Mesoscopic Fano Effect through a Quantum Dot in an Aharonov-Bohm Ring

Kensuke Kobayashi, **Hisashi Aikawa, Shingo Katsumoto, and Yasuhiro Iye**

Institute for Solid State Physics, University of Tokyo, Kashiwa, Chiba 277-8581, Japan

The Fano effect, which arises from interference between a localized state and the continuum, represents one of the most fundamental aspects of quantum mechanics [1]. This also gives a representative example how a localized state embedded in the continuum acquires itinerancy over the system. While this effect is a ubiquitous phenomenon observed in a large variety of physical systems, it has been difficult to obtain a Fano system with desired parameters. Here, we have realized a tunable Fano system in a quantum dot (QD) embedded in an Aharonov-Bohm (AB) interferometer, which is the first convincing demonstration of this effect in mesoscopic systems [2].

Figure 1 shows our system fabricated on a two-dimensional electron gas (2DEG) at an AlGaAs/GaAs heterostructure (mobility = 9×10^5 cm^2/Vs and sheet carrier density = 3.8×10^{11} cm^{-2}). One arm, consisting of 2DEG, has a continuum energy spectrum while the QD embedded in the other arm has a single discrete level for electrons to transmit. When the coherence of electrons is sufficiently preserved over the system, this device will serve as a single-site Fano system.

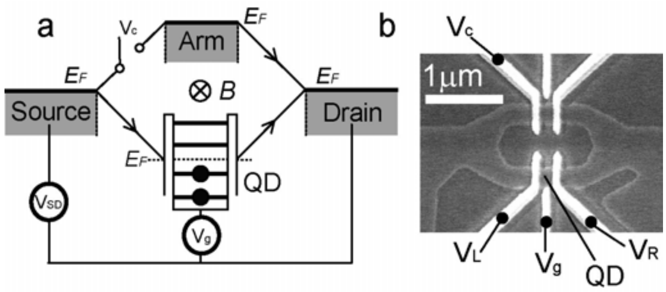

Fig. 1 (a) Schematic representation of the experimental setup. An electron injected from the source traverses the ring along two different paths through the continuum in the arm and the discrete level inside the QD and interferes. This corresponds to a single-site Fano system. **(b)** Scanning electron micrograph of the fabricated device by wet-etching the 2DEG. The white regions indicate the Au/Ti metallic gates. The three gates (V_R, V_L, and V_g) at the lower arm are used for controlling the QD and the gate at the upper arm (V_c) is for swiching on and off the path through the continuum in the system.

The transport measurement of this QD-AB-ring hybrid system has revealed several unique properties that can be attributed to the Fano effect. As shown in Fig. 2, when only the QD was transmissible with the other arm pinched off, ordinary Coulomb peaks with Lorentzian line shape were observed. As both arms were made open, the peaks became very asymmetric and showed even dip structures. These line shapes are successfully fitted to Fano's line shape. The differential conductance of this system has a resonance peak stretching along the zero bias line superposed by the Coulomb diamond (see Fig. 3). This means that, with the aid of the continuum at the arm, the discrete state in the QD becomes declocalized even in the Coulomb blockade (CB). While the mechanism is different, such delocalization of electrons in the CB region is highly analogous with that observed in the Kondo effects in QD's.

Since the continuum and the discrete level are spatially separated in our system, the Fano interference can be tuned through the phase of electrons by the magnetic field piercing the ring as shown in Fig. 4. Controlling the Fano line shape in this way has revealed that the Fano asymmetric parameter q, which has been implicitly treated as real, should be extended to a complex number. Moreover, the line shape modulation by the AB effect was found to be quite different from those in the phase measurements of electrons through a QD in the similar QD-AB-ring structures [3,4]. This indicates that our system should be regarded as a novel quantum system due to the highly preserved coherence over it.

References
[1] U. Fano, Phys. Rev. **124,** 1866 (1961).
[2] K. Kobayashi, H. Aikawa, S. Katsumoto, and Y. Iye, Phys. Rev. Lett. **88,** 256806 (2002).
[3] A. Yacoby *et al.* Phys. Rev. Lett. **74,** 4047 (1995).
[4] W. G. van der Wiel *et al.* Science **289,** 2105 (2000).

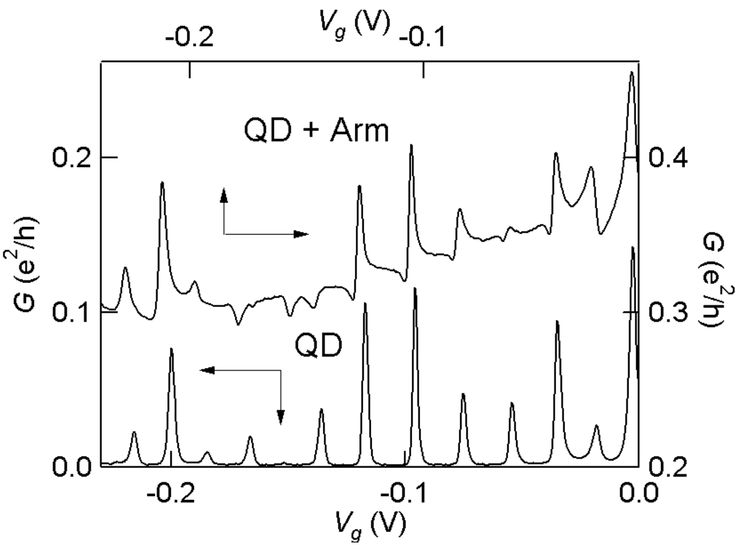

Fig. 2 Coulomb oscillation at V_c = ~0.12 V with the arm pinched off, and asymmetric Coulomb oscillation at V_c= –0.086 V with the arm transmissible. The latter shows a clear Fano effect. Both of them were obtained at 30 mK and B = 0.91 T. When the temperature increased, the asymmetric Fano line shapes gradually evolved into an ordinary Lorentzian line shape, making this system a classical parallel circuit of a QD and an arm.

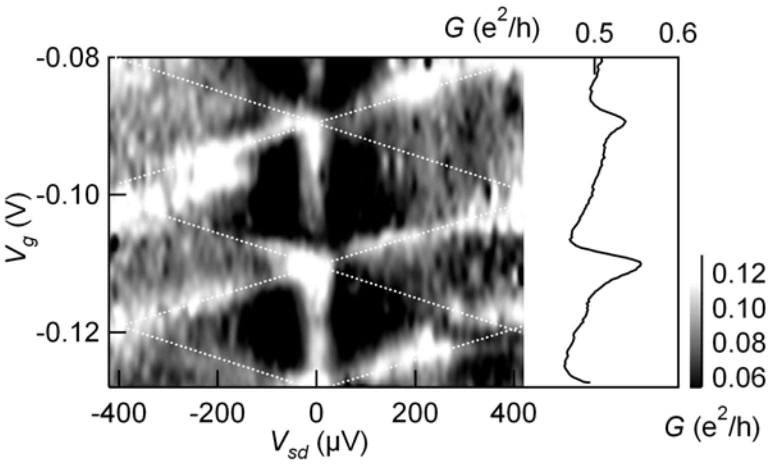

Fig. 3 Differential conductance obtained as a function of V_g at 30 mK and B = 0.92 T. The corresponding Fano line shape is also shown in the right panel. The zero-bias conductance peak exists in the Coulomb blockade region with a Coulomb diamond superimposed. The edge of the diamond is emphasized with white dashed lines.

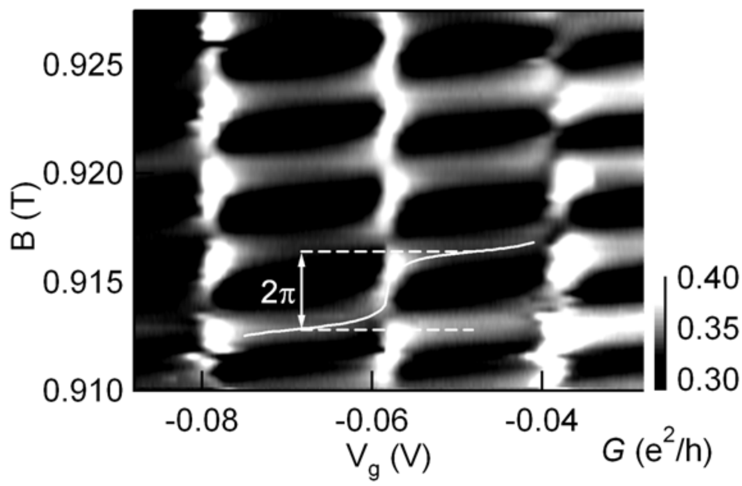

Fig. 4 The conductance of several Fano peaks as a function of V_g and B at 30 mK. AB oscillation exists even at the midpoints between the resonance peaks. The white line represents the AB phase as a function of V_g. Note that the AB phase changes by 2π through the resonance, and all the resonances are in phase. The overall behavior is quite different from the previous results [3,4].