Institute of Electronic Materials and Devices

Leibniz Universität Hannover

Grazing Incidence X-Ray Diffraction Analysis of the Periodic Dislocation Network of Ge/Si (001) Heterostructures

Yvo Barnscheidt[1], Jan Schmidt[1], and H. Jörg Osten[1,2]

[1] *Institute of Electronic Materials and Devices, Leibniz University Hannover, Schneiderberg 32, 30167 Hannover*

[2] *Laboratory of Nano and Quantum Engineering, Leibniz University Hannover, Schneiderberg 39, 30167 Hannover*

Motivation

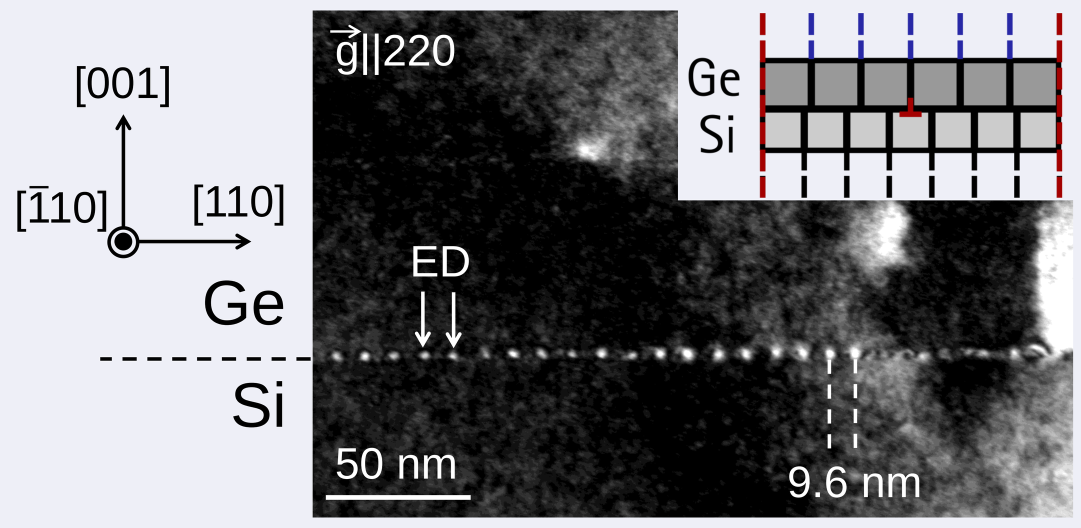
- Ge has significant advantages over Si ➔ aim to integrate Ge layers on Si wafers
- lattice mismatch of 4.2 % causes Stranski-Krastanov growth
- modified epitaxial growth process enhances plastic relaxation [1, 2]
  - ➔ misfit dislocation network along <110> directions at Ge/Si interface
  - ➔ edge dislocation (ED) spacing of 9.6 nm for full relaxation
- investigation of structural perfection: Transmission Electron Microscopy (TEM)
  - time-consuming, expensive, destructive

➔ alternative characterization technique of dislocation network preferred

Experimental

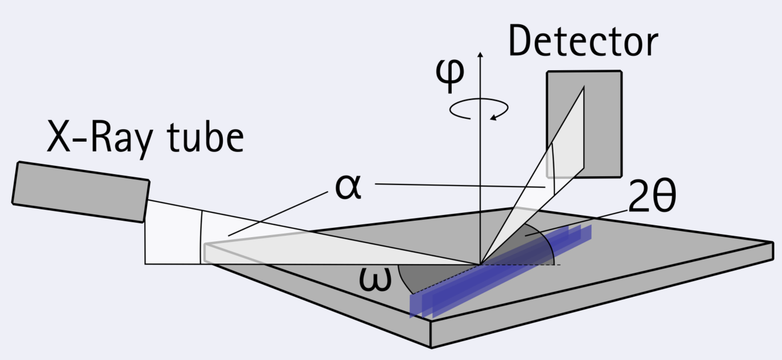
- 100 mm Si(001) wafers
- solid source molecular beam epitaxy
  - carbon-mediated growth of Ge [1, 2]

➔ ultrathin, smooth, fully relaxed, and intrinsic Ge layers



Measurements and modeling

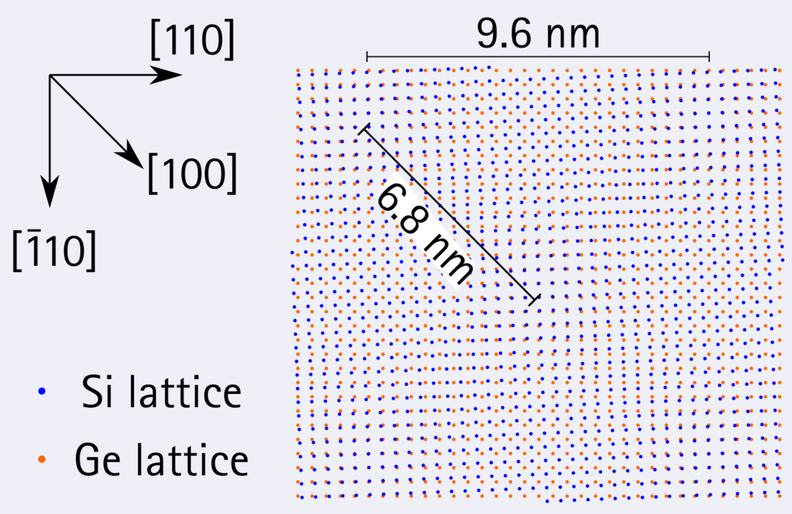
- Bruker D8 Discover II in GIXRD setup
- symmetric 2θ/ω scans along [110] and [001] axes
- azimuthal φ-scans
- variation of information depth by α increase



- Ge lattice planes tilted at the interface due to edge dislocations ➔ lattice tilt
- tilt angle $\beta = \frac{|\vec{b}|}{9.6\ \mathrm{nm}} \hat{=} 2.39\,°$

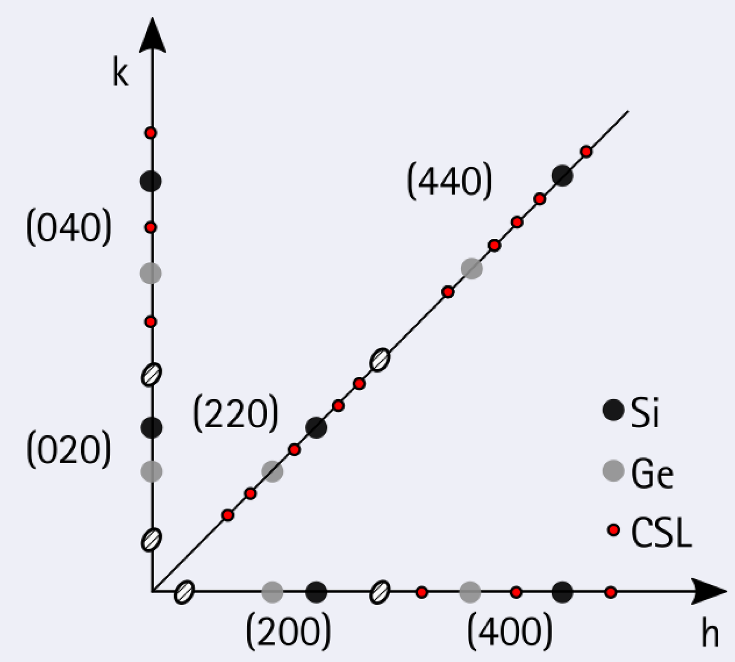
➔ coincidence site lattice (CSL) [3]

➔ new diffraction signals in in-plane direction corresponding to the CSL [4]



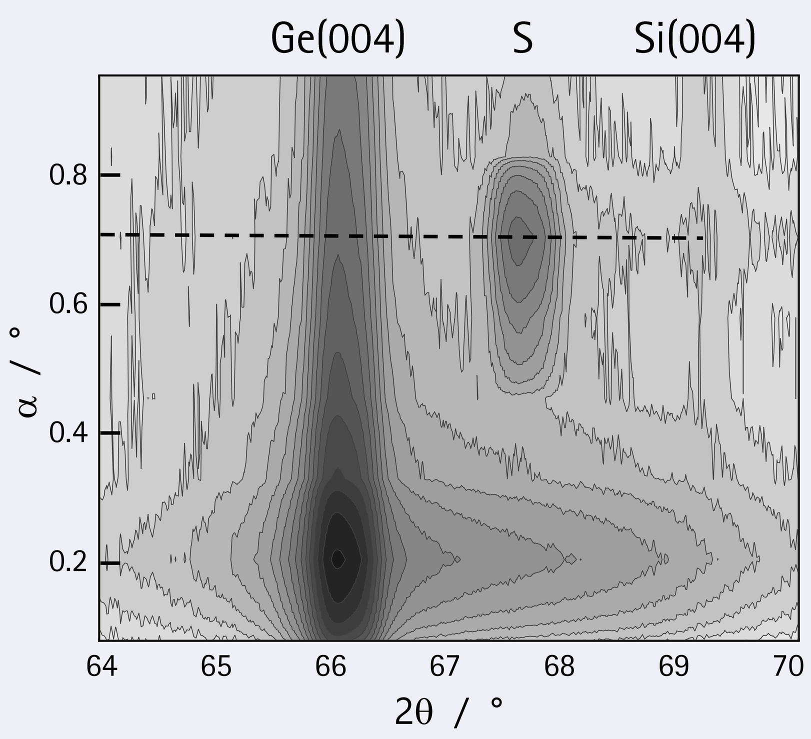
Results

- CSL-theory predicts satellite reflections caused by the periodic array of edge dislocations
- scans along [110] and [100] axes of thin Ge layers
- azimuthal φ-scan of satellite peak verifies 90° periodicity
- satellite S is centered halfway inbetween Ge and Si reflection
- multiple orders of satellite peaks
  - satellite spacing matches CSL theory



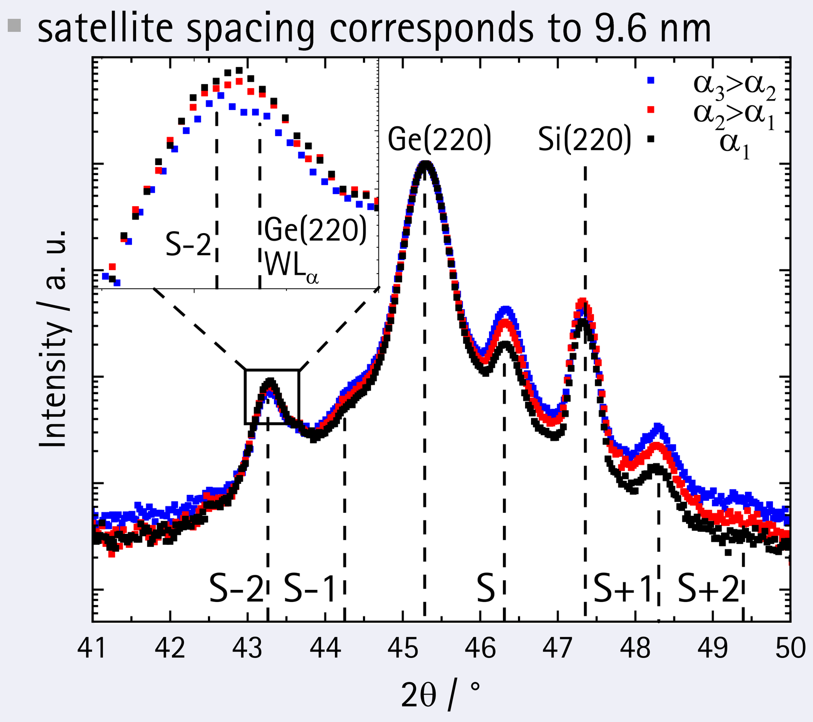
(400) reflection

- α (2θ/ω)-map reveals maximum of satellite peak at the interface
- satellite spacing corresponds to 6.8 nm



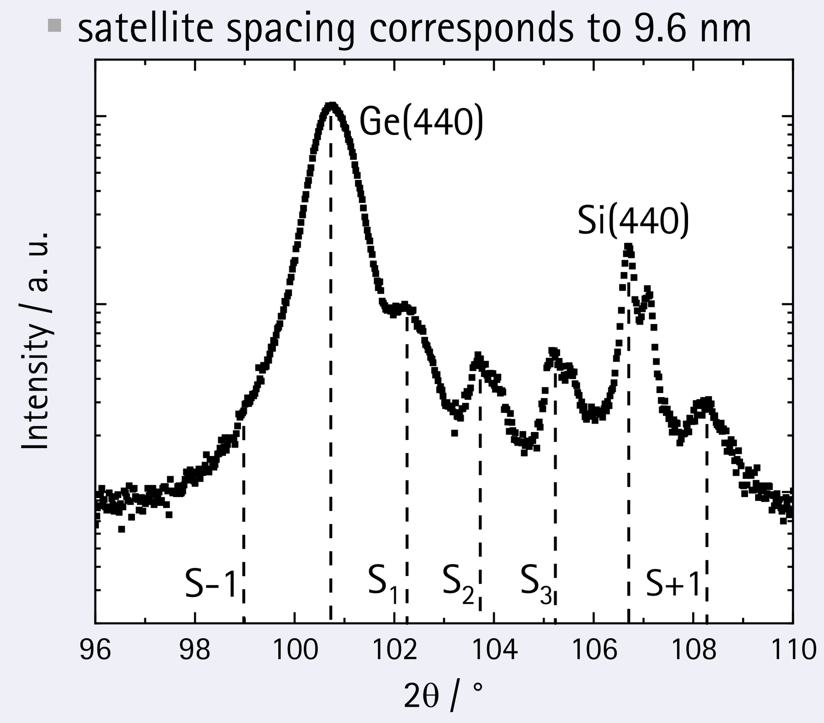
(220) reflection

- intensity of satellites can be tuned by penetration depth variation
- satellite spacing corresponds to 9.6 nm



(440) reflection

- three satellites centered inbetween Ge(440) and Si(440)
- satellite spacing corresponds to 9.6 nm



Conclusions

- GIXRD scans of Ge/Si(001) show satellite peaks
- coincidence-site-lattice theory explains the satellite peaks
- tilt of in-plane Ge lattice planes caused by edge dislocations
- periodic array of edge dislocations responsible for satellites
- satellite spacing corresponds to 6.8 nm in [100] and 9.6 nm in [110] direction

➔ GIXRD provides fast and non-destructive characterization of dislocation network

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Institute of Electronic Materials and Devices
Schneiderberg 32
30167 Hannover, Germany
Fon +49 511 762-5016
Fax +49 511 762-4229
barnscheidt@mbe.uni-hannover.de
www.uni-hannover.de

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DFG Deutsche Forschungsgemeinschaft German Research Foundation