C-V Characteristics of Undoped Si/SiGe Heterostructure Insulated-Gate Field-Effect Transistors

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Nai-Wen Hsu[1], Tz-Ming Wang[1], Chia-Tse Tai[1], Charles Thomas Harris[2], Tzu-Ming Lu[2], and Jiun-Yun Li[1,3,]*

National Taiwan University

[1] Graduate Institute of Electronics Engineering, National Taiwan University, Taipei 10617, Taiwan
[2] Sandia National Laboratories, Albuquerque, New Mexico 87185, USA
[3] Taiwan Semiconductor Research Institute, Hsin-Chu 30078, Taiwan
*email: jiunyun@ntu.edu.tw

Sandia National Laboratories

Center for Integrated Nanotechnologies (CINT)

Introduction

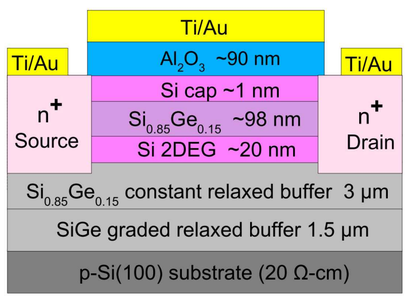
Motivation

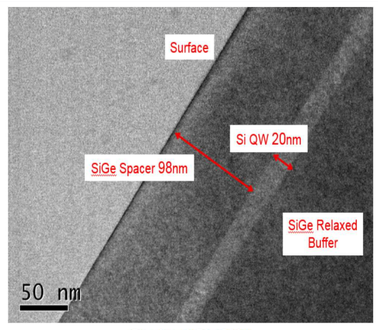
- Two-dimensional electron gases (2DEGs) in an undoped Si/SiGe heterostructures are a promising platform for quantum computing.
- Surface tunneling of a Si/SiGe heterostructure insulated-gate field-effect transistor (IGFET) at high gate biases was observed, but the electrostatics and transport properties haven't been studied in details.

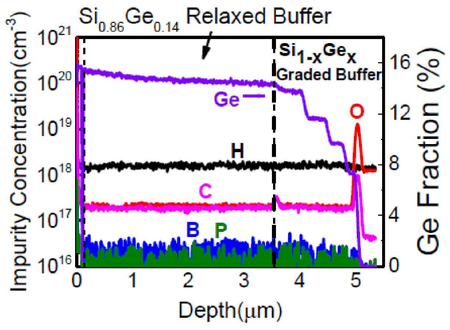
Key Results

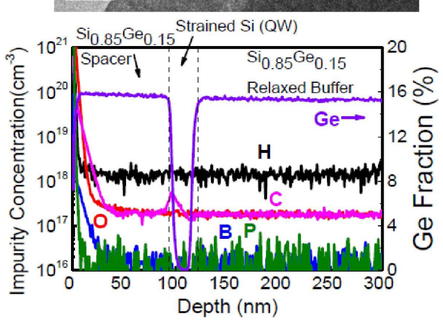
- We report the C-V characteristics and transport properties (n vs. V_g) in an undoped Si/SiGe IGFET at 4 ~ 300 K.
- At T < 45 K, the IGFET shows abnormal characteristics. Effective conduction first occurs in the buried 2DEG followed by the bilayer conduction of buried 2DEG and surface layer.
- At T > 45 K, normal transistor characteristics are observed.

Device Structures





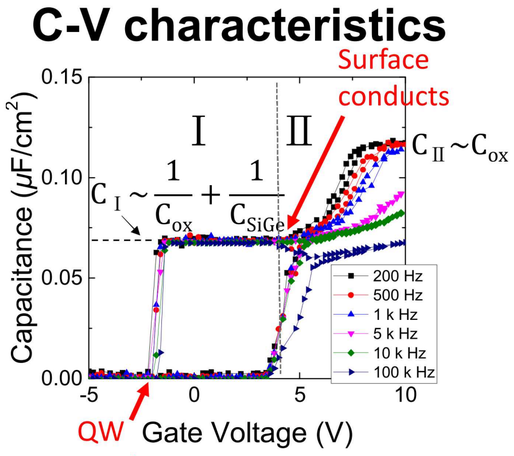




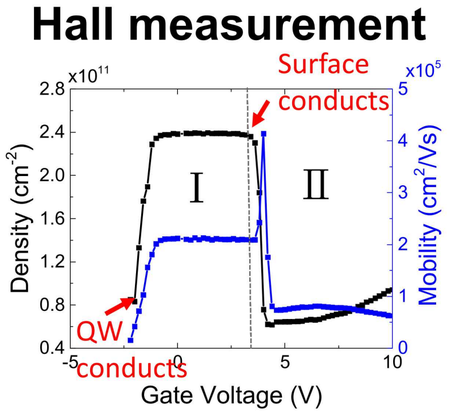
- Si/SiGe heterostructures are grown by UHVCVD with SiH_4 and GeH_4 as the precursors.
- Low impurity concentration (O, C < 10^{18} cm^{-3}.)

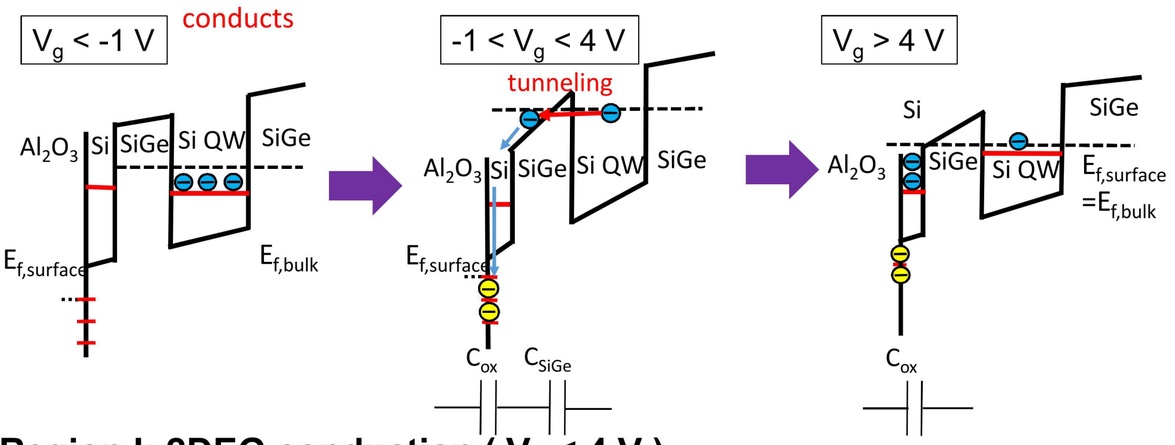
C-V and Hall Measurements at 4 K

C-V characteristics



Hall measurement





Region I: 2DEG conduction (V_g < 4 V)

- Electrons are first injected into the buried Si QW. As V_g increases, the stronger electric field cause electrons to tunnel to the surface and to be trapped in the Al_2O_3/Si interface states.
- Trapped electrons are immobile, so the capacitance and Hall density are constant as long as the surface is still insulating.

Region II: 2DEG + surface conduction (Vg > 4 V)

- Surface conducts after the interface states are effectively passivated by trapping electrons. (V_g > 8 V, C = C_{ox}.) Hall density decreases due to the lower mobility of surface carriers.
- Effective n_{Hall} and μ_{Hall} under parallel conduction:

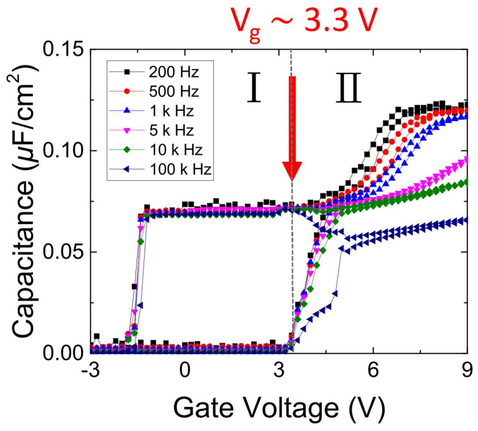
$$n_{Hall} = \frac{(n_1\mu_1 + n_2\mu_2)^2}{n_1\mu_1^2 + n_2\mu_2^2} \quad \mu_{Hall} = \frac{n_1\mu_1^2 + n_2\mu_2^2}{n_1\mu_1 + n_2\mu_2}$$

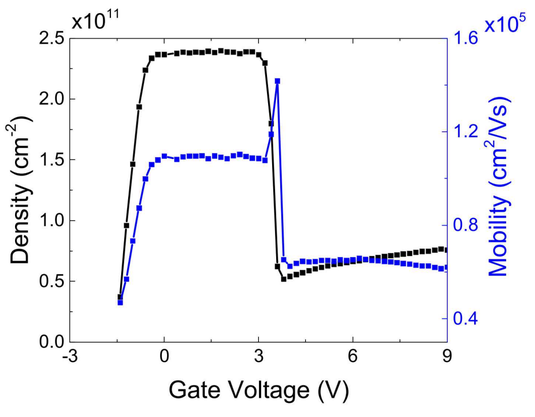
surface channel(denote 1) and buried QW(denote 2)

Temperature Dependence of C-V and Hall measurement

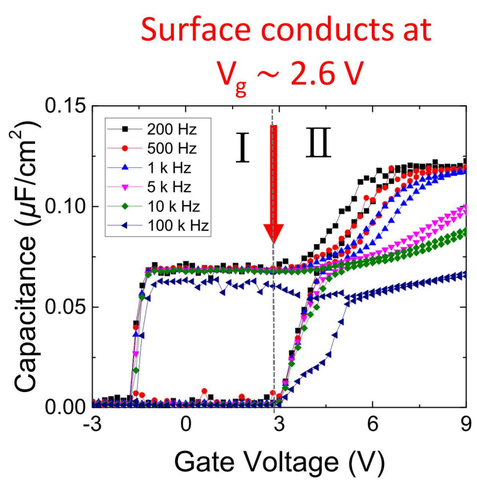
- **20 < T < 45 K**

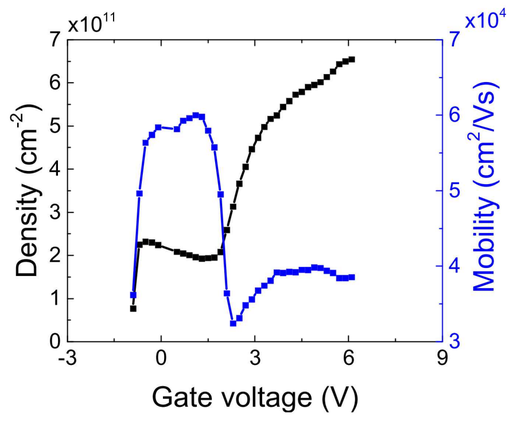
20 K





40 K

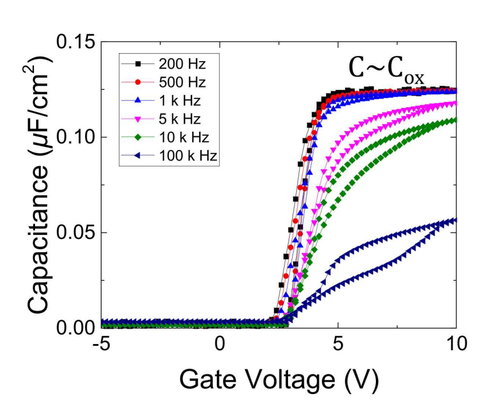


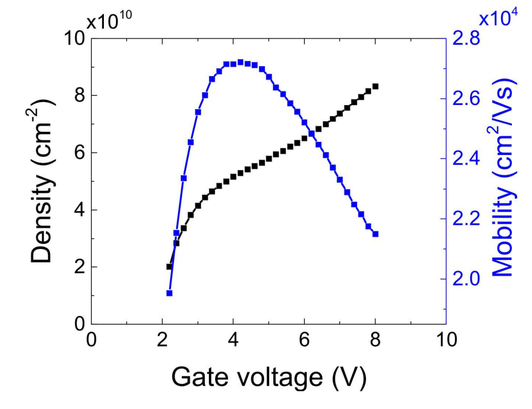


- As temperature increases, more energetic electrons can flow into the surface layer and passivate the interface states to contribute the surface conductions at a lower V_g.

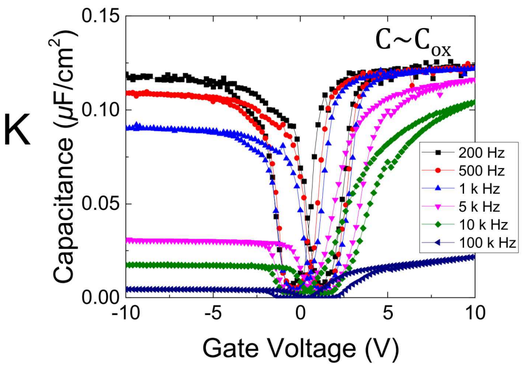
- **T > 60 K**

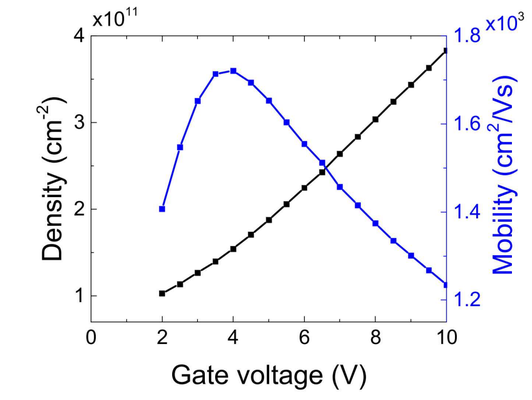
60 K





250 K





- At higher temperature, surface conducts soon after the buried 2DEG, capacitance saturates to C_{ox} and Hall density increases monotonically.

Conclusions

- C-V and Hall measurements of an undoped Si/SiGe 2DEG were performed at 4 ~ 300 K.
- At T < 45 K, the IGFET shows two-stage conduction. At low gate biases, only the buried 2DEG conducts since surface is insulating. After the defect states in Al_2O_3/Si interface are passivated by trapping electrons, both buried 2DEG and surface layer conduct.
- As temperature increases, more energetic electrons flow into the surface layer. The surface is no longer insulating, and normal transistor characteristics are observed.

Acknowledgement

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