Quasiparticle Poisoning in a Single Cooper-Pair Box

J.F. Schneiderman*, P. Delsing[†,‡], G. Johansson[†], M.D. Shaw*, H.M. Bozler*, and P.M. Echternach[‡]

[‡]*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA*
**University of Southern California, Dept of Physics and Astronomy, Los Angeles, CA 90089-0484, USA*
[†]*Chalmers University of Technology, Microtechnology and Nanoscience, MC2, 412 96 Göteborg, Sweden*

Abstract. We investigate the pheonomenon of quasiparticle poisoning in a single Cooper-pair box (SCB). We have designed, fabricated, and tested an SCB that demonstrates a transition between poisoned and unpoisoned Coulomb staircases, depending on the speed with which the gate charge is swept. Poisoning is shown to be suppressed at moderately high sweep rates. Coulomb staircases were measured for a variety of sweep rates, and quasiparticle tunneling rates were extracted from this data.

Keywords: SCB, quasiparticle, Coulomb blockade.
PACS: 03.67.Lz, 73.23.Hk, 74.50.+r, 85.25.Cp, 85.35.Gv.

The single Cooper-pair box (SCB)[1] consists of a small island of superconducting aluminum coupled to a reservoir of charge through a small-area Josephson junction. The SCB demonstrates the behavior of a two-level quantum system, which is useful both for investigations into fundamental physics and as a building block for quantum computation. Coherent oscillations between charge states corresponding to the number of Cooper-pairs on an SCB island have been demonstrated by several research groups[2,3,4,5].

A major problem associated with using the SCB as a qubit is the presence of odd quasiparticle (QP) states, dubbed "QP poisoning". Attempts to solve this problem have stimulated a number of recent studies[6,7]. QP poisoning occurs when the energy of the odd charge state of the island falls below the energy of the even charge ground state for a particular range of gate voltages. Within this range, quasiparticle tunneling results in transitions between the even and odd charge states, and a "short step" appears in the Coulomb staircase around the degeneracy point, spoiling the 2e-periodidicity. Poisoning prevents manipulation and control of the SCB charge state at the degeneracy point, since the extra quasiparticle state prevents operation as a two-level system. Understanding and eliminating QP poisoning is an essential step towards realizing quantum computation with charge qubits.

In this work, we measure Coulomb staircases from an SCB with an RF-SET[8] readout, and extract quasiparticle tunneling rates from this data. The staircase was measured by sweeping the SCB gate voltage and using the RF-SET to read out the charge transferred to the SCB. By changing the rate at which the gate voltage was swept (across a 7-electron span) from 10.44 Hz to 1044 Hz, and measuring staircases for each sweep rate, we were able to investigate the dynamical behavior of the system.

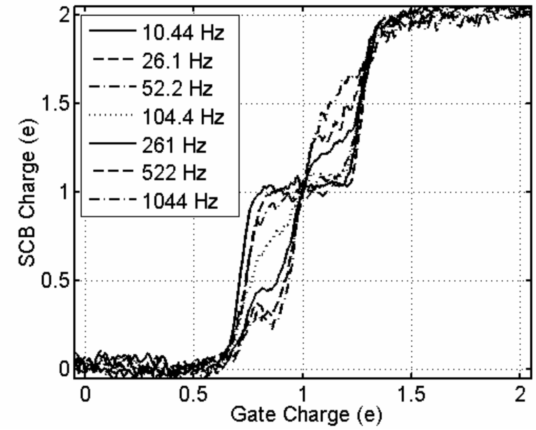

FIGURE 1. Coulomb staircases measured with various gate voltage sweep rates.

For the slower sweep rates, the system settles into the equilibrium state at each bias point, giving rise to a completely poisoned staircase. For faster sweep rates, the system does not have time to reach equilibrium and the staircase is only partially poisoned. This suggests that the problem of QP poisoning in charge qubits can be partially ameliorated by sweeping sufficiently quickly. A representative set of staircase data is shown in Figure 1.

To extract quasiparticle tunneling rates from the experimental data, we obtain the probability of the system being in the even state (Equation (1)) from the standard solution to the Hamiltonian of the SCB.

$$P_{Even} = \frac{1-<n>}{\left(\frac{4E_C(1-n_G)}{\sqrt{E_J^2+16E_C^2(1-n_G)^2}}\right)} \qquad (1)$$

Here, $<n>$ is the measured SCB charge at each gate charge value n_G. Figure 2 shows the even-state probability as a function of gate voltage for a number of sweep rates. To obtain the rates, we consider the two-state master equation

$$\frac{dP_{Ev}}{dt} = P_{Odd}(t)\Gamma_{OE}(n_G) - P_{Even}(t)\Gamma_{EO}(n_G) \quad (2)$$

where the time-dependence of the rates arises solely from sweeping the gate charge. The derivative is computed numerically, and the rates Γ_{OE} and Γ_{EO} are extracted by applying a linear regression. Figure 3 shows the rates obtained from a typical data set. Note that Γ_{EO} increases near n_G=1, where the ground state is odd. Meanwhile, Γ_{OE} peaks where the two energy levels cross, which is likely related to the peak in the density-of-states of the reservoir.

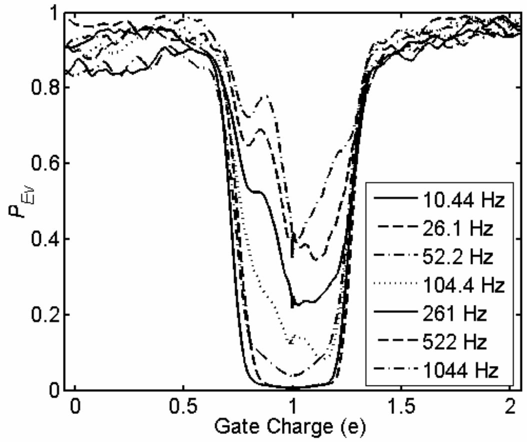

FIGURE 2. Probability of the system being in even state as a function of time for each sweep rate.

In conclusion, we have observed that quasiparticle poisoning can be suppressed in an SCB by quickly sweeping the gate charge. By measuring the staircase at different sweep rates, we extracted the rates of quasiparticle tunneling as a function of gate charge.

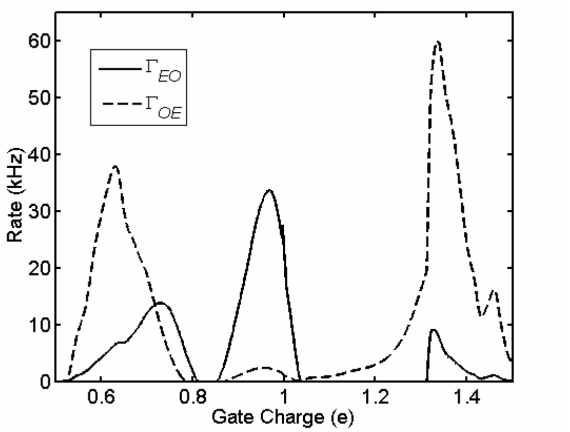

FIGURE 3. Quasiparticle tunneling rates extracted form $P_{Even}(t)$ data.

ACKNOWLEDGMENTS

We thank Richard Muller for the electron beam lithography. This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. We acknowledge support from the National Security Agency and the Advanced Research and Development Activity.

REFERENCES

1. D.V. Averin and Yu. V. Nazarov, *Phys. Rev. Lett.* **69**, 1993 (1992).
2. Y. Nakamura, Y.A. Pashkin, and J.S. Tsai, *Nature* **398**, 786 (1999).
3. T. Duty, D. Gunnarsson, K. Bladh, R. J. Schoelkopf, and P. Delsing, *Phys. Rev. B* **69**, 140503 (2004).
4. D. Vion, A. Aassime, A. Cottet, P. Joyez, H. Pothier, C. Urbina, D. Esteve, and M.H. Devoret, *Science* **296**, 886 (2002).
5. A. Guillaume, J.F. Schneiderman, P. Delsing, H.M. Bozler, and P.M Echternach, *Phys. Rev. B* **69**, 132504 (2004).
6. J. Aumentado, M.W. Keller, and J.M. Martinis, *Phys. Rev. Lett.* **92**, 066802 (2004).
7. J. Mannik, and J.E. Lukens, *Phs. Rev. Lett.* **92**, 057004 (2004).
8. R.J. Schoelkopf, P. Wahlgren, A.A. Kozhevnikov, P. Delsing, and D.E. Prober, *Science* **280**, 1238 (1998).