Superconductor within insulator: case of titanium nitride

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The superconductor-insulator phase transition in homogeneously disordered thin films is a quantum phase transition whose critical point can be approached at very low magnetic field 2. The lines from supports breakdown occurs across the sample size 2, while dependent charge transport is defined by a collective Coulomb barrier formed across the sample, while its magnetic field evaluation of the activation temperature Tc.

Current-voltage characteristics for sample S at different temperatures and some representative magnetic fields are plotted on upper figure. IV-curves display switching from the highly resistive (HR) to low resistant (LR) state at the threshold voltage Vth. At higher temperatures >70mK IVs are linear (Ohmic) at low voltages but develop characteristic steep, but continuous increase with increasing voltage. At high voltages all IVs for different temperatures merge. Below T<50 mK the switching of voltages increase on average and begin to scatter randomly over a finite temperature dependent voltage interval (see lower figures), that supports dielectric breakdown model. The most striking is that a power-law behavior 1/α = V with a dramatically growing exponent α(T) in the pre-switching regime. At T > 32mK the HR parts of IV's are concealed under the noise floor and a finite voltage springs up at VT in the LR part of the IV curves. In super-conductors vortex BKT transition is indicated by non linearity of voltage-current characteristics IV(S) = f(V). Having in mind duality between superconducting and superinsulating state in SIT, for super-insulator one expects IV(S) = f(V) to be an fingerprint of charge BKT transition.

References

Experimental

The data presented here are taken on two 5 nm thick TiN samples: the one denoted as “sample S” was superconducting at zero magnetic field and allowed for a fine tuning into an insulating state by applying a small magnetic field, and the second one insulating even for B = 0 T (“sample R”). Bias voltages were provided by a dc voltage source Yokogawa 7651 via a voltage divider. A highest sweeping rate used was 1mV/min. Currents were measured with DL1211 and Femto DDPCA-5 current preamplifiers. In the superconducting regime current biased four-probe measurements were carried out, while in the insulating regime two-probe voltage biased measurements were sufficient as the contact resistance was negligible below 1 Ω. The used setup enabled us to measure resistances exceeding 100GΩ.

Non-linear conduction

Switching: electron overheating vs superconducting islands

To explain switching effects in IV(S), model that relies on the assumption of negligible electron-phonon and strong electron-electron coupling was proposed recently [1,2]. It predicts that as the voltage bias increases electrons are mutually thermalized due to electron-electron coupling but overheated compared to the thermal bath because of decoupling from the phonon subsystem. “S” shaped IV(S) curves are predicted that in the instability region, where two branches overlap, force the system to jump from high (low) to low (high) resistive state. In this case, the IV(S) characteristics do not contain additional information beyond the strong coupling of the resistance, and the electron-phonon energy relaxation rate (see upper right figure)

References

Superconductor to insulator phase transition

The superconductor-insulator phase transition inhomogeneously disordered thin films is a quantum phase transition whose critical point can be approached at very low magnetic field 2. In the last years the topic has received renewed interest with the discovery of an Arrhenius-type of thermally activated conductance and dramatic non-linearities in the IV-characteristics on the insulating side of the transition 3.

Differential conductance dμ/dV plotted on inset is extracted from MR-curves, and exhibits activated behavior. The right panel gives the magnetic field evaluation of the activation temperature Tc.

Superconducting islands model

The nature of the insulating state – in particular the origin of its strong dependence on magnetic field – is currently under intense debate. Different models are proposed for its description, all based on a matrix of superconducting islands (SI) as building blocks. Cooper pair transport between SIs is determined by single-island charging energy E0, while taking into account Josephson coupling energy EJ too, leads to SQUID-like Josephson junction array (JJA) network. The model of Fistul and co-workers [4] describes successfully the most of existing experimental facts. It relies on a regular, finite-size JJA matrix that for very low temperatures (kBT < E0) enters to highly resistive superinsulating state of the charge Beresnievski-Kosterlitz-Thouless (BKT) type [5]. At higher temperatures (E0 < kBT < E0) sample-size dependent charge transport is defined by a collective Coulomb barrier formed across the sample, while its magnetic field dependence is set by a Josephson junction plaquette size.

The collective Coulomb barrier depends on sample-dimensions: in 2-D case depends linearly, while in 1-D logarithmically with sample size. The model described in Ref. [4] supposes that at Vc, a dielectric breakdown occurs across the sample, giving I-D JJA. The left figure supports that since Tc, indeed logarithmically depends on sample size L. The different magnetic field dependence of Vc and Vc comes from difference on E(φ) for SQUID chains and arrays, respectively. Lines on right panel are obtained from fits to correspong E(φ). The figure is taken from Ref. [4].

References