RADIATION DEFECT TRANSFORMATIONS UNDER ANNEALING OF P-TYPE SILICON

L.F. Makarenko*, M. Moll**, S.B. Lastovski***,
F.P. Korshunov***, N.V. Abrosimov****

**Belarusian State University, Minsk, Belarus*
***CERN, Geneva, Switzerland*
****Scientific-Practical Materials Research Centre of NAS of Belarus, Minsk, Belarus*
***** Leibniz Institute for Crystal Growth, Berlin, Germany*

Factors which determined the rate of defect annealing

There are several ways to change annealing temperatures for deep defects or defect complexes in silicon:

- To increase sink concentration;
- To change a defect charge state and consequently activation energy of its migration or dissociation;
- To stimulate a defect migration or dissociation by enhancing recombination process through this defect;
- etc.
-

This work presents some results of DLTS studies of factors which can influence radiation defect stability in p-type silicon.

Samples and irradiations

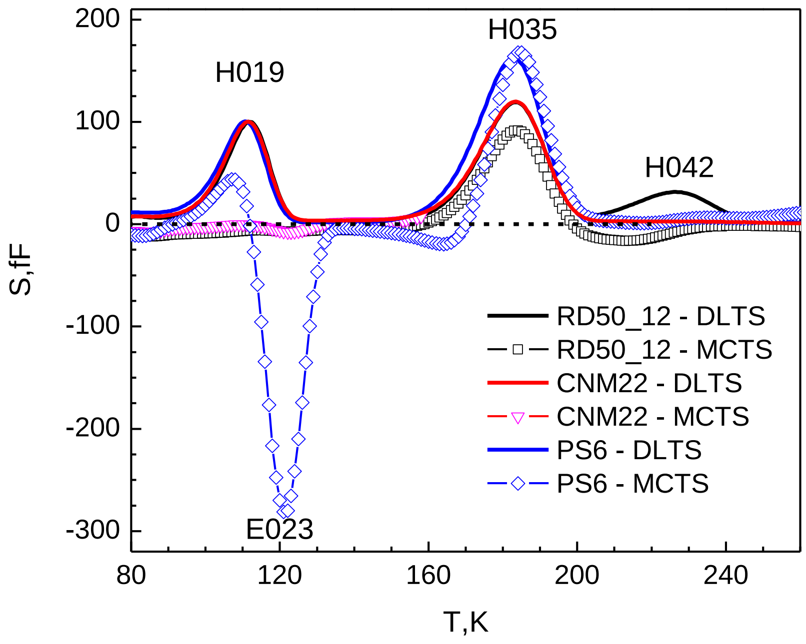
Silicon n^+-p diodes with different doping of p-region were used for investigations:

- $p=2.5\times10^{12}$ cm^{-3} (RD50-12)
- $p=1.3\times10^{13}$ cm^{-3} (CNM-22)
- $p=0.8\text{-}1.0\times10^{15}$ cm^{-3} (KD642 and PS-6)

Silicon-germanium n^+-p diodes had $p=2.0\text{-}2.2\times10^{15}$ cm^{-3} and Ge content was 1 %.

Diodes were irradiated with high energy electrons (E=3.5 or 5.5 MeV) or alpha-particles of Pu-239 (E≅ 5.15 MeV with penetration range into silicon of about 25 μm) source. Irradiation temperatures were usually 273-300 K (RT). Several diodes were irradiated at 78 K (LNT).

Stable defects registered by DLTS in p-type Si and SiGe



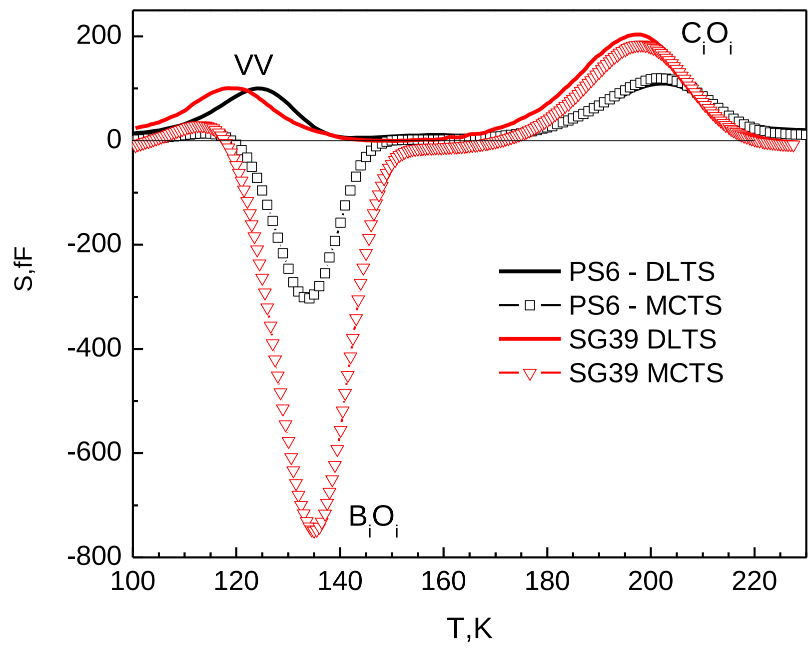


Fig.1. Normalized DLTS and MCTS spectra for Si diodes irradiated with high energy electrons (E=5.5 MeV). The amplitude of divacancy peak (H019) is asserted as 100 fF. Rate window is 19.5 s^{-1}.

Fig.2. Normalized DLTS and MCTS spectra for Si and SiGe diodes irradiated with alpha particles (E=5.15 MeV). The amplitude of divacancy peak (H019) is asserted as 100 fF. Rate window is 19.5 s^{-1}.

Evolution of DLTS spectra under isochronal annealing of diodes with different oxygen content

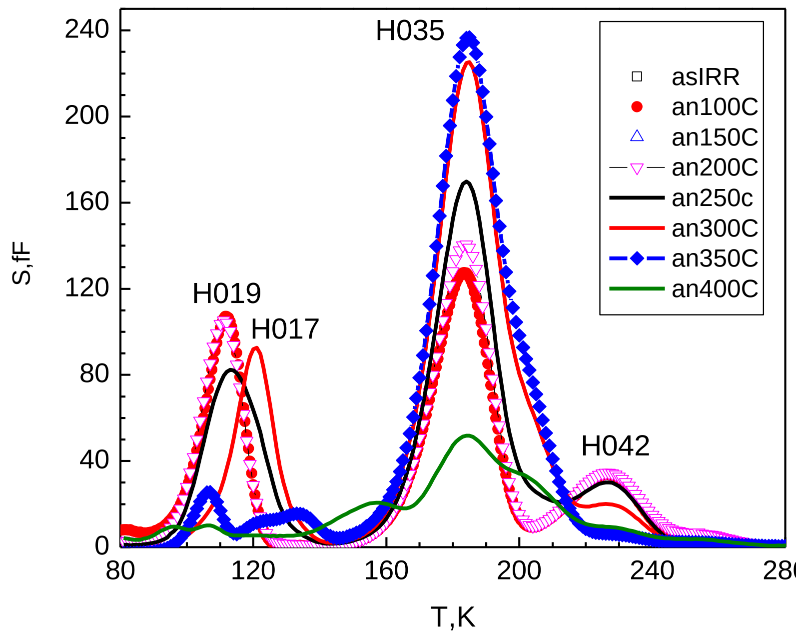


Fig.3. Normalized DLTS spectra for diodes made of MCz Si (RD50-12) irradiated with high energy electrons (E=5.5 MeV). Rate window is 19.5 s^{-1}.

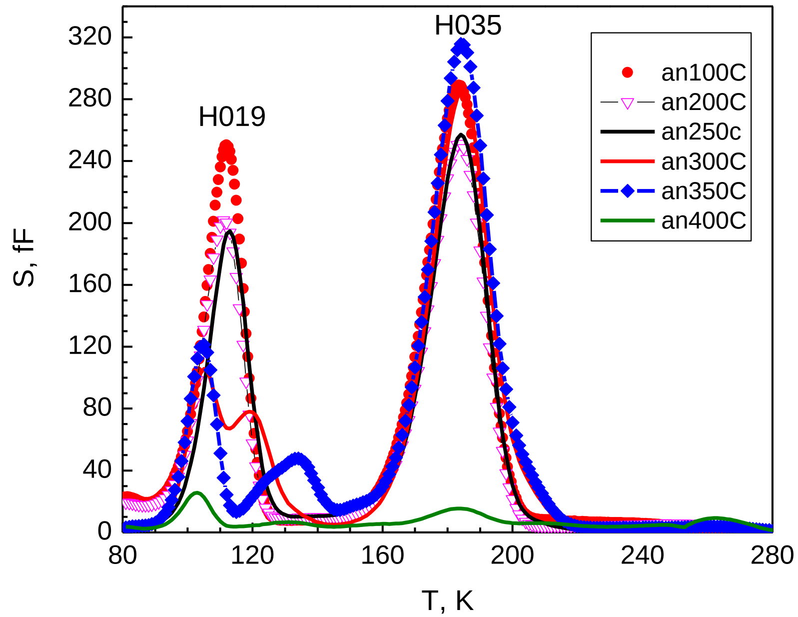


Fig.4. Normalized DLTS spectra for diodes made of epitaxial Si (CNM-22) irradiated with high energy electrons (E=5.5 MeV). Rate window is 19.5 s^{-1}.

Evolution of DLTS spectra under isochronal annealing of epitaxial diodes with different boron content

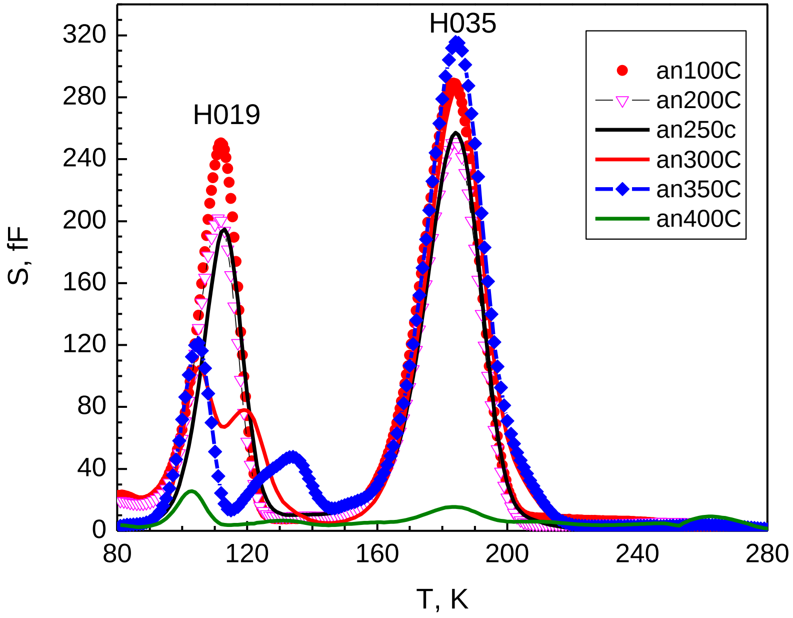


Fig.4. Normalized DLTS spectra for diodes made of epitaxial Si (CNM-22) irradiated with high energy electrons (E=5.5 MeV). Rate window is 19.5 s^{-1}.

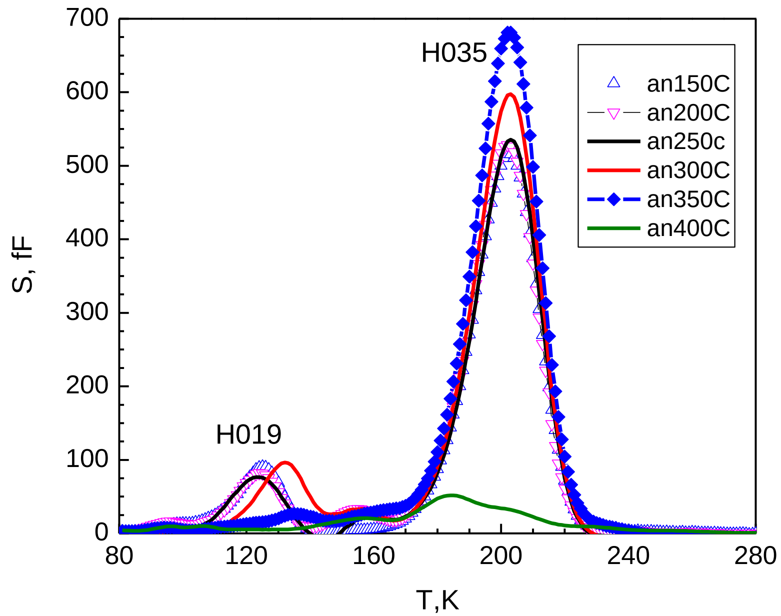
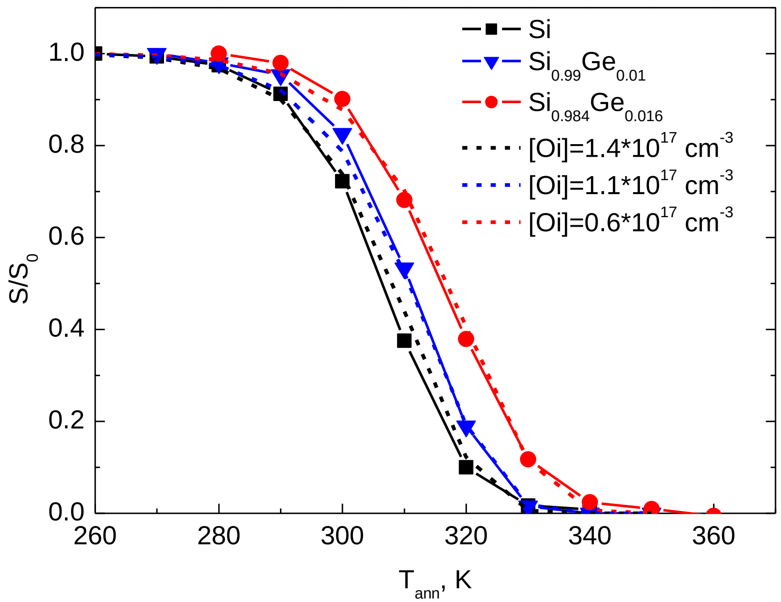


Fig.5. Normalized DLTS spectra for diodes made of epitaxial Si (PS-6) irradiated with high energy electrons (E=3.5 MeV). Rate window is 195 s^{-1}.

Injection enhanced annealing of C_i



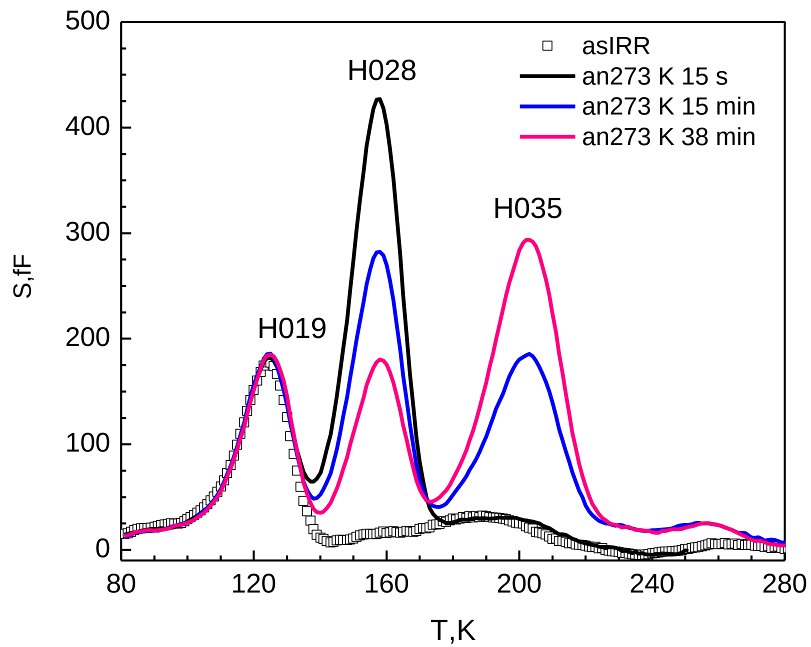


Fig. 6. Isochronal annealing of interstitial carbon (H028) in Si (PS6) and SiGe diodes. The time step was 15 minutes.

Fig. 7. Evolution of DLTS spectra for alpha-irradiated Si diode annealed at 273 K under direct current injection. The current density was 16 A/cm^2.

Annealing of interstitial boron-interstitial oxygen complex

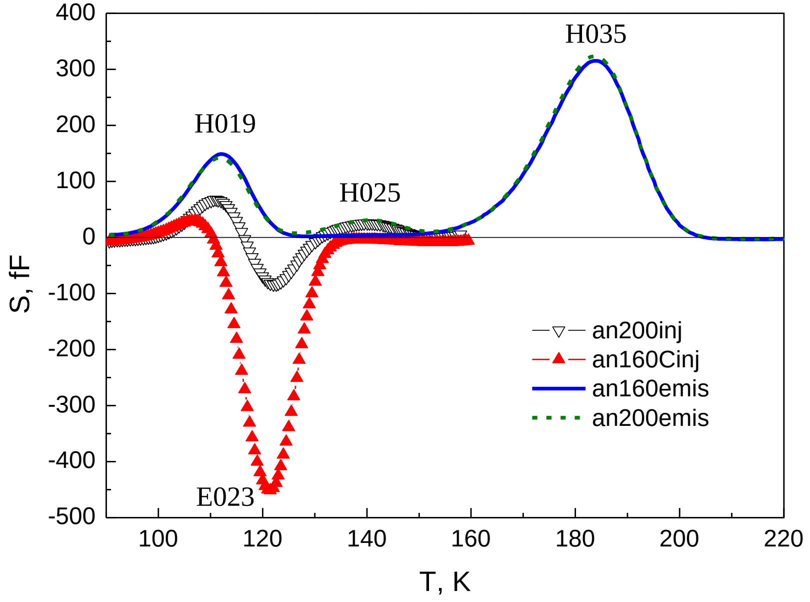


Fig. 8. Evolution of DLTS and MCTS spectra for electron irradiated Si diode (PS-6) annealed at temperatures ≤200 °C.

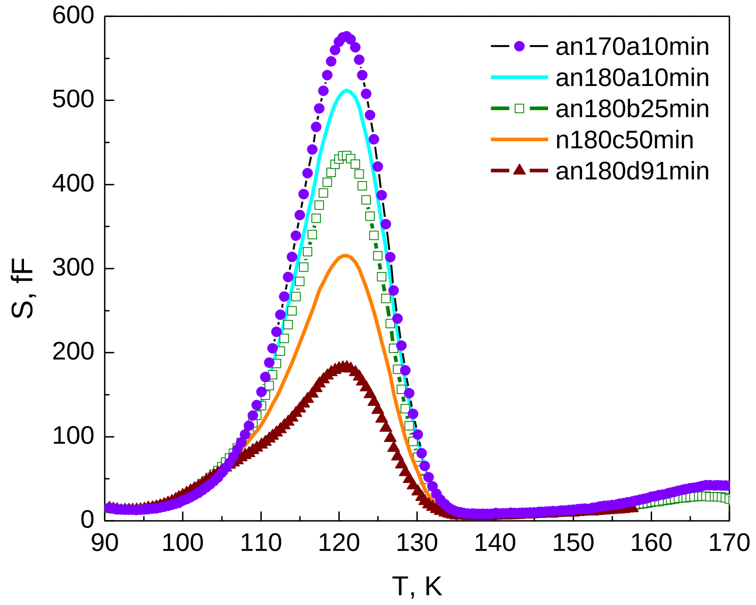


Fig. 9. Decrease of E023 peak for electron irradiated Si diode (PS-6) annealed at 180 °C.

Annealing of interstitial boron-interstitial oxygen complex

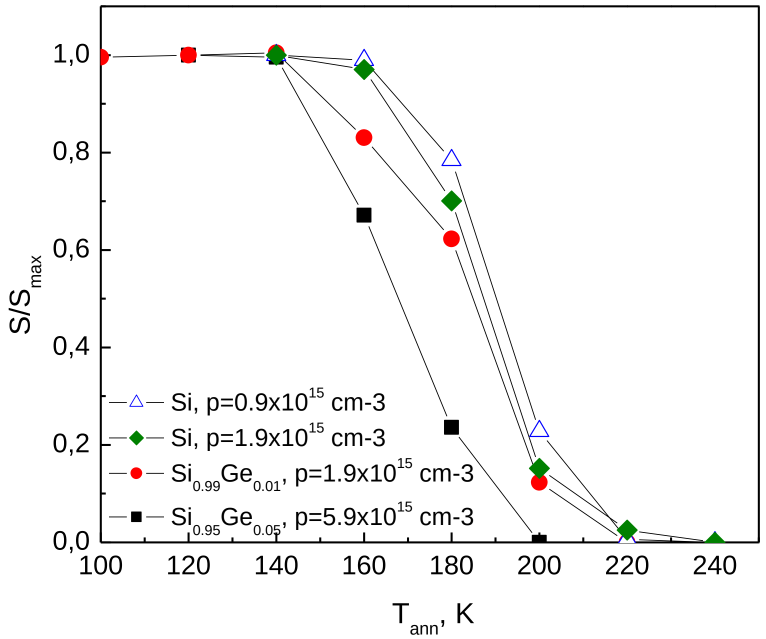


Fig. 10. Isochronal annealing of B_iO_i in defferent Si and SiGe diodes. Temperature step was 20 K and time step was 20 minutes.

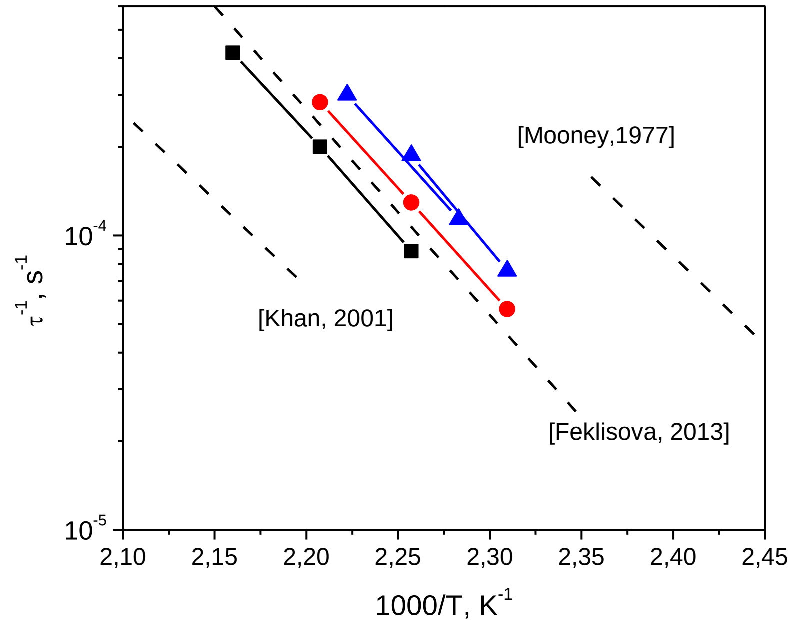


Fig. 11. Annealing rate of B_iO_i complex in Si (black squares) and Si_xGe_{1-x} (red and blue symbols). Results of other authors are presented with dash lines.

1. P. Mooney et al., Phys. Rev. B 15, 3836–3843 (1977).
2. A. Khan et al. J. Appl. Phys. 90, 1170 (2001).
3. O. Feklisova, N. Yarykin, J. Weber, Semiconductors (2013) (to be published).

Injection enhanced annealing of B_iO_i

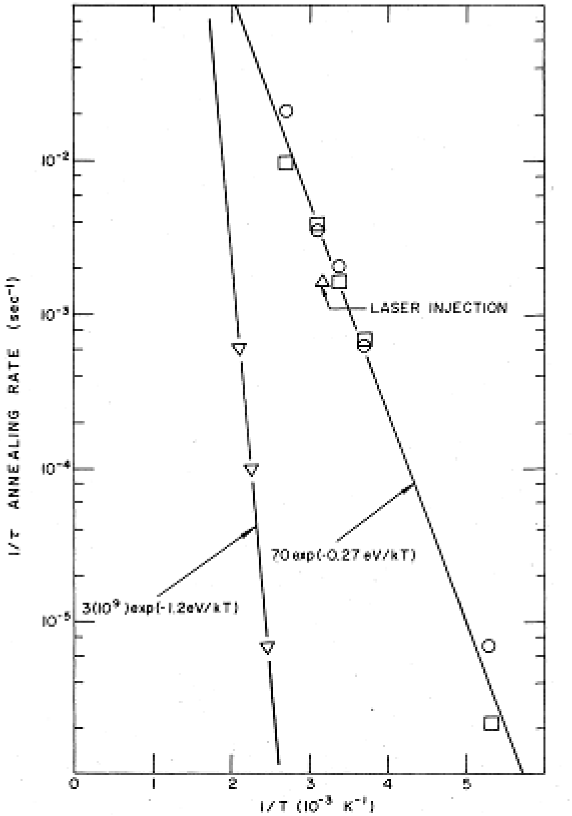


FIG. 5. Temperature dependence of the recovery rate of the $H3$ defect, (a) under short-circuit conditions (∇), (b) under saturated forward bias injection conditions (□, 0.8 A/cm²; ○, 3.6 A/cm²). Also shown (Δ) is the result for recovery at 320 K under Nd-YAG laser illumination.

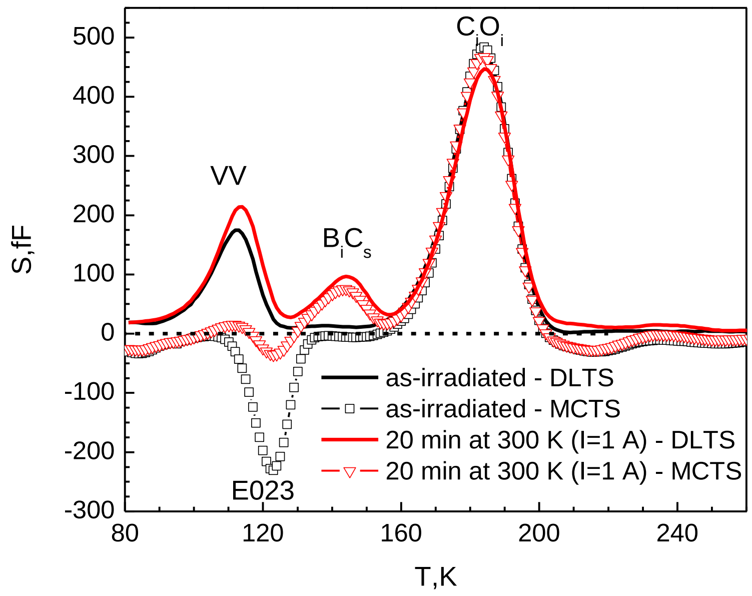


Fig. 12. Annealing of B_iO_i complex in Si having $p=7\text{-}8\times10^{13}$ cm^{-3} under forward current injection.

Recombination-enhanced migration of interstitial aluminum in silicon
J. R. Troxell, A. P. Chatterjee, G. D. Watkins, and L. C. Kimerling
Phys. Rev. B **19**, 533 (1979)

Effect of Ge doping on annealing behavior of divacancy

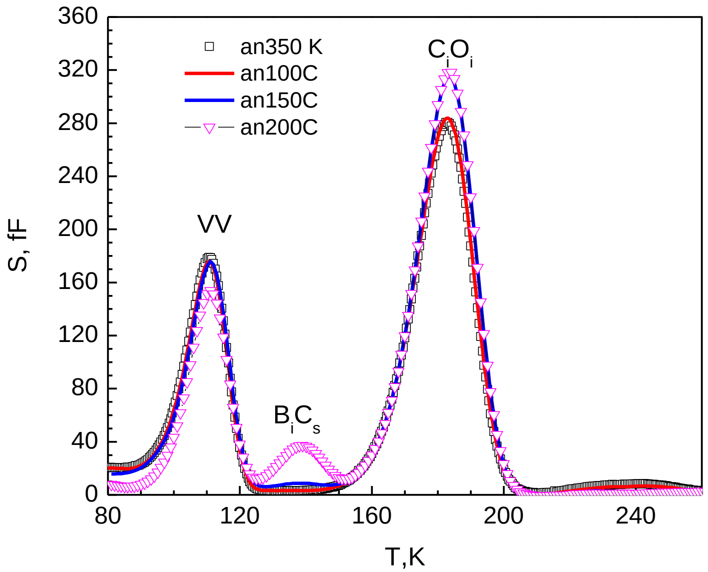


Fig. 13. Isochronal annealing of traps in alpha irradiated Si. Temperature step was 20 K and time step was 20 minutes.

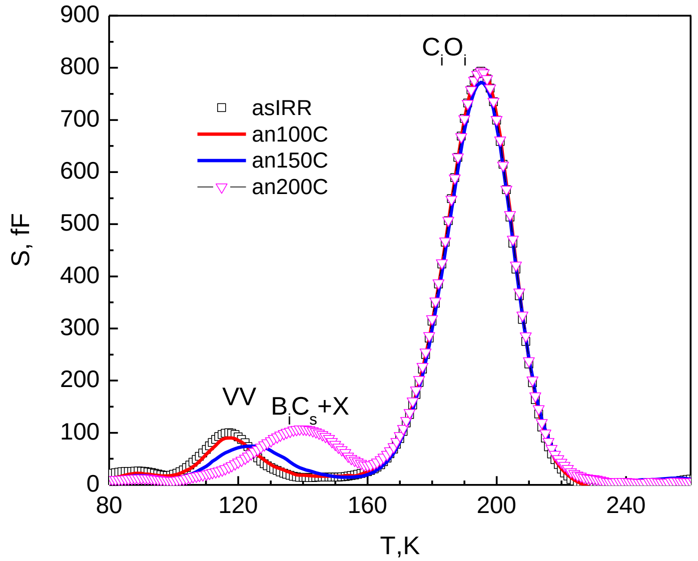


Fig. 14. Isochronal annealing of traps in electron irradiated SiGe. Temperature step was 20 K and time step was 20 minutes.

CONCLUSIONS

Comparative studies of radiation defect annealing in p-type silicon diodes made by different producers have been performed. We have studied as pure silicon so silicon-germanium diodes. Radiation defects have been produced by irradiation with electrons and alpha-particles at different temperatures.

- It has been found that under annealing at temperatures >250 °C the concentration of interstitial carbon-interstitial oxygen complex grows up to 50 % in diodes with the highest resistivity.
- Germanium doping influences annealing behavior of vacancy-type defects but not interstitial-type defects.
- Direct current injection essentially lowers annealing temperature not only for primary defects but for other secondary interstitial defects and some of their complexes also.