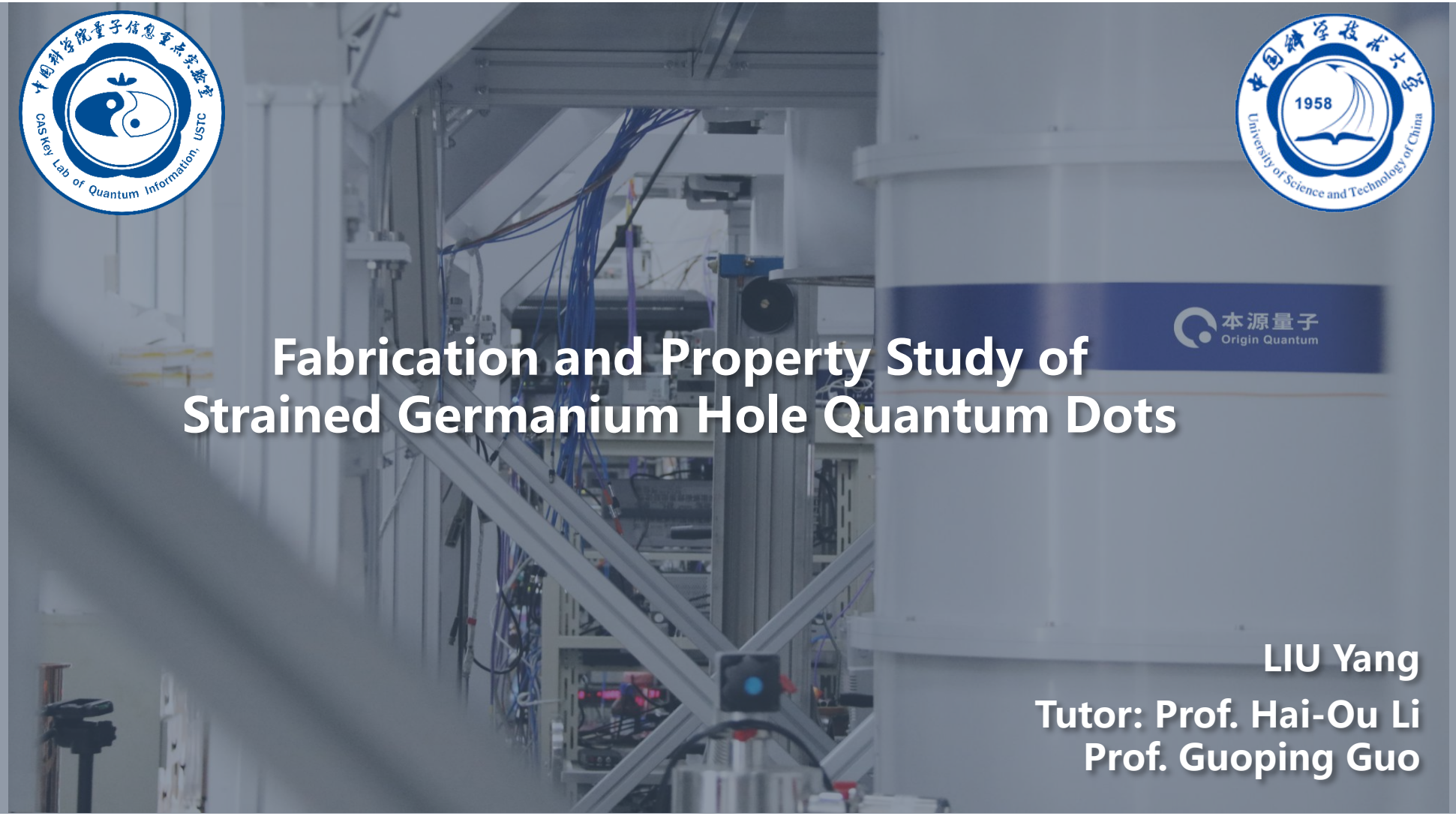


Fabrication and Property Study of Strained Germanium Hole Quantum Dots

LIU Yang

Tutor: Prof. Hai-Ou Li
Prof. Guoping Guo

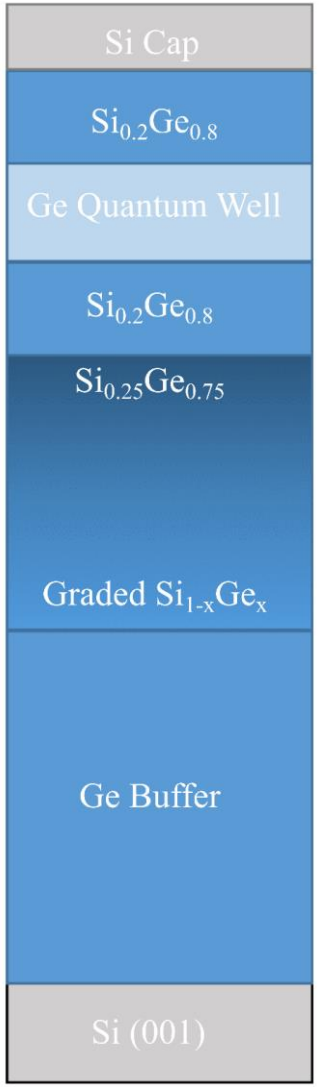
CATALOGUE

01 Self-Introduction

Key Laboratory of Quantum information, CAS
Team of Prof. Hai-ou Li & Prof. Guoping Guo

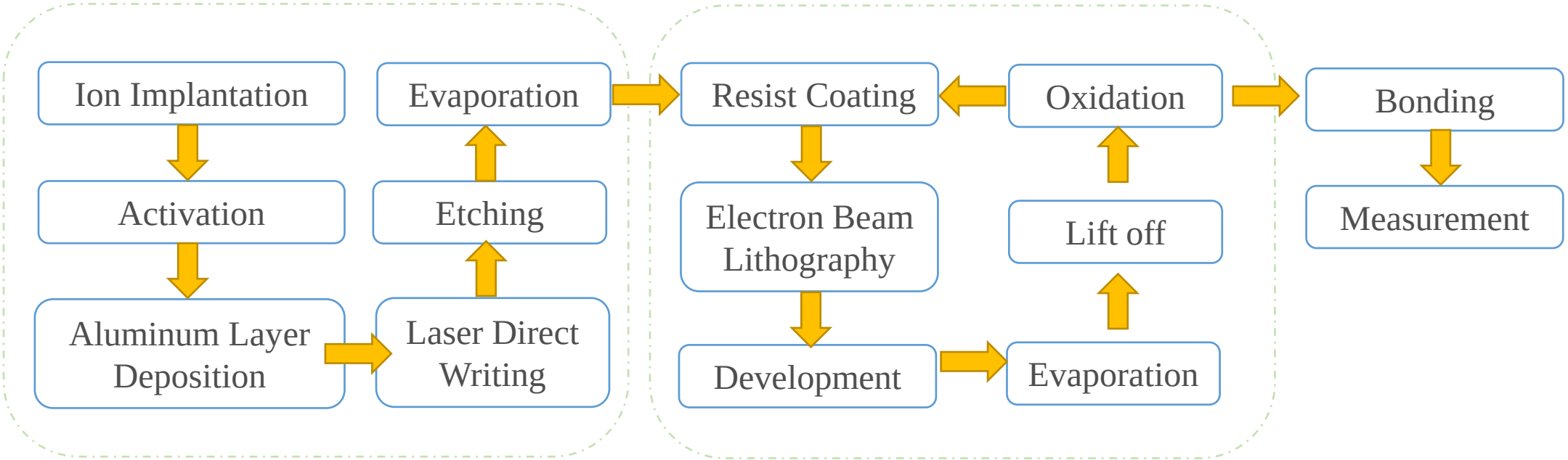
Experimental Partner: Yuchen ZHOU

01 Device Fabrication-Substrate and Fabrication



Micro-scale Fabrication:
Ohmic Contacts

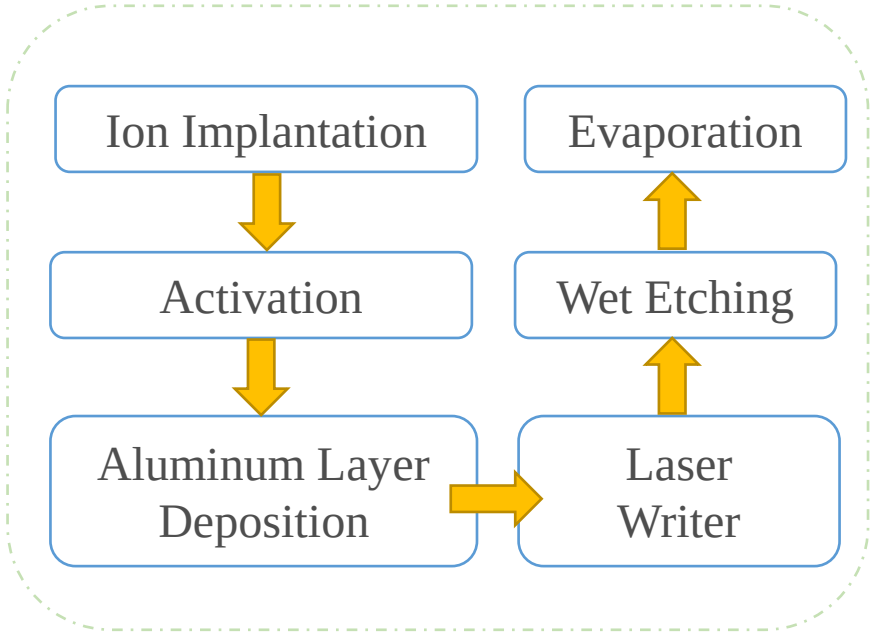
Nano-scale Fabrication:
Aluminum Electrodes



Integrated Circuit Advanced Process R&D Center, Institute of Microelectronics, Chinese Academy of Sciences, Beijing 100029, P. R. China

01 Device Fabrication-Ohmic Contacts

Micron-scale Fabrication:
Ohmic Contacts



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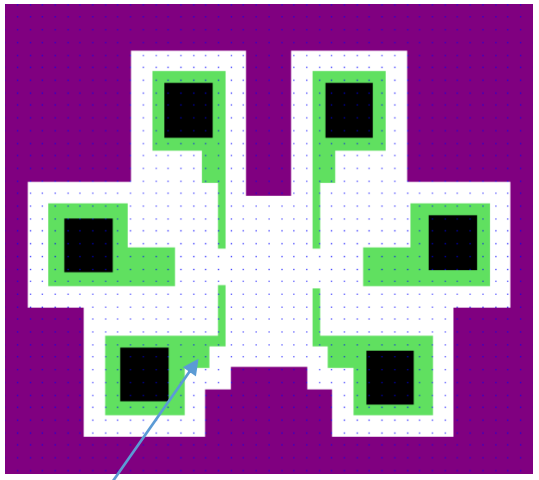

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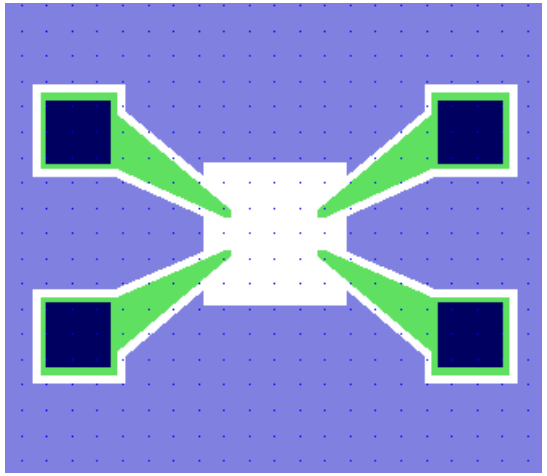

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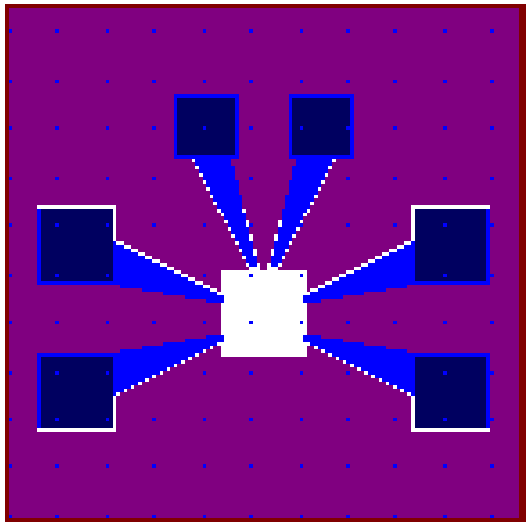
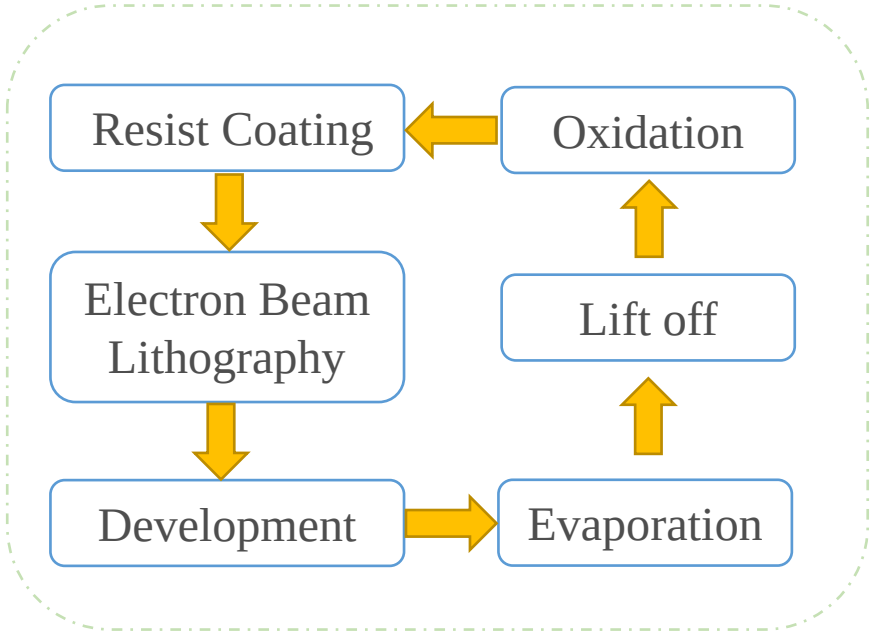
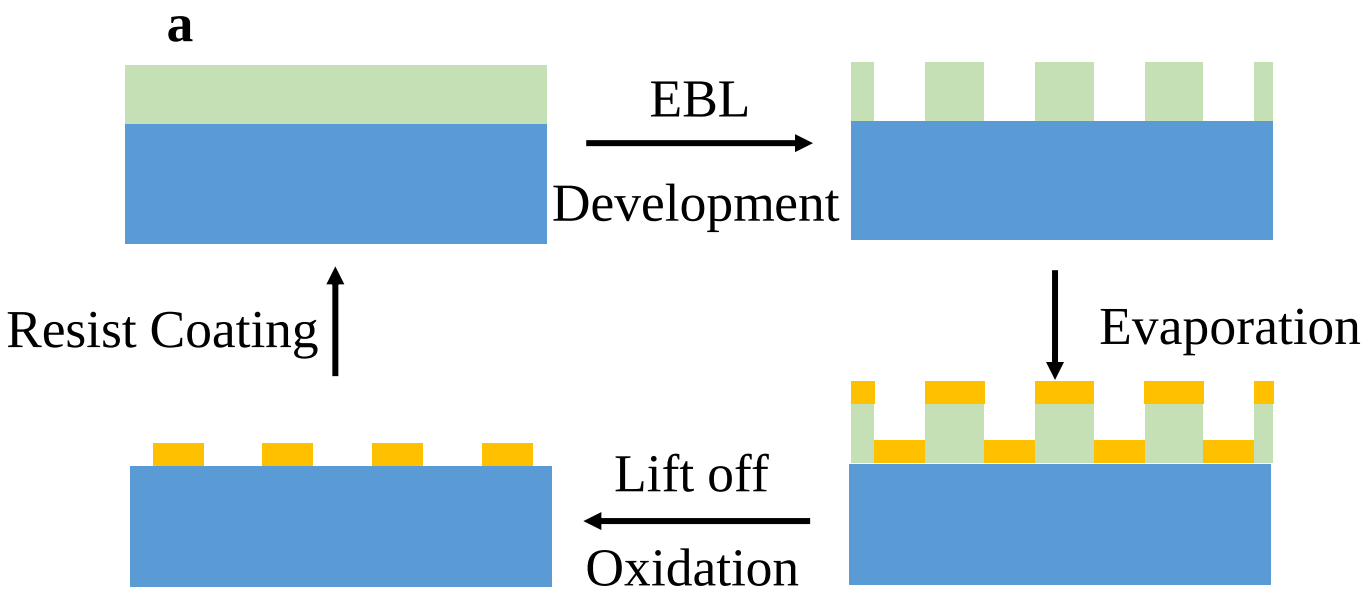
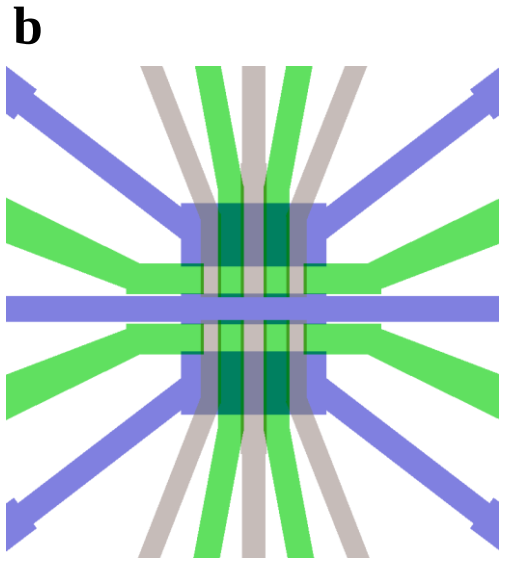


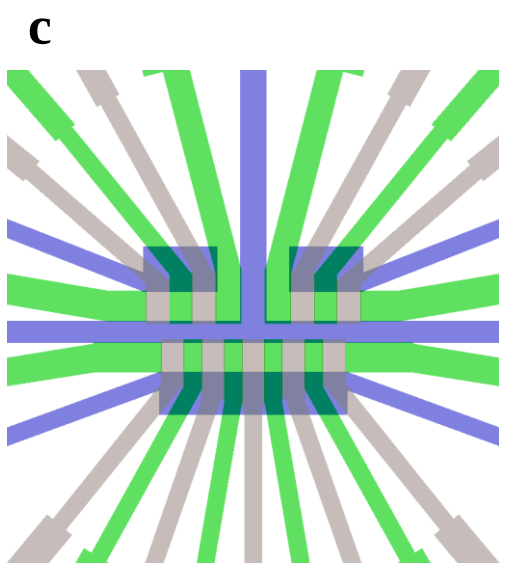
01 Device Fabrication-Aluminum Electrodes

Nano-scale Fabrication:
Aluminum Electrodes





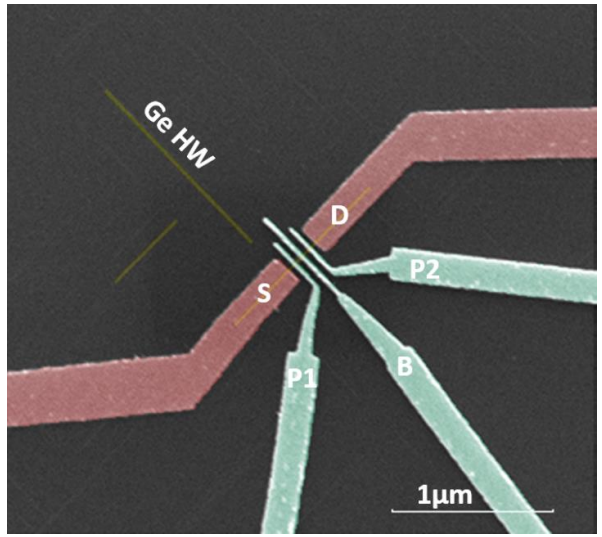




CATALOGUE

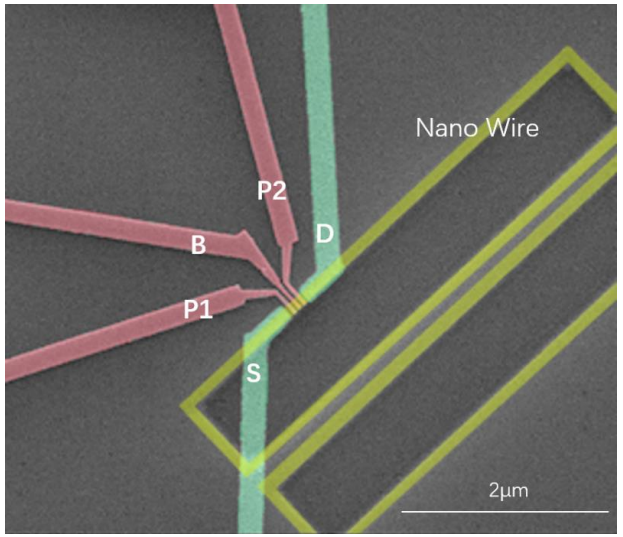
02 **Device Fabrication**-Quantum Dot Device in Ge Hut Wire

a



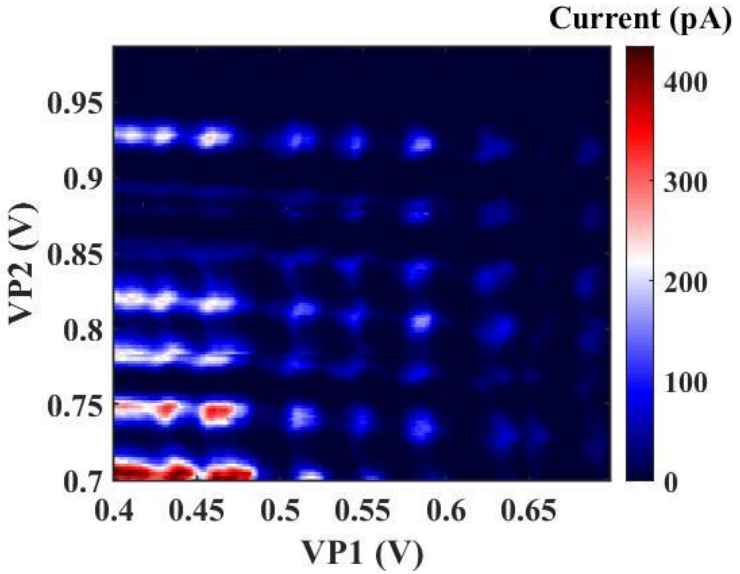
Ge Hut Wire

b



Site-Controlled Ge Hut Wire

c

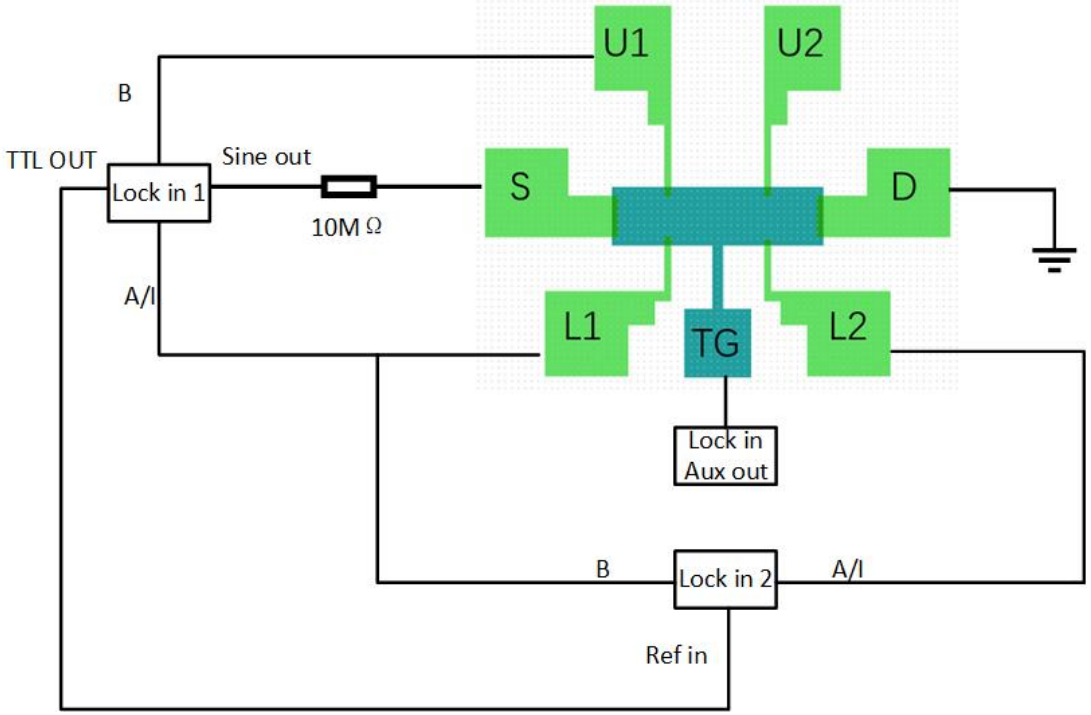


Measured in Liquid Helium (4K)

02 Device Measurement I-Quantum Hall Effect

a

Standard Four-probe Lock-in Technique



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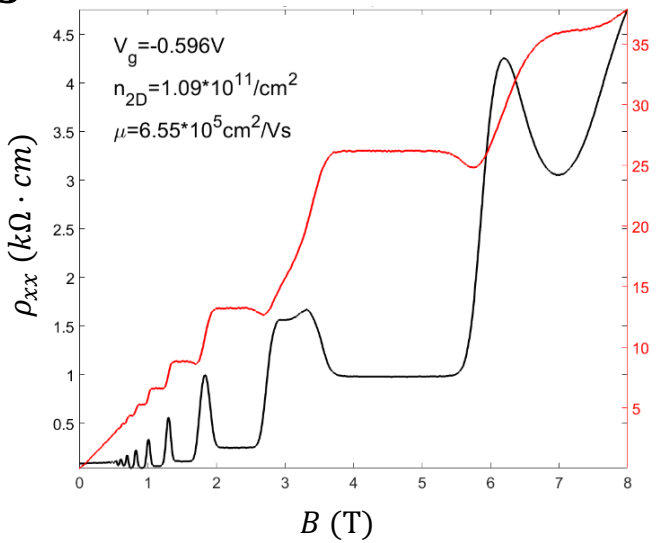

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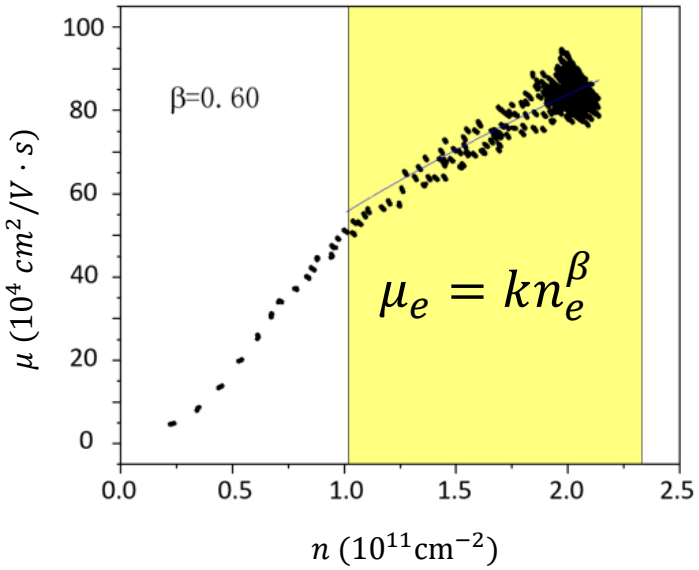
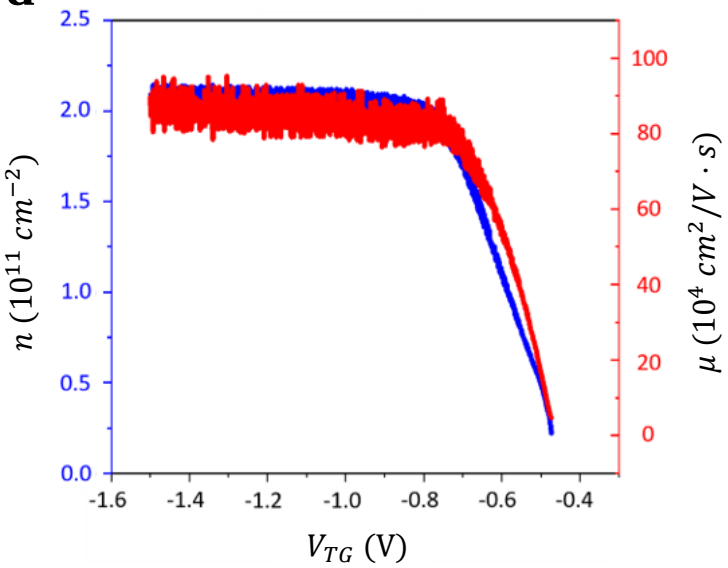


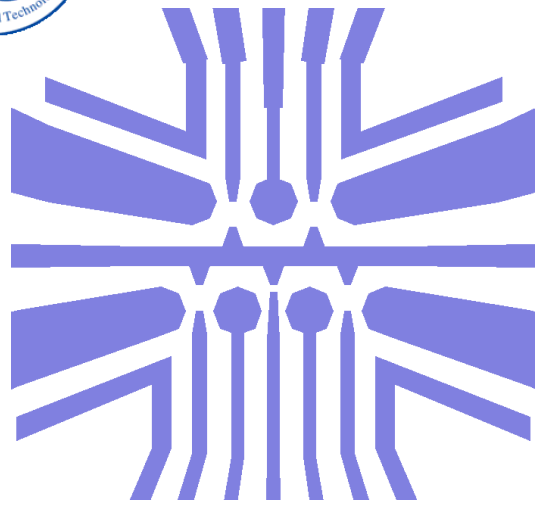
d



1. $n_e = \dfrac{\Delta B}{e\Delta R_{xy}}$
2. $\mu_e = \dfrac{L}{n_e e R_{xx} W}$

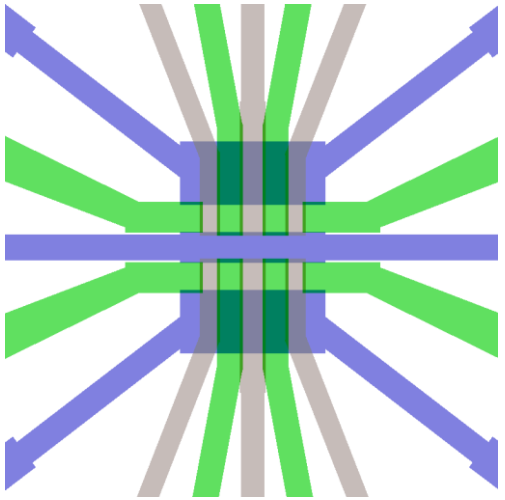
02 Device Measurement I-Different Electrode Layouts

a



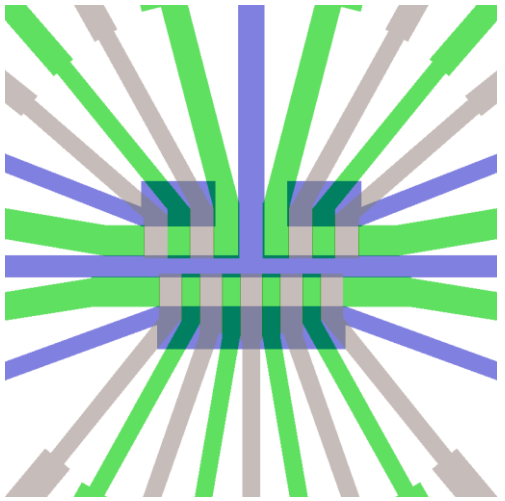
Single Layer Structure: DQD

c

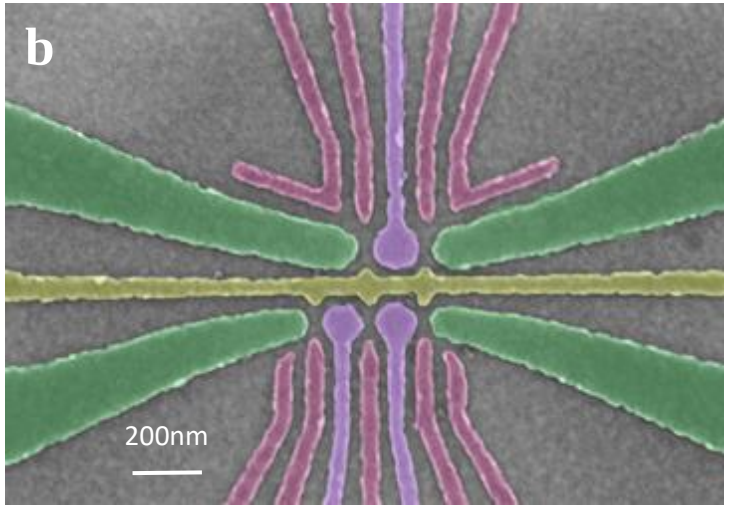


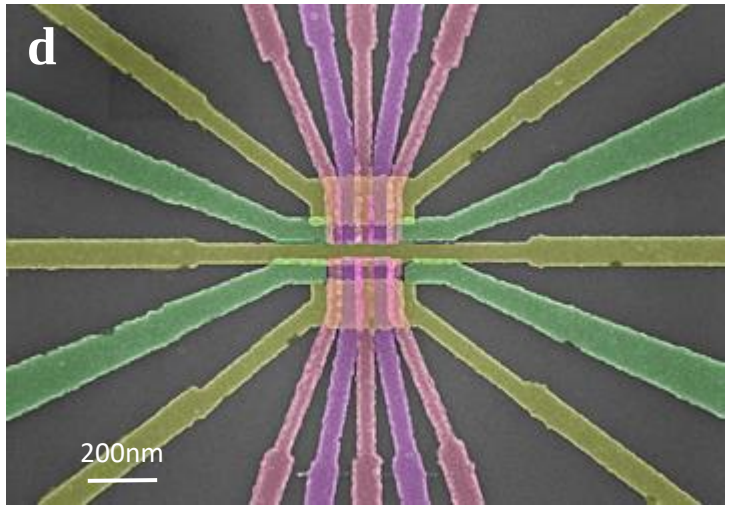
Overlapping structure: DQD

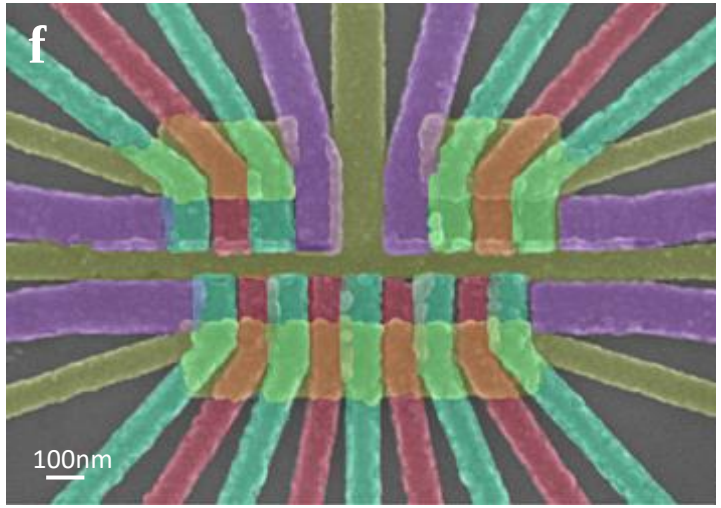
e



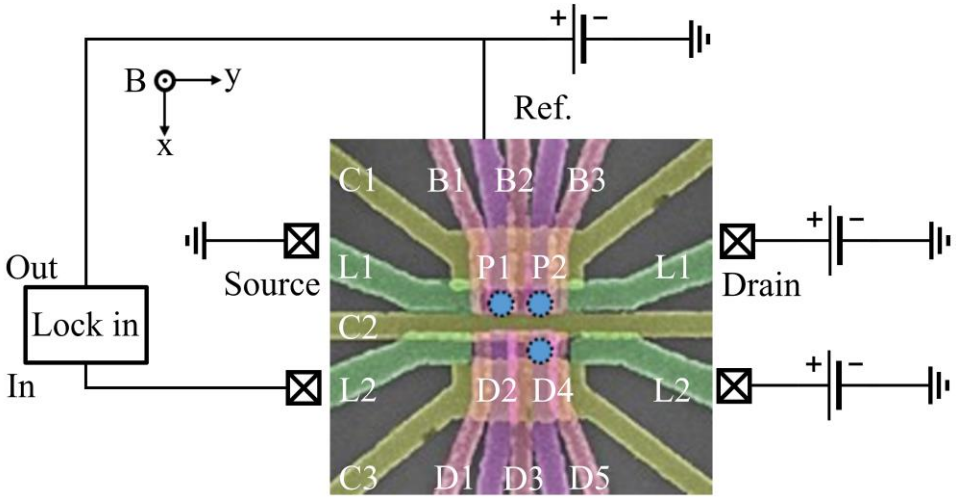
Overlapping Structure: QQD

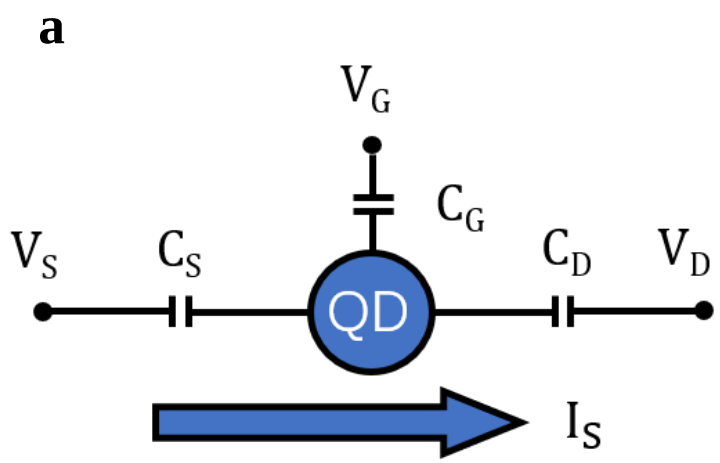


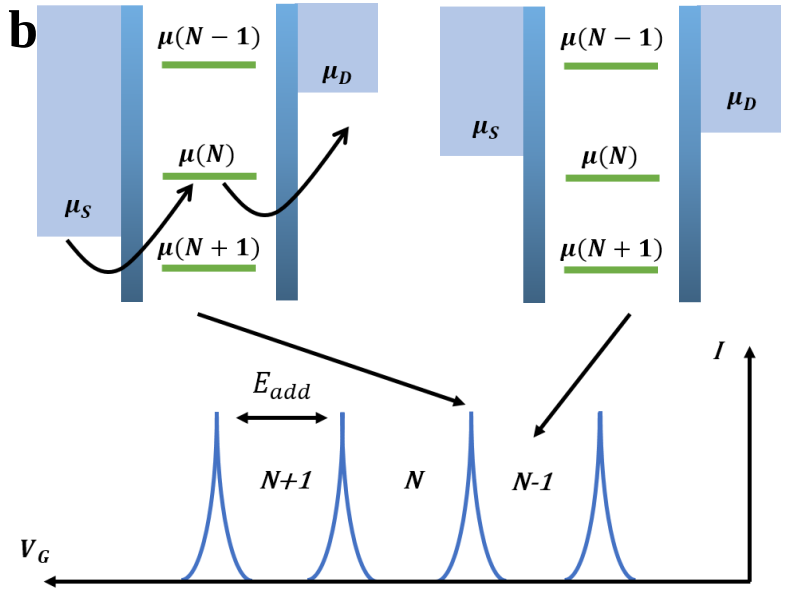


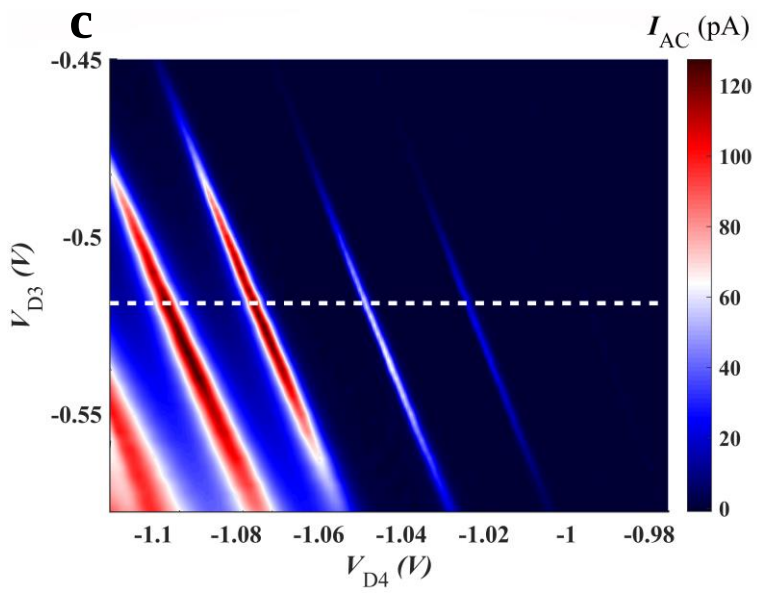


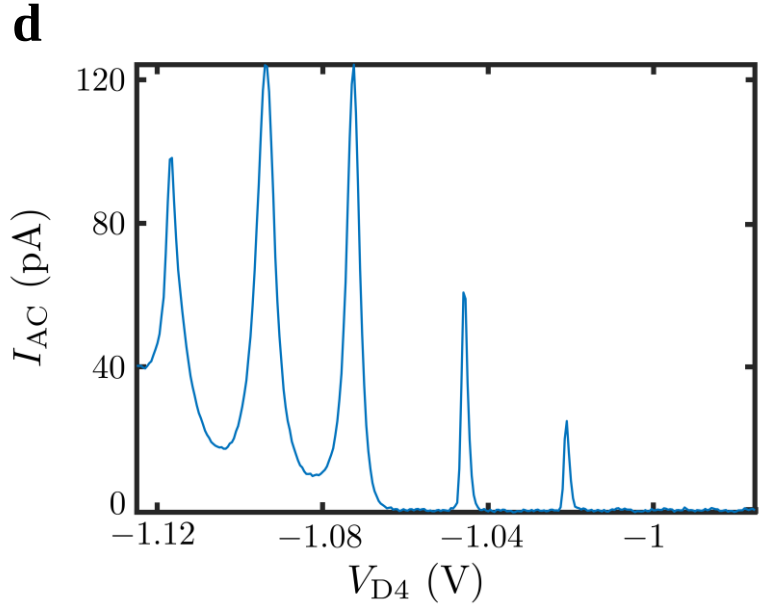
02 Device Measurement I-Coulomb Peak



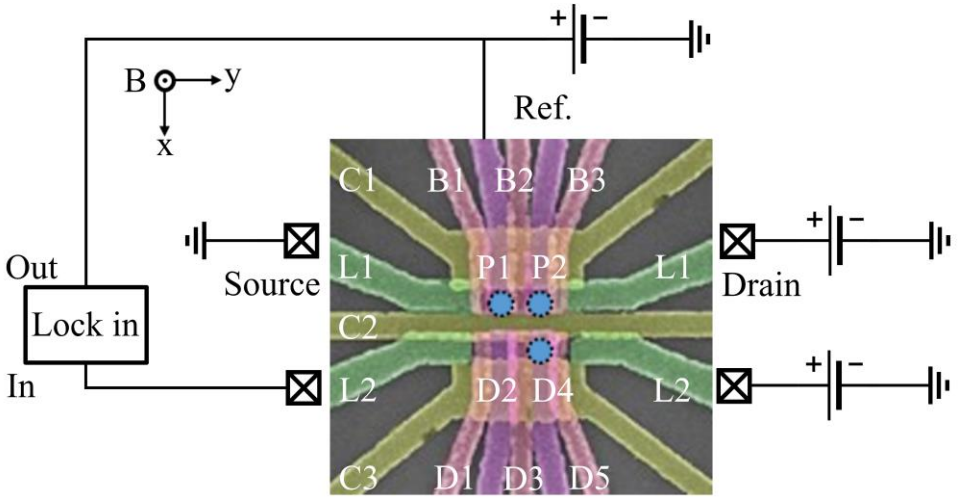








02 Device Measurement I-Honey Comb Diagram



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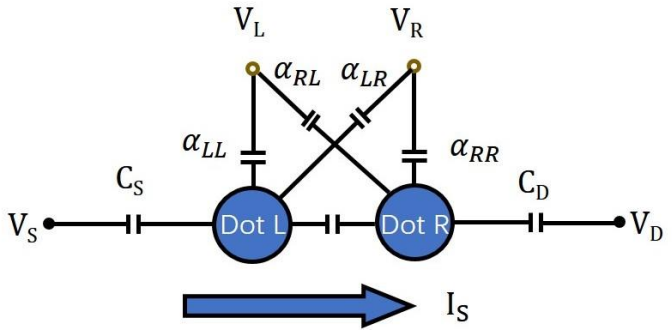

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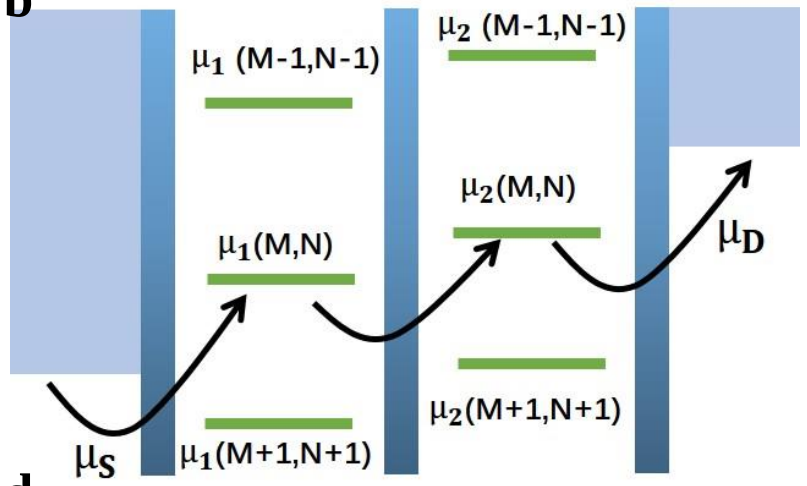

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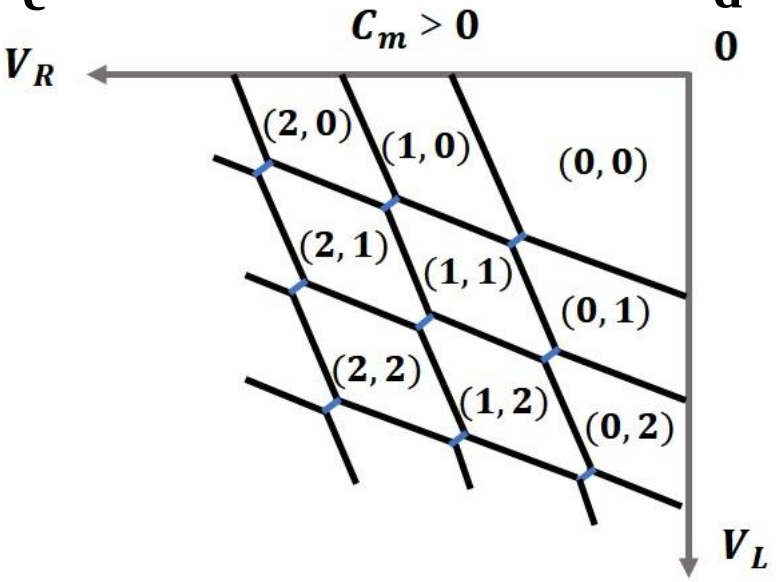

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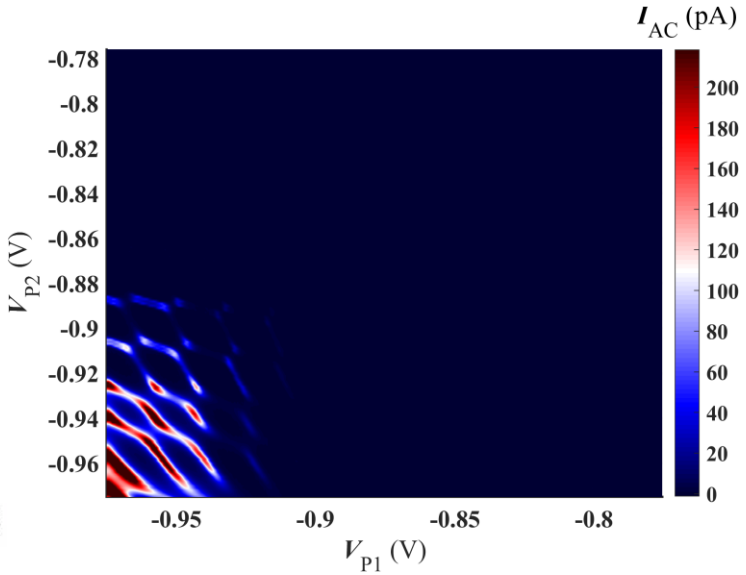
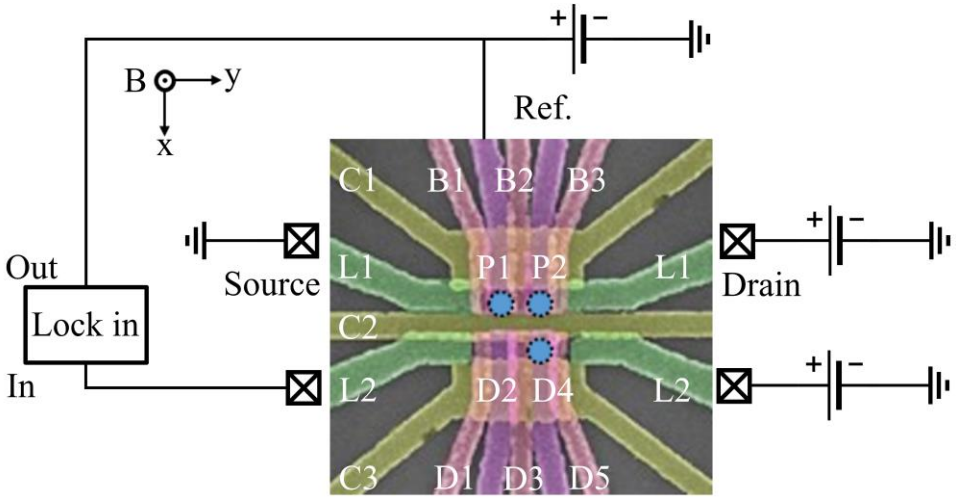
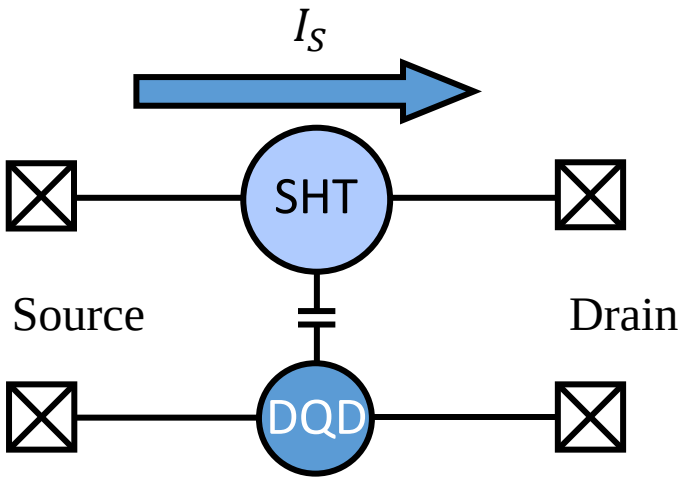


02 Device Measurement I-Single Hole Transistor Readout



$$I_{lockin} = \Delta g \times V_{DC} = \frac{dg}{dV_g} \times V_g \times V_{DC}$$
$$= \frac{dI}{dV_g} \times \Delta V_g$$

a



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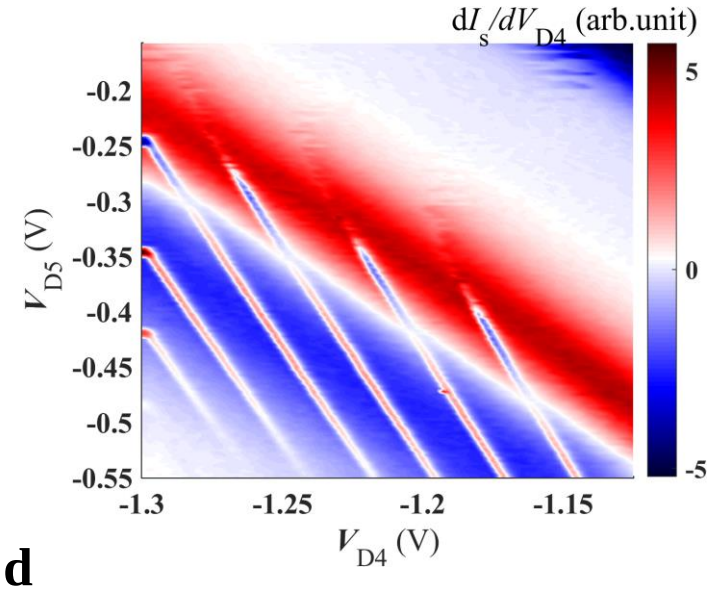

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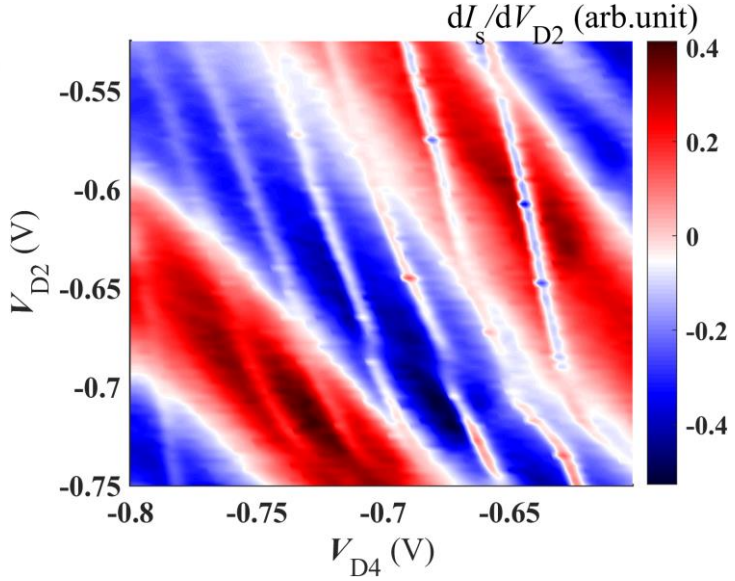

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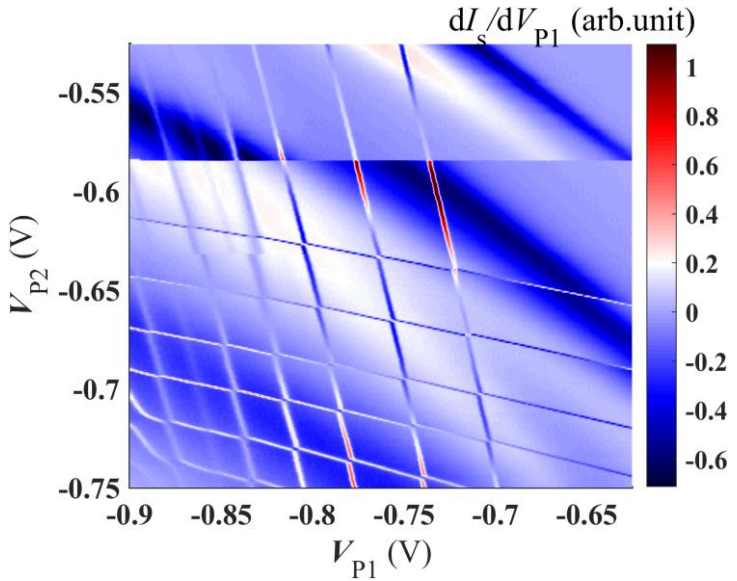
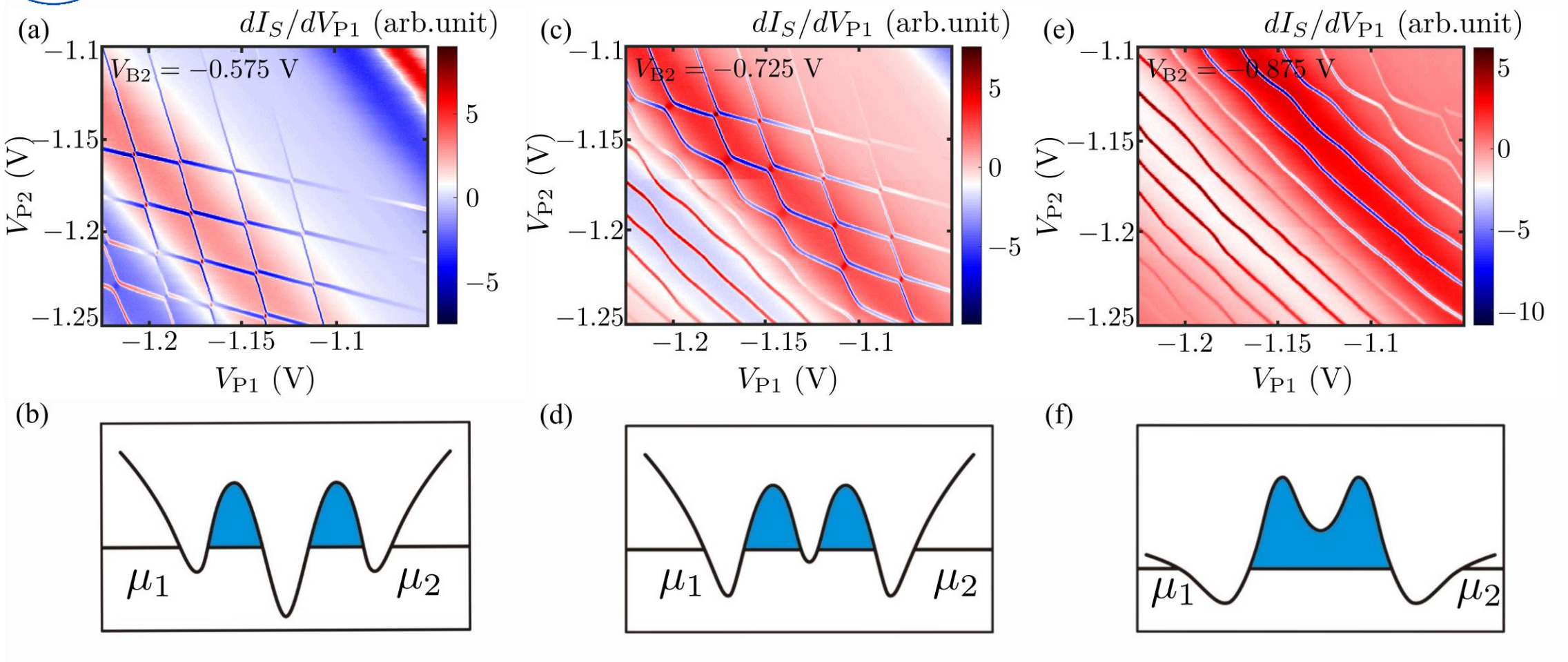
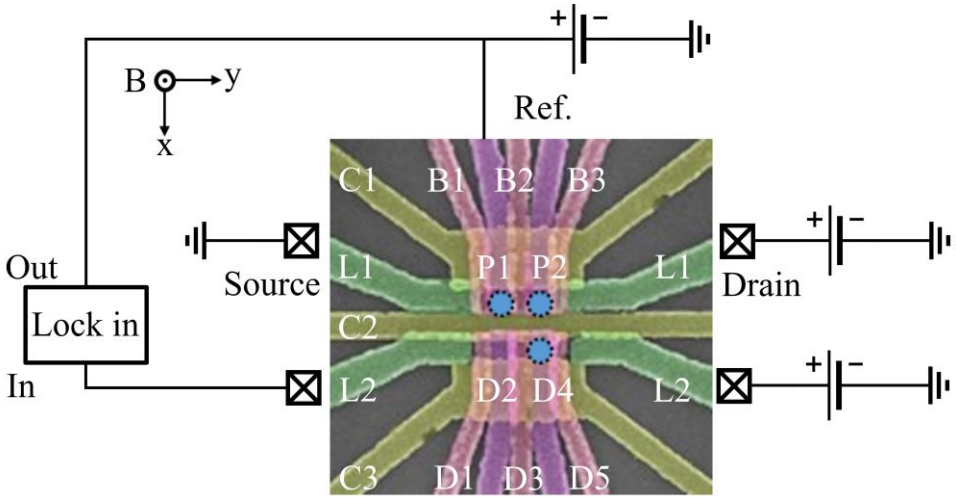


03 Device Measurement I-Well Tunable Quantum Dots



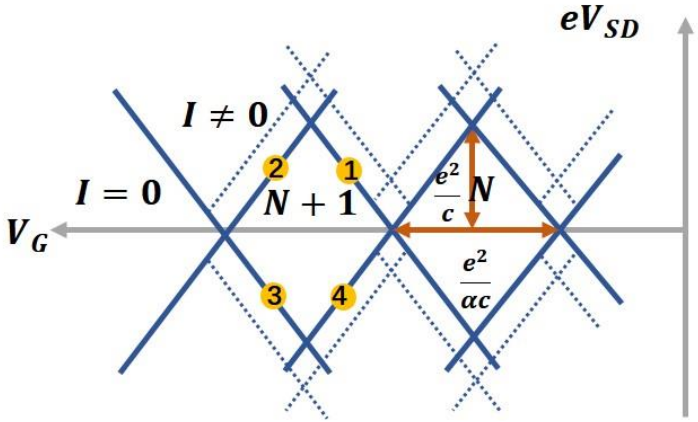
Double Quantum Dots → Single Quantum Dot

02 Device Measurement I-Coulomb Diamond & Bias Triangle



$$Lever\ arm:\ \alpha = \frac{\Delta V_G}{\Delta V_{SD}}$$

a



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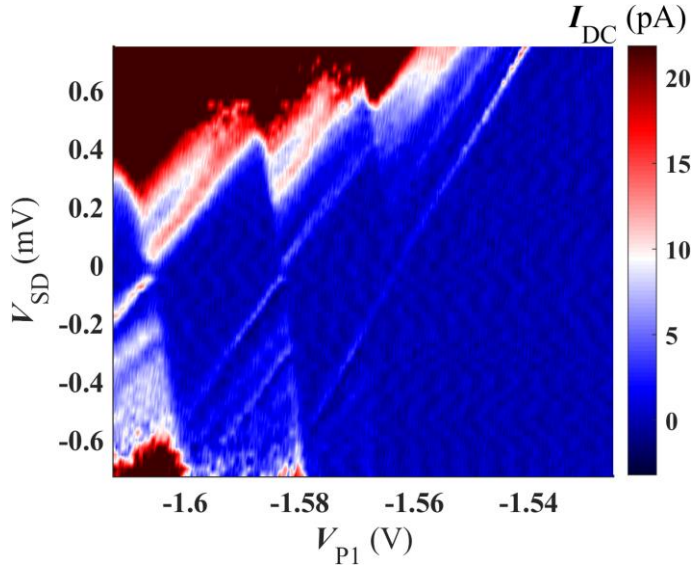

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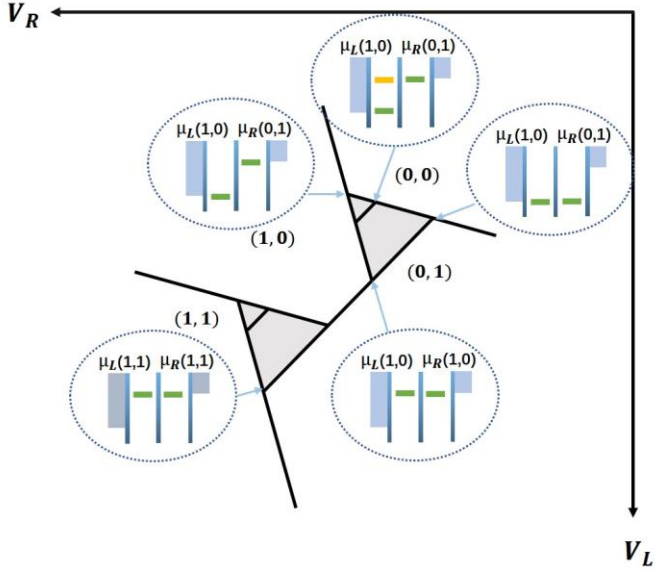

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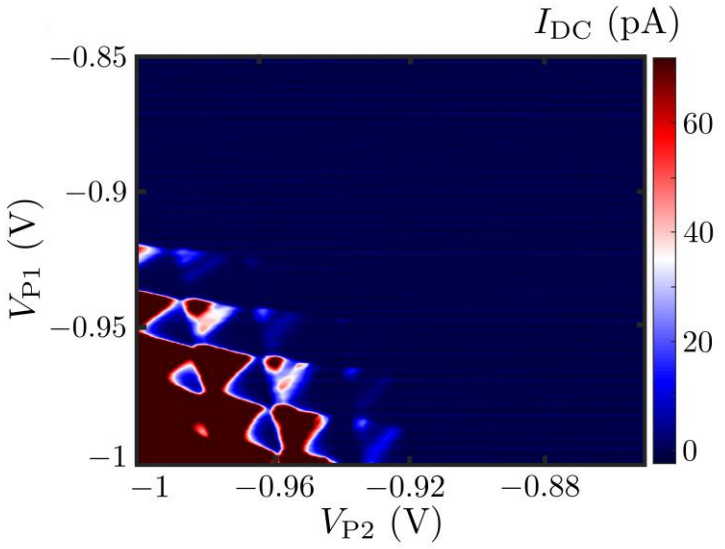
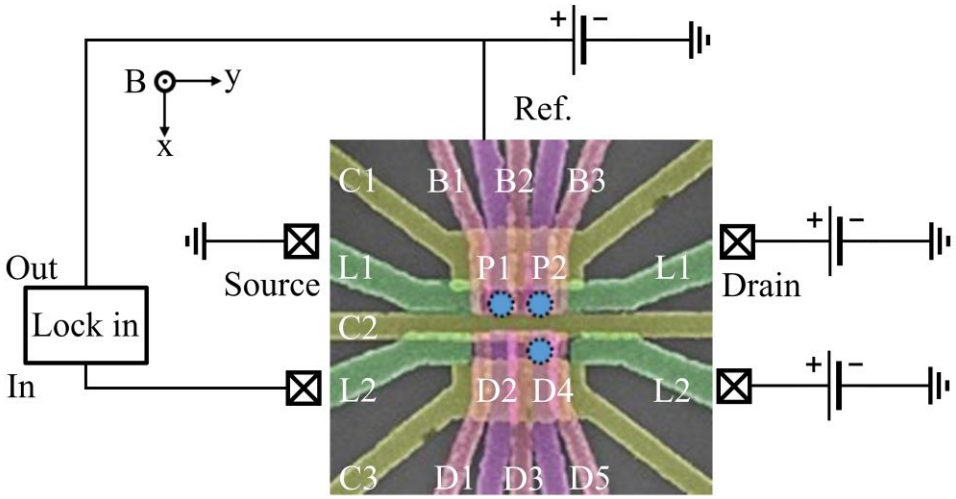
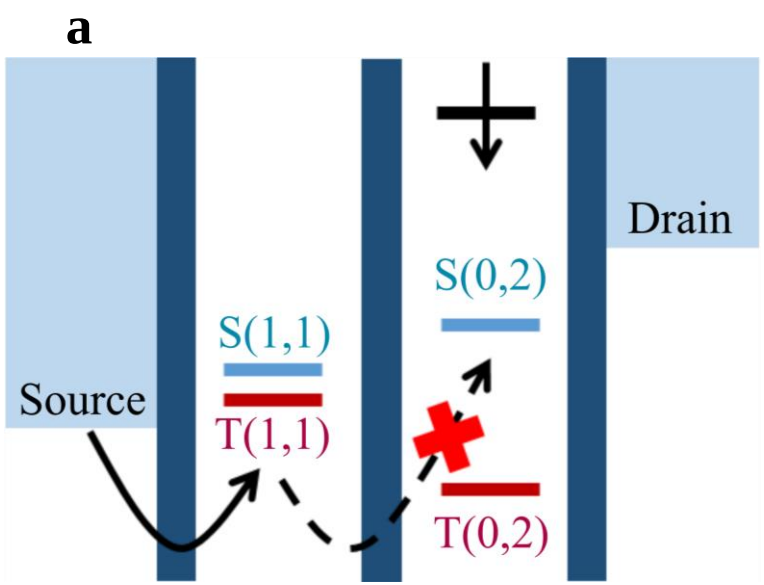
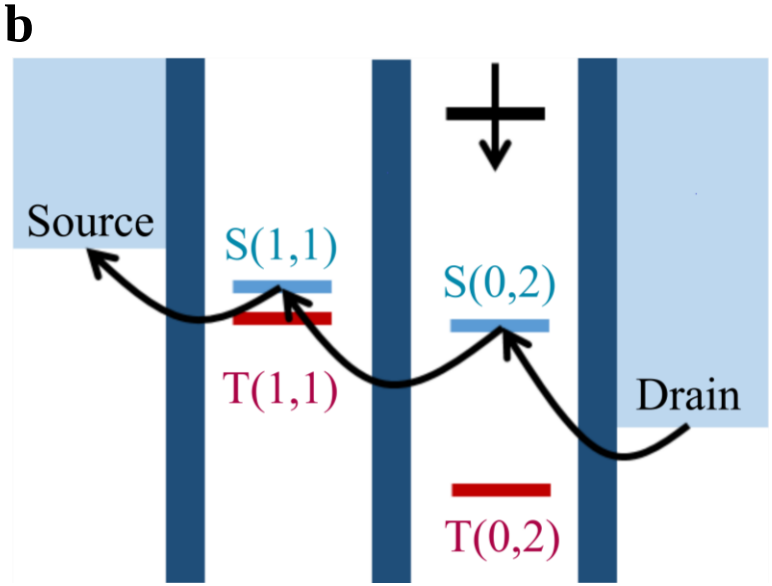


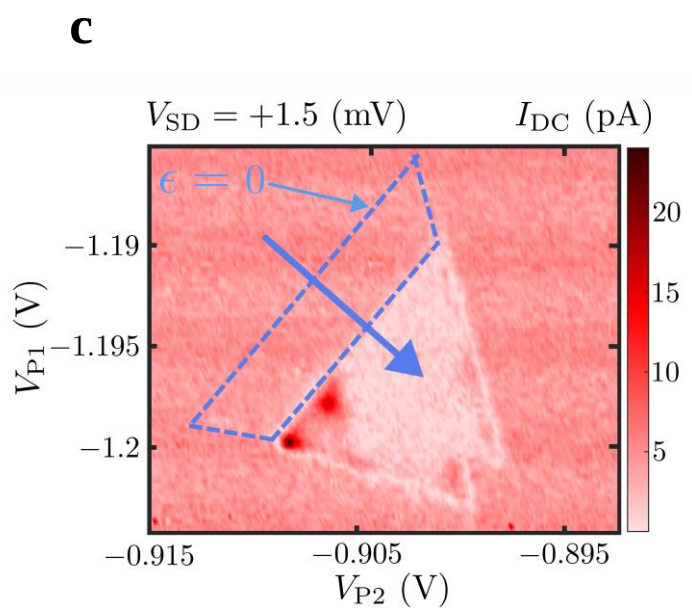
02 Device Measurement I-Pauli Spin Blockade

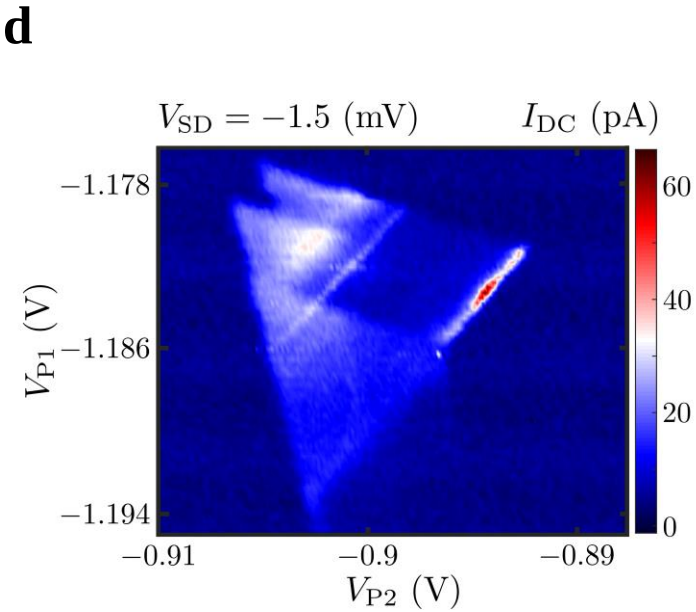


$$\text{Det}uning\text{: } \epsilon = e(V_L - V_R)$$



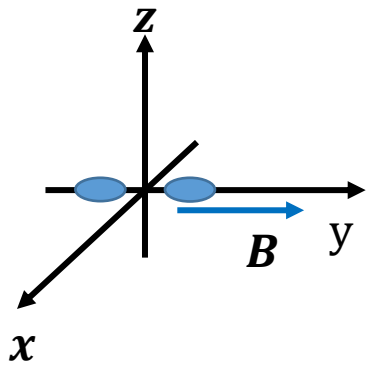






02 Device Measurement I-Leakage Current

a



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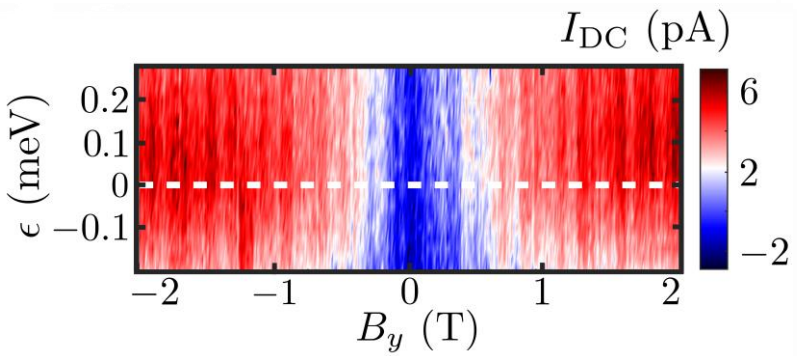

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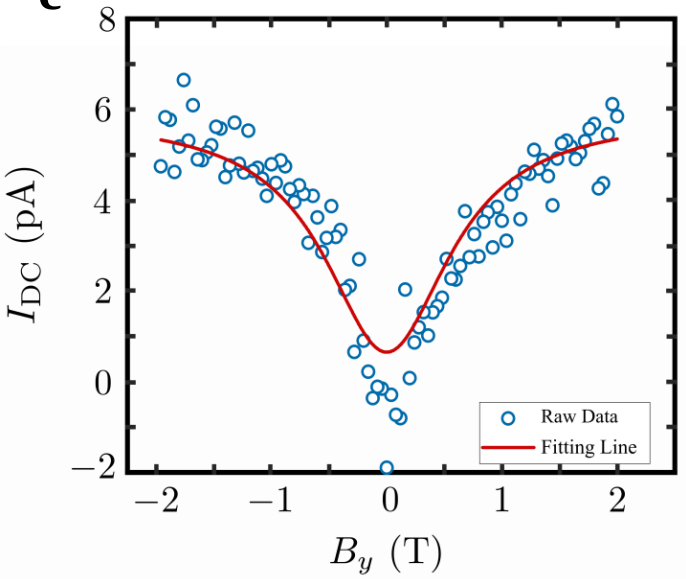
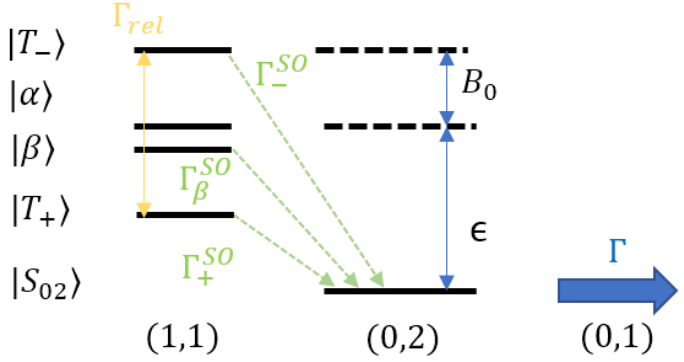


Eigenstates of 2-spin-system:

$$|S(1,1)\rangle = \frac{1}{\sqrt{2}}(|10\rangle - |01\rangle)$$
$$|T_-(1,1)\rangle = |00\rangle$$
$$|T_0(1,1)\rangle = \frac{1}{\sqrt{2}}(|10\rangle + |01\rangle)$$
$$|T_+(1,1)\rangle = |11\rangle$$

$$H_{SO} = it_0|T_0\rangle\langle S(0,2)| + it_-|T_-\rangle\langle S(0,2)| + it_+|T_+\rangle\langle S(0,2)| + \text{h.c.}$$

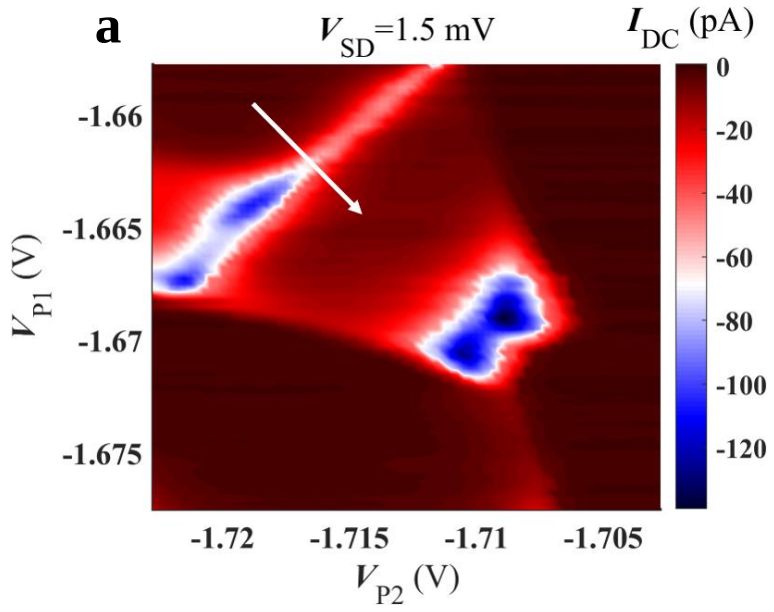
d

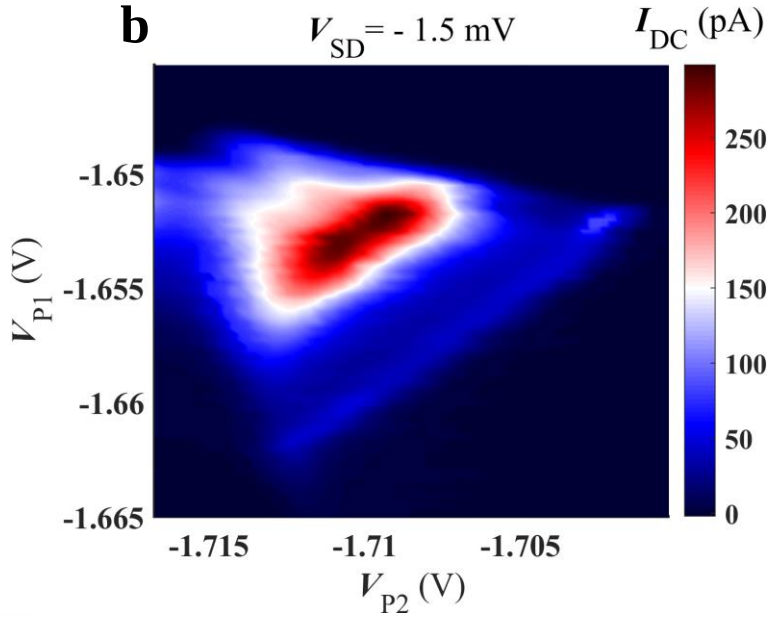


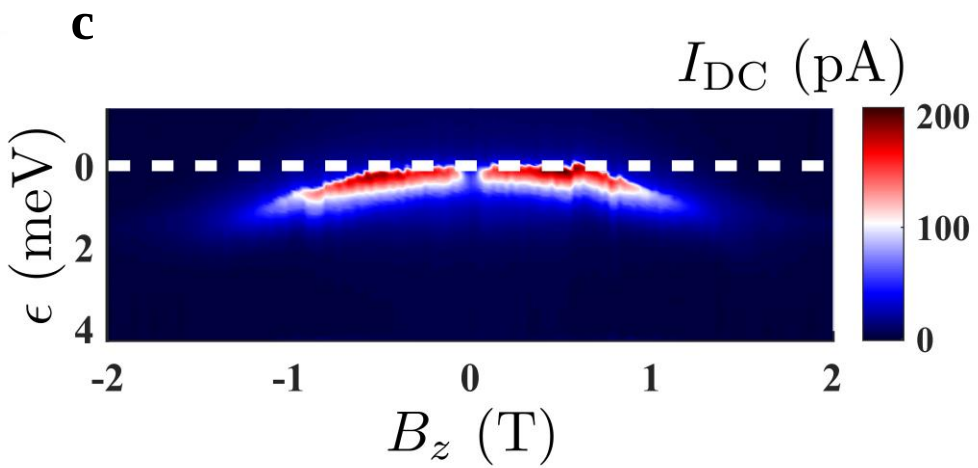
$$I = I_{max}\left(1 - \frac{8}{9}\frac{B_c^2}{B_c^2 + B^2}\right)$$

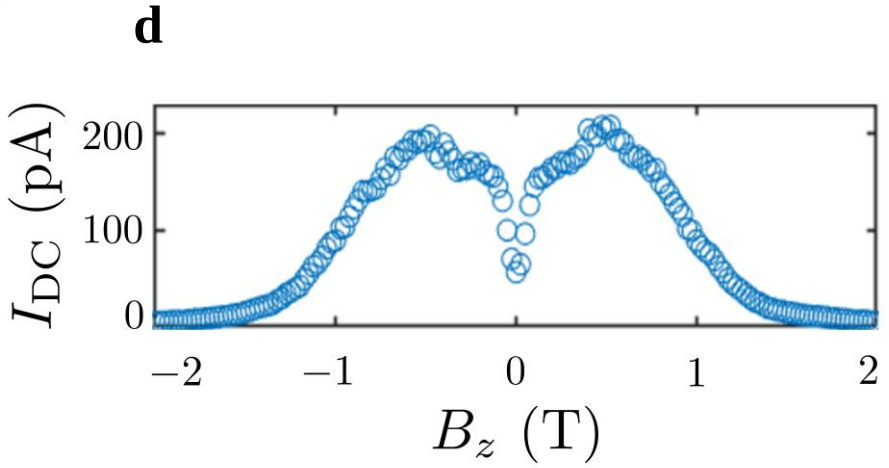
J. Danon *et al.*, PRB 80, 041301 (2009)

02 Device Measurement I-Pauli Spin Blockade

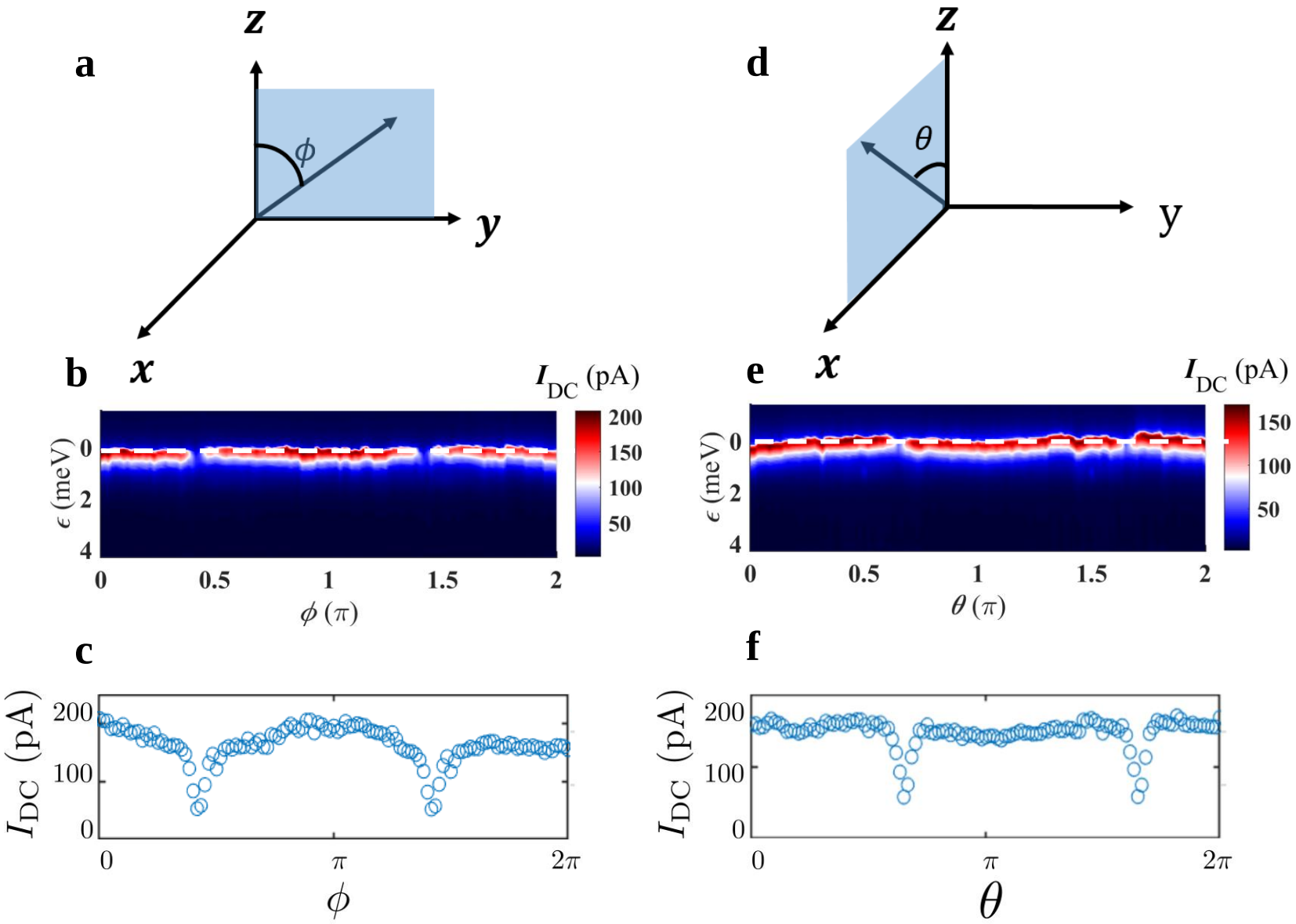






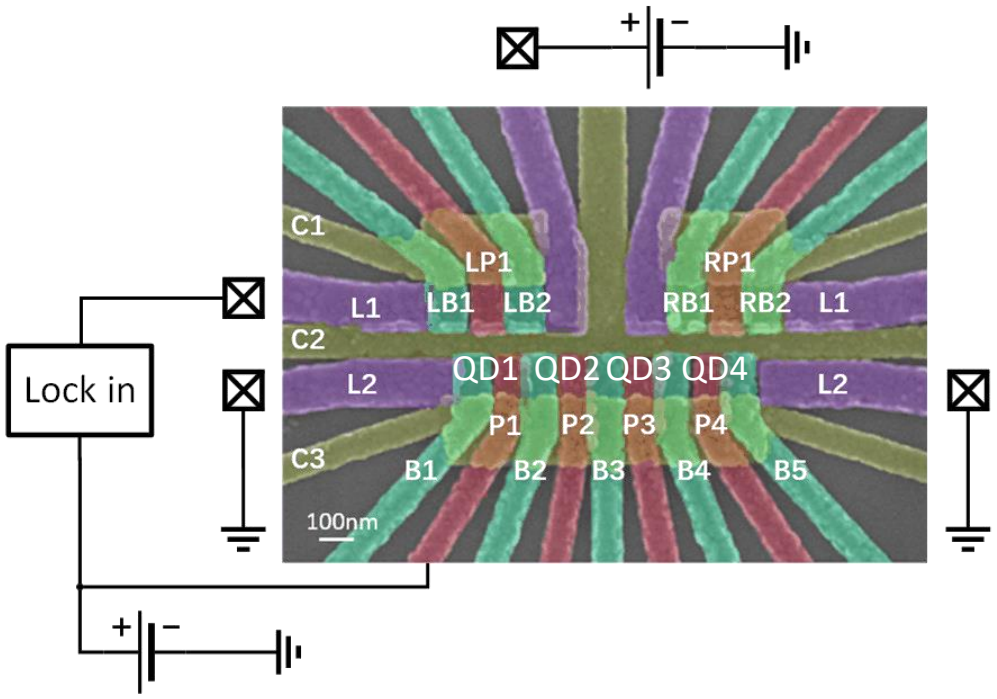


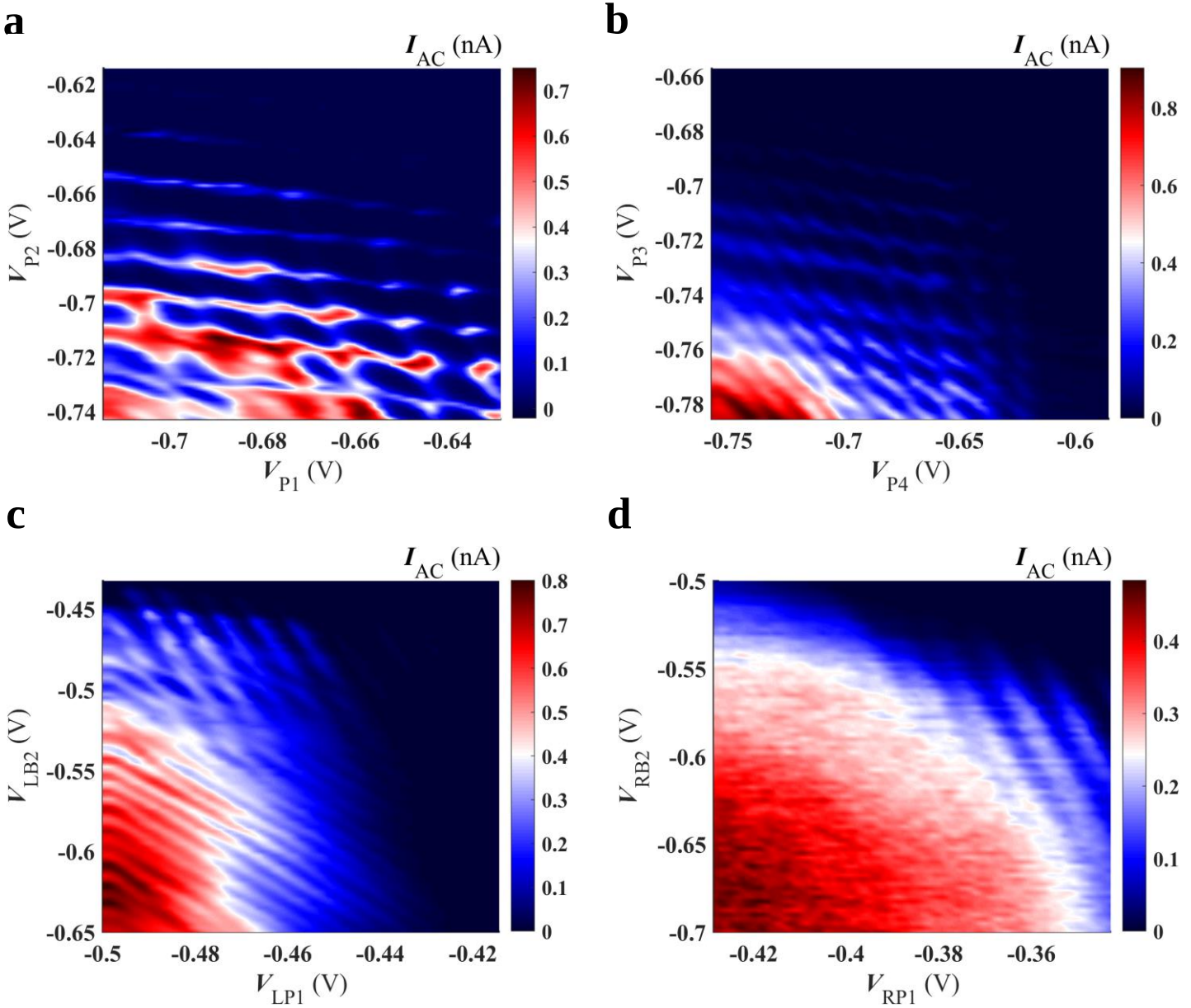
02 Device Measurement I-Leakage Current



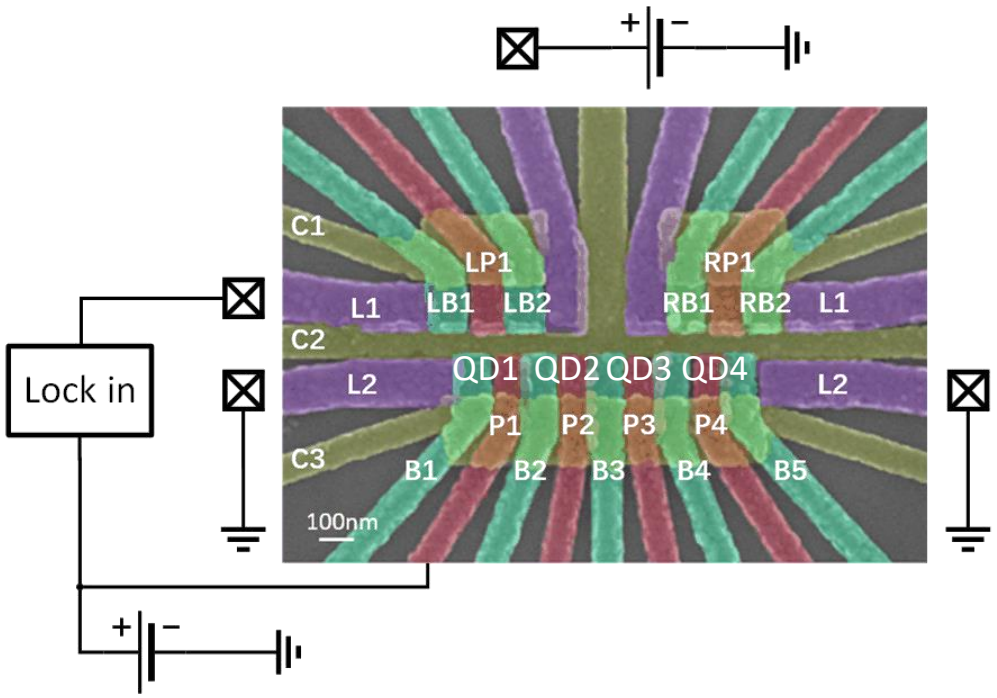
CATALOGUE

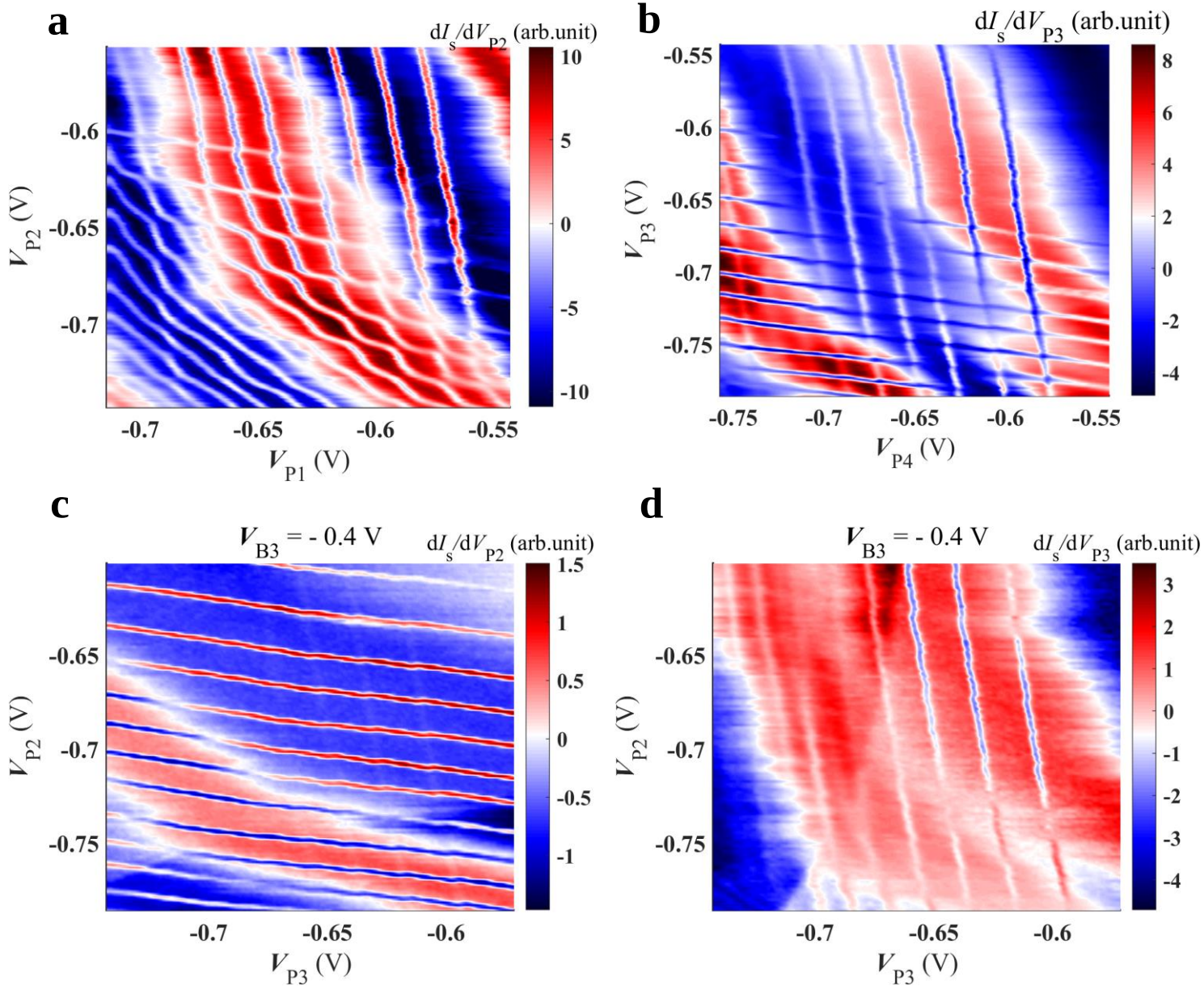
03 Device Measurement II-Stability Diagram





03 Device Measurement II-SHT Readout





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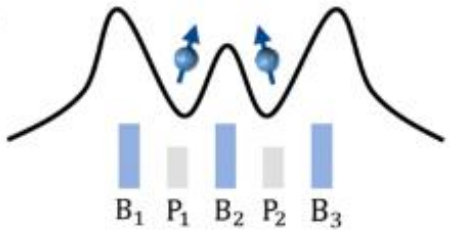

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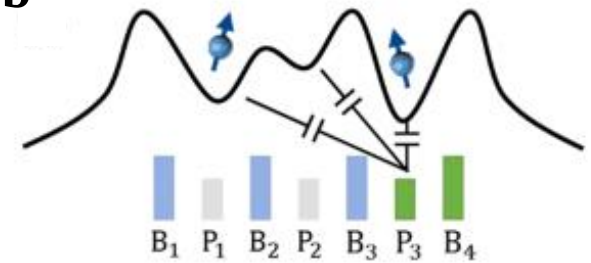

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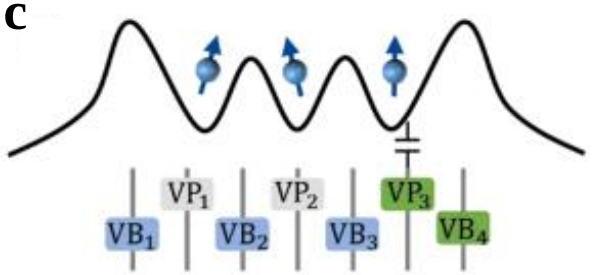
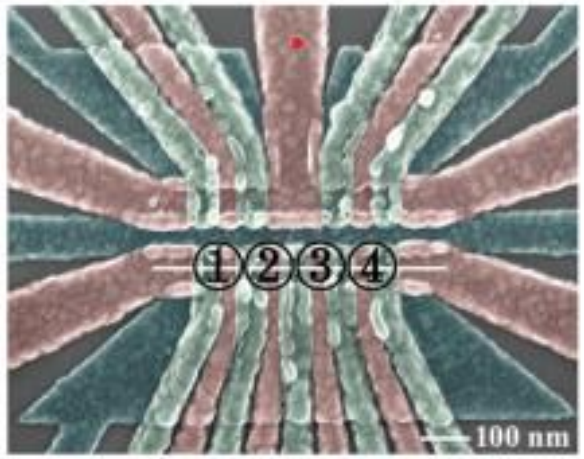


$$\begin{pmatrix} \mu_{P1} \\ \vdots \\ \mu_{Pn} \end{pmatrix} = \begin{pmatrix} G_{11} & \cdots & G_{1n} \\ \vdots & \ddots & \vdots \\ G_{n1} & \cdots & G_{nn} \end{pmatrix} \begin{pmatrix} V_{P1} \\ \vdots \\ V_{Pn} \end{pmatrix},$$

$$G_{ij} = \frac{\Delta N_i}{\Delta Mj}$$

d



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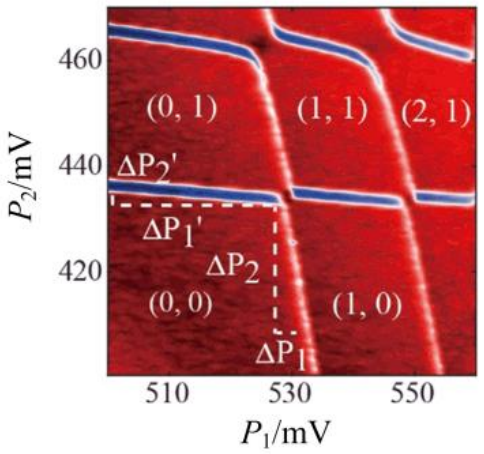

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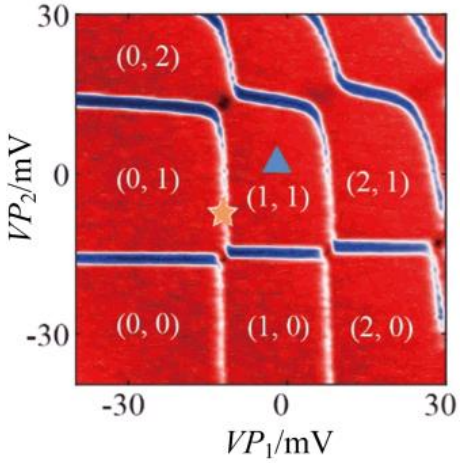

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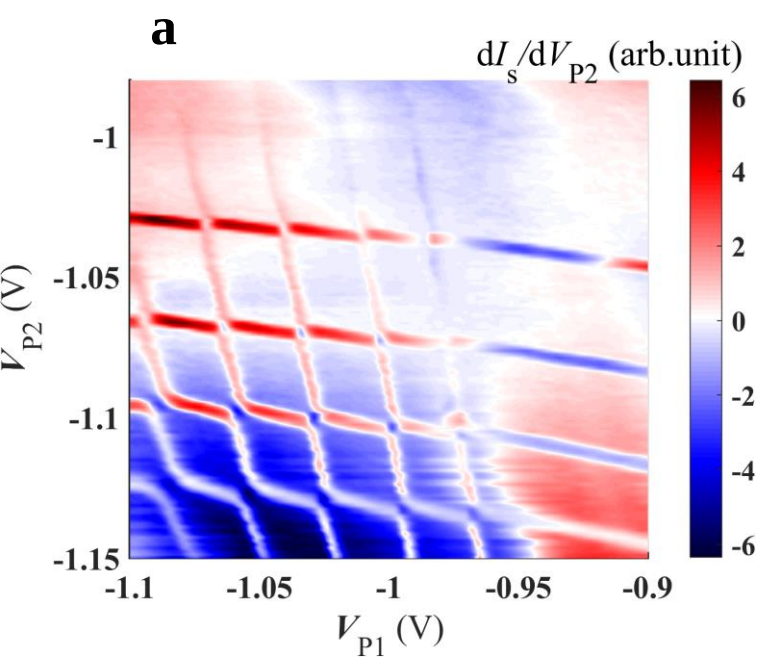
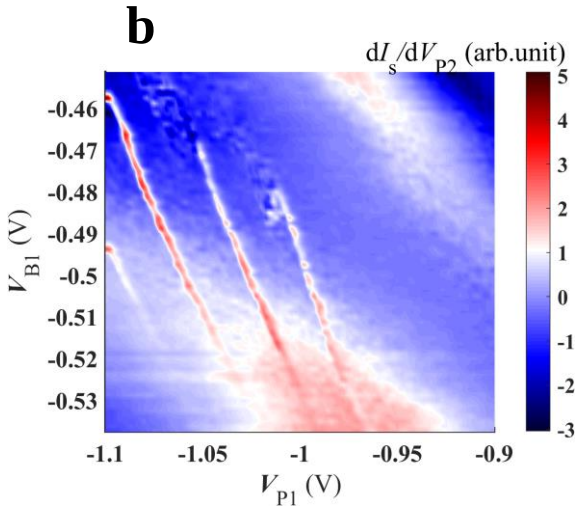
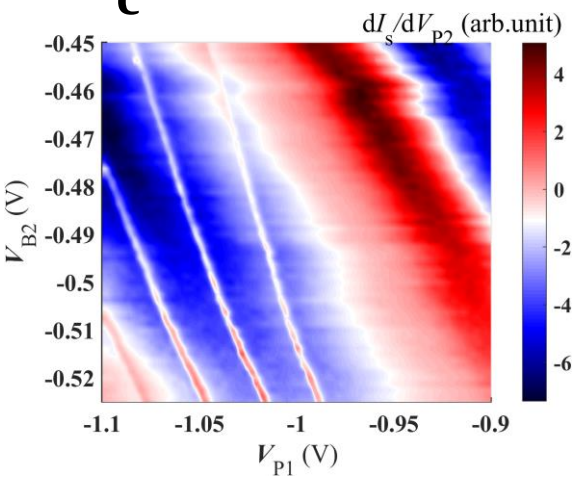
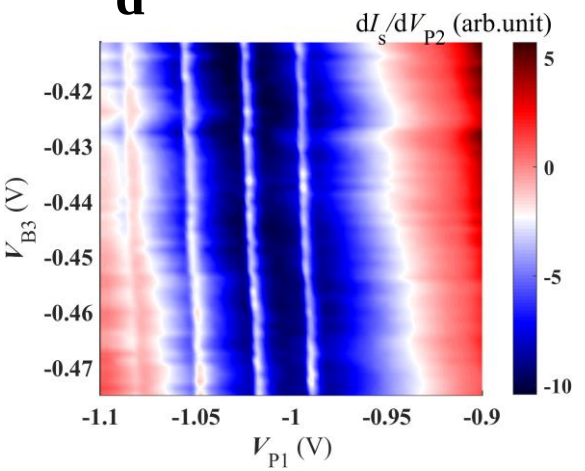
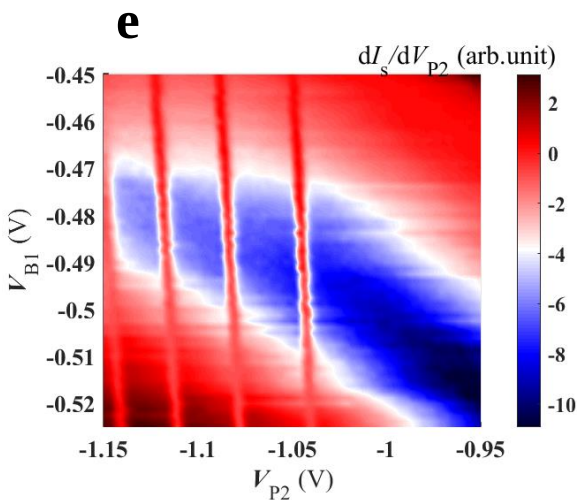
03 Device Measurement II-Virtual Gate

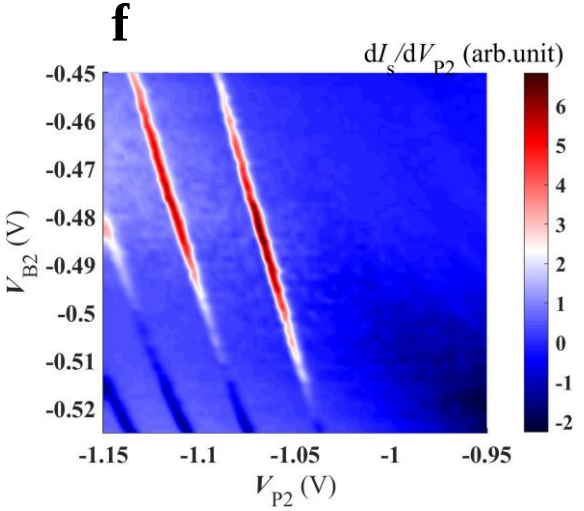


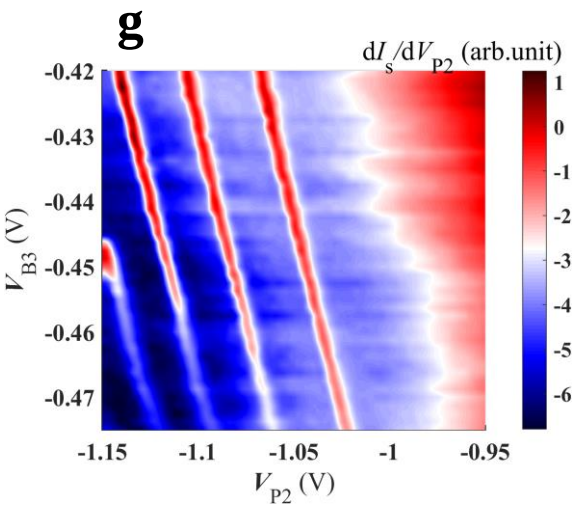




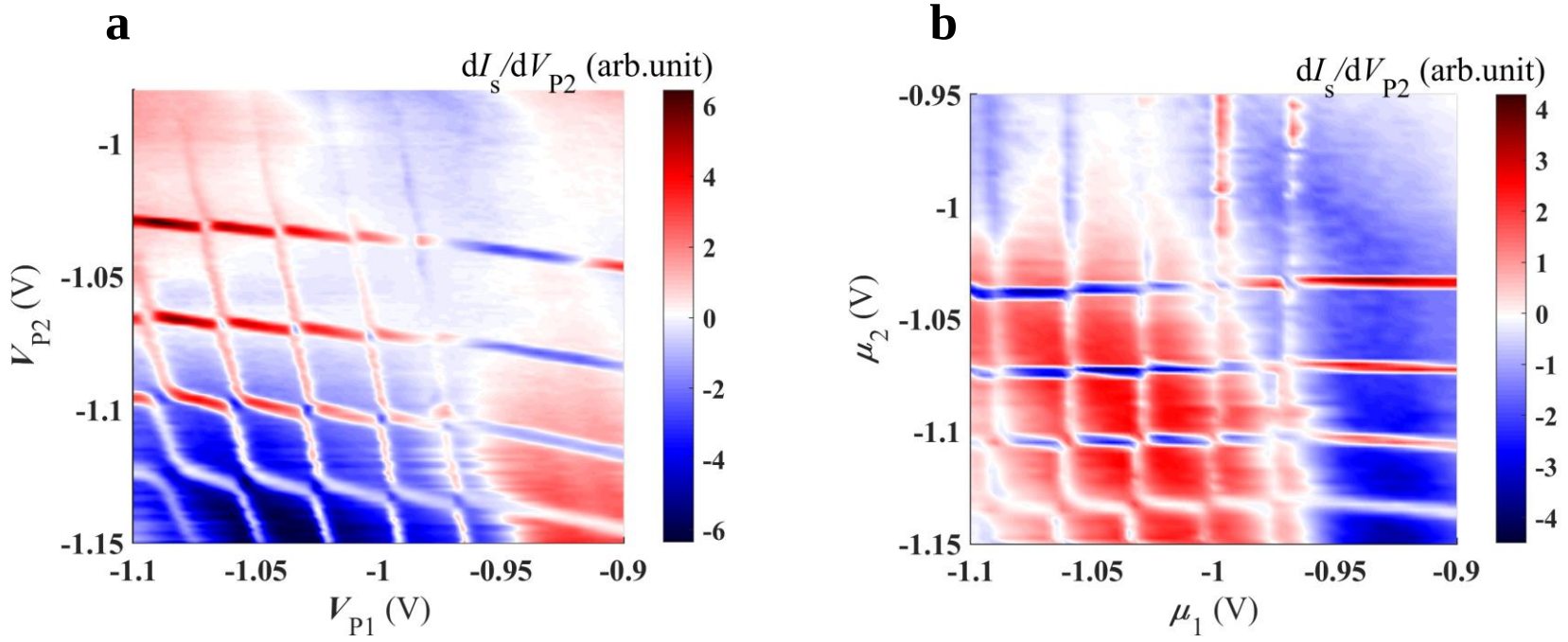








03 Device Measurement II-Virtual Gate



CATALOGUE

04 Conclusions-Fabrication Process

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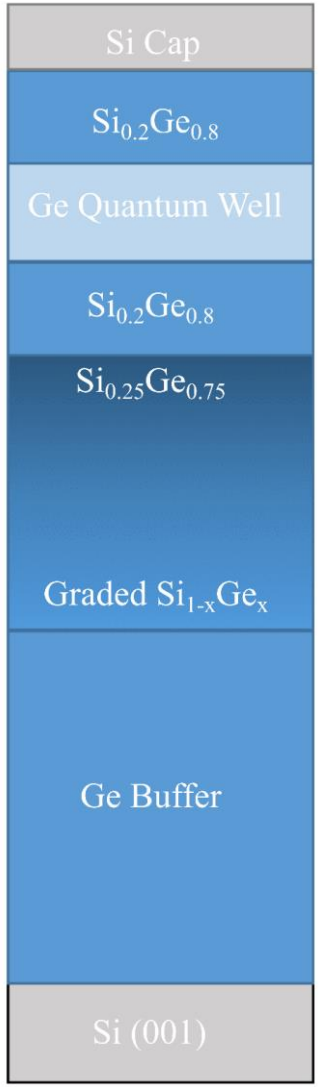

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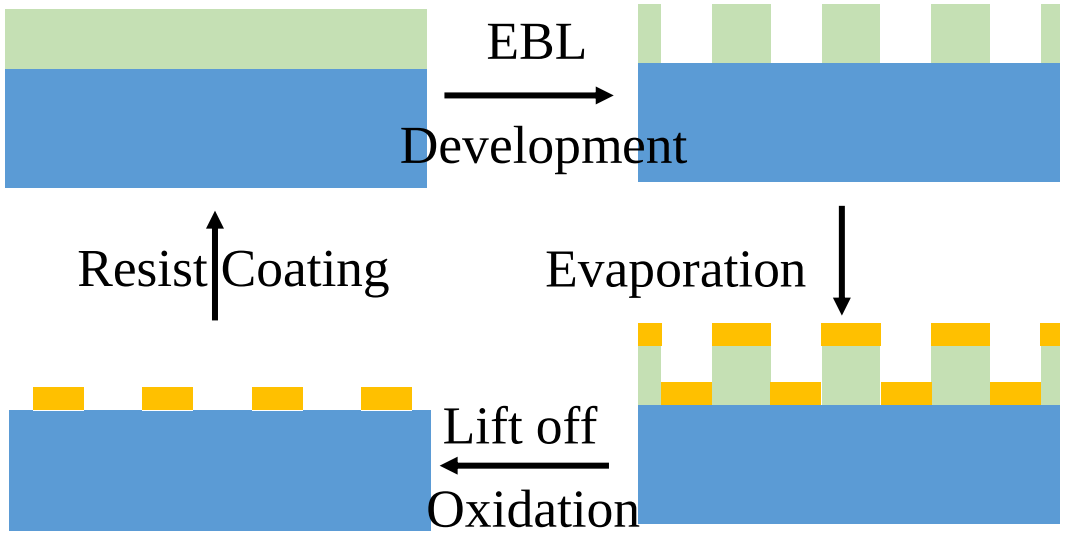

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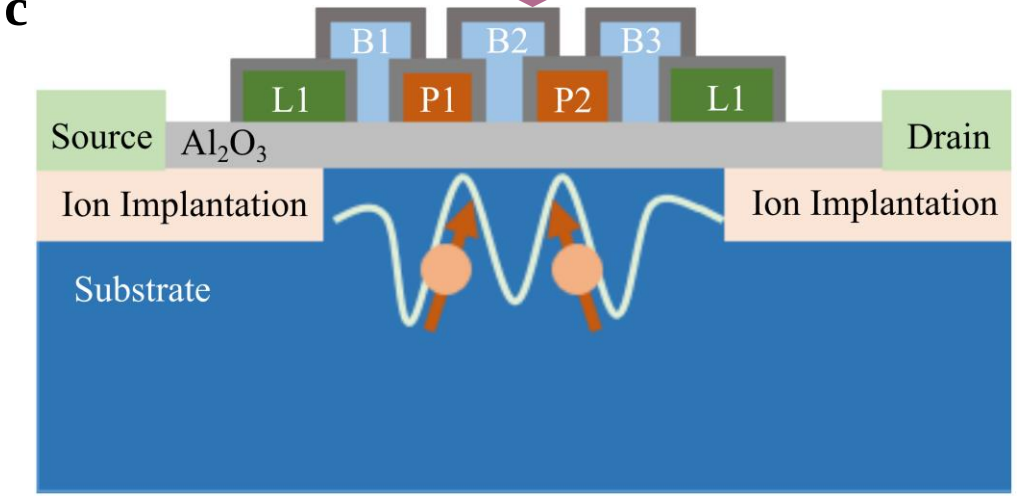

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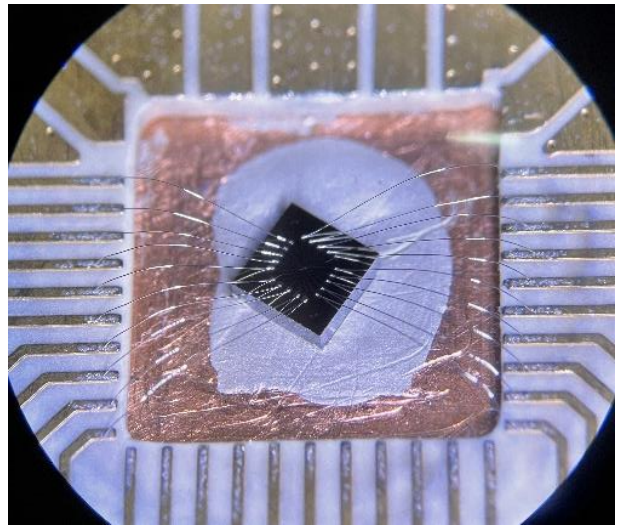
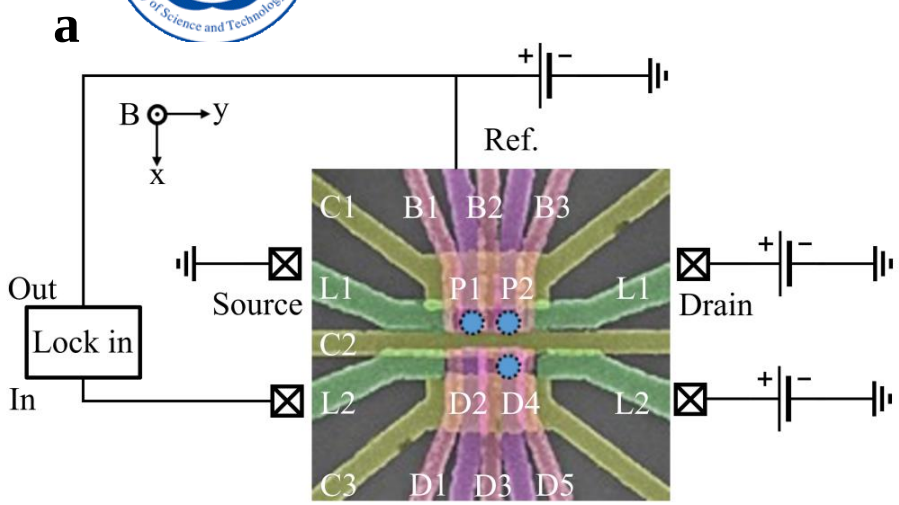
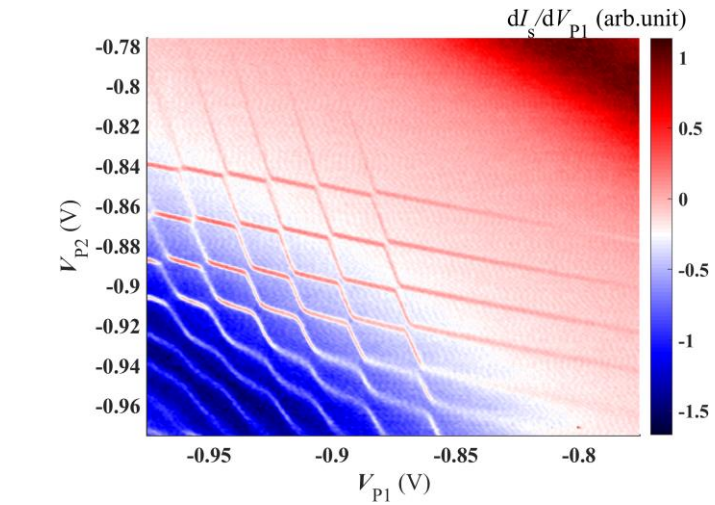
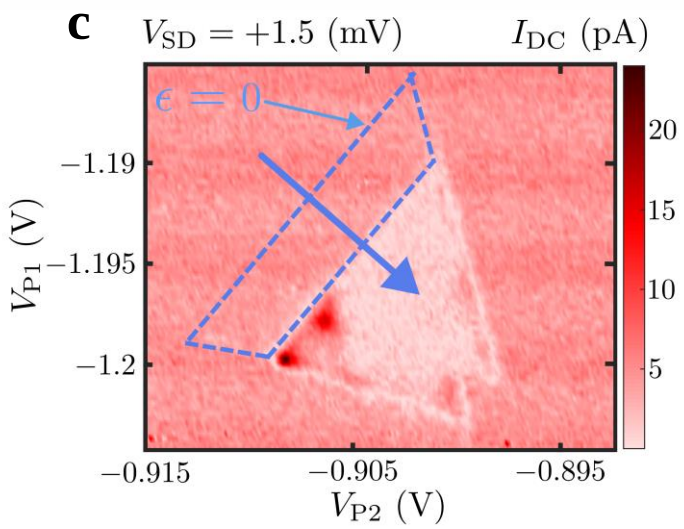
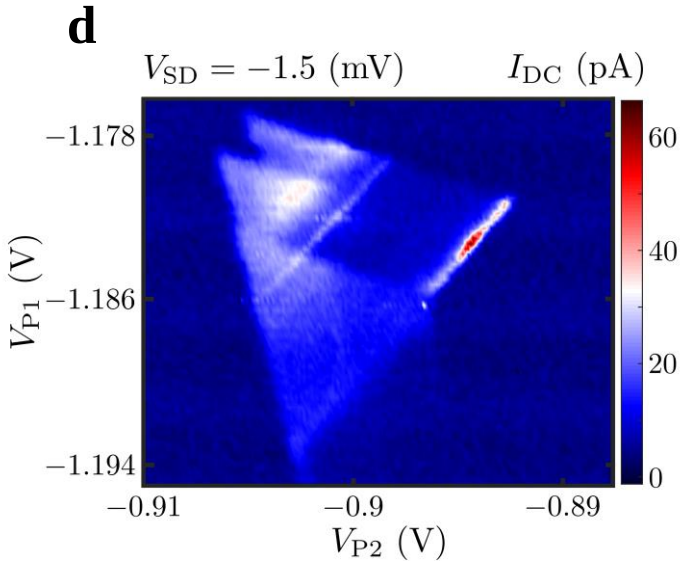


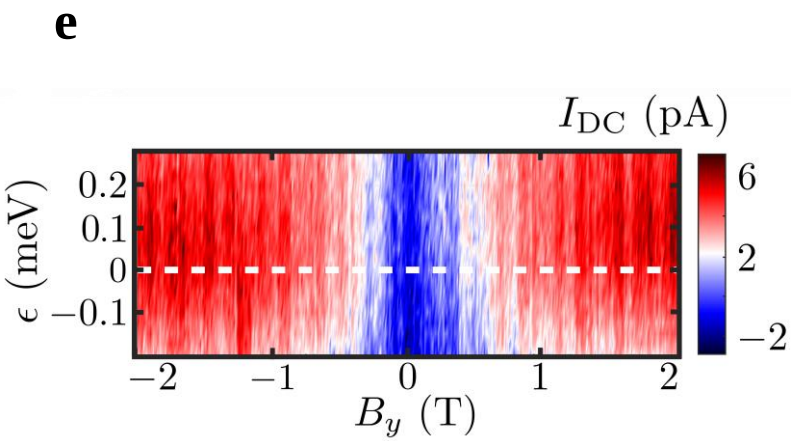
04 Conclusions-DQD Device Measurement

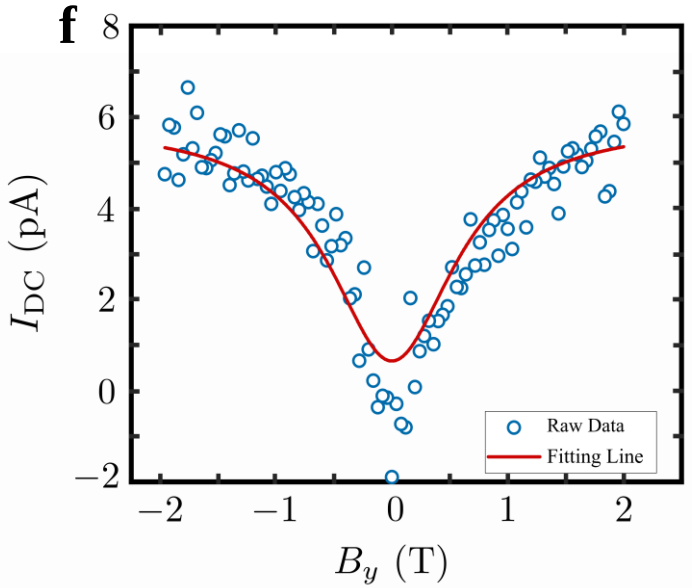




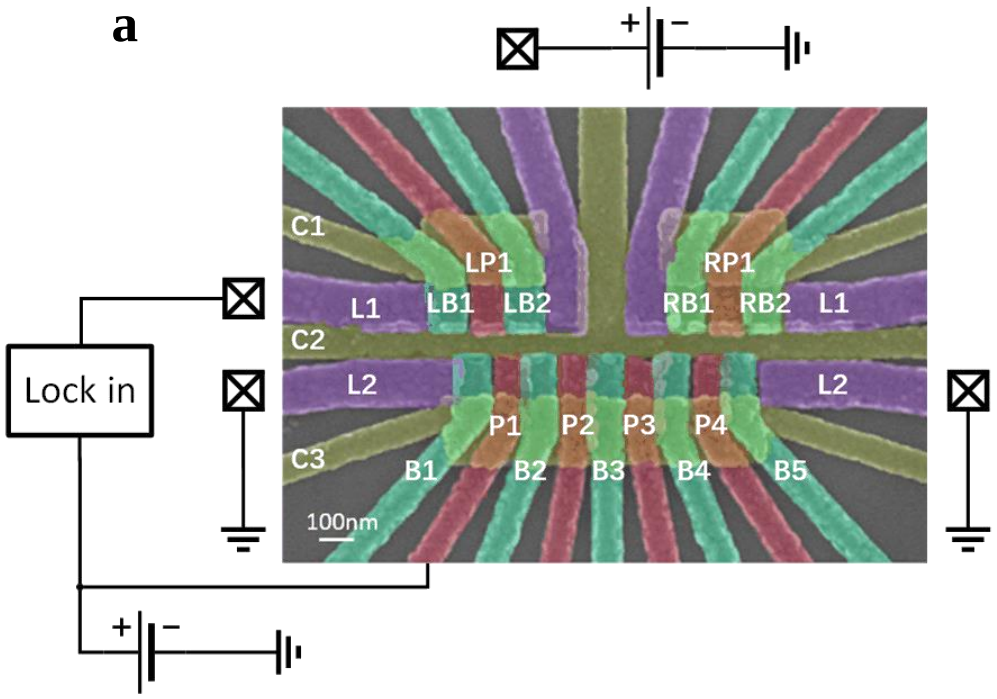


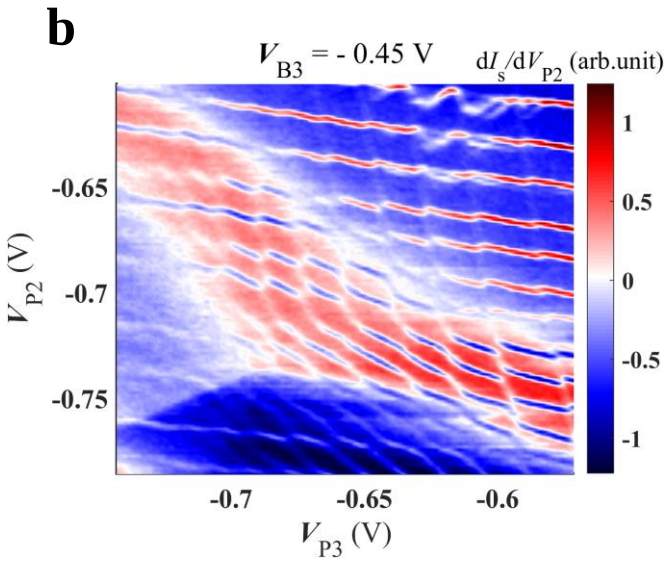


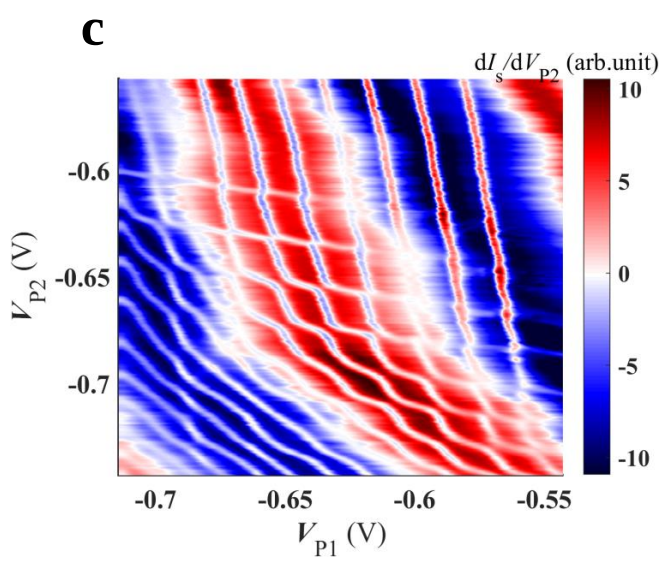


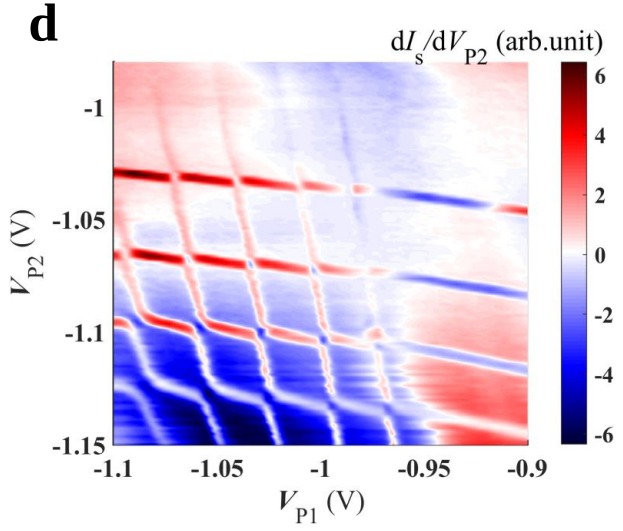


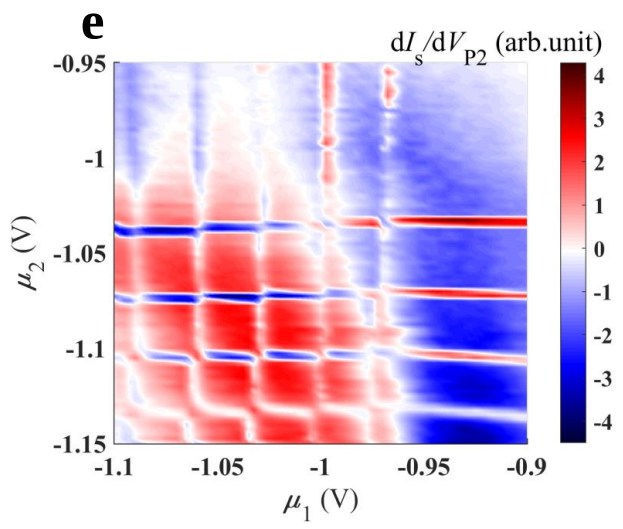
04 Conclusions-QQD Device Measurement











Danke!

LIU Yang
Tutor: Prof. Hai-Ou Li
Prof. Guoping Guo