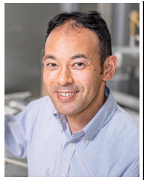
【Grant-in-Aid for Scientific Research (S)】

Research on semiconductor quasiparticle wave engineering



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	Keywords : electronic correlation, quasiparticles, wave engineering, quantum information	

Purpose and Background of the Research

●Outline of the Research

We will investigate fundamental properties of "quasiparticles" that propagate through many-electron systems in solids, maintaining quantum nature. This research should lead to the future development of quantum devices using propagating electrons. We will study generation, deformation, quantum properties, wave control, and interactions of charge quasiparticles that propagate over long distances in one-dimensional electron systems and Kondo quasiparticles defined for many-electron systems consisting of localized spins and conduction electrons.

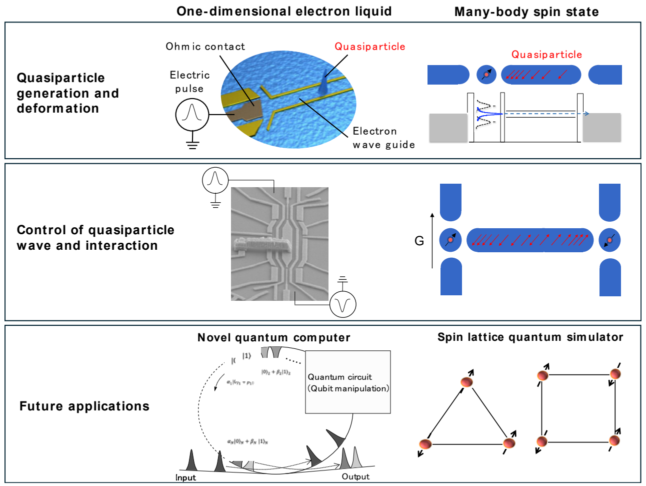

Figure 1. Outline of the research on semiconductor quasiparticle wave engineering.

●Research Background

A single electron incident on a many-body electron system consisting of many electrons in a solid loses its quantum properties in a short time due to interaction with the surrounding electrons. This means that the quantum mechanical degrees of freedom of the incident electron are immediately diffused to the surrounding electrons. For the electron wave engineering, we take the viewpoint of "quasiparticles," which are particles composed of many electrons and responsible for the properties of the system. These include plasma-like quasiparticles in one-dimensional interacting electron systems, and Kondo quasiparticles for the system consisting of localized spins and surrounding conducting electrons. These quasiparticles are known to behave differently from ordinary electrons, and are able to transmit their quantum information over long distances. If their flow can be controlled quantum mechanically, we can develop ultimately high-speed quantum devices that exploit the quantum nature of conducting electrons or quasiparticles.

●Research Purpose

The purpose of this research is to elucidate the physics of generation, deformation, and interaction of quasiparticles that carry information as electron waves, and to establish a guiding principle for quantum mechanical control of their states based on wave engineering. This will add quantum nature to the electron flow and lead to the development of ultimate electron wave devices. Our research targets the dynamical control of charge quasiparticles (electron wave packets) in one-dimensional electron waveguides and Kondo quasiparticles formed by the quantum coupling of many spins. Future applications after this research include a novel quantum computer using quantum information defined by the states of charged quasiparticles and a quantum simulator for spin-lattice systems in which localized spin and conduction electrons are quantum mechanically coupled. In addition, through this research, we will review general semiconductor circuits from the viewpoint of the propagation of quasiparticles and fundamentally reconstruct their design concepts, that should lead to the development of more advanced quantum systems in the future.

Expected Research Achievements

●Plasmonic quasiparticles in one-dimensional electron systems

Charge quasiparticles are generated as electron wave packets by applying short voltage pulses to small ohmic contacts. First, we will develop a technique to generate short voltage pulses and investigate the transport properties of the quasiparticle wave packets. (a) generation and deformation of quasiparticles, (b) verification of quantum nature, and (c) interaction between quasiparticles will be the research topics. In these experiments, we will precisely measure the propagation velocity and shape of quasiparticle wave packets by time-resolved measurements using gate electrodes (quantum point contacts: QPC) placed on the propagation channel (Figure 2).

●Kondo quasiparticles

The Kondo effect is a typical correlation effect caused by the interaction between localized spins and conducting electrons. In the low-temperature limit, the signature of the localized spin screening remains only in the quasiparticle's phase shift. We will conduct researches on the following topics related to the Kondo quasiparticles: (a) dynamics of the Kondo states and Kondo quasiparticles formation, (b) quasiparticle interactions using "Kondo boxes" that deform Kondo states, and (c) the properties of quasiparticles in systems with multiple localized spins. Time-resolved experiments will be employed to investigate when and to what extent the Kondo state extends by using Fabry-Perot interference (Figure 3).

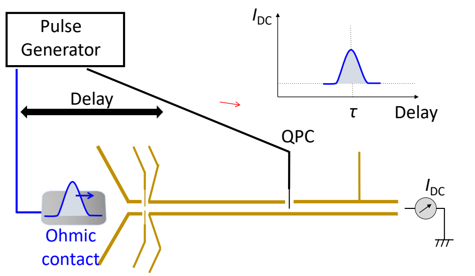

Figure 2. measurement of the propagation velocity and shape of quasiparticles.

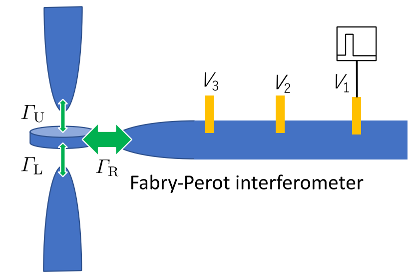

Figure 3. Time-resolved experiment for the Kondo state formation.

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