ARTIFICIALLY STRUCTURED SEMICODUCTORS TO MODEL NOVEL QUANTUM PHENOMENA

FINAL TECHNICAL REPORT
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ABSTRACT

Research in this project seeks to design, create and study a class of tunable artificial quantum structures in order to extend the range and scope of new and exciting physical phenomena and to explore the potential for new applications. Advanced nanofabrication was used to create an external potential landscape that acts as a lattice of confinement sites for electrons (and/or holes) in a two-dimensional electron gas in a high perfection semiconductor in such a manner that quantum interactions between different sites dictate the significant physics. Our current focus is on 'artificial graphene' (AG) in which a set of quantum dots (or sites) are patterned in a honeycomb lattice. The combination of leading edge nanofabrication with ultra-pure semiconductor materials in this project extends the frontier for small period, low-disorder AG systems, enabling the exploration of graphene physics in a semiconductor platform.

TECHNICAL DESCRIPTION

Contemporary condensed matter science has entered an era of discovery of new low-dimensional materials, such as graphene and other atomically thin materials, that exhibit exciting new physical phenomena that were previously inaccessible. Concurrent with the discovery and development of these new materials are impressive advancements in nanofabrication, which offer an ever-expanding toolbox for creating a myriad of high quality patterns at nanoscale dimensions.

This project started about four years ago. Among its major achievements are the realizations of very small period artificial lattices with honeycomb topology in GaAs quantum wells. In our most recent work the periods of the 'artificial graphene' (AG) lattices extend down to 40 nm. These small periods are about three times smaller than previously reported in GaAs quantum wells. This milestone establishes a new state-of-the-art in fields of research and nanofabrication. In experiments using optical scattering methods we uncovered evidence that free electrons in the small period AG lattices display novel features that arise from the symmetry of the honeycomb lattice.

These achievements create semiconductor platforms for explorations of novel states and effects that offer opportunities to create quasiparticles with tunable character. The quest for the discovery of novel quantum physics by nanofabrication of 'artificial structures' in semiconductor quantum structures overlaps with the development of quantum simulators.

Nanopatterns were created at Columbia University by the group of co-PI Shalom Wind using a 100keV e-beam nanolithography instrument (along with associated processing) that is part of the Columbia Nano Initiative. Optical experiments were carried out in the group of PI Aron Pinczuk. GaAs/AlGaAs quantum wells(QWs) of world-class perfection that serve as electron hosts are the starting material grown by molecular beam epitaxy (MBE) by our partners Dr. Loren Pfeiffer (Princeton Univ.) and Prof. Michael Manfra (Purdue Univ.). The inductively coupled plasma reactive ion etching (ICP-RIE) was carried out at the PRISM Micro/Nano Fabrication Laboratory of Princeton University. Dr. Vittorio Pellegrini (Istituto Italiano di Tecnologia, Genoa, Italy) has contributed critical insight on this research. Two graduate students in this project Sheng Wang and Diego Scarabelli, graduated in the summer/fall of 2016. Dr. Yuliya Kuznetsova has been a postdoc in the group. The current work is led by Dr. Lingjie Du, a postdoctoral scientist that joined the group of the PI on October 15th, 2016.

Since the start of this project we have focused primarily on developing protocols towards the fabrication of the artificial lattices [1], and in the implementation of characterization methods to identify the new electron states that are created [2,3]. A major milestone is the realization of the Dirac cones that emerge in honeycomb lattices.

In the next phases of this project, and as we achieve further milestones, we wish to expand our experimental platform so that we will be better positioned to access emergent novel quantum behavior and phases of electrons in artificial lattices designed and fabricated with 'exquisite' precision. The AG lattices with greatly reduced disorder from nano-processing that we have already created [4} demonstrate that we are poised for the next stage exploration of graphene physics and applications in semiconductor quantum structures.

References

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