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Experimental Tuning of Lifetime of Cooper pairs in Aluminum

Abstract: Here we propose an experiment, which shows that the lifetime of Cooper pairs and associated supercurrents in a conventional superconductor (aluminum) is tunable in a range from picoseconds up to some seconds. The long-lived Cooper pairs indicate that in aluminum can flow a persistent supercurrent. The short-lived pairs cause a dissipative (non-superconducting) state.

An experiment may show that a main difference between superconducting (SC) and non-superconducting aluminum is the lifetime of Cooper pairs. In other words, permanent pairs provide permanent (non-dissipative) supercurrents, while the pair breaking leads to supercurrent dissipation.

1. **Experiment description**.

Briefly, the experiment can be described as follows. We produce layered flat rings (washers with a hole in the middle), layer planes coincide with the plane of the flat rings. Every flat ring consists of 4 layers in sequence:
Layer 1. Bulk silicon, more than 30 monolayers (MLs)
Layer 2. Aluminum thin film (2D-Al), 4 MLs
Layer 3. Silicon or another insulator/semiconductor with variable thickness, number of MLs is 0, 1, 2 ... 15
Layer 4. Bulk aluminum (3D-Al), more than 40 MLs

We use a result that T_c of 2D-Al is larger than T_c of bulk Al [1]. We induce in every of 16 flat rings an identical supercurrent at temperature just above T_c of bulk Al (above 1.18 K) and below T_c of 2D-Al. We measure the supercurrent lifetime in every ring by observing the induced magnetic field.

2. **Expected results**.

The lifetime of supercurrents and corresponding electron pairs increases with increasing thickness of insulating layer (layer 3) between 2D-Al and 3D-Al. The range of the supercurrent lifetime is from picoseconds up to a few seconds (and, probably, longer). One can smoothly tune the supercurrent lifetime by varying the thickness and material of insulator (layer 3).

3. **Explanation of the expected results**.

As shown experimentally in [1] the SC gap on the interface Si/Al in 2D-Al is larger than in 3D-Al. Hence at T above T_c of 3D-Al and below T_c of 2D-Al, electron pairs in 3D-Al break and recombine, while in 2D-Al all pairs remain stable. If 3D-Al and 2D-Al areas are electrically connected, then pairs from 2D area can drift into 3D area and, thus, take part in the breaking/recombining process. So every pair in the system is **non-permanent**; broken pairs lose their ordered momenta, so the supercurrent lifetime is very short. If 3D-Al and 2D-Al areas are electrically disconnected by a thick insulator, then pairs from 2D-Al area cannot drift into 3D-Al area and, thus, do not break/recombine. Then the pairs in 2D-Al are **permanent**. So the disconnected 2D-Al area remains superconducting and the supercurrent may be long-lived. The pair drift density is tuned by the thickness of the separating layer 3, hence the average lifetime of the SC state in 2D-Al is also tuned.

The role of permanent electronic states for superconductivity is described in [2].

The experiment can show that the permanent (non-breaking) electron pairs are a necessary condition for permanent (non-dissipative) supercurrents and, thus, generally for SC. The experiment principle is applicable for other SC metals. We hope that the community will be interested to perform the experiment proposed.

References.

[1] Werner M. J. van Weerdenburg et al, *Extreme enhancement of superconductivity in epitaxial aluminum near the monolayer limit*, *SCIENCE ADVANCES*, 1 Mar 2023, Vol 9, Issue 9, https://doi.org/10.1126/sciadv.adf5500 (2023)

[2] Stanislav Dolgopolov, *Experimental Verification of the BCS Theory of Superconductivity by Using Persistent Supercurrents*, https://vixra.org/abs/2209.0127 (2022)