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Short-range scattering sources of two-dimensional hole gases in undoped Ge/GeSi heterostructures

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Introduction

Motivation

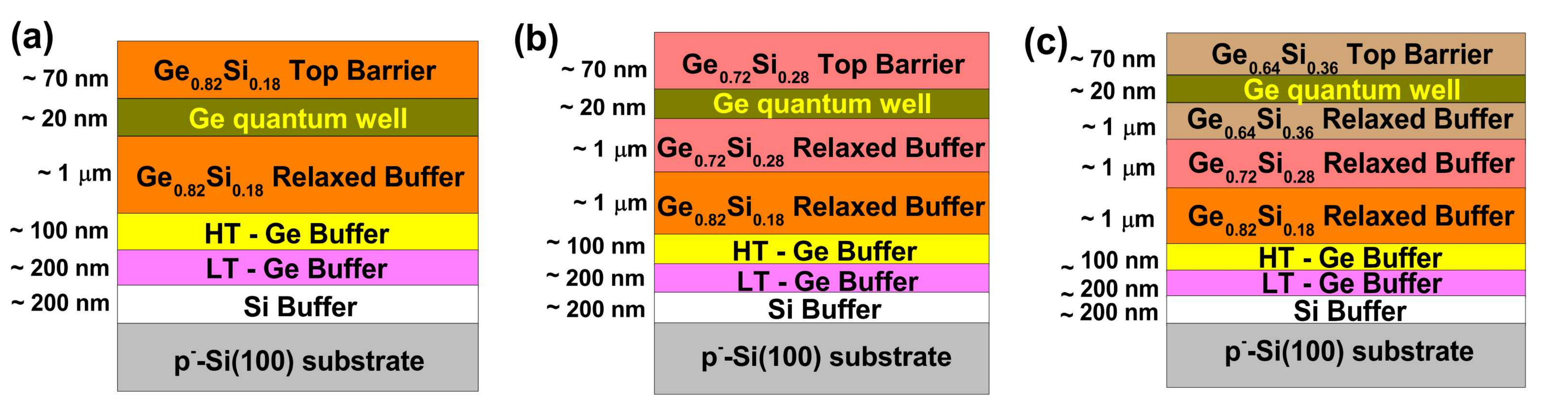
- Germanium has recently gained attentions due to its strong spin-orbit coupling for spintronic applications.
- While most prior studies were done on modulation-doped Ge/GeSi heterostructures, only few reports on the mobility-limiting mechanisms in **undoped structures** were reported.

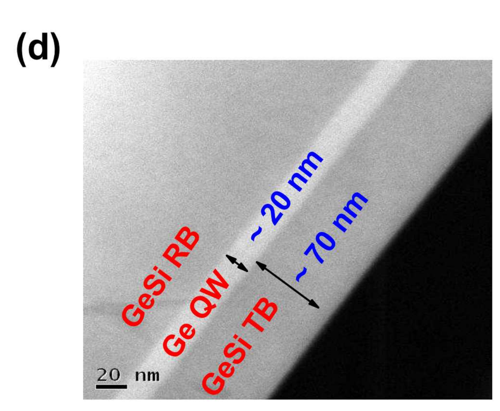
Key Results

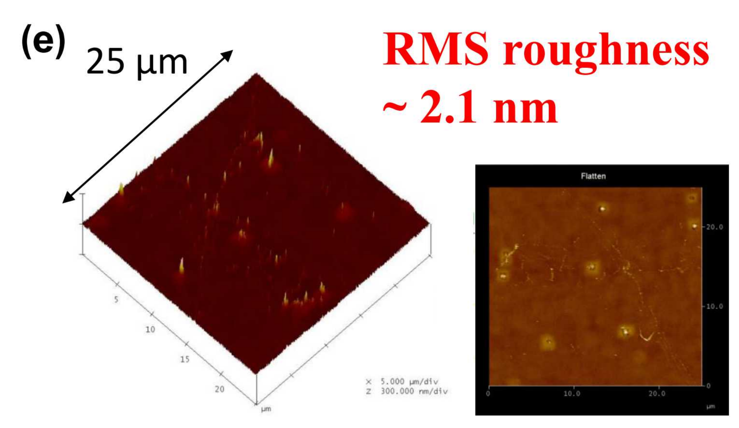
- Electrostatics and magneto-transport properties of two-dimensional hole gases (2DHGs) in undoped Ge/GeSi heterostructures with different Si fractions were investigated.
- The quantum transport data were correlated with material properties, such as **dislocation densities** and **oxygen concentrations**.

2DHGs in Ge/GeSi Heterostructures

$Ge/Ge_{1-x}Si_x$ 2DHG, x = (a) 0.18 (b) 0.28 (c) 0.36 (d) (e) TEM, AFM image of (c) x = 0.36



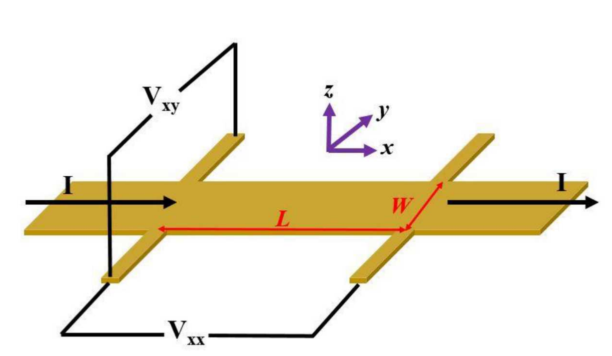


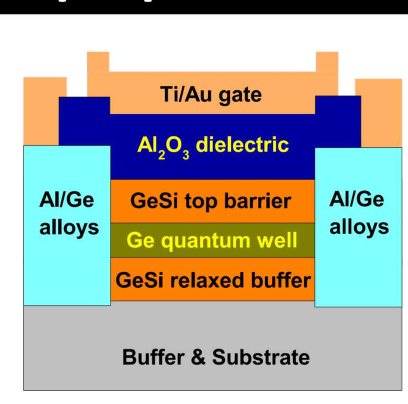


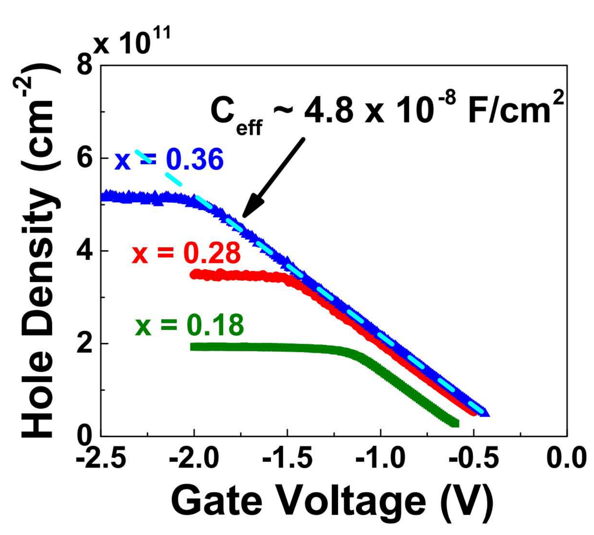
Undoped Ge/GeSi heterostructures

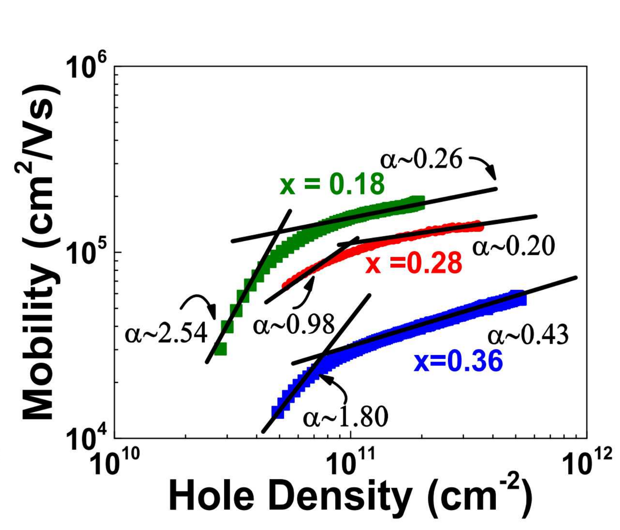
- Grown by reduced pressure chemical vapor deposition (RPCVD)
- Ge virtual substrate and GeSi buffer with different Si fractions
- TEM (d), AFM (e), SIMS, and RSM to characterize heterostructures

Electrostatics & Magneto-transport properties of 2DHGs





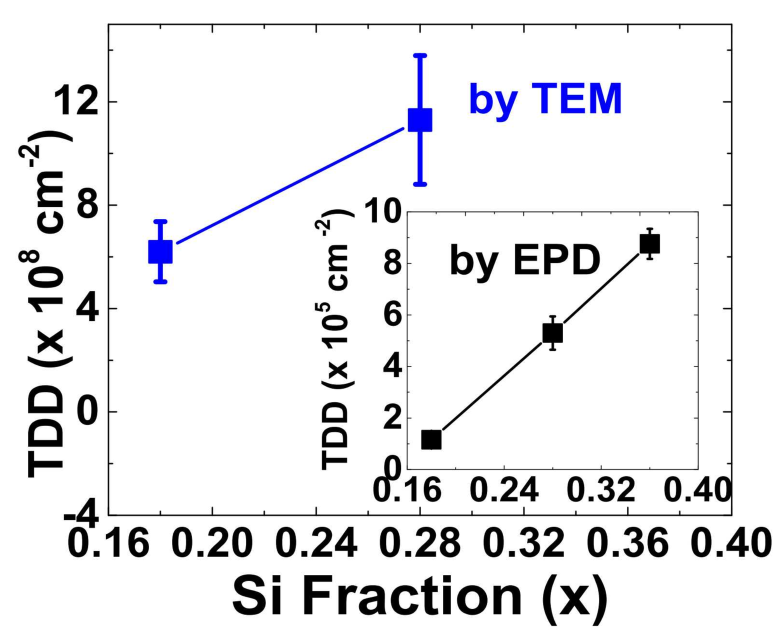


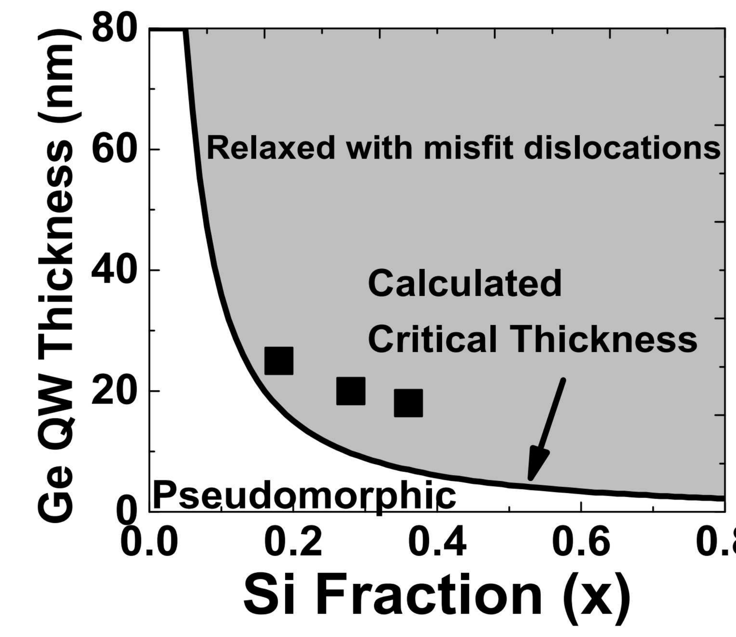


Enhancement-mode Hall bar devices fabricated for low-temperature mobility measurements (upper figure)

- **Electrostatics (lower left):**
  - Density saturation for all devices → surface tunneling
- **Magneto-transport properties (lower right):**
  - Mobility decreases with the Si fraction → surface roughness or induced dislocations ?
  - Weak density dependence of mobility → ruled out remote impurity scattering at the oxide interface

Scattering by Misfit & Threading Dislocations

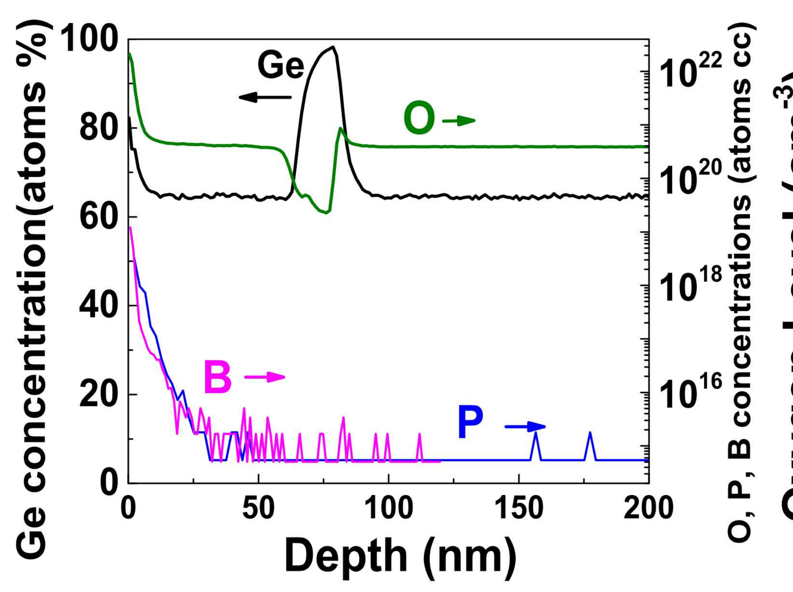


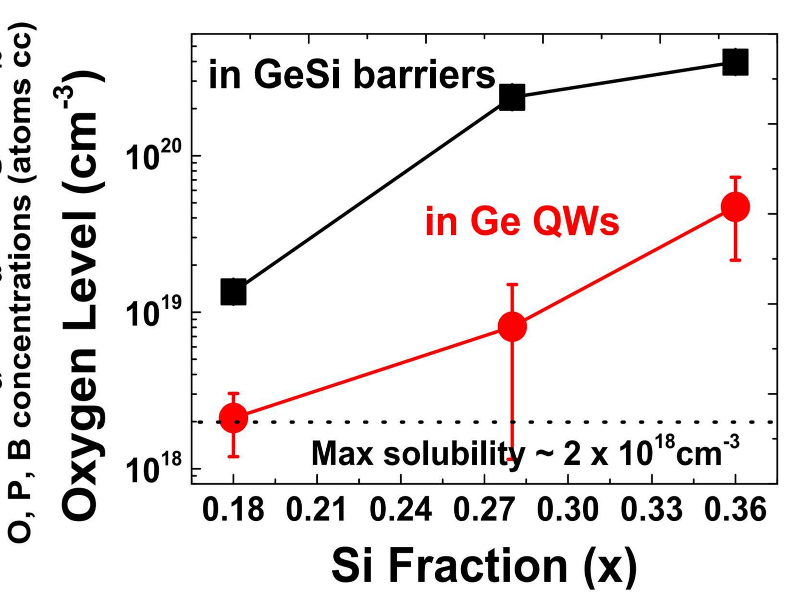


Dislocation-induced scattering

- TDDs characterized by planar-view TEM and EPD experiments increase with the Si fraction (left).
- For all devices, Ge quantum well layers exceed critical thickness, which could lead to misfit dislocations (right).

Scattering by Oxygen Impurities

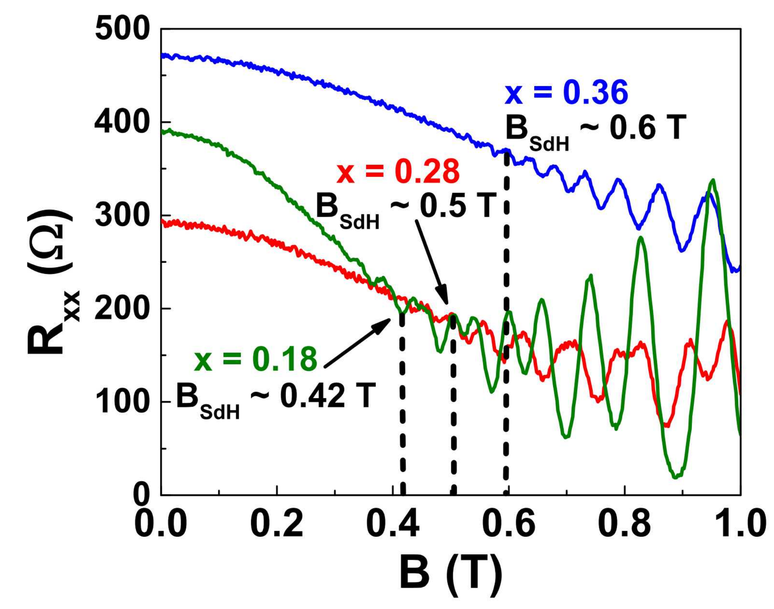


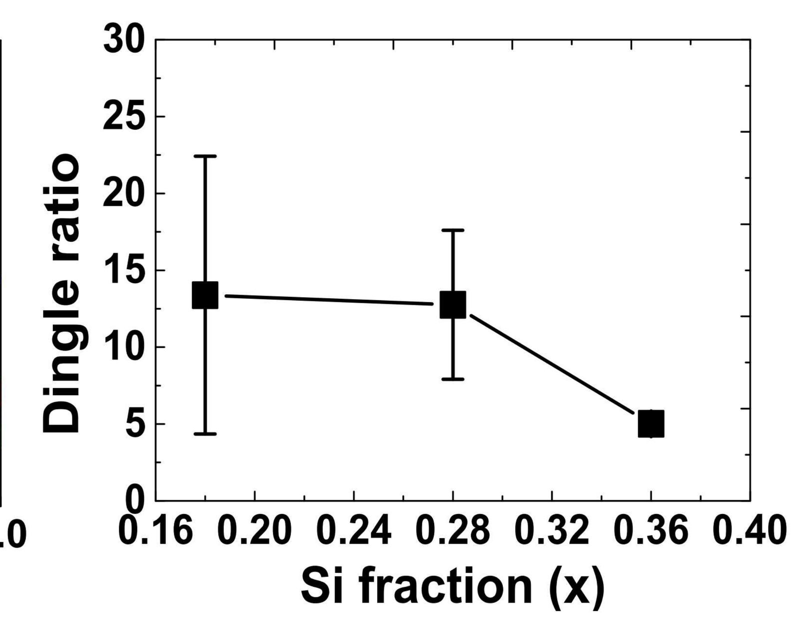


Oxygen-induced scattering

- SIMS (left) reveals ~10^{19} cm^{-3} of oxygen impurities in Ge quantum well layers, of which the concentration increase with Si fraction (right) due to stronger Si-O over Ge-O bonding.
- Oxygen-induced structural defects, but not ionized impurities are more likely to be responsible for scattering, according to mobility-limiting estimations.

Shubnikov-de Hass oscillations & extracted Dingle ratios





Short-range scattering

- Small Dingle ratios (5-14, right) extracted from SdH data (left) indicates short-range (large-angle) scattering.
- As the Si fraction increases, the Dingle ratio decreases.
  → short-range scattering getting stronger !

Conclusions

Scattering mechanisms in Ge/GeSi 2DHG

- Weak density-mobility dependence and small Dingle ratios suggest that the dominant scattering sources are dislocations and oxygen impurities.

Related Publications

[1] Y. Zhou, et al., *Phys. Rev. B* **84**, 125323 (2011).
[2] Y.-H. Su, et al., *Phys. Rev. Materials* **1** , 044601 (2017).
[3] T. M. Lu, et al., *Appl. Phys. Lett.* **99**, 153510 (2011).
[4] I. Yonenaga, et al., *Physica B: Condens. Matter*, **539** (2001).
[5] M. Reiche, *Phys. Status Solidi (a)* **138**, 409 (1993).
[6] X. Mi, et al., *Phys. Rev. B* **92** (2015)

Acknowledgement

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