Superconductor-Insulator transition in a single Josephson junction

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For ultrasmall Josephson junctions, when quantum effects become important, *dissipative phase transition* (DPT) has been predicted [1]. The physical origin of this transition is the suppression of macroscopic quantum tunneling of the phase by the interaction with dissipative quantum-mechanical environment. Macroscopic quantum tunneling destroys superconductivity of a junction, whereas suppression of tunneling restores superconductivity. Hence, this transition is often called a superconductor-insulator transition (SIT). SIT was predicted for various systems, but its detection in a *single* Josephson junction is of principal importance since it is the simplest system where this transition is expected, without any risk of being masked by other physical processes, as is possible in more complicated systems like regular or random Josephson junction arrays.
In this Letter we present results of our measurements on $R = dV/dI$ vs. I curves, for a variety of single small isolated Josephson junctions, shunted and unshunted, with different values of capacitance C and normal state tunneling resistance R_T. We have detected a crossover between two types of RI-curves with an essentially different behavior at small currents. On the basis of this crossover, we are able to map out the *whole* phase diagram for a Josephson junction [2].
The position of the observed phase boundary did not agree with that expected from the original theory. However, the theory revised to take into account a finite accuracy of our voltage measurements (*viz.*, the minimum voltage which we are able to detect), explains well the observed phase diagram.
Our important conclusion is that the concept of *dissipative phase transition* (DPT) and *superconductor-insulator transition* (SIT) are not completely identical as assumed before. Both are accompanied by the sign change of the thermoresistance, which is traditionally considered as a signature of SIT. Thus any DPT is SIT, but not *vice versa*. We argue that the real signature of DPT is a modification of VI curves as observed in our experiment.
Our work is a strong demonstration of quantum effects in a single Josephson junction, especially, of the Josephson phase delocalization and the band picture of the phase motion.

[1] A.J. Leggett *et al*, Rev. Mod. Phys. **59**, 1 (1987); G. Schön and A.D. Zaikin, Phys. Rep. **198**, 237 (1990).
[2] J.S. Penttilä, Ü. Parts, P.J. Hakonen, M.A. Paalanen, and E.B. Sonin, Phys. Rev. Lett. **82**, 1004 (1999).