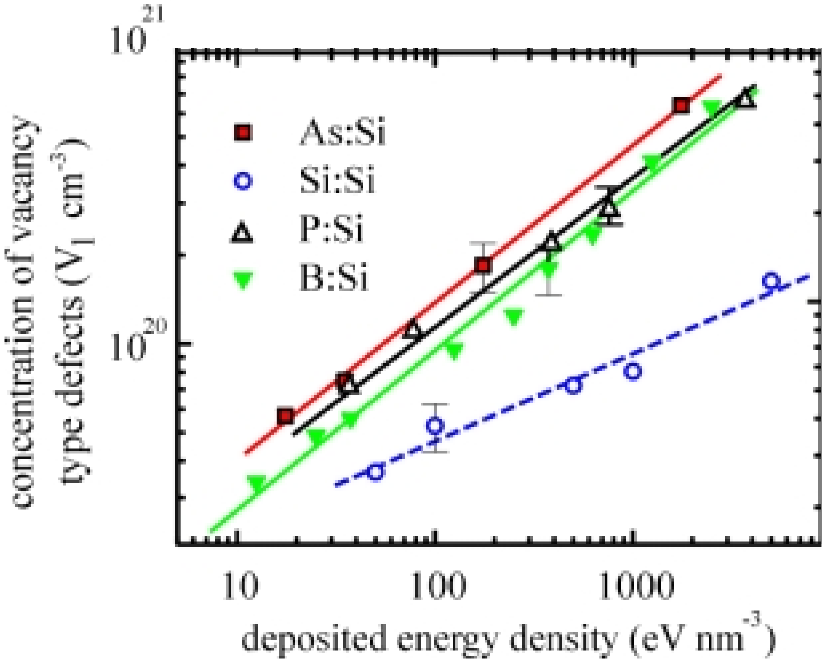


(Polity et al., 1997)

Ion implantation in Si

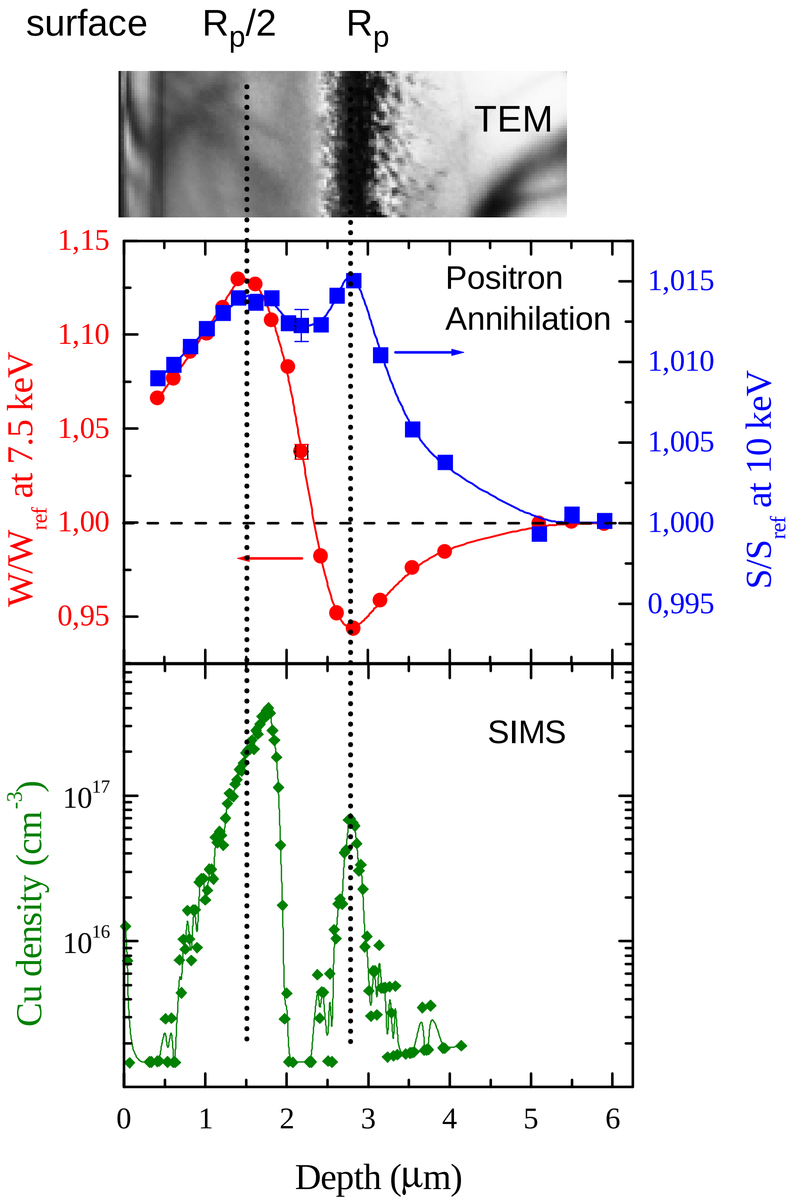
- ion implantation is most important doping technique in planar technology
- problem: generation of defects ⇒ positron beam measurements





(Eichler et al., 1997)

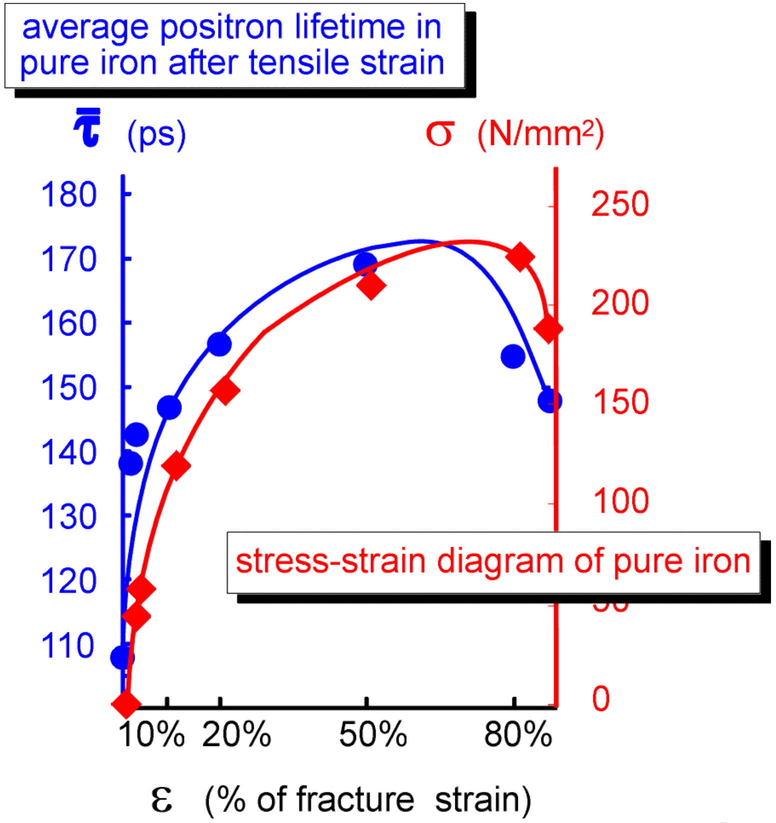
Getter centers after high-energy self-implantation in Si

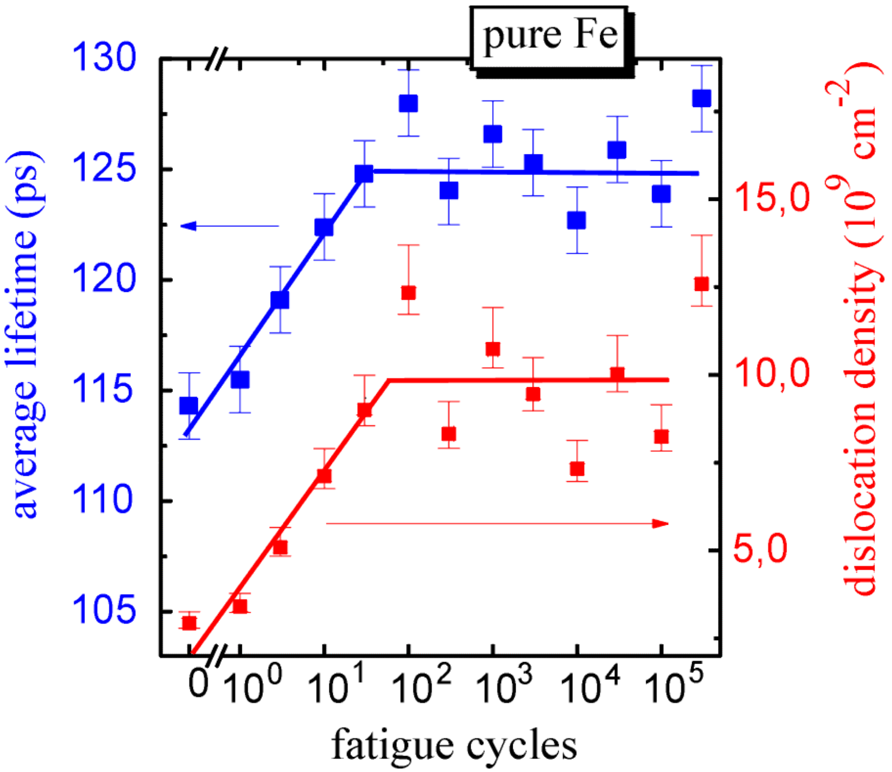


- **high-energy silicon self-implantation** creates additional gettering zones at $R_p/2$ and R_p (projected range of silicon ions)
- E_{Si+}=3.5 MeV; sample annealed 30sec at 900°C
- **at R_p**: network of interstitial-type dislocation loops captures diffusing impurities
- **at $R_p/2$**: no indication of extended defects by TEM
- positrons show: open-volume defects (small vacancy clusters)
- after intentionally Cu contamination: positron traps are decorated by Cu

Non-destructive testing in iron

- we performed an extended study of defects in iron alloys and different steels
- positrons are very sensitive for fatigue damage and may detect damage during high-temperature creep aging
- positron annihilation is a suitable tool for non-destructive testing in many cases





(Somieski et al., 1996)

Conclusions

- Positrons are suitable probes to observe lattice defects
- objects: vacancies, vacancy cluster, dislocations, grain boundaries in very fine-grained materials, precipitates
- sensitivity limit, e.g. for vacancies in Si: 5×10^{14} cm^{-3}

This presentation can be found as pdf-file at our Webpage:

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