Fast single-charge sensing with a rf quantum point contact

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We report high-bandwidth charge sensing measurements using a GaAs quantum point contact embedded in a radio frequency impedance matching circuit (rf-QPC). With the rf-QPC biased near pinch-off where it is most sensitive to charge, we demonstrate a conductance sensitivity of $5 \times 10^{-6} e^2/h$ Hz$^{-1/2}$ with a bandwidth of 8 MHz. Single-shot readout of a proximal few-electron double quantum dot is investigated in a mode where the rf-QPC back action is rapidly switched.

instance, a $dg_{\text{QPC}}=0.01 e^2/h$ conductance change to be measured with unity SNR in $t_{\text{int}}=500$ ns. Above $\sim 8$ MHz, the $Q$ factor ($\sim 15$) of the impedance matching circuit limits the sensitivity, as shown in Fig. 2(b). The SNR increases with applied carrier power [Fig. 2(c)] up to the energy scale set by the one-dimensional subband spacing (typically several millivolts). A source-drain bias of 1 mV requires a carrier power of approximately $-70$ dBm. For the charge sensing measurements described below, carrier power was set to $-75$ dBm. For this power, $\sim 80\%$ of the output noise is the intrinsic shot noise of the QPC. Figure 2(d) shows the dependence of the sideband SNR on carrier frequency, consistent with reflected power measurements [Fig. 1(c)].

We demonstrate the operation of the rf-QPC by detecting single-electron changes in charge configuration of a double quantum dot in the few-electron regime. For this demonstration, the QPC was biased on the steep edge of a conductance riser at $g_{\text{QPC}}\sim 0.3 e^2/h$, where the conductance is a sensitive function of the local electrostatic potential [see Fig. 1(d)]. Figure 3 shows $dV_{\text{rf}}/dV_L$ as a function of gate voltages $V_L$ and $V_R$, which control the number of electrons in the left and right dots. Stable charge configurations of the double dot correspond to the red colored regions with labels $(n, m)$ indicating the electron occupancy on the left and right dot. Charge transitions appear in the derivative of $V_{\text{rf}}$ as black and yellow lines.

Focusing on the $(2,0)-(1,1)$ transition, Fig. 4(a) shows $V_{\text{rf}}$ as a function of $V_R$ and $V_L$ with each data point averaged 32
times. In the device studied, a change in QPC conductance of ∼1% (∼0.003 e²/h) is associated with an electron transition between (1,1) and (2,0). Using the measured conductance sensitivity $S_\text{C} = 5 \times 10^{-5} e^2/h \text{ Hz}^{-1/2}$, we find a charge sensitivity of $\sim 10^{-3} e \text{ Hz}^{-1/2}$, i.e., $\sim 5 \mu s$ is needed to perform charge readout with SNR of unity for this device.

Coupling rf power to the QPC has two effects on the rf carrier: an electrical delay between the room temperature un-blanked carrier and the QPC and a cross coupling using SONNET SUITES software. This interval measurement scheme. Each pixel is an average over of an integration time $t_{\text{int}} = 60 \mu s$. Black trace is $V_\text{rf}$ which is sampled for $t_\text{int} = 60 \mu s$ following the measurement trigger (red trace). An electrical delay between the room temperature un-blank trigger and $V_\text{rf}$ is observed.

High-fidelity readout in the present device is limited by the small coupling between the QPC and the double dot, a device parameter that can be increased considerably by improved sample design, as demonstrated, for example, in Ref. 14. The rf-QPC may also be useful in detecting small changes in mesoscopic capacitance$^{28}$ that alter its resonance frequency and in the simultaneous measurement of many rf-QPCs using multiplexing techniques.$^{29,30}$

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21. CoiCraft 1206CS-821XL.
22. Mini-Circuits mixer ZP-3MH and directional coupler ZEDC-15-2B.
23. CoilCraft 1206CS-821XL.
25. The circuit board was designed to minimize parasitic capacitance and cross coupling using SONNET SUITES software.
28. Mini-Circuits ZASWA-2-50DR.