

Zero resistance when metals mixed with insulators

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Abstract

A false zero resistance behavior was observed during our study on the search of superconductivity in Ge-doped GaNb_4Se_8 . This zero resistance was proved to be caused by open-circuit in multi-phase samples comprised of metals and insulators by measuring with four-probe method. The evidence strongly suggests that the reported superconductivity in hydrides should be carefully re-checked.

Full Text

Preamble

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Abstract

A false “zero resistance” behavior was observed during our search for superconductivity in Ge-doped GaNb_4Se_8 . This “zero resistance” was proved to be caused by open-circuit conditions in multi-phase samples comprised of metals and insulators when measured using the four-probe method. The evidence strongly suggests that reported superconductivity in hydrides should be carefully re-checked.

Superconductors exhibit two well-known effects: zero resistance and perfect diamagnetism. Both effects are independent and unique, and are simple and beautiful. In principle, either of the two effects can prove the existence of

superconductivity, because no other state of matter exhibits these properties so far. Researchers routinely present both properties as complementary evidence to confirm the discovery of a new superconductor. However, in some experiments involving multi-phase samples, highly air-sensitive powders, metastable samples, tiny nanotubes or nanowires, interfaces, or high-pressure samples under extreme conditions, the measurement and judgment of superconductivity becomes quite difficult, and researchers often make mistakes even with the help of the most advanced modern instruments.

Beyond measurements, certain conceptual confusions frequently arise in superconductivity research nowadays. These conceptual confusions include:

- 1. The zero-resistance criterion has been widely and incorrectly replaced by a resistive transition or drop behavior.**
- 2. The shift of the resistive transition under magnetic fields has been widely and incorrectly used as a criterion for judging superconductivity.**
- 3. The background subtraction method has been widely and incorrectly used for calculating the diamagnetic signal.**

These erroneous criteria have not only caused significant confusion among beginners entering this field, but have also misled experienced researchers and senior scientists, leading to widespread misconceptions for the judgment of a superconductor. In 2024, fifteen eminent scientists concluded that “hydride superconductivity is real” based on unreliable data and incorrect criteria [1]. This raises the question: why has the field of superconductivity become so chaotic in recent years?

Here we present a false “zero resistance” phenomenon observed in Ge-doped GaNb_4Se_8 samples to explain why hydride superconductivity is still in need of critical scrutiny, or to put it bluntly, why there is no solid evidence for the occurrence of superconductivity in these hydrides under high pressures.

Figure 1 [Figure 1: see original paper]. Temperature dependence of the electrical resistance for two Ge-doped GaNb_4Se_8 samples showing false “zero resistance” transitions, with “zero resistance” obtained in (a) and a positive residual resistance shown in (b).

During our study on the superconductivity of Ge-doped GaNb_4Se_8 —which mainly comprises the Mott insulating GaNb_4Se_8 and metallic NbSe_2 —we often observed another type of “zero resistance” besides our claimed superconducting zero resistance in Ref. [2]. The data are shown in Fig. 1, measured with the standard four-probe method using a 16 T PPMS. A sharp resistance transition at 72 K was observed in the sample shown in Fig. 1a, and the resistance actually dropped to zero at lower temperatures (the resistance values were about 10^{-5} ohm, corresponding to measured voltage of about 10^{-8} V with a current of 1

mA). As more samples were measured, we found that the residual resistance showed interesting behavior across different samples: it could be positive, zero, or negative, and usually appeared as a flat line versus temperature, though sometimes not. Fig. 1b shows another sample with positive residual resistance. This led us to consider open-circuit conditions in the voltage probes, where the residual resistance values depend on the electromagnetic environment of the electric circuit. However, when we removed the sample for inspection, every probe was found to be normal. This “zero resistance” effect was stable and reproducible even after several months on the same sample.

Figure 2 [Figure 2: see original paper]. (a) Measurement of the temperature dependence of the electrical resistance for one Ge-doped GaNb_4Se_8 sample with three channels. Inset shows another sample's resistive transition shifting under magnetic fields. (b) Changes of the applied current in the three channels showing the open-circuit of two voltage probes at low temperatures. Inset shows the wire connections on the sample for three channels.

We soon designed a simple measurement method to solve this problem. As shown in Fig. 2, we used three channels of the PPMS to measure one sample simultaneously. We quickly found that at low temperatures, the conductive path between I^+ and I^- probes remained unobstructed, but the voltage probes V^+ and V^- became isolated at certain temperatures and their currents dropped to zero. The explanation is simple: in the multi-phase Ge-doped GaNb_4Se_8 samples, the main component GaNb_4Se_8 becomes completely insulating at low temperatures and isolates the voltage probes V^+ and V^- , while sometimes the impurity NbSe_2 (which is metallic and has low resistivity) creates a conductive path between I^+ and I^- probes. This produces the false “zero resistance” recorded by the equipment. This false “zero resistance effect” occurs when metals are mixed with insulators and measured with the four-probe method.

We note that this false “zero resistance transition” clearly shifts with applied magnetic field or applied current, as shown in the inset of Fig. 2a for fields up to 16 T, though not in a monotonic manner—a detail that will not be discussed further here.

Now let us discuss hydride superconductivity. In Ref. [3], the authors presented four experimental evidences to claim superconductivity at 203 K in H_3S : (1) “a sharp drop of the resistivity to zero,” (2) “a decrease of the transition temperature with magnetic field,” (3) “magnetic susceptibility measurements,” and (4) “a pronounced isotope shift of T_c .” Let us review these evidences from last to first.

Some researchers may recall the debate over isotope effects in iron-based superconductors at an ISS conference some years ago, where two contradictory experimental results were reported yet both were theoretically explained. From an experimentalist's standpoint, these isotope effect experiments should not have been conducted except to waste funds before the superconducting T_c could be stably and identically reproduced again and again—a task that is extremely difficult in the laboratory for these high- T_c superconductors. The hydrides are

encountering the same situation. A reproduction experiment for H_3S by high-pressure expert SHIMIZU shows the onset of resistance transition occurring across a temperature range of 70–180 K in Ref. [4].

Regarding magnetic susceptibility measurements: back in 2006, when REN worked in AKIMITSU' s lab on the superconductivity of carbon nanotubes, after two years of study, REN and AKIMITSU reached the consensus that the background subtraction method had been widely misused to calculate resistance or susceptibility, leading to numerous mistakes in that community. Basically, one can obtain desired curves through sufficient measurements, data selection, and background subtraction. Particularly for susceptibility measurements of weak signals, many ferromagnetic contamination signals have been mistakenly subtracted to produce superconducting evidence. The hydrides are encountering the same background subtraction issues, rendering the susceptibility data unreliable.

As for “a decrease of the transition temperature with magnetic field,” this is indeed a behavior of superconducting transitions, but not a criterion for judging superconductivity. As stated above, a false “resistance transition” also shifts with applied magnetic field.

For the most important and supposedly solid evidence, “a sharp drop of the resistivity to zero,” it is clear that the hydrides are multi-phase and include insulators, as shown in Extended Data Figure 2 of Ref. [1], which closely resembles the multi-phase GaNb_4Se_8 samples. The sharp drop is also clearly reproduced in the GaNb_4Se_8 experiments through open-circuit conditions, though there remains the possibility that hydride superconductivity is different and genuine. For the reported resistance transitions in hydrides, there are two most significant points of doubt. First is the unusual width of the transition (as small as 0.5 K for a 203 K superconductor in Fig. 1d of arXiv Ref. [1]), which HIRSCH has consistently opposed with reasonable judgments [5]. Second is the residual resistance at low temperatures, which can be observed as positive values in Extended Data Figure 3e [Figure 3: see original paper] of Ref. [1] and Extended Data Fig. 3c of Ref. [6], and as negative values in Fig. 1 and Extended Data Fig. 6c [Figure 6: see original paper] of Ref. [6]. These residual resistance values are actually quite large in the aforementioned figures and cannot be neglected. These evidences strongly suggest that the measured resistance transitions in hydrides should be carefully re-checked.

In summary, we observed two types of “zero resistance transition” during our search for superconductivity in Ge-doped GaNb_4Se_8 . After careful examination, we conclude that one represents genuine superconducting phenomenon, while the other was proved to be caused by open-circuit conditions in multi-phase samples comprised of metals and insulators when measured with the four-probe method.

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