Quantum Interference on Electron Wave Spreading over a Coupled Dot

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Abstract

The characteristics of the conductance fluctuations, observed in the low-temperature magnetoresistance of an open quantum-dot molecule formed from a pair of split-gate quantum dots, have been studied. The evolution of these fluctuations suggests a decrease in the typical area for coherent interference with decreasing the coupling strength between the two dot. We discuss this behavior in terms of a transition from multi- to single-dot interference as a function of the inter-dot coupling. Moreover, an existance of interference trajectories which were independent of the dot coupling was also found in our analysis.

Key words: quantum interference; coupled dot; magnetoconductance; quantum-dot molecule; low temperature

1. Introduction

In semiconductor quantum wires and dots, the low-temperature transport are strongly affected by the influence of quantum interference [1]. As the application for the future device technologies, wave function coherence in the coupled quantum dot is quite interesting for the quantum computing [2]. In order to investigate the wave function dynamics in the quantum cavity, we have studied the low-temperature magneto-conductance in a coupled dot defined by a split-gate technique with several pairs of an independently controlled quantum point contact (QPC), and observed highly reproducible conductance fluctuations (CF), which indicates the existence of the characteristic electron trajectories involved in coherent interference. Analyzing the CF, we could obtain the reduction in the typical area for coherent electron interference by weakening the coupling strength. It indicates an existence of molecular-like trajectories spreading over the two dots.

2. Sample and exteriments

The coupled dot was formed with the standard split-gate technique on the surface of a high mobility GaAs/AlGaAs wafer, which has individually controllable QPCs. The two-dot system consists of five strip gates that lie opposite to a two-open-mouth gate so that three QPC and two plungers are constructed. We can independently control the coupling strength between the two dots by changing the gate voltage of the central QPC. The electron density and mobility in the two-dimensional electron gas are 3.9×10^{15} m^{-2} and 80 m^2/Vs, respectively. Designed sizes of the left and right dot are 1.0×1.0 and 1.2×1.2 μm^2 , respectively. The low temperature transport measurements were performed at 100 mK in the dilution refrigerator with a low power excitation using a lock-in amplifier system.

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3. Results and discussion

To investigate the influence of the inter-dot coupling on the characteristics of electron interference, fixed voltages were applied to all gates of the structure, except for the central, coupling, QPC. These voltages were chosen from the individual pinch-off characteristics to form three propagating modes for the outermost QPC. The center QPC was then changed from -0.6 to -3.0 V, over which range is corresponding to the propagating-mode number from eight to essentially zero. Using this gate configuration, only the coupling strength between the two dots was modified without changing the size of each dot.

The magnetoresistances at various center-gate voltages were shown in Fig.1. For each of the curves, the amplitude of the fluctuations is seen to be of order 0.1 e^2/h, indicating that a reasonable degree of electron coherence is maintained across the entire coupled-dot structure. From the Fourier analysis of the magnetoresistance, we have obtained a Fourier contour plot (Fig. 2a). The two main features of this contour are the presence of strongly dependent components on the gate voltage in the frequency range of ~250-300 T^{-1}, and the presence of invariant frequency components are much lower frequencies (~20 T^{-1}). In a correlation analysis of the data, the correlation field (B_c) decreased with increasingly negative center-gate voltage. Plotting the results on Fig. 2a, it is consistent with the evolution of high frequency components in the Fourier contour. The B_c is corresponding to the characteristic interference area, $S_c=h/eB_c$, which decreases with increasing the gate voltage as shown in Fig. 2b. It suggests that the effect of reducing the inter-dot coupling is to suppress the contribution to interference on orbit that coherently span double dot. Therefore, it is interpreted that the molecular-like trajectories are suppressed by decreasing the coupling strength, and the interference characteristics close to be a single-dot behavior[3]. Moreover, we believe that our observations provide strong support for the notion that high-frequency components in the fluctuations result from a controlled energy -hybridization in the coupled-dot system [3,4].

In addition, we found clear higher harmonics in the Fourier analysis of the result of the correlation function analysis. The value of the characteristic field is muching to the low frequency component in the Fourier contour. It is interpreted that there would exist also very small interference area trapped in such a wave function scar, and the coherency could be maintained for the multiple times rotation in the trapped site.

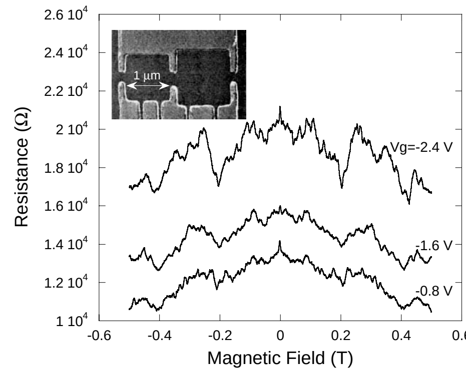

Fig. 1. The magnetoresistance in the double-dot system at three different values of the center-gate voltage (indicated). The inset is the scanning electron micrograph of the sample.

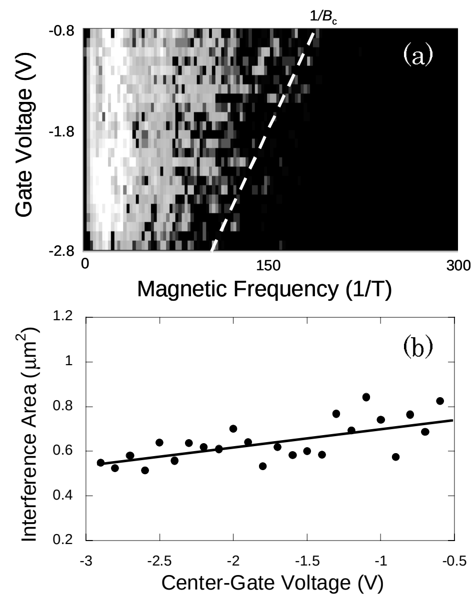

Fig. 2. (a) The Fourier contour plot. (b) The gate voltage dependence of the correlation field B_c. Dotted lines are intended as guides to the eye.

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