Two-Level System Interactions with Qubits and Resonators

They're the worst.... Or are they? They are.

John Rinehart

Department of Physics
University of Waterloo

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Outline

Glasses

- In the late 80's W.A. Phillips reported on experimental results analyzing two-level system affects on thermodynamic properties of solids (heat capacity and thermal conductivity).
- Then, it was postulated that systems tunneling between two available states were the cause of the anomolous behavior of the properties of glasses.[1]

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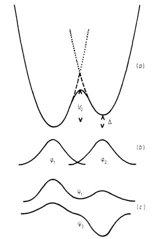
Before 2000's

Potentials



Coupled Hamiltonian

$$\begin{pmatrix} E_1 + <\phi_1|V - V_1|\phi_1> & <\phi_1|H|\phi_2> \\ <\phi_2|H|\phi_1> & E_2 + <\phi_2|V - V_2|\phi_2> \end{pmatrix}$$

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First Ideas

- Affect oscillation amplitude (Not T_1).
- Early publications emphasized first measured single TLS-qubit interaction (not bulk).[2]
- Theory (< 2004) concluded on current coupling. [3]

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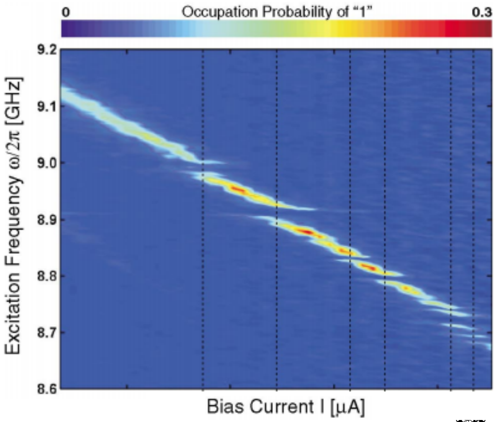
TLS Properties

1. Energy level repulsion.[5]



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3. Full warm-up and cool-down repopulates the system with TLS.
4. TLS location in frequency can change spontaneously.

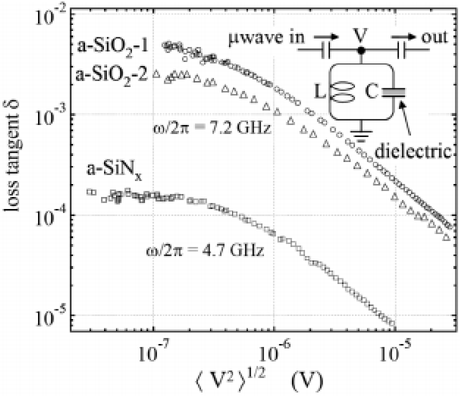
Storing Data in TLS

In 2008, the Martinis Group (UCSB) coupled a phase qubit to a two-level system. They coherently swapped arbitrary states between the qubit and the two-level system with high fidelity (79%).[4]

However, this is likely not to see further application (uncontrolled TLS location, other methods available, uncontrolled coupling strength, etc.)

Avoiding Them

- Use Silicon-Nitride for junctions (not $Si0_2$)[5]



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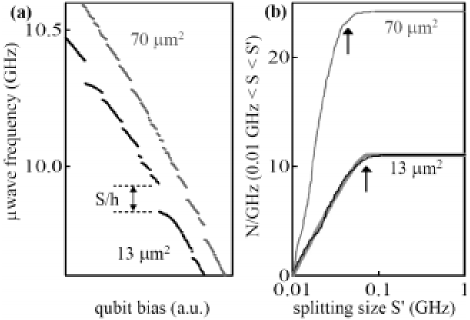

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Avoiding Them

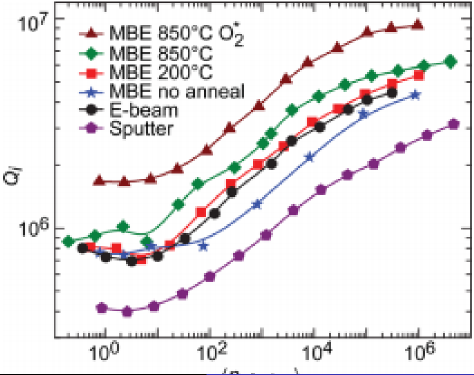
- Use Silicon-Nitride for junctions (not $Si0_2$)[5]
- Reduce junction size[5]
- Use better resonator materials[6]

TABLE I. Fit values for tan δ_{eff}.

Metal	Dielectric	W (μm)	tanδ_{eff}
Nb (poly)	Wet SiO_2/Si	10	2.4e-5
Nb (poly)	Si	10	1.5e-5
Nb (poly)	Sapphire	10	1.8e-5
Al (poly)	Dry SiO_2/Si	10	2.0e-5
Al (poly)	Si	10	1.5e-6
Al (poly)	Sapphire	10	1.6e-6
Al (epi)	Sapphire	10	1.8e-6
Re (epi)	Sapphire	10	1.8e-6
TiN (poly)	Si	10	9.6e-7
Nb (poly)	Wet SiO_2/Si	3	5.7e-5
Nb (poly)	Si	3	3.7e-5
Nb (poly)	Sapphire	3	2.3e-5
Al (poly)	Dry SiO_2/Si	3	NA
Al (poly)	Si	3	NA
Al (poly)	Sapphire	3	NA
Al (epi)	Sapphire	3	6.5e-6
Re (epi)	Sapphire	3	3.3e-6
TiN (poly)	Si	3	3.0e-6

Avoiding Them

- Use Silicon-Nitride for junctions (not $Si0_2$)[5]
- Reduce junction size[5]
- Use better resonator materials[6]
- Use MBE deposition[7]



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[1] Phillips, W. A. "Two-level States in Glasses." Reports on Progress in Physics 50, no. 12 (1987): 1657.

[2] Simmonds, R. W., K. M. Lang, D. A. Hite, S. Nam, D. P. Pappas, and John M. Martinis. "Decoherence in Josephson Phase Qubits from Junction Resonators."

[3] Martinis, John M., K. B. Cooper, R. McDermott, Matthias Steffen, Markus Ansmann, K. D. Osborn, K. Cicak, et al."Decoherence in Josephson Qubits from Dielectric Loss." Phys. Rev. Lett. 95, no. 21 (November 2005): 210503. doi:10.1103/PhysRevLett.95.210503.

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References II

[4] Neeley, Matthew, M. Ansmann, Radoslaw C. Bialczak, M. Hofheinz, N. Katz, Erik Lucero, A. O Connell, H. Wang, A. N. Cleland, and John M. Martinis. "Process Tomography of Quantum Memory in a Josephson-Phase Qubit Coupled to a Two-Level State." Nat Phys 4, no. 7 (July 2008): 523 - 526. doi:10.1038/nphys972.

[5] Martinis, John M., K. B. Cooper, R. McDermott, Matthias Steffen, Markus Ansmann, K. D. Osborn, K. Cicak, et al. "Decoherence in Josephson Qubits from Dielectric Loss." Phys. Rev. Lett. 95, no. 21 (November 2005): 210503. doi:10.1103/PhysRevLett.95.210503.

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[6] Sage, Jeremy M., Vladimir Bolkhovsky, William D. Oliver, Benjamin Turek, and Paul B. Welander. "Study of Loss in Superconducting Coplanar Waveguide Resonators." Journal of Applied Physics 109, no. 6 (2011): 063915. doi:10.1063/1.3552890.

[7] Megrant, A., C. Neill, R. Barends, B. Chiaro, Yu Chen, L. Feigl, J. Kelly, et al. "Planar Superconducting Resonators with Internal Quality Factors above One Million." Applied Physics Letters 100, no. 11 (2012): 113510. doi:10.1063/1.3693409.

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