Solid State Technology and Devices Seminar

The Hunt for Mobile Holes Induced by Polarization in GaN

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Friday, April 9, 2021

Abstract: Two-dimensional electron gas (2DEG) in the GaN semiconductor family can be readily induced by polarization discontinuity without impurity dopants at a heterointerface, which is the heart of a high-electron mobility transistor (HEMT). Over the past decade, GaN HEMTs have been employed in 5G base stations, faster and miniature battery chargers etc. thanks to the high-speed operation and high power density afforded by this semiconductor family.

As a fundamental departure from impurity-doping and modulation-doping, the two well-known doping schemes in semiconductors, polarization-induced three-dimensional electron gas in GaN was also postulated and experimentally demonstrated for the first time in 2002 [1]. Thanks to the advent of high-quality bulk GaN substrates, polarization-induced three-dimensional hole gas in GaN was demonstrated in 2010, with assistance of impurity dopants; for the first time, p-type conductivity in GaN was measured down to cryogenic temperatures, 4 Kelvin [2]. This was nearly an impossible feat in impurity-doped p-type GaN due to carrier freeze-out. It has been about 20 years since the existence of mobile holes in GaN heterostructures without impurity dopants, the counterpart of 2DEG, was postulated. Only recently, undisputable experimental observations are achieved in our lab [3].

The long-missing polarization-induced two-dimensional hole gas (2DHG) is finally observed in undoped gallium nitride quantum wells. Experimental results provide unambiguous proof that a 2D hole gas in GaN grown on AlN does not need impurity doping, and can be formed entirely by the difference in the internal polarization fields across the semiconductor heterojunction. The measured 2D hole gas densities, about 4x1013 cm-2, are among the highest among all known semiconductors and remain unchanged down to cryogenic temperatures. Some of the lowest sheet resistances of all wide-bandgap semiconductors are seen. The observed results provide a new probe for studying the valence band structure and transport properties of wide-bandgap nitride interfaces, and simultaneously enable the missing component for gallium nitride-based p-channel transistors for energy-efficient electronics [4].

[1] D. Jena, H. Xing et al., Appl. Phys. Lett. 81(23), 4395-4397 (2002). DOI: 10.1063/1.1526161

[2] J. Simon, H. Xing, D. Jena et al., Science 327, 60 (2010) DOI: 10.1126/science.1183226

[3] R. Chaudhuri, H. Xing, D. Jena et al., Science 365, 1454 (2019) DOI:10.1126/science.aau8623.

[4] K. Nomoto et al, IEDM 2020.

Bio: Dr. Huili Grace Xing is currently the William L. Quackenbush Professor of Electrical and Computer Engineering, Materials Science and Engineering at Cornell University. She was with the University of Notre Dame from 2004 to 2014. She received B.S. in physics from Peking University (1996), M.S. in

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