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Fabrications and transport properties of SiGe self-assembled quantum dots

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Abstract

In group-IV quantum dots (QDs), manipulation and detection of single electron spins have been rapidly developed as fundamental technologies of spin-based quantum computing [1]. Here, we focus on a hole system in SiGe self-assembled QDs (SAQDs) because the confined holes are expected to have a reduced contact hyperfine interaction with nuclei and a strong spin-orbit interaction (SOI) due to their p-like wavefunction [2]. In this work, we present the fabrications of SiGe SAQD transistors with different source-drain electrode metals and their electrical transport properties at low temperatures.

1. Introduction

Electron spins in QDs have much attentions for applications to quantum information technologies, in particular, quantum computing. Recently, it has been recognized that the silicon or other group IV materials are suitable materials for quantum dots because of the reduced number of nuclei with nuclear spin. Indeed, extremely long electron spin coherence time has been reported in isotopically enriched ^{28}Si QDs [3]. There should be more space for materials and device designs to further developments for realizing spin qubits with high performance. Here, we focus on a hole system in SiGe self-assembled QDs (SAQDs). Because of the band alignment between a Ge island and a thin Si cap, Fermi level lies in the valence band of Ge [2]. The confined holes are expected to have very weak contact hyperfine interaction with nuclei and strong SOI due to their p-orbital symmetry of wavefunction [2]. Therefore, hole-SiGe SAQDs would provide a new root for novel spin qubits toward applications to quantum information processing. In this work, we present the fabrications of SiGe SAQD transistors with two different electrode metals and the transport properties at low temperatures.

2. Device

SiGe SAQDs were grown by molecular beam epitaxy in Stranski-Krastanov mode. We fabricated SiGe SAQD transistors in two different ways; one was contacted by aluminum without any preceding cleaning processes before metal deposition on the QD, the other was contacted by palladium after removing surface native oxide on the SiGe QD by BHF etching [4]. The buried p-dope Si layer or highly p-doped Si substrate was used as a back-gate. The distance between two source-drain electrodes ranges from 30-50 nm.

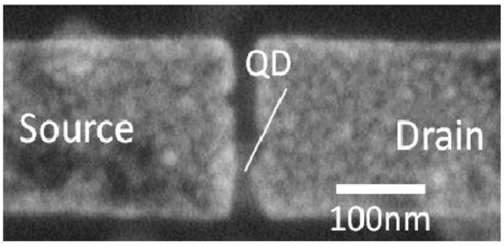

Fig. 1. SEM image of a SiGe SAQD contacted to Al electrodes.

2. Experimental results

Al devices

Several devices have been successfully fabricated. Almost all devices seem to be in a relatively strong tunnel couple regime. Figure 2 shows the back-gate voltage dependence of the differential conductance of one of the devices (Sample A). This behavior infers us that the devices locates close to an intermediate transport regime between Coulomb oscillation and Fabry-Perot type transport. In the following measurements, in order to focus on the basic transport properties of SiGe SAQD devices, we suppressed the superconductivity by applying a magnetic field higher than the critical field. In another device (Sample B), a zero bias conductance peak is observed, which can be attributed to the Kondo effect. By increasing perpendicular magnetic field, the zero bias peak shows splitting due to the Zeeman splitting in the QD. Further increment of the magnetic field enters the inelastic co-tunneling regime. From the these features, we evaluate hole g-factor for perpendicular magnetic field to be 2.03, comparable to the value reported previously for hole-SiGe SAQDs, suggesting that our dot is also a hole QD system [5].

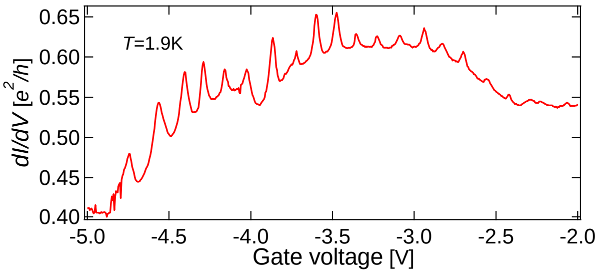

Fig.2. Back-gate voltage dependence of the differential conductance SiGe SAQD with Al electrodes (Sample A).

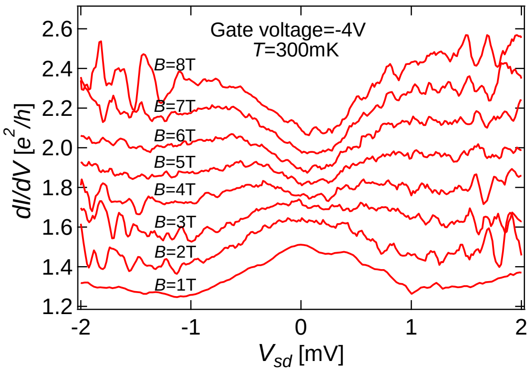

Fig. 3. Magnetic field evolution of zero-bias conductance peak of Sample B.

Pd devices

We also fabricated the devices contacted to palladium electrodes since palladium is also often used for SiGe nanowires [6] and SiGe hutwires [7] as source and drain electrodes. In a device (Sample C), the amplitude of the Coulomb peaks was very small, indicating that the device was in a weak tunnel coupling regime.

In the other device (Sample D), the neighboring Coulomb peaks strongly overlap each other. The tunnel coupling is estimated about 2 meV by fitting a Coulomb peak to a Lorentzian [8]. The obtained value of the tunnel coupling is sufficiently larger than the energy of temperature. This result indicates that this device is in a strong tunnel coupling regime. Comparison between Sample C and D infers us that in the case of palladium electrodes, the strength of the tunnel coupling may widely disperse. This may depend on the condition of the interface between QD and palladium. Furthermore, we measured the magnetic field dependence of Coulomb peak positions in Sample D. Application of relatively high perpendicular magnetic field shifts the energy of the electronic states higher. As shown in Fig. 4, the Coulomb peak position are shifted towards the negative back-gate voltage direction. This is opposite trend to the case of electron QD [9]. This is probably consistent with the hole-confined SiGe SAQD.

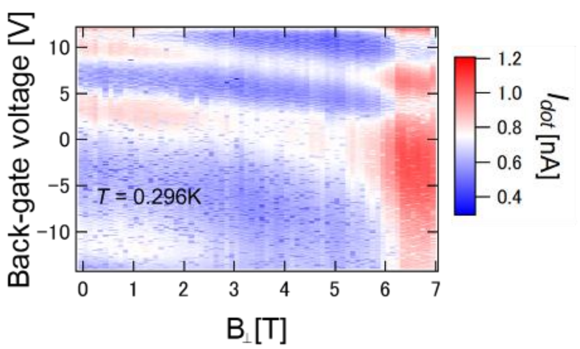

Fig. 4. Magnetic field dependence of Coulomb peak positions of Sample D.

3. Conclusions

We fabricated single electron transistors consisting of SiGe self-assemble quantum dots (SAQD) contacted to either Al or Pd electrodes. We observed Kondo effect of in a SiGe quantum dot in an Al device. From the magnetic field dependence of the Kondo zero-bias peak we evaluated g-factor for perpendicular magnetic field to be 2.03 similar to the value reported for a hole-SiGe SAQD previously [5]. The hole-SiGe SAQD is also deduced from the magnetic field dependence of Coulomb peak positions in a SiGe SAQD contacted to Pd.

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