Journal Club - Zumbühl Group

Universität Basel

Ultrafast coherent control of a hole spin qubit in a germanium quantum dot

Ke Wang, Gang Xu, Fei Gao, He Liu, Rong-Long Ma, Xin Zhang, Zhanning Wang, Gang Cao, Ting Wang, Jian-Jun Zhang ✉, Dimitrie Culcer, Xuedong Hu, Hong-Wen Jiang, Hai-Ou Li ✉, Guang-Can Guo & Guo-Ping Guo ✉

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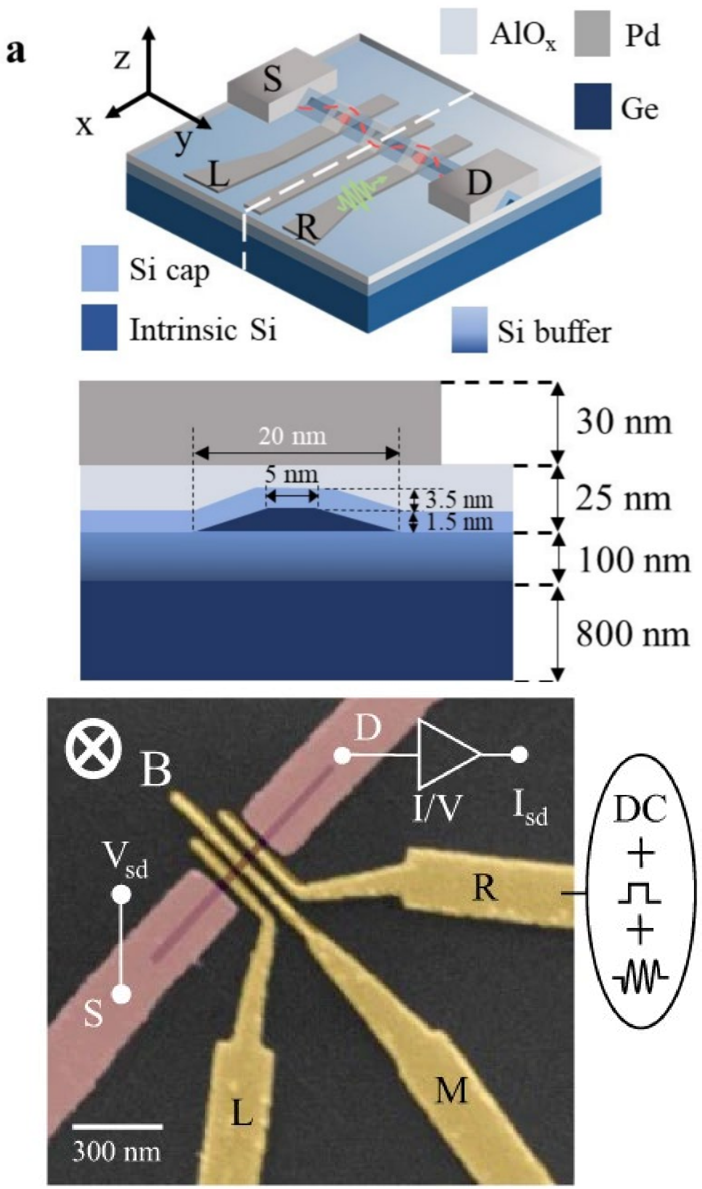
Pierre Chevalier Kwon
21.01.2022

Device architecture



- intrinsic Si substrate (I guess the SiO2 was removed)

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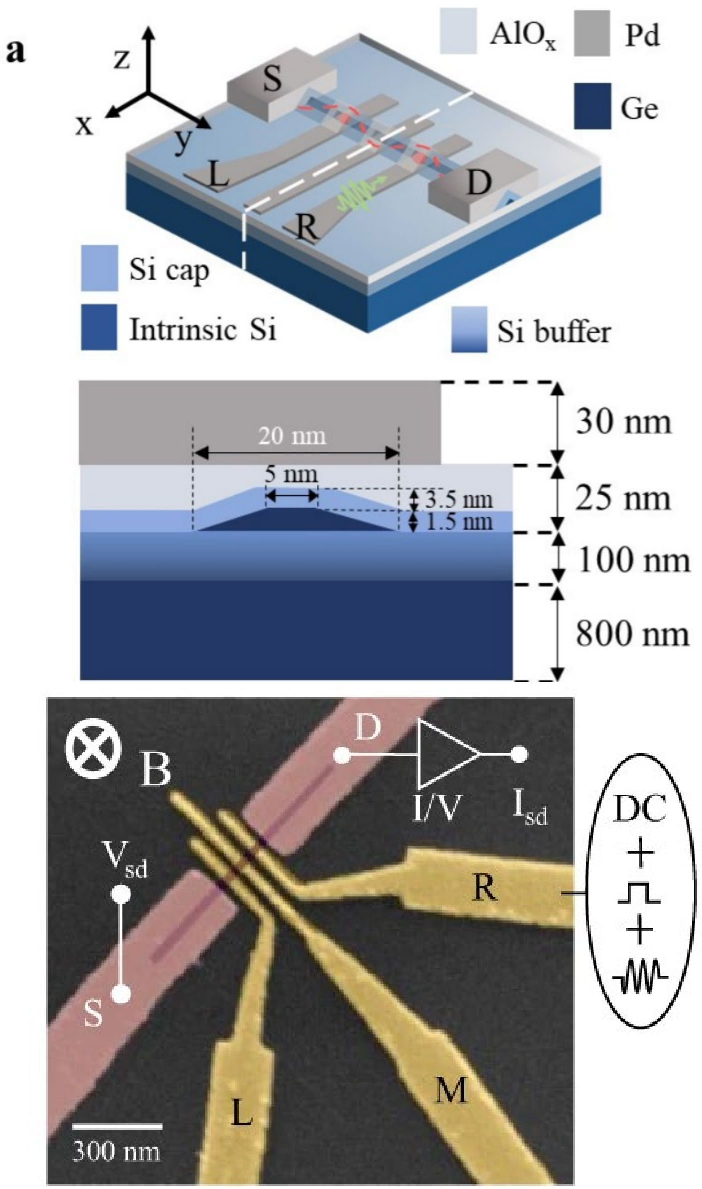

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- Germanium hut wire:
  - Ge layer (1.5 nm) deposited by S-K growth mode
  - 3.5-nm-thick Si cap then grown on top

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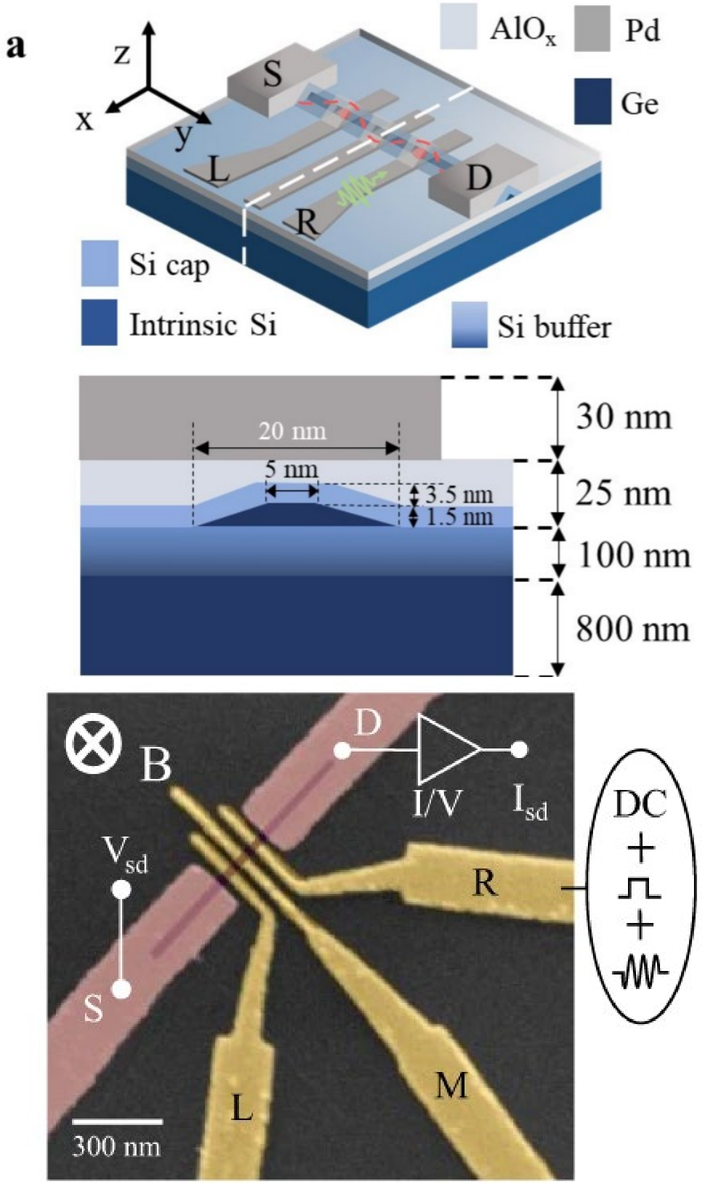

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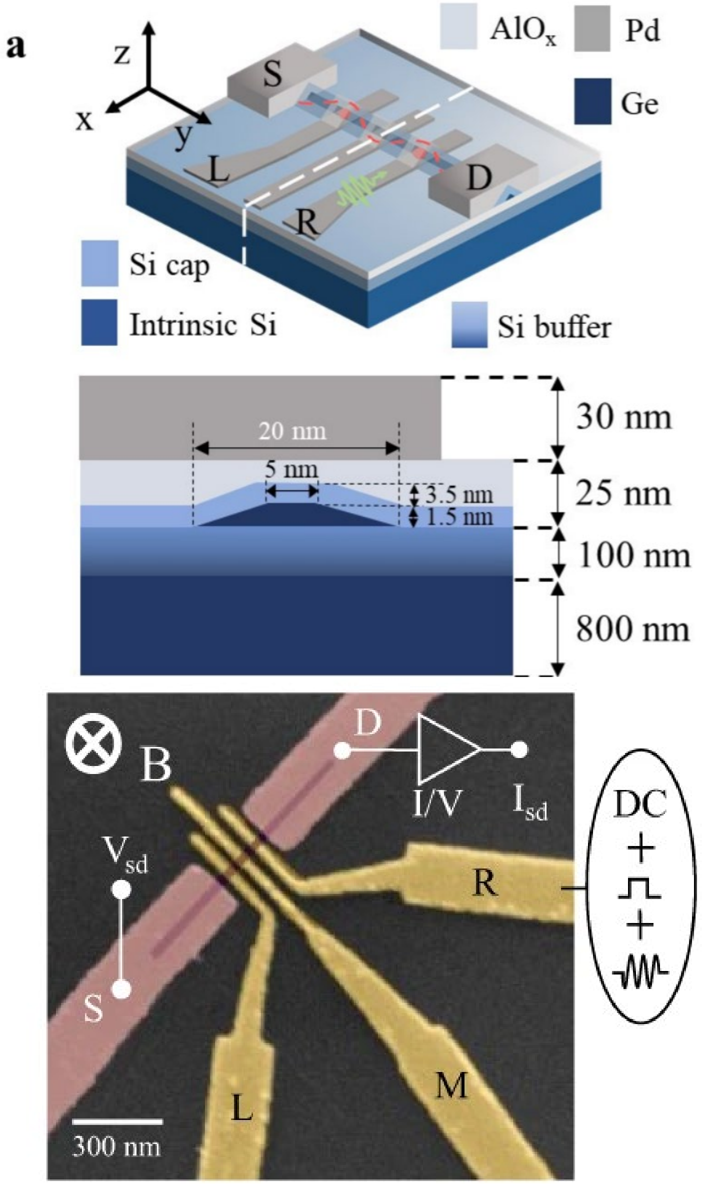

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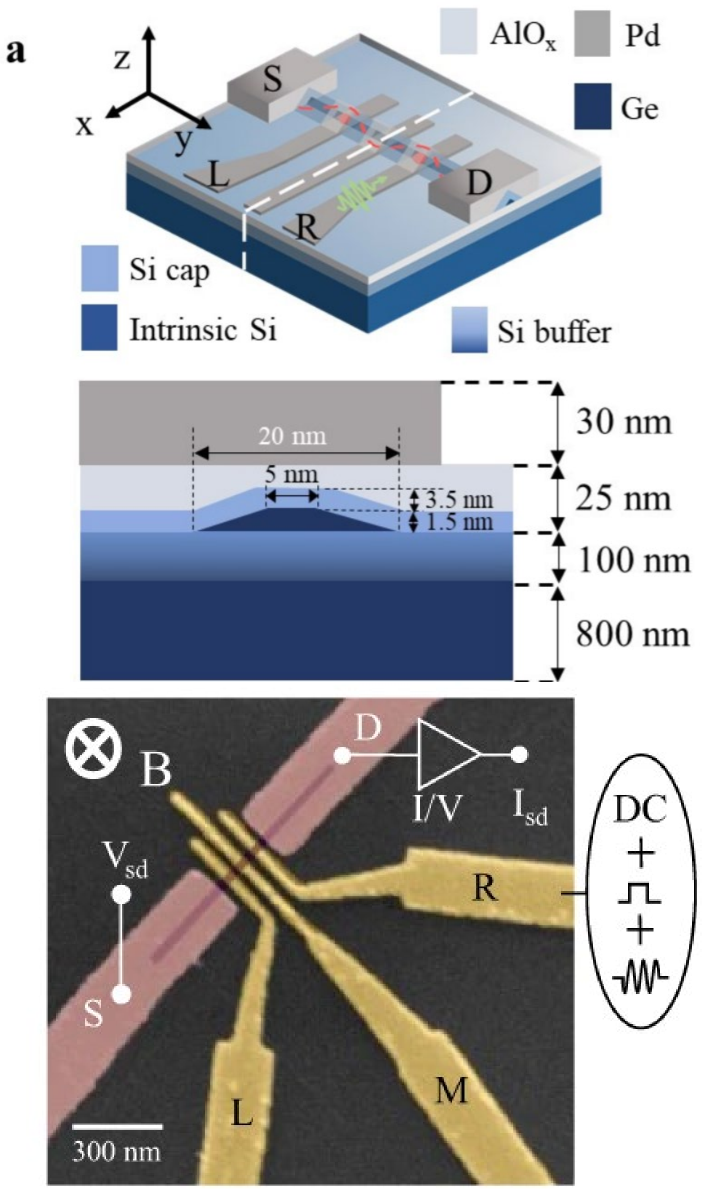

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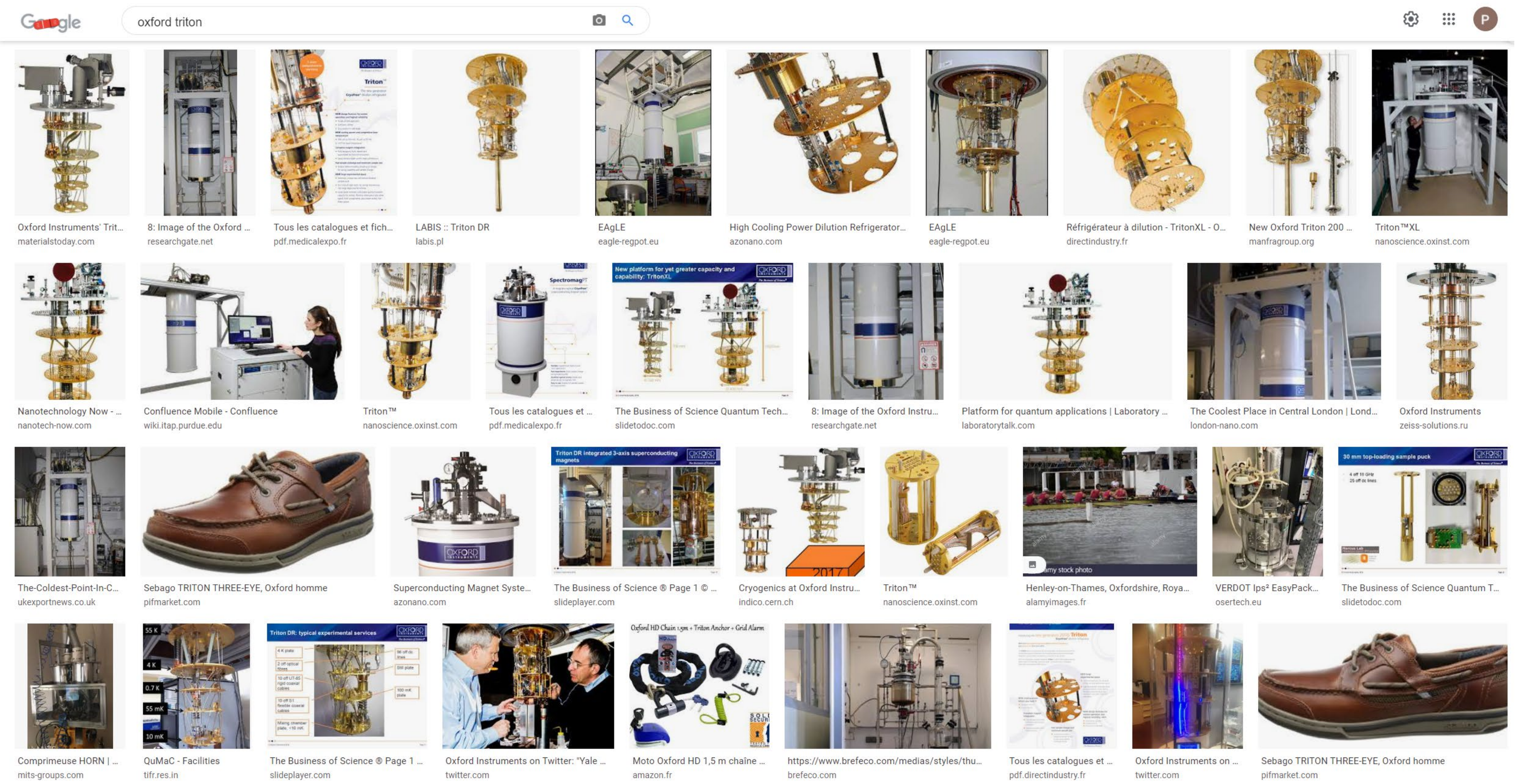
- Germanium hut wire:
  - Ge layer (1.5 nm) deposited by S-K growth mode
  - 3.5-nm-thick Si cap then grown on top
- Source and Drain Pads made with Pd
- 20 nm of Aluminium oxide
- 3 confinement gates (no plunger) made with Pd
  - 35 nm wide (I found ~40 ± 5 nm)
  - Center to center distance of 65 nm
  - Microwave pulses are applied via gate R

Device setup

- Oxford Triton dilution refrigerator at a base temperature of 10 mK

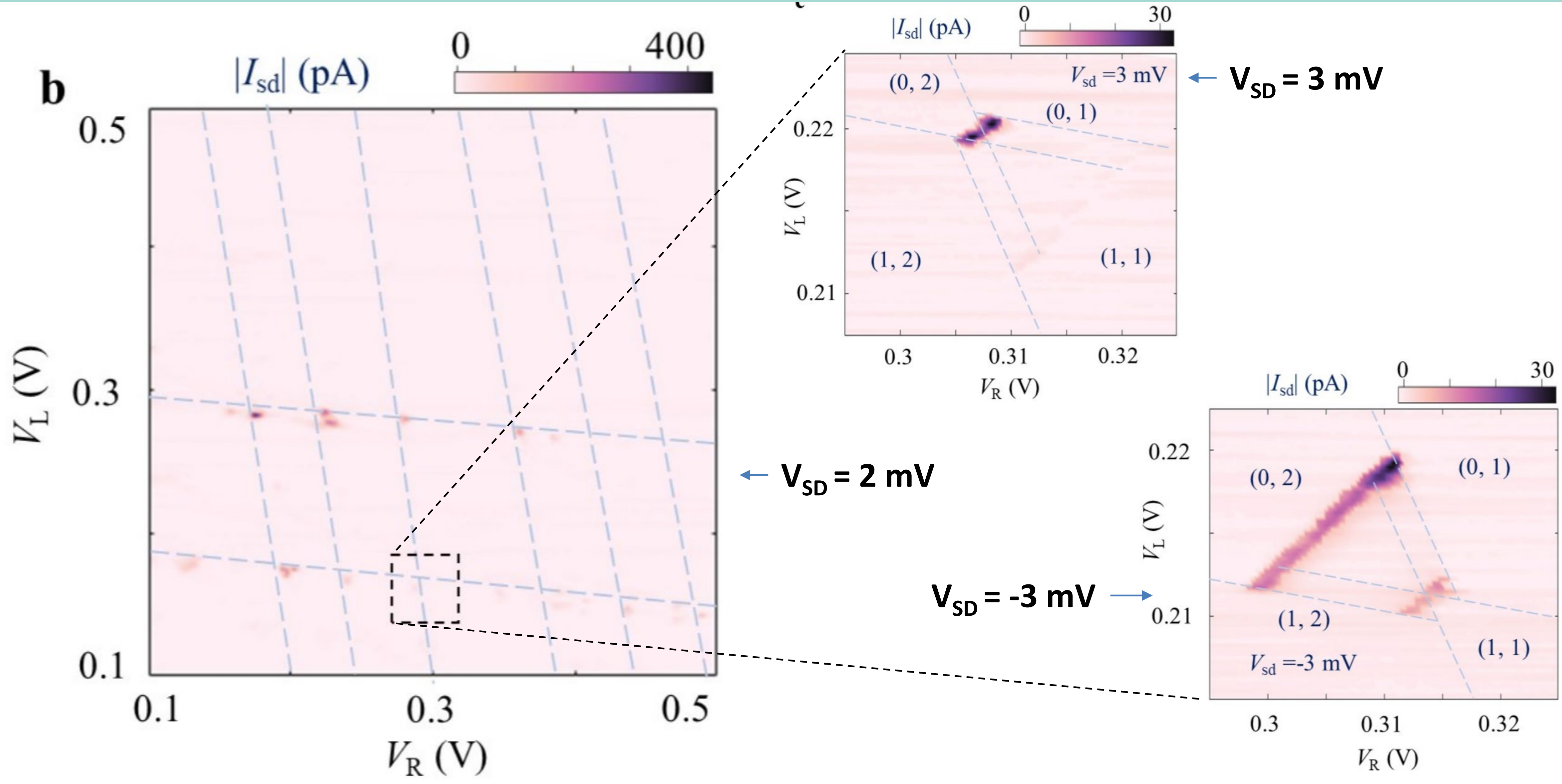
Device setup



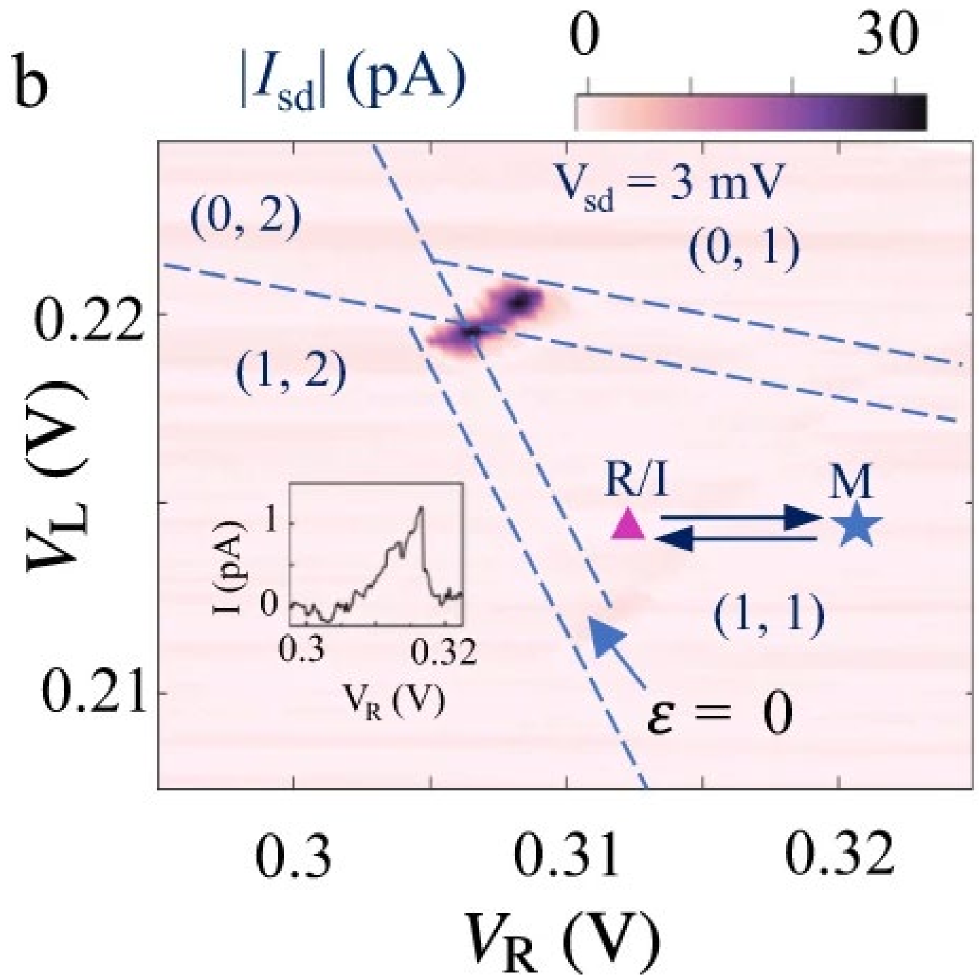
Device setup

- Oxford Triton dilution refrigerator at a base temperature of 10 mK
- AWG: Keysight M8190A
- Vector source: Keysight E8267D

DQD configuration

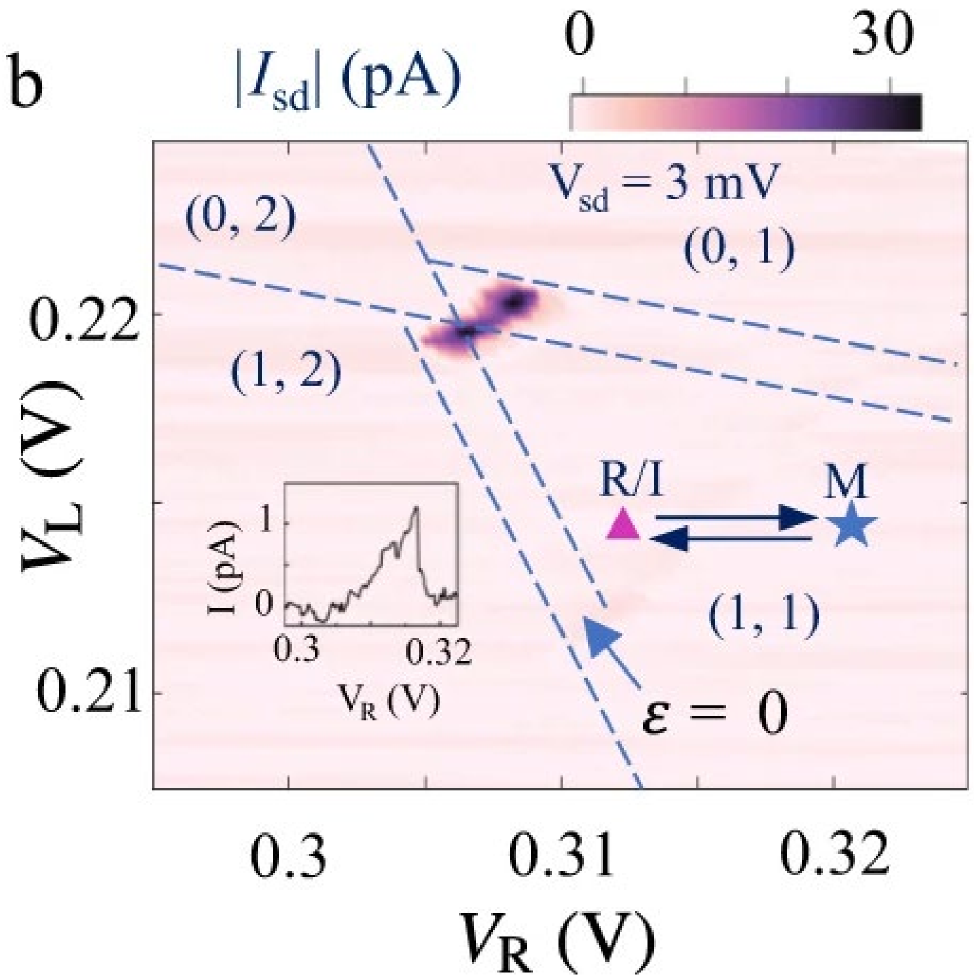


DQD configuration



- They found PSB (see previous slide)

DQD configuration



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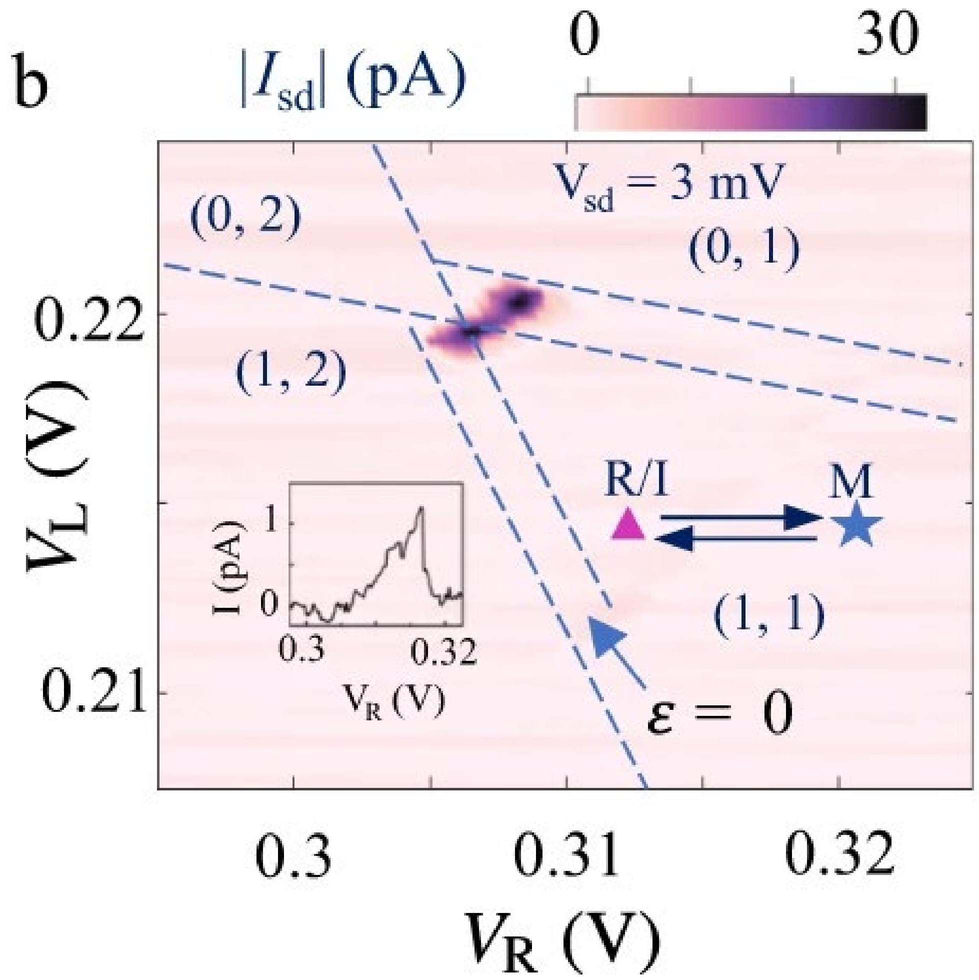
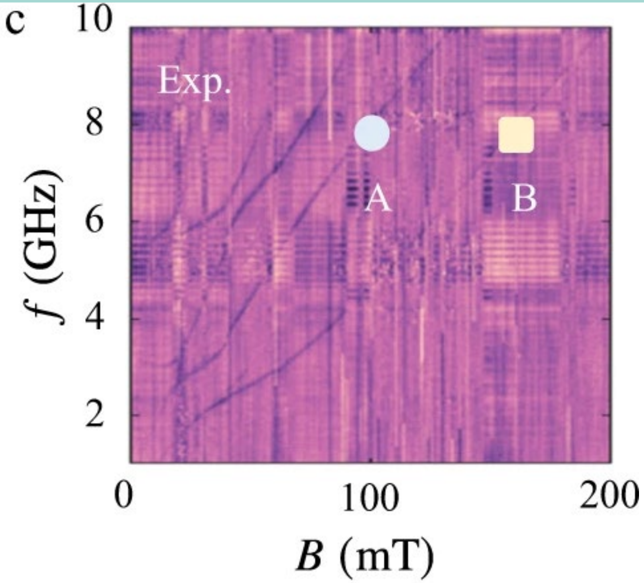
- Claim to have about 5 holes in the left dot and 10 holes in the right dot

DQD configuration



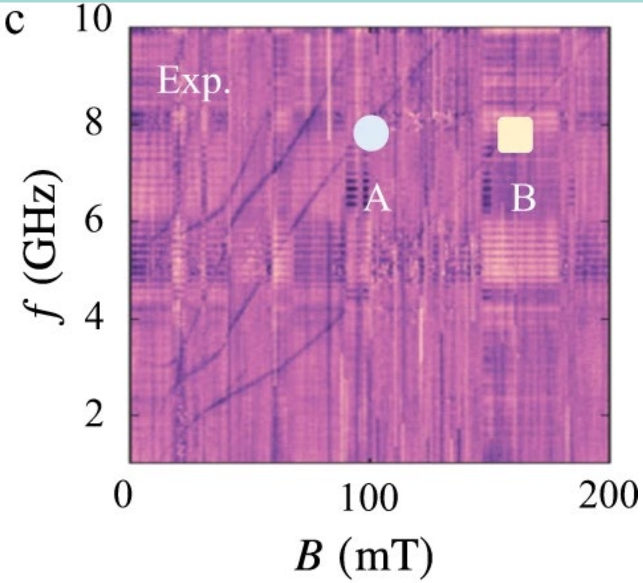
- They found PSB (see previous slide)
- Claim to have about 5 holes in the left dot and 10 holes in the right dot
- Extract from these maps:
  - Intra-dot Coulomb energy (orbital splitting) of 10 meV
  - Inter-dot Coulomb interaction of 0.5 meV

EDSR

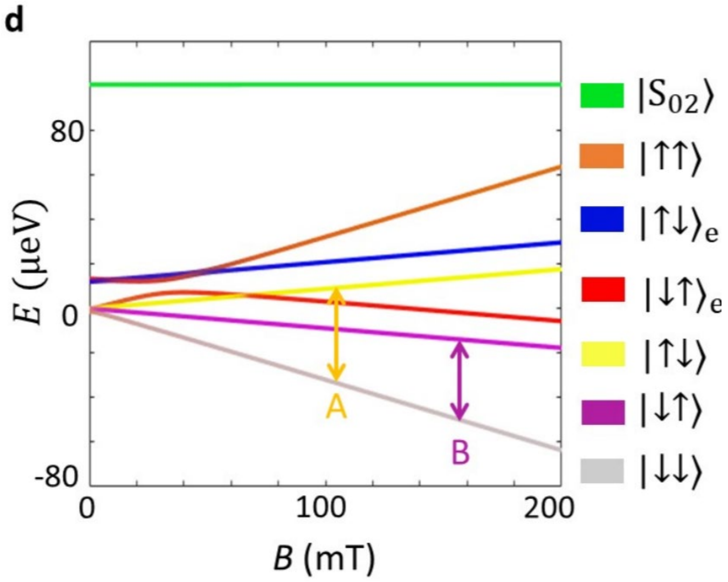


- EDSR measured by applying microwave with a power of −15 dBm (at the point R/I)

EDSR



- EDSR measured by applying microwave with a power of −15 dBm (at the point R/I)
- from their "effective two-hole model", they fit the data:



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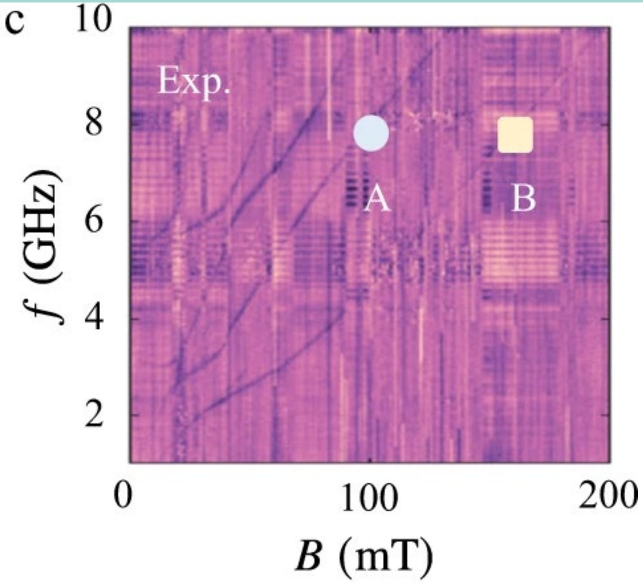
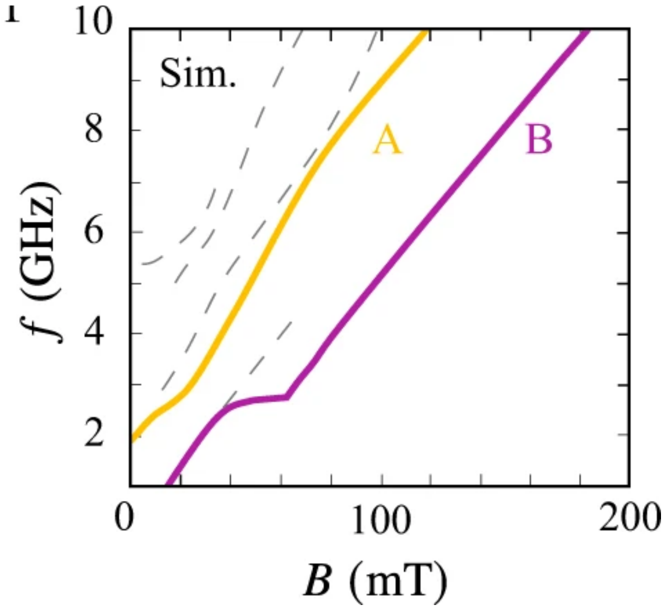
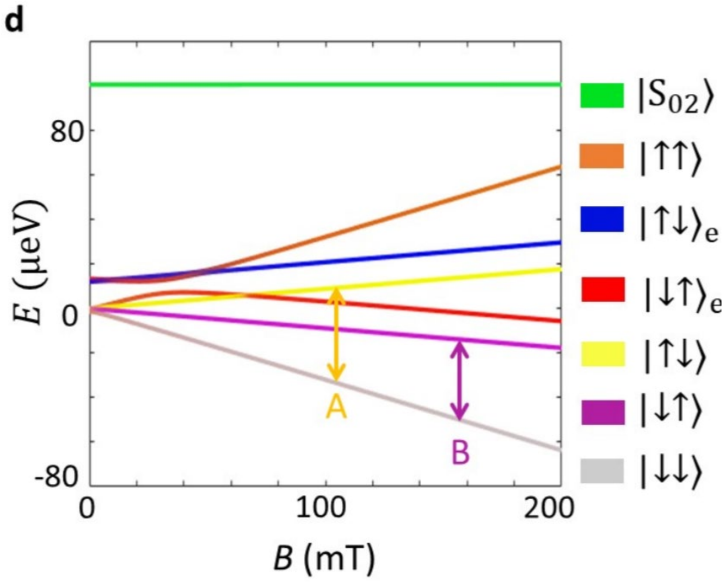
EDSR



- EDSR measured by applying microwave with a power of −15 dBm (at the point R/I)
- from their “effective two-hole model”, they fit the data: Purple (B) and yellow (A) resonances correspond to spin-flips between |↓↓⟩ and, respectively, |↓↑⟩ / |↑↓⟩





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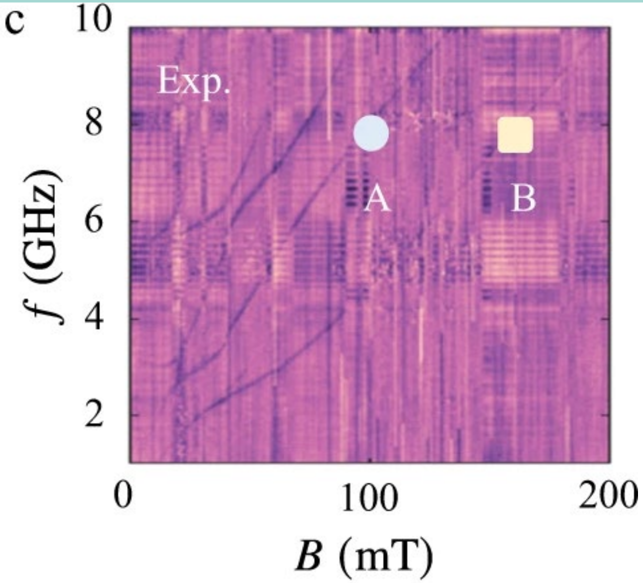
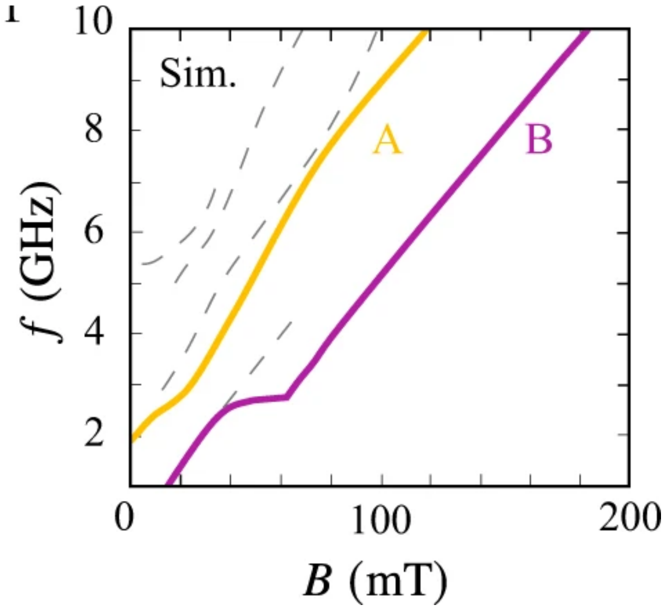
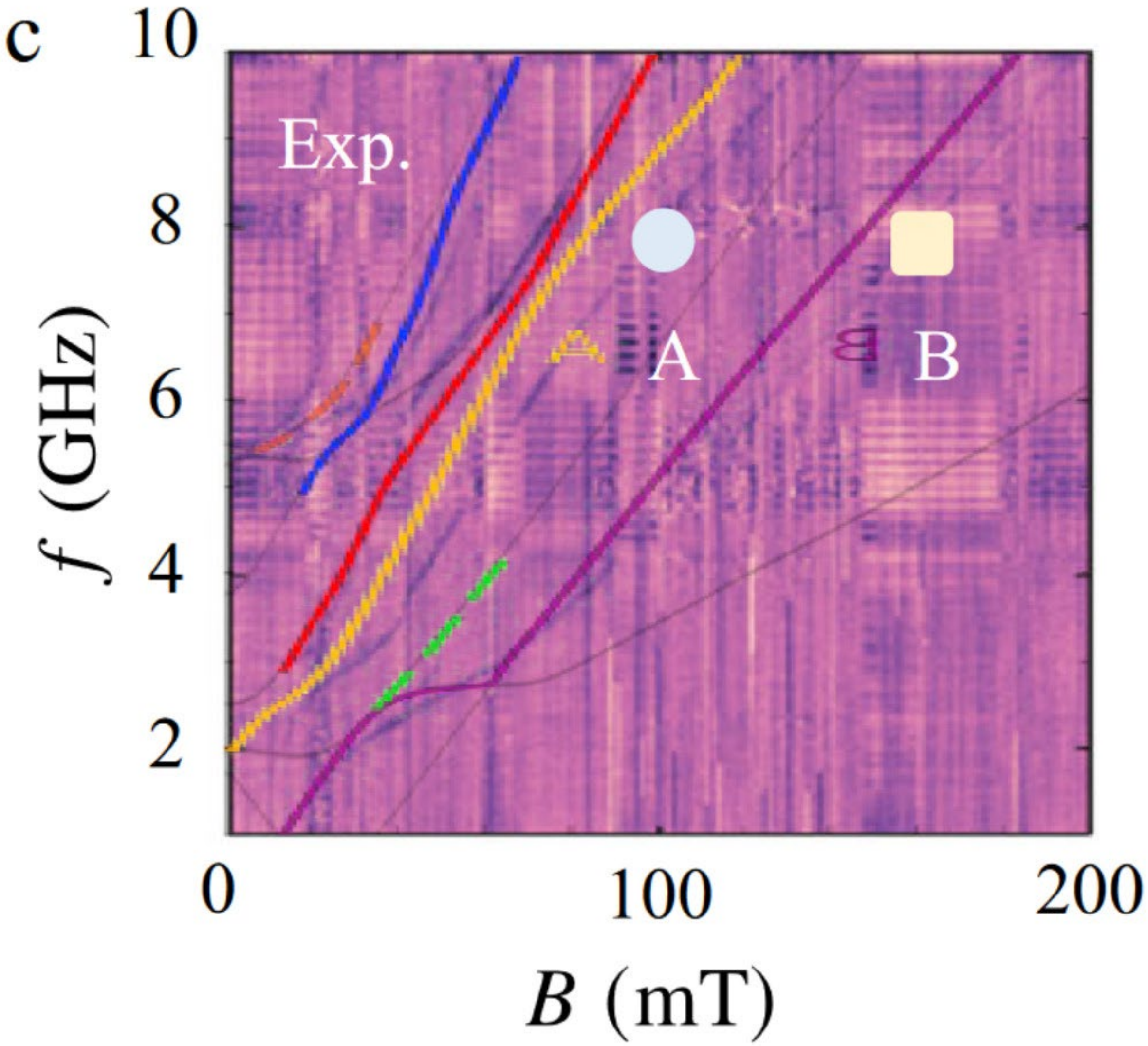


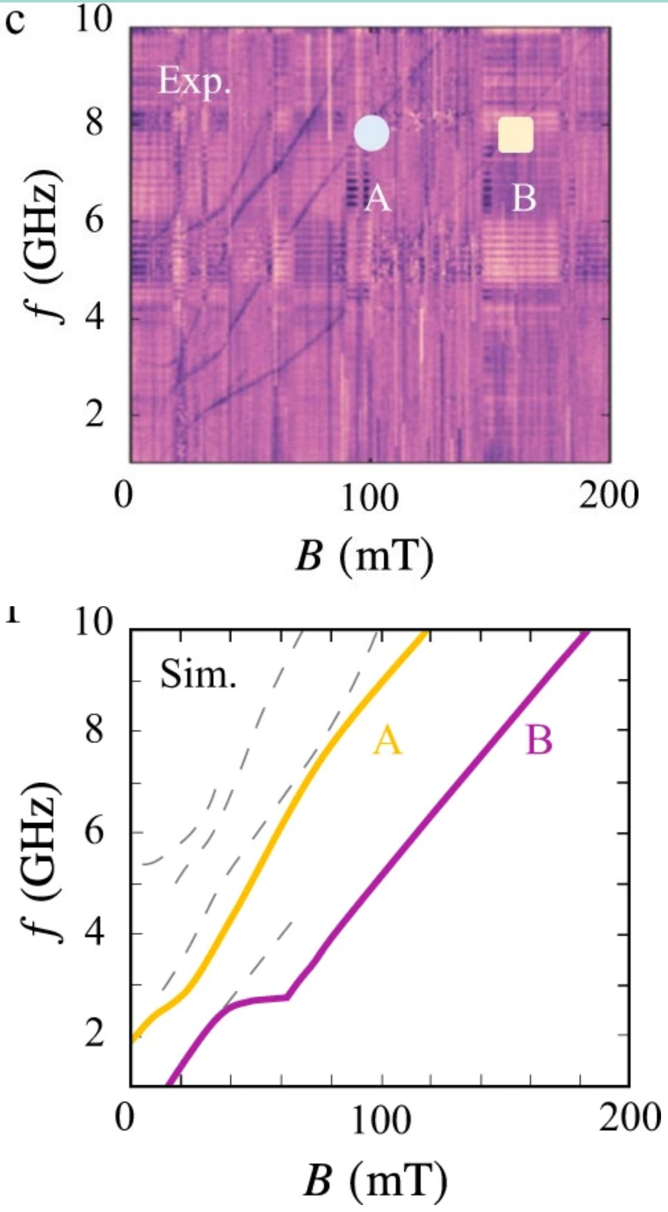


- EDS ... /er of −15
- fror ... data: Pur ... flips bet ... ⟩



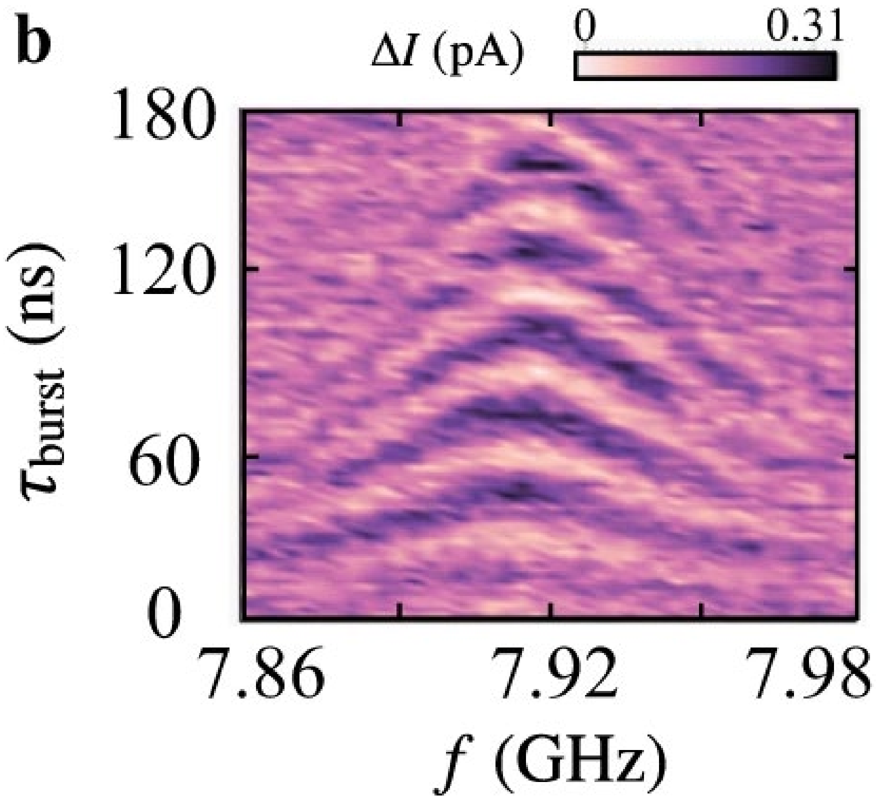
Thanks to Simon Geyer for the Photoshop!

EDSR



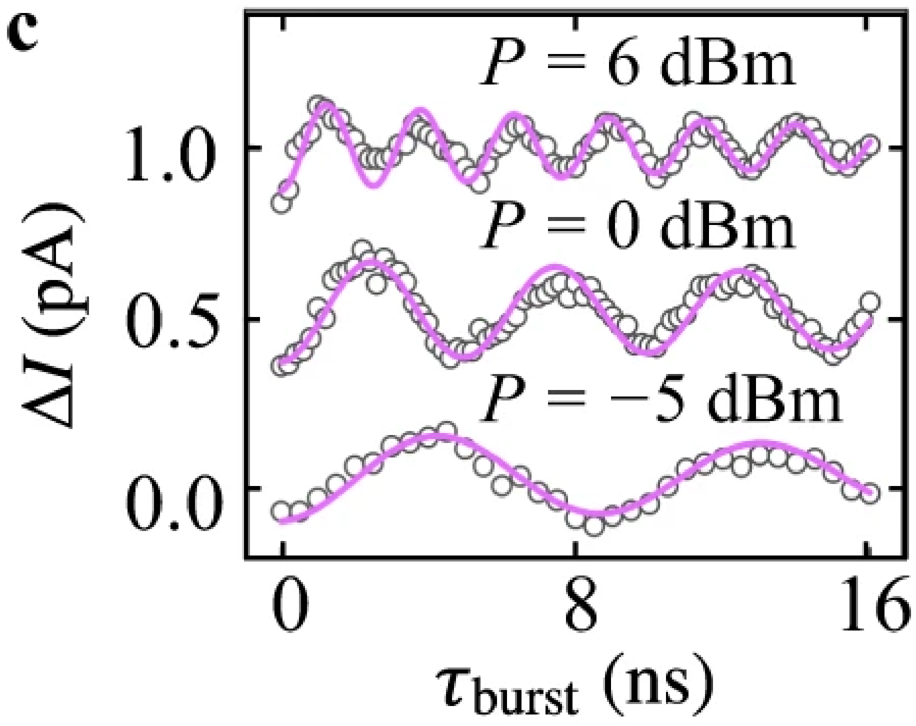
- EDSR measured by applying microwave with a power of −15 dBm (at the point R/I)
- Purple and yellow resonances correspond to spin-flips between |↓↓〉 and, respectively, |↓↑〉 / |↑↓〉
- Find very different g-factors: $g_L = 7$ and $g_R = 3.95$
  - Proposed explanation: unequal hole occupations between the two dots

Rabi oscillations



- They operate in the mode A (see previous slide) with a Larmor frequency of **f = 7.92 GHz**

Rabi oscillations



- They operate in the mode A (see previous slide) with a Larmor frequency of **f = 7.92 GHz**
- Rabi at 3 microwave power P = −5, 0, 6 dBm with an **averaging** over **100** cycles (reduce charge noise).
  - Maximum Rabi frequency of $\mathbf{f_{Rabi}}$ **= 542 ± 2 MHz** for mode A (and 291 ± 1 MHz for mode B) achieved

Spin orbit lenght

- Using a single-hole model calculation, they get:

$$hf_{\mathrm{Rabi}} = g\mu_{\mathrm{B}}B \cdot \frac{a_x}{l_{\mathrm{so}}} \cdot \frac{eE_{\mathrm{ac}}a_x}{\hbar\omega_y}$$

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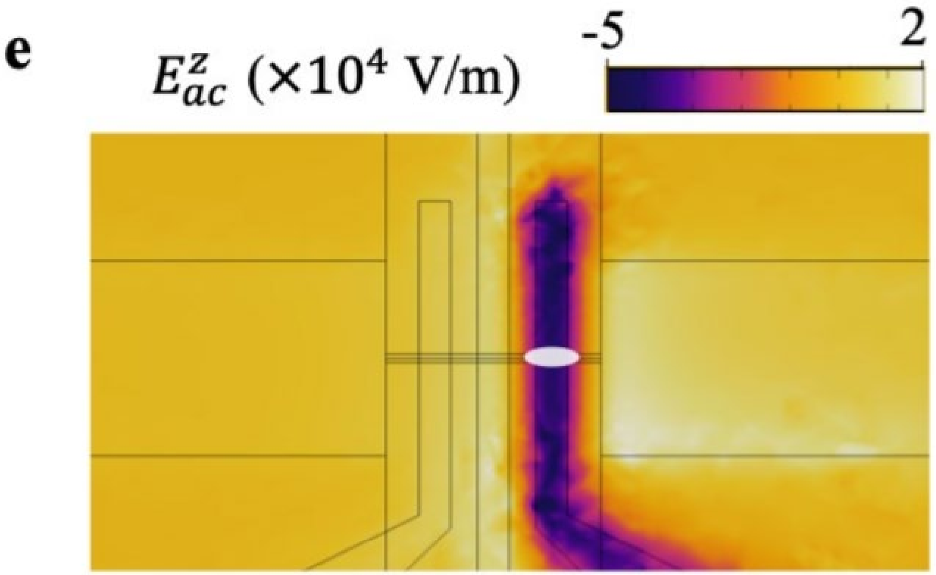

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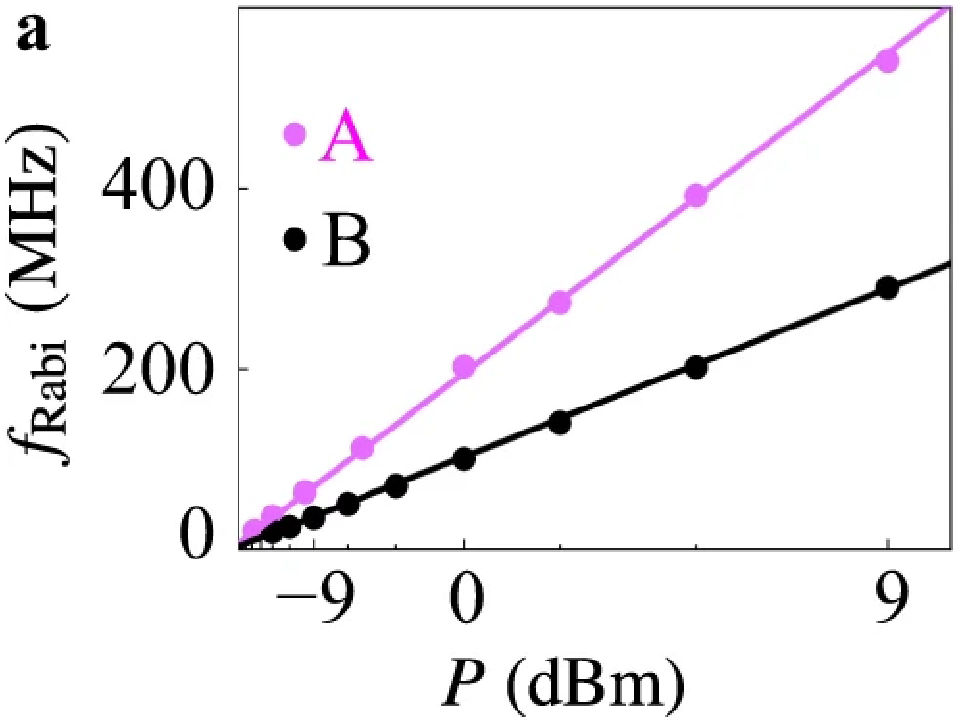

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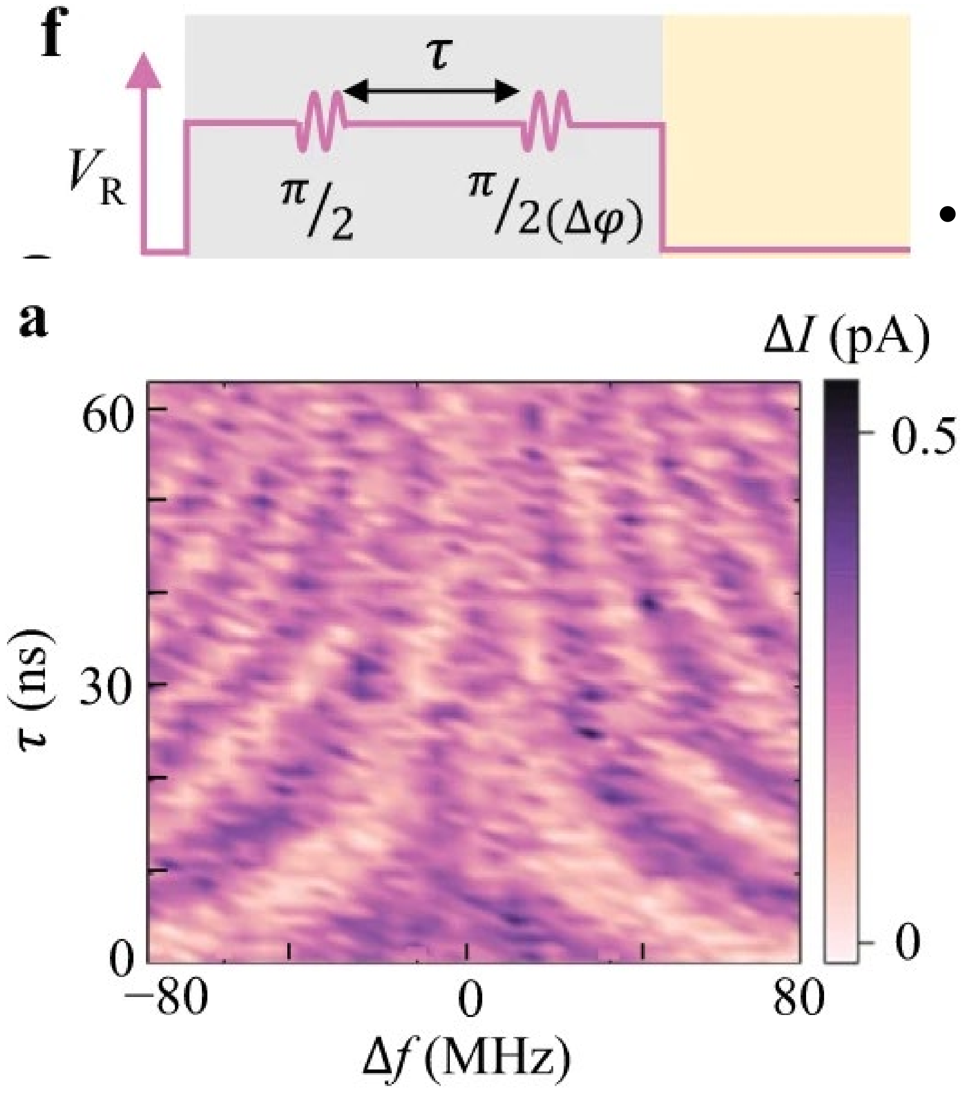
- They simulate on Comsol their device to get $E_{ac} = f(P)$
- After plotting P (E_{ac}) function of f_{Rabi} one is able to get Spin orbit length:
  - 1.5 nm and 1.4 nm for, respectively, mode A and B

Ramsey



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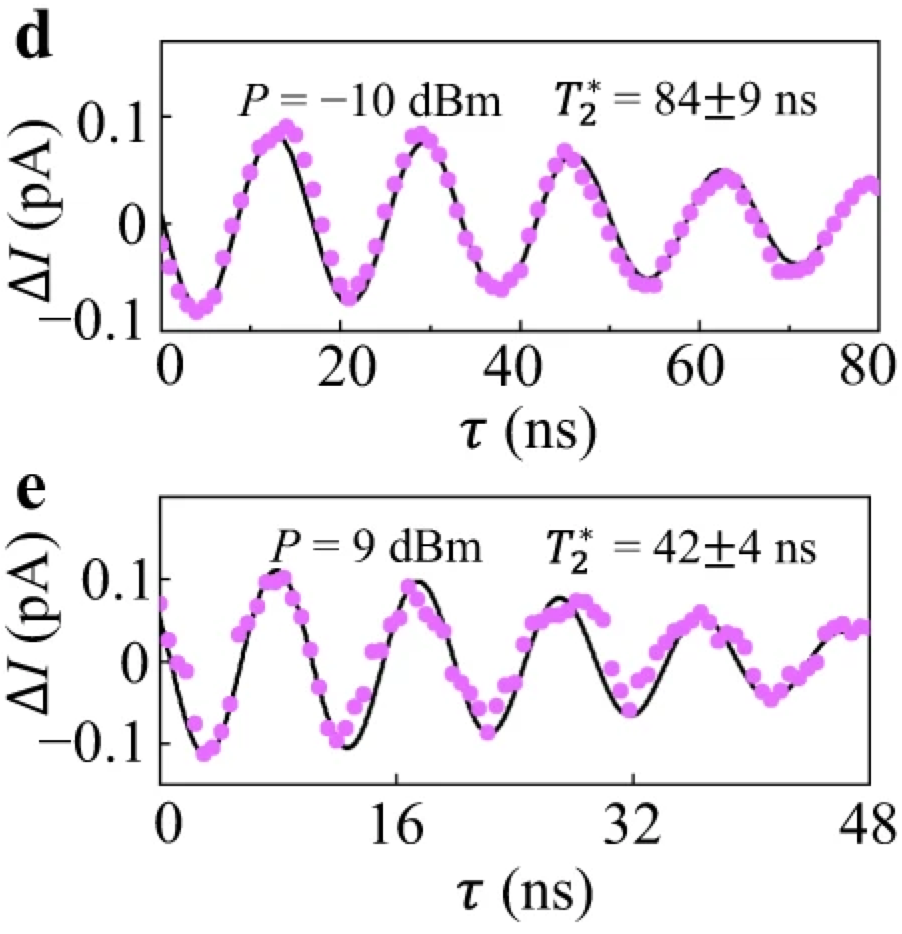

- They perform Ramsey experiment
- They extract the dephasing time:
  T_2* = 84±9 ns and T_2* = 42±4 ns at P = −10 dBm and P = 9 dBm (mode A)
  - "The former is a better representation of hole spin dephasing, while the latter reflects coherence degradation from the onset of microwave-induced heating"

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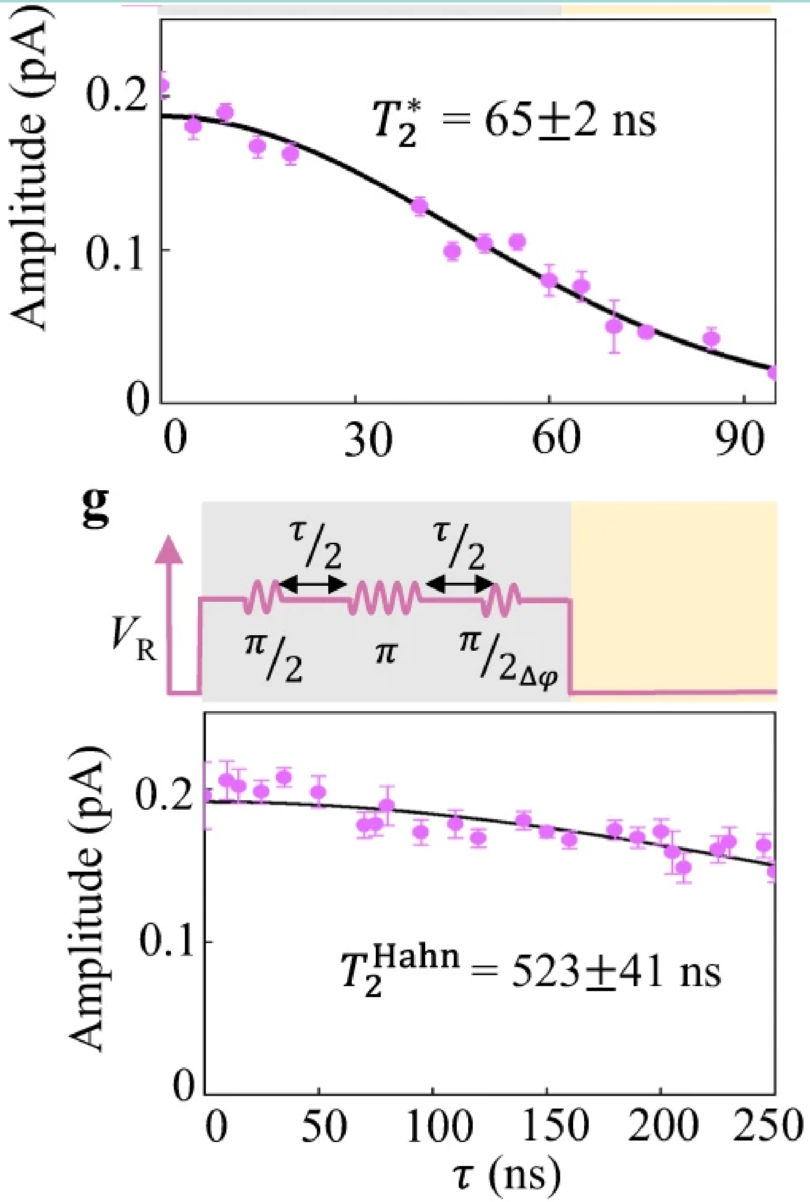
Ramsey



- They perform Ramsey experiment
- They extract the dephasing T_2*=84±9 ns and T_2*=42±4 ns at P = −10 dBm and P = 9 dBm (mode A
- They compare a Ramsey of the mode B (T_2* = 65 ±2 ns) to a Han echo which impove the dephasing time: T_2^{han} = 523 ±4 ns

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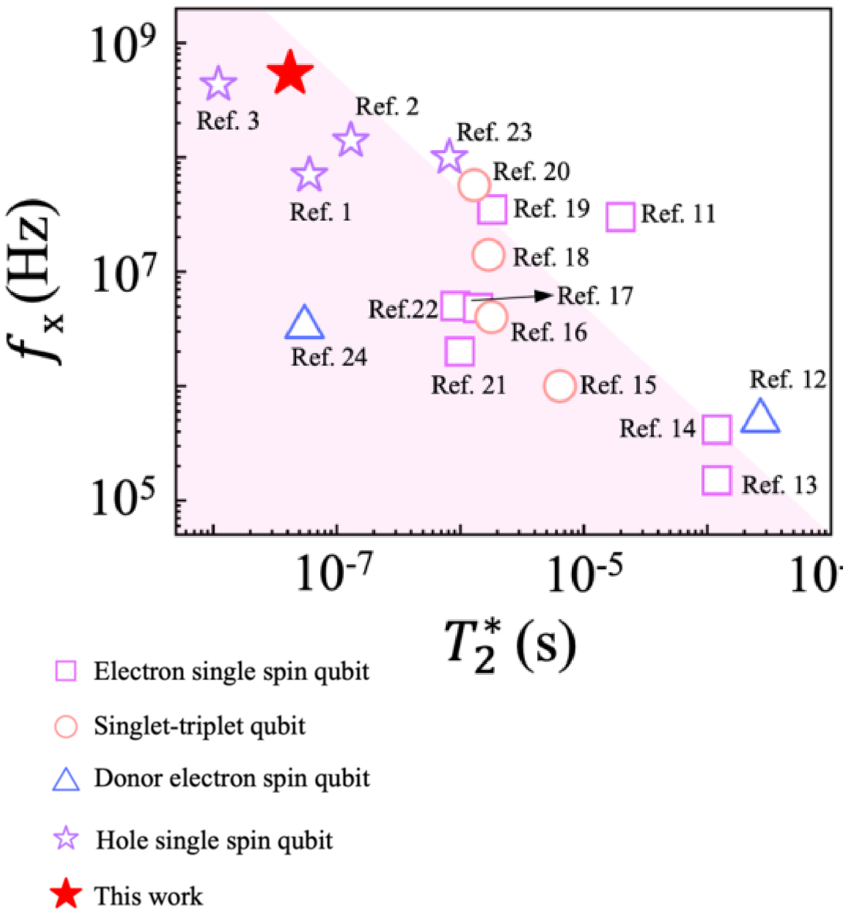
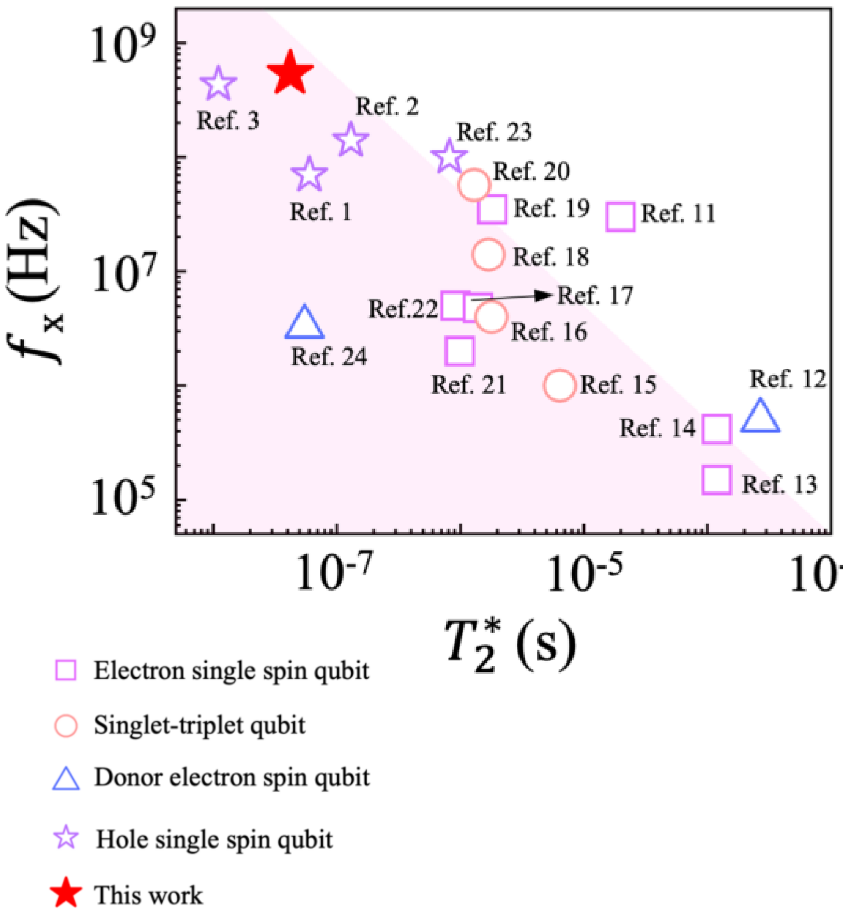
Conclusion



<u>Summary of results:</u>

- Ultrafast spin manipulation in a Ge HW

Conclusion



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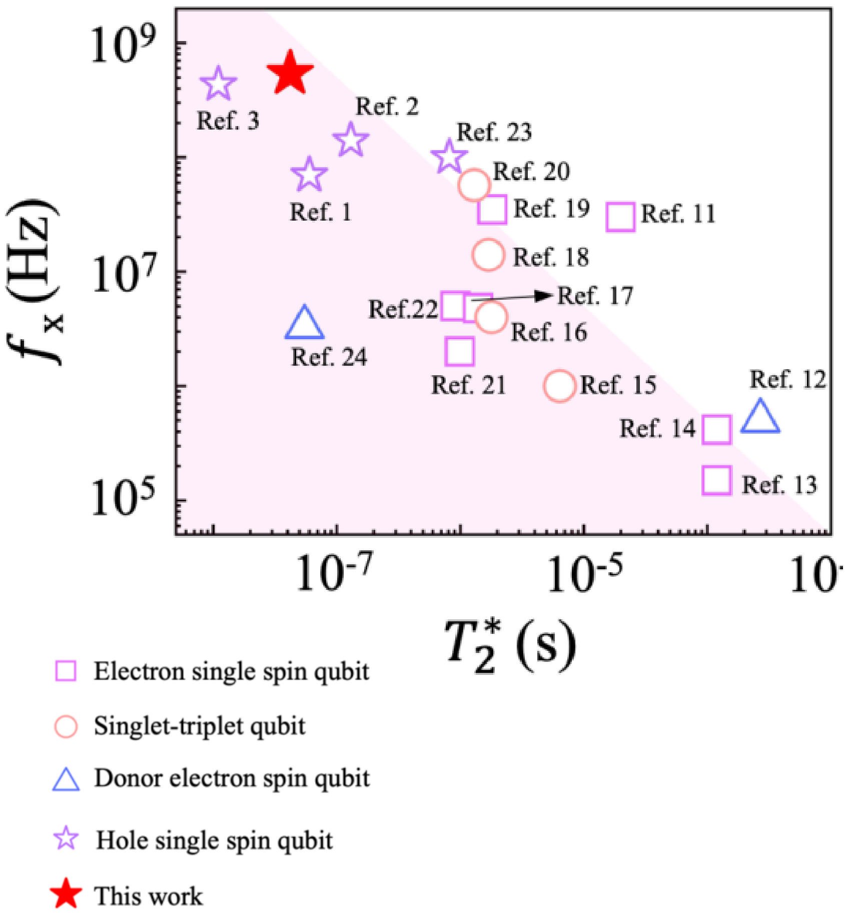

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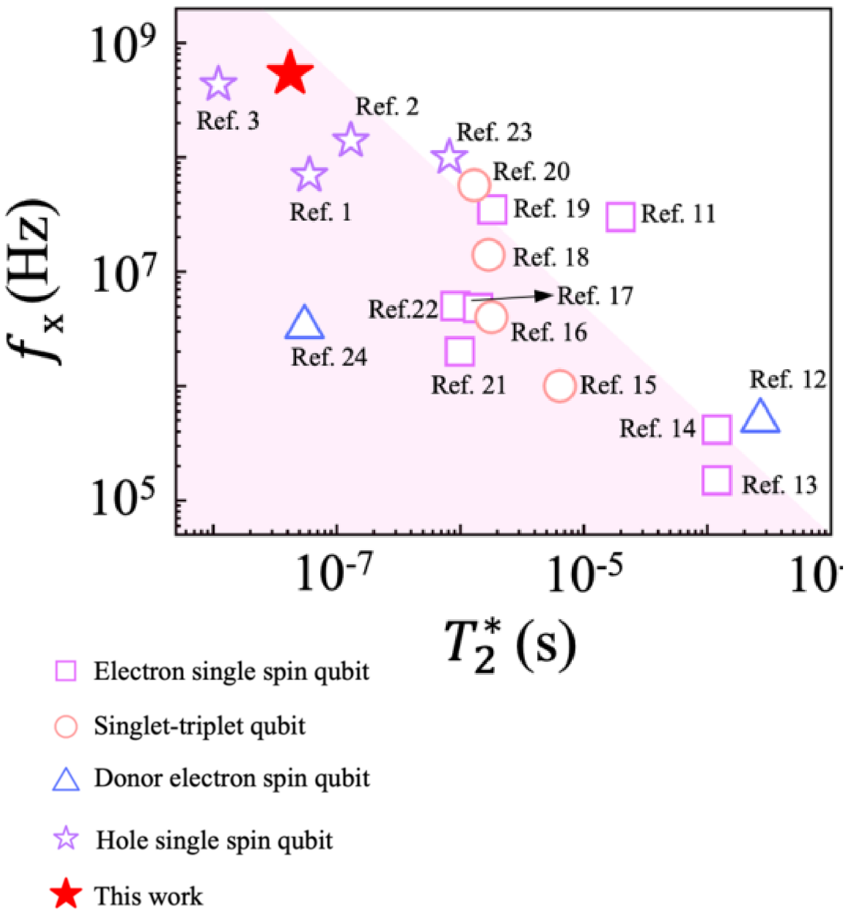

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Thanks

Thank you for your attention!