Interaction between quantum dots and superconducting microwave resonators

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Tobias Frey
Motivation

Interconnect the worlds of semiconductor and superconductor based quantum circuits
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Spin qubits in quantum dots

Circuit quantum electrodynamics
Motivation

Interconnect the worlds of semiconductor and superconductor based quantum circuits

Spin qubits in quantum dots

Circuit quantum electrodynamics

Potential benefits:

• To enable long distance coherent coupling
• Implement alternative measurement / read-out scheme
• Realize interfaces between quantum systems
Hybrid quantum device

Microwave resonator

GaAs/AlGaAs
35nm 2DEG depth

Aluminum resonator
\[ \nu_{\text{res}} \approx 6.75 \text{ GHz} \]
\[ Q \approx 2600 \]

Hybrid Quantum Dot / Circuit QED Measurement Setup

Hybrid Quantum Dot / Circuit QED Measurement Setup

hybrid sample holder

~10 mK plate of cryostat

Hybrid Quantum Dot / Circuit QED Measurement Setup

hybrid sample holder

~10 mK plate of cryostat

Pulse tube cooled cryostat

Single dot physics

(a)

S \quad QD \quad D

V_L \quad V_{PG} \quad V_R

(b)

\begin{align*}
\Delta V_{PG} \\
V_{PG}
\end{align*}

Single dot physics

Charge stability diagram: double dot

Each dot coupled only to its gate

Slide courtesy of Klaus Ensslin
Charge stability diagram: double dot

Each dot coupled **only** to its gate

Each dot coupled to **both gates**
Charge stability diagram: double dot

Each dot coupled only to its gate

Each dot coupled to both gates

Both dots coupled to each other

Slide courtesy of Klaus Ensslin
Transport through the double quantum dot

charging energy $\sim 1$ meV; many electron regime

Transport through the double quantum dot

charging energy ~1 meV; many electron regime

Double Dot Current and Resonator Transmission

Transport measurements:

Resonator transmission:
- amplitude
- phase

Double Dot Current and Resonator Transmission

Transport measurements:

Resonator transmission:
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- phase

Charging Diagrams in Current, Amplitude and Phase

Charging Diagrams in Current, Amplitude and Phase

- systematic changes in transmission amplitude and phase
- equivalent charging diagrams …
- … but different physical origin of signal

Charging Diagrams in Current, Amplitude and Phase

current:

amplitude:

phase:

detuning \( \delta \):
Charging Diagrams in Current, Amplitude and Phase

**current:**

**amplitude:**

**phase:**

total energy $\varepsilon$:

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Charging Diagrams in Current, Amplitude and Phase

current:

amplitude:

phase:

tunnel coupling $t$:

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Resonator/Double-Dot Interaction
Center Gate Voltage ($V_c$) Influence

Tune $t$, with $V_c$

Resonator/Double-Dot Interaction

Center Gate Voltage ($V_C$) Influence

$V_C$ more negative

Detailed Resonator/Double-Dot Interaction

Detailed Resonator/Double-Dot Interaction

Non-Resonant Frequency Shifts

\[ h \nu_q \]

\[ h \nu_r \]

\[ 2t \]

\[ \delta \]

\[ \Delta V_{L_0} - \Delta V_{R_0} \text{ [mV]} \]

\[ \Delta V_{L_0} - \Delta V_{R_0} \text{ [mV]} \]


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Summary

- Fabricated integrated semiconductor/superconductor device
- Explored novel measurement scheme for quantum dots
- Observed first indications of controlled resonator/quantum dot dipole-coupling

Outlook

- Explore limits of coherence
- Work towards coherent interface
- Evaluate potential to investigate spin physics
- Use resonator as a coupling bus in semiconductor-based QIP