Impact of the gate geometry on adiabatic charge pumping in InAs double quantum dots

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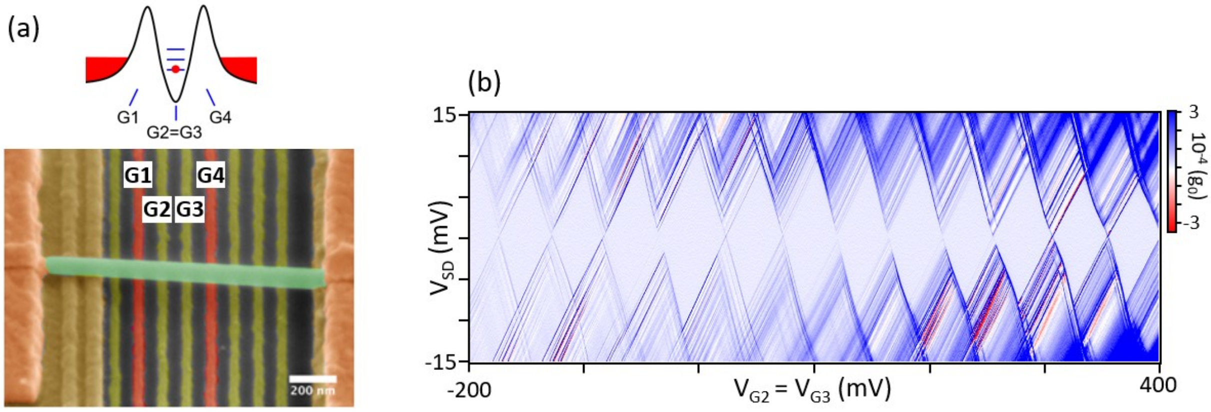

FIG. S1 (a) Scanning electron microscopy image of device A. The two gates G1 and G4 form a large quantum dot and the middle two gates G2 and G3 control the energy level of this quantum dot. (b) Charge stability diagram measured as a function V_{SD} and V_{G2}=V_{G3} confirms that the quantum dot is very clean.

Table 1. Summary of parameters of DQD device A and B. $E_C^{L(R)}$ is the charging energy of the left (right) QD. $\alpha_{L(R)}$ is the lever arms for the left (right) QD, $C_{1(2)}$ is the total capacitance of the left (right) QD, and C_m is the mutual capacitance. The parameters are extracted from each charge stability diagram.

Device	E_C^L [meV]	E_C^R [meV]	α_L	α_R	C_1 [aF]	C_2 [aF]	C_m [aF]	C_S [aF]	C_D [aF]
A	13.7	6	0.07	0.03	12.1	28.3	3.6	7	8.3
B (First tuning)	7.8	11.4	0.1	0.16	21.7	14.9	4.2	Not measured	
B (Second tuning)	16	10	0.1	0.08	10	16.3	2.1	Not measured	

Mechanism of DQD charge pumping

The pump mechanism of the electron trajectory (left in FIG. S2(b)) is illustrated in FIG. S2(c): (A) the energy level on the left QD is lowered as the voltage on the left gate V_L is increased, loading a single charge from the lead onto the left QD; (B) the energy level on the right QD is lowered as the voltage on the right gate V_R increases, which allows the excess charge on the left QD to tunnel to the right QD, while tunneling back into the reservoirs is forbidden because both levels are positioned below the Fermi energy; in (C) the empty level of QD1 is lifted beyond the Fermi level, followed in (D) by the occupied level of QD2, at which point the excess charge on QD2 preferentially tunnels out into the drain contact and the system returns to its original charge configuration. When the same path encircles the other triple point (hole), the polarity of the current is reversed (not shown) because electrons are pumped in the opposite directions.

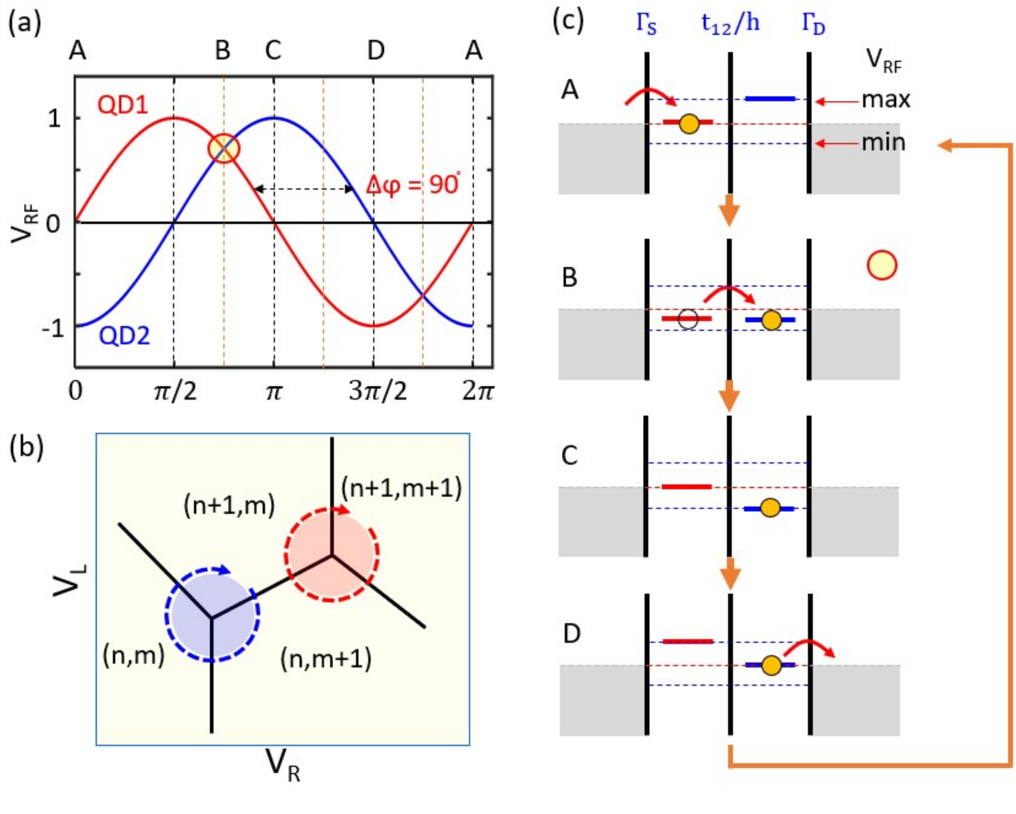

FIG. S2 Illustration of the charge pump mechanism in a double quantum dot. (a) 90˚ Phase-shifted sine waves added to the DC voltages to modulate the QD levels. (b) Pumping trajectories around the triple points in the DQD stability diagram. The color indicates the polarity of the current which is possible for the two triple points. (c) Illustration of the potential landscape during a charge pumping cycle in a DQD.

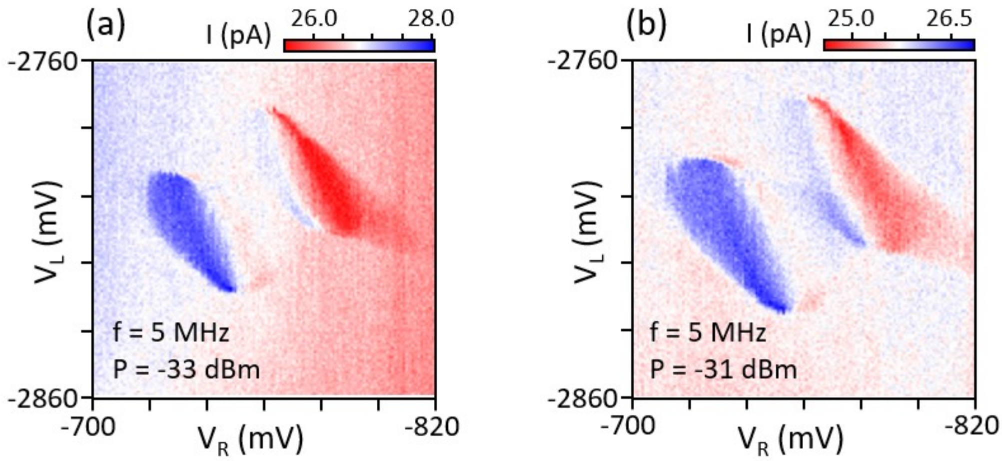

FIG. S3 Pumped current at f = 5 MHz in device A as a function of modulation power. (a) P = –33 dBm, (b) P = –31 dBm. The current plateaus expand as increasing the modulation power is increased.

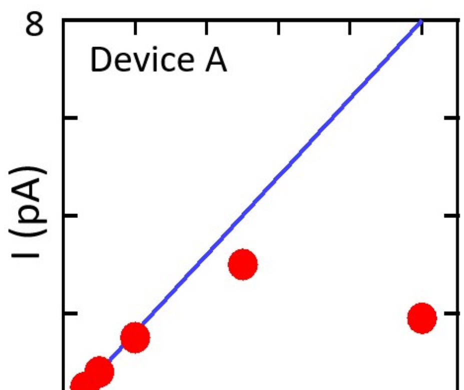

FIG. S4 Frequency dependence of the pump current taken from device A.

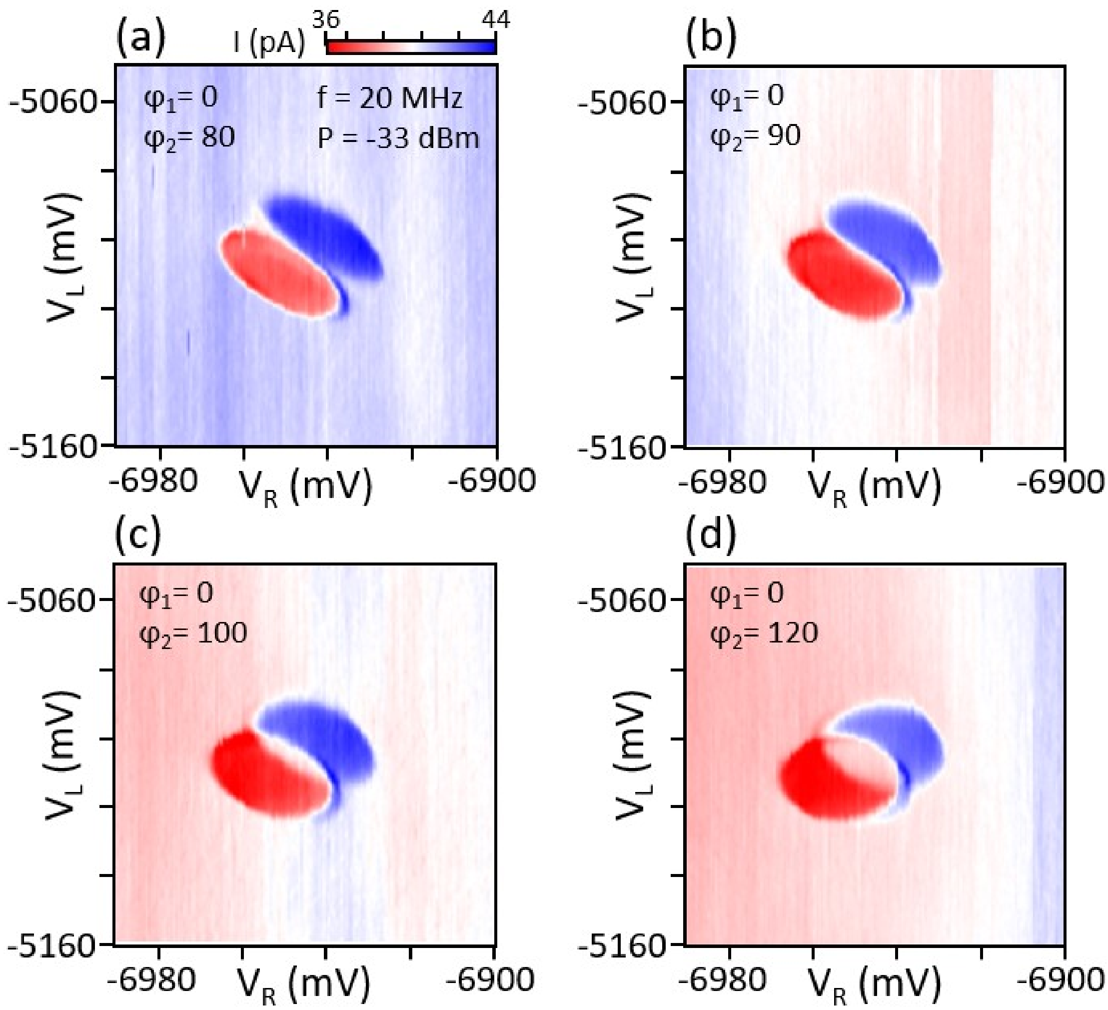

FIG. S5 (a)-(d) Phase shift dependence of the pumped current at f = 20 MHz and P = –33 dBm (V_{PP} = 14.157 mV) in device B.

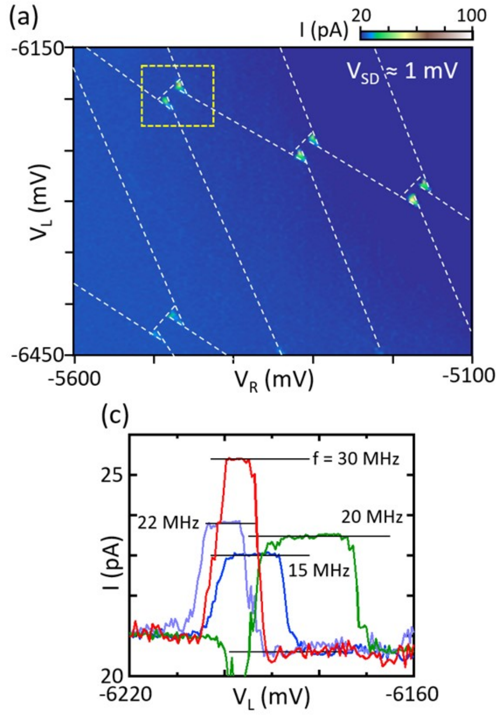

FIG. S6 Charge stability diagram measured for the second tuning of device B. Three gates with the applied voltage V_L, V_M, and V_R are used to form a DQD in the nanowire by setting $V_M = -8.2$ V. (b) Pump current at the triple points indicated by the dashed line box in (a). The pump frequency and power are $f = 15$ MHz and $P = -31$ dBm ($V_{PP} = 17.822$ mV). (c) Line traces of the pump current for different pump frequencies. (d) Frequency dependence of the pump current.