Identification of Getter Defects in high-energy self-implanted Silicon at Rp/2

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• Introduction: The Rp/2 effect in Si
• Study using depth-resolution enhanced Positron Beams
• Conclusions
Defects in high-energy self-implanted Si — The $R_p/2$ effect

- After high-energy (3.5 MeV) self-implantation of Si ($5 \times 10^{15}$ 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

- 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]

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Conventional positron beam technique

- positron annihilation successful in characterization of open-volume defects
- positron beam of mono-energetic positrons
- positron implantation depth varied by accelerating voltage

magnetically guided positron beam system at Univ. Halle
Investigation of the $R_p/2$ effect by conventional VEPAS

- the defect layers are expected in a depth of 1.7 $\mu$m and 2.8 $\mu$m corresponding to $E_+ = 18$ and 25 keV
- implantation profile too broad to discriminate between the two zones
- simulation of $S(E)$ curve gives the same result for assumed blue and yellow defect profile (solid line in upper panel)
- furthermore: small effect only
- no conclusions about origin of $R_p/2$ effect possible
Getter centers after high-energy self-implantation in Si

- VEPAS with improved depth resolution shows 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

![Graphs showing Cu density, Positron Annihilation, SIMS, and W/W']
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 $R_p/2$: $\tau_d = 450$ ps (vacancy cluster, $n > 10$)
- at $R_p$: $\tau_d = 320$ ps (open volume = divacancy)

**Conclusions**
- $R_p/2$: small vacancy clusters are getter centers
- $R_p$: positrons are trapped by defects at dislocation loops
Further proof: additional implantation into $R_p/2$ region

- **experiment:**
  - high-energy self-implantation ($\text{Si}^+$ energy: 3.5 MeV)
  - RTA annealing (30s @ 900°C)
  - Cu contamination and diffusion
    $\Rightarrow$ normal $R_p/2$ effect
  - additional $\text{Si}^+$ implantation into depth of 1.7 $\mu$m ($R_p/2$ region)
  - sample etched by 1.2 $\mu$m to obtain optimum depth resolution for positrons
  - decrease of $S$ parameter: open volume shrinks

- vacancy clusters at $R_p/2$ partly filled by Si interstitials of post-implantation
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: \( L_\alpha (\text{Si @ 300K}) \approx 230 \text{ nm} \)
- both regions well visible:
  - vacancy clusters with increasing density down to 2 µm (\( R_p/2 \) region)
  - in \( R_p \) region: lifetime \( \tau_2 = 330 \text{ ps} \); corresponds to open volume of a divacancy; must be stabilized or being part of interstitial-type dislocation loops

![Positron Microscopy Diagram](image)
SIMS profile of Cu
Conclusions

• Vacancy agglomerates are the getter centers at $R_p/2$

• Depth profiling using positron microscope very promising

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