SAND2017-5036C

An Equilibrium-Nonequilibrium Crossover in Charge Distributions and Weak Antilocalization of Ge and GeSn Two-Dimensional Hole Gases

Yi-Hsin Su[1], Yen Chuang[1], Chia-You Liu[1], Po-Yuan Chiu[2], Nai-Wen Hsu[2], Tzu-Ming Lu[3], and Jiun-Yun Li[1,2,4].

[1] Graduate Institute of Electronic Engineering, National Taiwan University, Taipei, Taiwan
[2] Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan
[3] Sandia National Laboratories, Albuquerque, NM, US
[4] National Nano Device Laboratories, Hsinchu, Taiwan
*email: jiunyun@ntu.edu.tw; phone: +886-2-33663700

National Taiwan University

Sandia National Laboratories

Introduction

Motivation

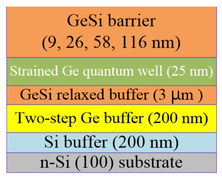
- Two-dimensional hole gases (2DHGs) in undoped Ge/GeSi and GeSn/Ge heterostructures for spin-orbit interactions (SOI)
- Few work on undoped Ge/GeSi heterostructures
- Expectedly stronger SOI in GeSn/Ge heterostructures

Key Results

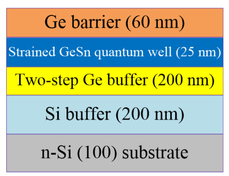
- Electrostatics and magneto-transport of 2DHGs in undoped Ge/GeSi and GeSn/Ge heterostructures investigated.
- Saturation density crossover from equilibrium to non-equilibrium observed
- Mobility enhancement observed due to the remote screening by the surface tunneling
- Clear weak antilocalization effect indicating strong SOI in GeSn/Ge heterostructures

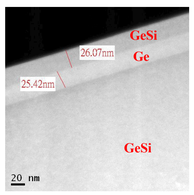
2DHG in Ge/GeSi and GeSn/Ge Heterostructures

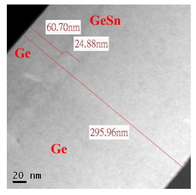
Ge/GeSi 2DHG



GeSn/Ge 2DHG



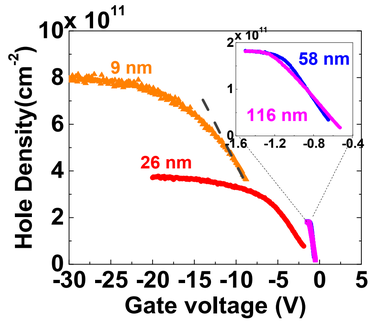


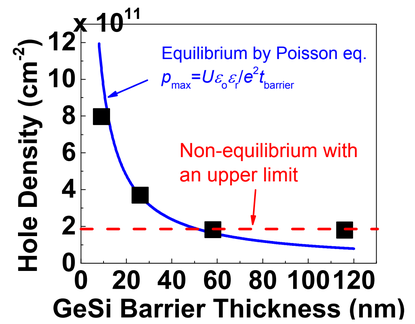


Ge/GeSi & GeSn/Ge heterostructures

- RPCVD with GeH_4, SiH_4, Ge_2H_6, and $SnCl_4$ as precursors
- Two-step Ge virtual substrate
- Constant GeSi relaxed buffer for Ge/GeSi heterostructures
- GeSi setback layer varied (from 9 nm ~ 116 nm) to characterize density saturation in Ge/GeSi 2DHG
- Ge setback layer (60 nm) for GeSn/Ge heterostrucures

Equilibrium-Nonequilibrium Crossover of Saturation Density

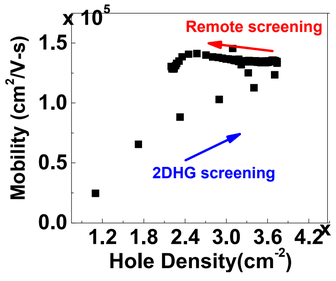


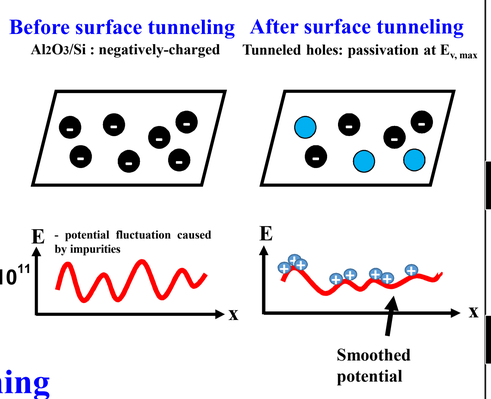


Crossover of 2DHG saturation density from non-equilibrium to equilibrium

- Density saturation for all devices– due to **surface tunneling**
  - **Deep-channel devices:**
  - **-> surface conduction prohibited, non-equilibrium**
  - **Shallow-channel devices:**
  - **-> surface conduction allowed, equilibrium**

Mobility Enhancement: Remote Carrier Screening

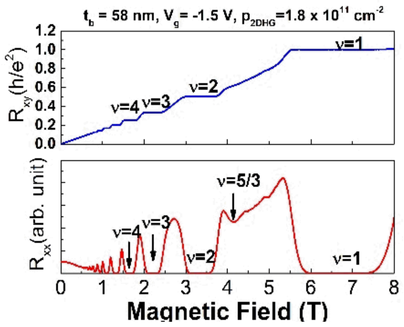




Remote carrier screening

- The tunneled holes smooth out the potential fluctuations at the surface, leading to a more correlated potential.

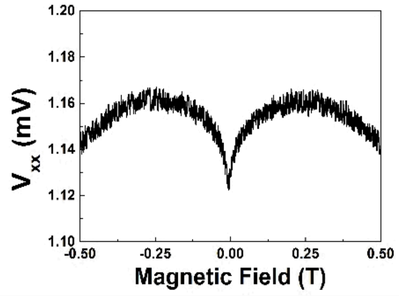
IQHE & FQHE for Ge/GeSi 2DHG



Clear IQHE&FQHE

- Clear quantum Hall plateaus observed in R_{xy} with the corresponding vanishing R_{xx}
- A fractional quantum Hall state $\nu = 5/3$ indicating the high quality of Ge/GeSi heterostructure

Weak Antilocalization Effect for GeSn/Ge 2DHGs



WAL features in V_{xx} vs. B

- Mobility ~ 5000 cm^2/V-s at 0.3 K
- Clear WAL features observed at low magnetic fields, a strong evidence of SOI
- Further work will be done to investigate the spin physics in GeSn

Conclusions

- Crossover of equilibrium and non-equilibrium of 2DHG saturation density
- Mobility enhancement for Ge/GeSi 2DHG due to the remote screening by the surface tunneling
- Clear integer quantum Hall plateaus and a fractional quantum Hall state indicating high epitaxial quality
- Clear WAL features in magneto-resistance for GeSn/Ge heterostructures

References

[1] T. M. Lu, C.-H. Lee, S.-H. Huang, D. C. Tsui, and C. W. Liu, *Appl. Phys. Lett.* **99**, 153510 (2011);
[2] C.-T. Huang, J.-Y. Li, K. S. Chou, and J. C. Sturm, *Appl. Phys. Lett.* **104**,243510 (2014).
[3] D. Laroche, S.-H. Huang, E. Nielsen, Y. Chuang, J.-Y. Li, C. W. Liu, and T. M. Lu, *AIP Advances* **5**, 107106-1 (2015)

Acknowledgements

This work at NTU has been supported by the Ministry of Science and Technology (103-2112-M-002-002-MY3) and National Applied Research Laboratories through I-Dream project (05105A2120). This work at Sandia National Laboratories been supported by the Division of Materials Sciences and Engineering, Office of Basic Energy Sciences, U.S. Department of Energy (DOE). This work was performed, in part, at the Center for Integrated Nanotechnologies, a U.S. DOE, Office of Basic Energy Sciences, user facility. Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.