Illumination effects in electron irradiated 6H n-type SiC observed by positron annihilation spectroscopy

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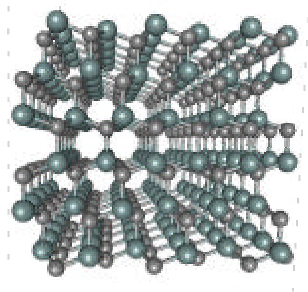
Introduction

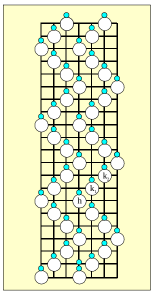
- SiC - Key material for high power and high frequency electronic devices
- Ion implantation - standard procedure for selective doping of SiC
- Electron irradiation - controling of minority carrier lifetime
- Identification of vacancy-type defects induced by electron irradiation
- E1/E2 level (negative-U behavior DLTS [Hem99]) - related to vacancy-type defects?
- Observation of metastable defect [Hem99a] through optical illumination with white and monochromatic light

Experimental

- N-doped SiC bulk wafers were purchased by Nippon Steel Company [N]=1x10^{17}cm^{-3}
- Samples were irradiated in Japan Atomic Energy Research Institute (JAERI) with 2 MeV electrons for two different doses (1x10^{17} cm^{-2} and 3x10^{17} cm^{-2}) at room temperature
- Sample size 5x5mm²
- Positron source: ^{22}NaCl (10-90µCi)
- Conventional fast fast positron lifetime and Doppler bradening spectrometer (FWHM =260ps and 1 keV)
- Monochromatic light available: 0.3-3.2 eV
- Annealing proceeded up to 1300°C under vacuum and above under ambient argon atmosphere

Structure, material



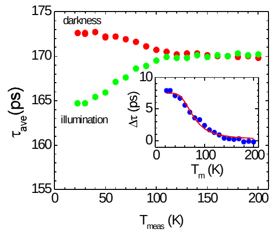


6H SiC structure
carbon sites
silicon sites

Properties:

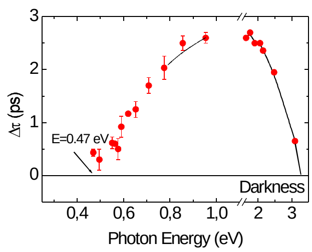
- Band gap at the temperature 5K: 3.101 eV
- Hexagonality :33%
- Lattice parameter: a = 3.0806 Å, c = 15.1173Å (297 K)
- Density ρ=3.211g/cm^3
- Very low diffusion coefficent of dopants
- Great mechanical hardness

Illumination



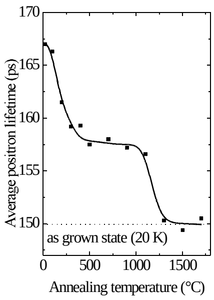
- After illumination with white light a decrease of the average positron lifetime appears below 110 K
- The spectra decomposition shows a defect-related lifetime of 185 ps (V_{Si}) [Bra96] either in darkness or under illumination. The intensity decreases from 45% to 17% under illumination.
- The illumination effect appears also in as-grown material. The irradiation with 2 MeV was done to introduce additional Frenkel pairs.
- In the inset the difference of positron lifetime under illumination and darkness is presented. (the fitted Energy barrier: 32 meV)
- $\Delta\tau = \tau_{dark} - \tau_{illum}$

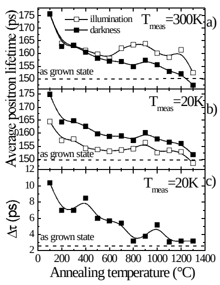
Illumination

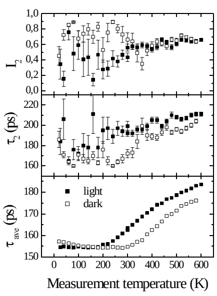


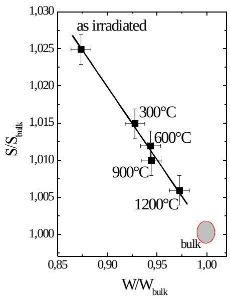
- The data were fitted to the Lucowsky model [Luc65] which gives the cross section for electron transition from a localized state to a parabolic and isotropic band. The threshold energy is determined to be E=0.47eV.
- Illumination effect disappears above 3eV due to direct transition of electrons from the valence band to the conduction band.
- Above 0.4 eV electrons are probably excited from localized levels to the conduction band. Thus, the charge state will change from negative to neutral.

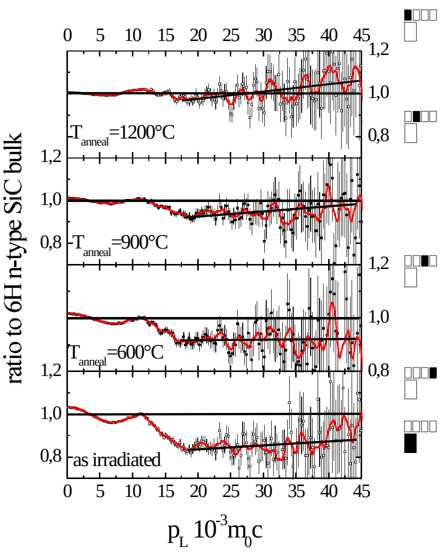
Annealing











- 2 step annealing for electron irradiation (dose:1x10^{17}cm^{-2})
  First step : annealing of Frenkel pairs and carbon vacancy
  Second step : annealing of complexes with silicon vacancies
- Some vacancy type defects remain after 1700°C heat treatment
- Four step annealing was observed
  First step: annealing of Frenkel pairs
  Second step: carbon vacancies become mobile
  Third step: silicon vacancies become mobile and form complexes
  Fourth step: annealing of most defects introduced by electron irradiation
- Decomposition of lifetime spectra for high dose irradiated sample and annealed at 800°C as a function of measurement temperature
- More than one defect act as a trapping center for a measurement temperature at 300K
- S- and W-parameter behavior indicates that one defect ist main trapping center
- Coincidence Doppler broadening spectra for different annealing temperatures
- Slight increase of high momentum spectrum indicate, that the vacancies are surrounded by C-atoms (similar behavior from theory) ⟶ silicon vacancy

Summary

- after irradiation with 2 MeV electrons, the illumination effect (difference of the average positron lifetime under illumination and in darkness in the as grown state was Δτ=2.5ps) in n-type 6H SiC increases
- most of induced defects annealed out at a temperature of 1400°C
- the decomposition of the lifetime spectra shows a defect-related positron lifetime similar to the silicon vacancies
- the observed treshold energy for the illumination effect (0.47eV) is higher than the measured energy level (DLTS:0.3eV/0,4eV) for the E_1/E_2 defect

Literature

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