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Fundamental Research Insights

GO 2021

Valley and Spin Blockade in Graphene Quantum Dots

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Motivation: Towards Graphene Quantum Dot Qubits

Graphene quantum dots:

- low spin-orbit interaction
- hyperfine interaction

} long spin coherence time[1]

- 2-fold spin and 2-fold valley degrees of freedom

→ Promising for spin/valley quantum dot qubits

Spin ↑, ↓ Valley K^-, K^+

- Spins in a magnetic field B:

$\Delta E_\uparrow: +\frac{1}{2} g_s \mu_B B$

$\Delta E_\downarrow: -\frac{1}{2} g_s \mu_B B$,

where $g_s = 2$.

- Valleys in a perpendicular magnetic field B (low field limit):

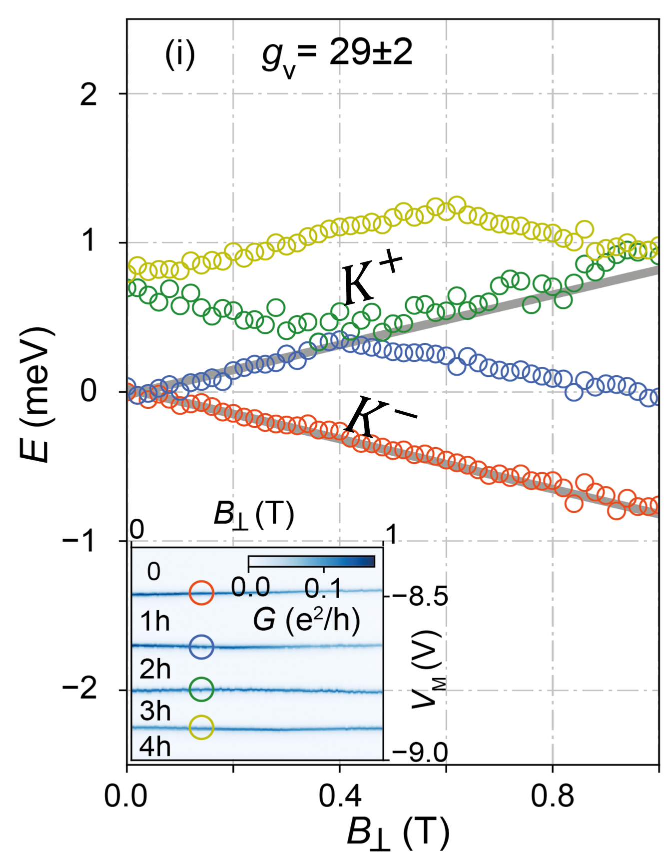
$\Delta E_{K^+}: +\frac{1}{2} g_v \mu_B B$

$\Delta E_{K^-}: -\frac{1}{2} g_v \mu_B B$,

where $g_v \sim 20 - 90$ is:

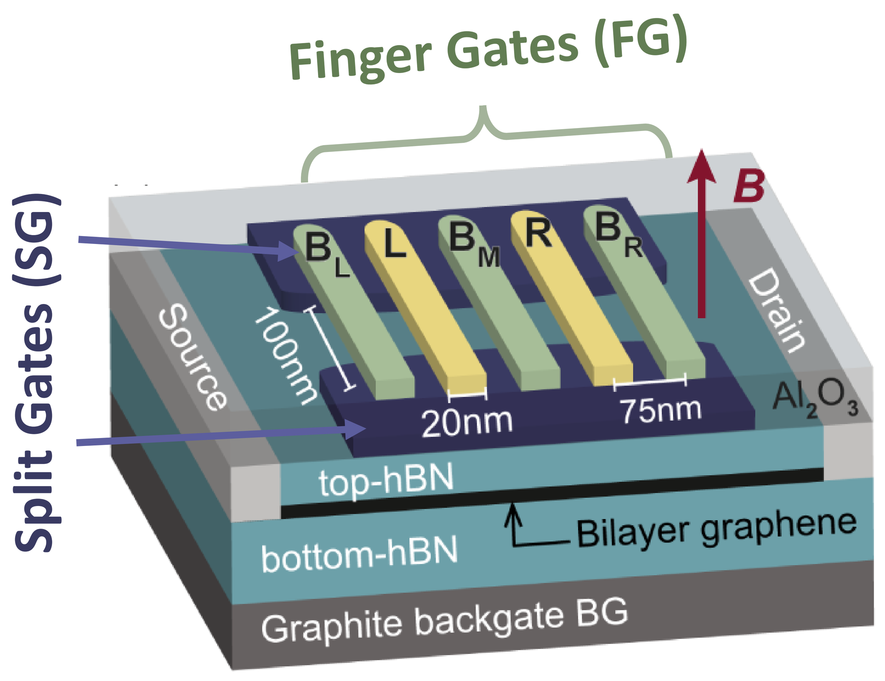
- dependent on dot size and BLG gap size

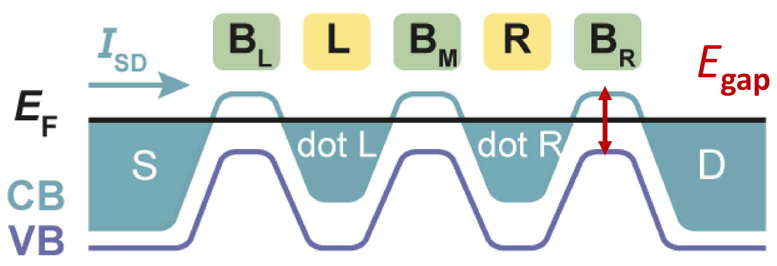
(both gate voltage tunable *in situ*)



Single particle level spectrum extracted from Coulomb resonances [3].

Formation of Bilayer Graphene Quantum Dots





Bilayer Graphene (BLG):

- Electric field perpendicular to BLG opens a band gap E_{gap} [2]

- Device = Van der Waals stack + metallic gate
- Top- + back-gates opens bandgap E_{gap} + tune Fermi energy E_F:

→ Split gates define a conducting channel

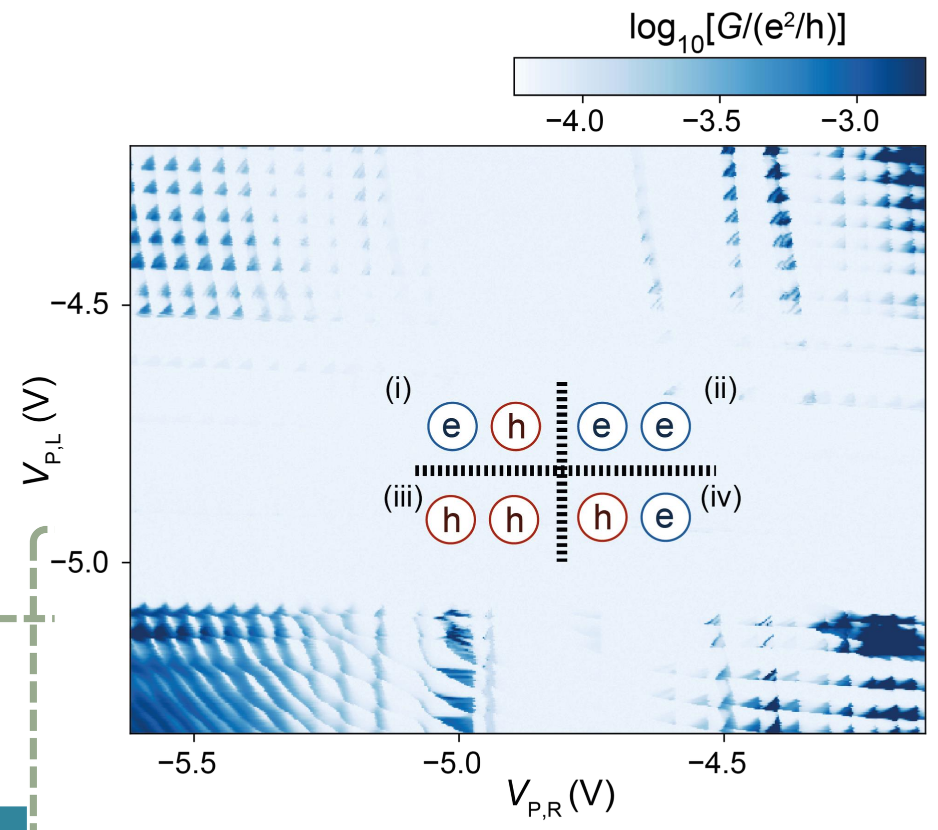
→ Finger gates tune the channel locally

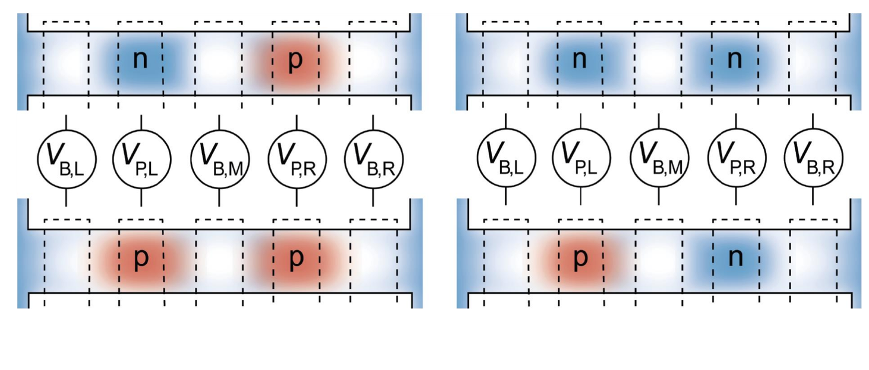
e.g. +ve V_{BG} & -ve V_{SG} & -ve V_{FG}s

→ *n*-type double dots in *n*-type channel

- Define gaps as tunnel barriers by barrier gate voltages V_Bs
- Switch between hole ↔ electron dot by plunger gate voltages $V_{L,R}$.

→ Double dots with reversible polarity





Double dot charge stability diagram [3], with V_{bias} = 2 mV.

Peculiar two–particle states & Pauli Spin and Valley Blockade

- From excited-state measurements for 2 particles in one dot [4] **(2,0)** :

(A): low-field **ground state**:

Spin-triplet valley-triplet : $|T_s^-\rangle|S_v\rangle$

+ One exchange energy E_{ch} above:

Spin-singlet valley-triplet : $|S_s\rangle|T_v^{-,+}\rangle$

Perpendicular B field couples to the valleys and lower $|S_s\rangle|T_v^-\rangle$ by $2\Delta E_{K^-}$:

(B): high-field **ground state**:

Spin-triplet valley-triplet : $|S_s\rangle|T_v^-\rangle$

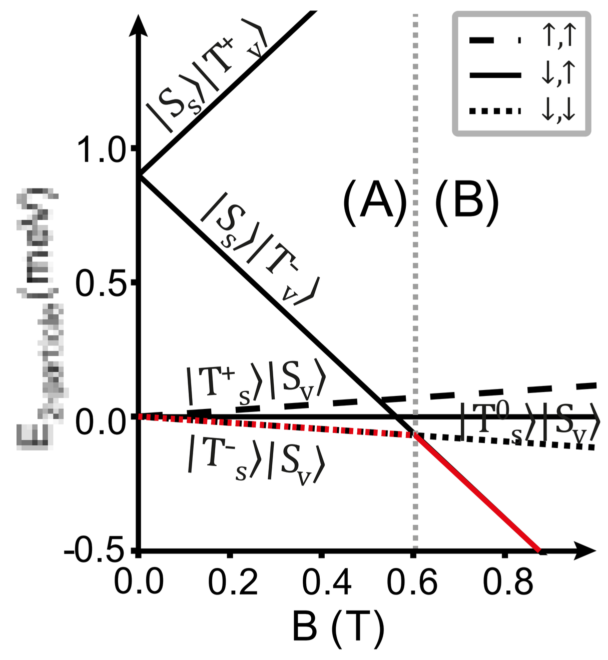
+ $E_{ST} = 2\Delta E_{K^-} - E_{ch}$ above:

Spin-triplet valley-triplet : $|T_s^-\rangle|S_v\rangle$

- 2-particles each on one dot **(1,1)**, for weak enough interdot coupling:

→ two x 4 single-particle levels

→ 16 levels with 10 different energies



No (2,0) states match with quantum numbers of (1,1) ground state!

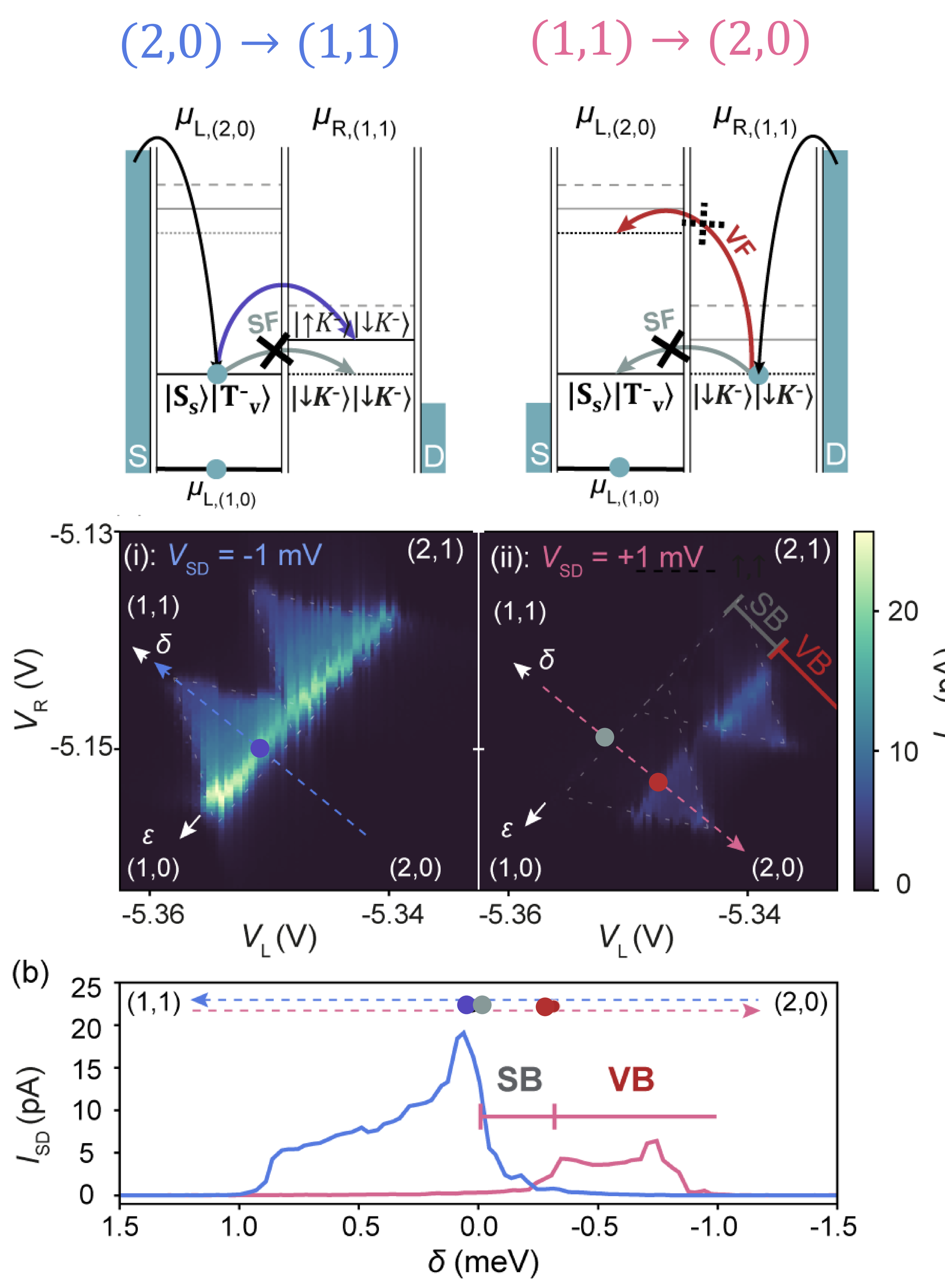
→ For (1,1)→(2,0) spin or valley flip always required

Change of GS for (2,0):

→ (1,1)→(2,0) valley blockade at low field,

Spin blockade at high field

@$B = 800mT$:



Ground state (always): $|\downarrow K^-\rangle|\downarrow K^-\rangle$

Spin blockade: suppresses current by > 50 times (<300fA)

Valley blockade: suppresses current by 5 times

Conclusion & Outlook

- Mature graphene quantum dot technology
  - High quality samples
  - Gate tunable parameters (carrier occupancy, tunnel barrier, polarity, size, valley g-factor etc…)
  - Good understanding of QDs
- Robust Pauli spin and valley blockade
- **Ready for spin and valley qubit manipulation and readouts**

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