

# Mobility Enhancement in Buried Two-Dimensional Electron and Hole Gases by Remote Carrier Screening

Yi-Hsin Su<sup>1</sup>, Kuan-Yu Chou<sup>1</sup>, Yen Chuang<sup>1</sup>, Po-Yuan Chiu<sup>2</sup>, Nai-Wen Hsu<sup>2</sup>, Tzu-Ming Lu<sup>3</sup>, and Jiun-Yun Li<sup>1,2,4\*</sup>

<sup>1</sup>Graduate Institute of Electronic Engineering, National Taiwan University, Taipei, Taiwan <sup>2</sup>Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan

<sup>3</sup>Sandia National Laboratories, Albuquerque, NM, US <sup>4</sup>National Nano Device Laboratories, Hsinchu, Taiwan; \*email: [jiunyun@ntu.edu.tw](mailto:jiunyun@ntu.edu.tw); phone: +886-2-33663700



National Taiwan University

Sandia National Laboratories

<h3>Introduction</h3> <p><b>Motivation</b></p> <ul style="list-style-type: none"> <li>Two-dimensional hole gases (2DHGs) in modulation-doped Ge/GeSi heterostructures have attracted considerable interests due to its rich physics, such as the fractional quantum Hall effect and spin-orbit interactions (SOI).</li> <li>There were few studies on undoped Ge/GeSi heterostructures.</li> </ul> <p><b>Key Results</b></p> <ul style="list-style-type: none"> <li>Electrostatics and magnetotransport of two-dimensional hole gases (2DHGs) in undoped Ge/GeSi heterostructures were investigated.</li> <li>A saturation density crossover from equilibrium to non-equilibrium and unexpectedly low gate effective capacitances in Ge 2DHGs due to surface tunneling were reported for the first time.</li> <li>A mobility enhancement was observed due to the remote screening by the tunneled electrons or holes in Ge/GeSi 2DEGs and Si/SiGe 2DHGs.</li> </ul>	<h3>Results: Equilibrium-non-equilibrium crossover</h3> <p><b>Crossover of 2DHG saturation density from non-equilibrium to equilibrium</b></p> <ul style="list-style-type: none"> <li>Density saturation for all devices— due to surface tunneling</li> <li>- Deep-channel devices: → surface conduction prohibited, non-equilibrium</li> <li>- Shallow-channel devices: → surface conduction allowed, equilibrium</li> </ul>	<h3>Results- Remote carrier screening</h3> <p><b>Remote carrier screening</b></p> <ul style="list-style-type: none"> <li>The tunneled carriers smooth out the potential fluctuation at the surface, leading to a more correlated potential, which is believed to boost the mobility.</li> </ul>
<h3>Experiment</h3> <ul style="list-style-type: none"> <li><b>Ge/GeSi heterostructures</b> <ul style="list-style-type: none"> <li>lightly-doped n-Si substrates</li> <li>virtual Ge substrates</li> <li>s-Ge QW on top of GeSi relaxed buffer</li> <li>GeSi TB, varied barrier thickness</li> </ul> </li> <li><b>TEM &amp; Process Flow</b> <ul style="list-style-type: none"> <li>high quality CVD growth</li> <li>high-quality oxide interface</li> </ul> </li> </ul>	<h3>Results: Unexpectedly low gate effective capacitance</h3> <p><b>Unexpectedly low gate effective capacitance in shallow-channel devices</b></p> <ul style="list-style-type: none"> <li>Surface tunneling decreases the holes in the buried QW, leading to the reduction of effective capacitance.</li> </ul>	<h3>Conclusion</h3> <p><b>Observations for the first time</b></p> <ul style="list-style-type: none"> <li>A cross-over of equilibrium and non-equilibrium of 2DHG saturation density</li> <li>Unexpectedly low gate effective capacitance</li> <li>Density transition in a single Si/SiGe 2DEG</li> <li>Mobility enhancement in both Si/SiGe 2DEG and Ge/GeSi 2DHG</li> <li>We attribute these observations to the <b>surface tunneling and remote carrier screening</b>.</li> </ul>
		<h3>Acknowledgement</h3> <p>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 was 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 Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. DOE's National Nuclear Security Administration under contract DE-AC04-94AK15500.</p> <h3>Related Publications</h3> <p>[1] T. M. Lu, C.-H. Lee, S.-H. Huang, D. C. Tsui, and C. W. Liu, <i>Appl. Phys. Lett.</i> <b>99</b>, 153510 (2011);          [2] C.-T. Huang, J.-Y. Li, K. S. Chou, and J. C. Sturm, <i>Appl. Phys. Lett.</i> <b>104</b>, 243510 (2014).          [3] D. Laroche, S.-H. Huang, E. Nielsen, Y. Chuang, J.-Y. Li, C. W. Liu, and T. M. Lu, <i>APL Advances</i> <b>5</b>, 107106-1 (2015)</p>