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Shot Noise in Single and Double Quantum Point Contacts

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Shot noise in mesoscopic devices has attracted growing interest because it arises from the discreteness of the electron charges and is able to probe the transport properties, complementary to conventional conductance measurements. A quantum point contact can be a good candidate for studying the shot noise properties. The transmission probability, T, is varied as a function of the gate voltage and one can expect the suppression of the shot noise from the classical value of $2eI$ to $2eI(1-T)$ due to Fermi-Dirac quantum statistics. However, to date there are only few experiments reported on the shot noise properties mainly due to difficulties in distinguishing the shot noise from large 1/f noise. In this paper, we use a measurement technique similar to, but more sensitive than, the previous technique[1)] to measure the shot noise, and discuss excess noise for a single point contact at high bias voltages and noise for two point contacts connected in series with various separation lengths. The latter is especially interesting to clarify the noise suppression mechanism: whether the phase coherence is crucial in determining the noise or not.

The point contacts used are electrostatically induced by surface Shottky gates on a GaAs/AlGaAs HEMT wafer. In our lock-in technique to measure the shot noise, the bias voltage is modulated around zero as $Vds=V\cdot \cos \omega t$, not as $Vds=V/2\cdot (1+\cos \omega t)$, which was used in the previous report[1)], thus minimizing the heating effect by the average DC offset current. The shot noise from 2 MHz to 12 MHz range was measured at 1.5 K.

Figure 1 shows conductance and noise characteristics of a typical point contact at the drain-source voltage of 1 mV. Peaks are observed in the noise spectra between quantized conductance plateaus as expected. The noise spectra for the bias voltages from 0.5 mV to 4 mV are shown in Fig. 2. As the bias voltage increases, the noise at the peaks increases linearly with the current, which manifests that the observed noise is shot noise. However, excess noise starts to appear at positions between the peaks in the noise spectra when the bias voltage is further increased above ~1.5 mV. A part of this excess noise may be generated by hot electrons tunneling into the higher-lying subband, as suggested by the shift of the noise peaks toward negative gate voltage shown by the triangles.

In some point contacts, we observe peculiar noise spectra as shown in Fig.3. There is an additional structure near pinch-off as shown by the arrow. A dip is seen in the Fano factor, which is a ratio of the observed noise power to the full shot noise value, $2eI$, at the corresponding gate voltage. This can be due to suppression of shot noise associated with some kind of correlated electron motion. We expect such a correlation effect resulting from, for example, a charge build-up in an accidentally formed island when the point contact is pinched off.

Finally, we discuss noise of the two point contacts connected in series. Figure 4 shows the observed Fano factor and the conductance. The noise characteristic is slightly different when the gate of each point contact is separately biased while keeping the gate voltage of the other point contact zero. When the gates of the two point contacts are simultaneously biased, the conductance reduces to half the single point contact value because the separation of the two point contacts (2.4 μm in this case) is too large for an electron emitted from the first point contact to ballistically pass through the second. As for the noise, no significant difference is observed in Fano factor from the single point contact case although the overall transmission coefficient is half. Similar result is obtained when the separation is 0.6 μm. This is clearly different from the case where two independently fluctuating current sources are connected in series. Detailed investigation on this is now under way.

1)M. Reznikov, M. Heiblum, H. Shtrikman, and D. Mahalu, Phys. Rev. Lett. **75**, 3340 (1995).

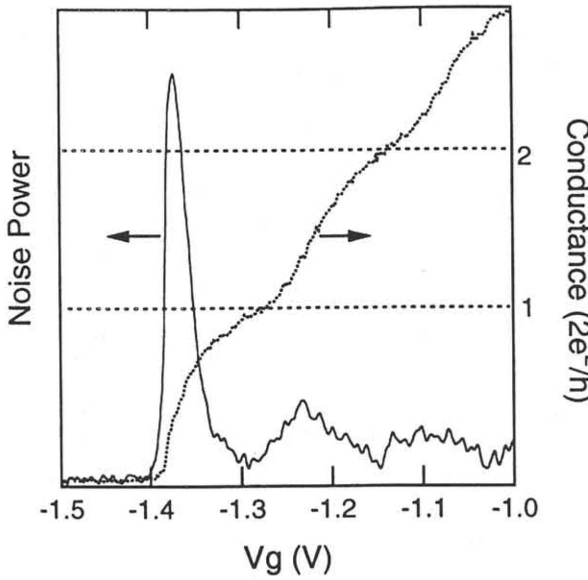

Fig. 1: Typical conductance and noise characteristics at Vsd=1 mV. The peaks in the noise power spectrum are observed at the gate voltages between the quantized conductance steps.

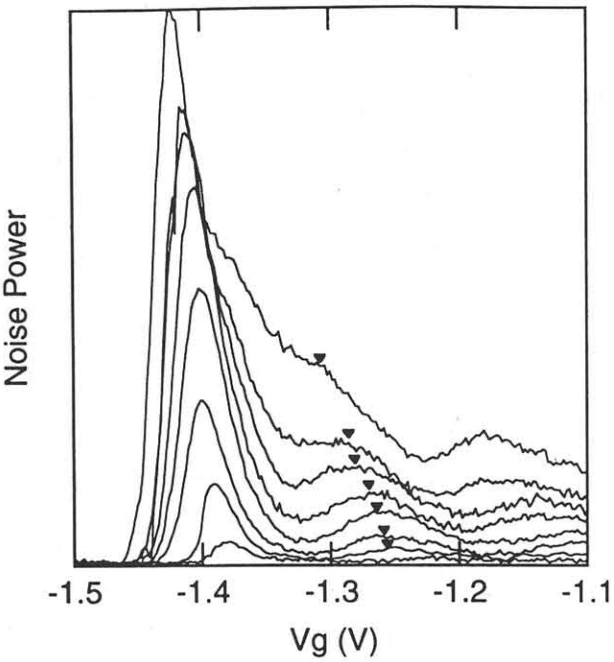

Fig. 2: The noise power as a function of the gate voltage. The bias voltage is varied from 0.5 mV to 4 mV in 0.5 mV step from bottom to top.

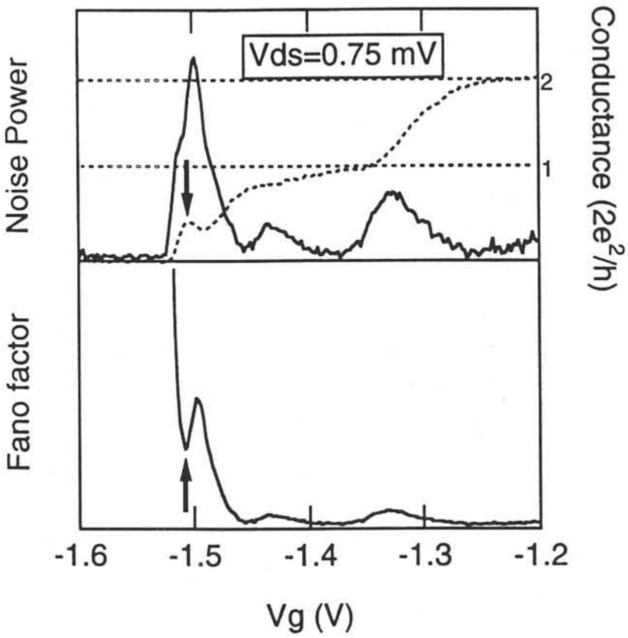

Fig. 3: Noise and conductance characteristics of a point contact that exhibits peculiar structure as shown by the arrow close to the pinch-off. The Fano factor shows a dip at the corresponding position suggesting correlated tunneling of electrons.

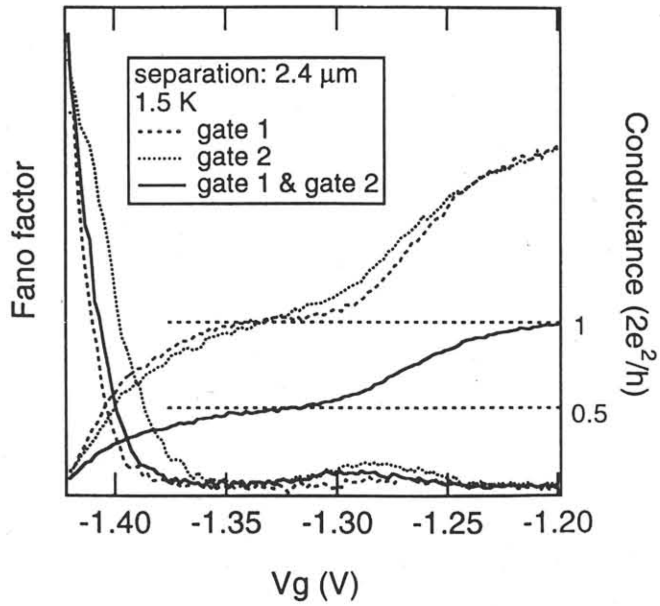

Fig. 4: Fano factor and conductance characteristics of coherently coupled two point contacts whose separation is 2.4 μm. The noise does not show clear difference from the case when each point contact is separately biased.