ABSTRACT

Saeed Fallahi Ph.D., Purdue University, June 2019. Growth and characterization of two-dimensional III-V semiconductor platforms for mesoscopic physics and quantum devices. Major Professor: Michael J. Manfra.

Achievements in the growth of ultra-pure III-V semiconductor materials using state of the art molecular beam epitaxy (MBE) machine has led to the discovery of new physics and technological innovations. High mobility two-dimensional electron gas (2DEG) embedded in GaAs/$Al_xGa_{1-x}As$ heterostructures provides an unparalleled platform for many-body physics including fractional quantum Hall effect. On the other hand, single electron devices fabricated on modulation doped GaAs/$Al_xGa_{1-x}As$ heterostructures have been extensively used for fabrication of quantum devices such as spin qubit with application in quantum computing. Furthermore, epitaxial hybrid superconductor-semiconductor heterostructures with ultra clean superconductor-semiconductor interface have been grown using MBE technique to explore rare physical quantum state of the matter namely Majorana zero modes with non-abelian exchange statistics.

Chapter 1 in the manuscript starts with description of GaAs MBE system at Purdue University and continues with the modifications have been made to MBE hardware and growth conditions for growing heterostrcutures with 2DEG mobility exceeding $35 \times 10^6 cm^{-2}/Vs$. Utilizing an ultra-high pure Ga source material and its further purification by thermal evaporation in the vacuum are determined to have major impact on growth of high mobility GaAs/$Al_xGa_{1-x}As$ heterostructures.

Chapter 2 reports a systematic study on the effect of silicon doping density on low frequency charge noise and conductance drift in laterally gated nanostructures fabricated on modulation doped GaAs/$Al_xGa_{1-x}As$ heterostructures grown by Molecular Beam Epitaxy (MBE). The primary result of this study is that both charge noise

and conductance drift are strongly impacted by the silicon doping used to create the two-dimensional electron gas. These findings shed light on the physical origin of the defect states responsible for charge noise and conductance drift. This is especially significant for spin qubit devices, which require minimization of conductance drift and charge noise for stable operation and good coherence.

Chapter 3 demonstrates measurements of the induced superconducting gap in 2D hybrid Al/$Al_{0.15}In_{0.85}As$/InAs heterostructures which is a promising platform for scaling topological qubits based on Majorana zero modes. The 2DEG lies in an InAs quantum well and is separated from the epitaxial Al layer by a barrier of $Al_{0.15}In_{0.85}As$ with thickness d. Due to hybridization between the wave functions of 2DEG and superconductor, the strength of induced gap in the 2DEG largely depends on the barrier thickness. This chapter presents a systematic study of the strength of the induced gap in hybrid Al/$Al_{0.15}In_{0.85}As$/InAs superconductor/semiconductor heterostructures as a function of barrier thickness.