Superconductivity at 20 mK in Compacted Submicrometer Platinum Powders

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Abstract

The superconducting transition temperature and critical magnetic field observed in compacted Pt powder samples with *sub*micrometer grain size are as high as 20 mK and 18 mT and thus more than one order of magnitude larger than for those with larger (micrometer) grain size. The submicrometer samples exhibit strong lattice strain and significantly smaller Debye temperatures compared to bulk platinum. Moreover, the ferromagnetic spin fluctuations of the conduction electrons are partially quenched in these compacts.

Key words: superconductivity; granular superconductors; physical properties in normal and superconducting state; heat capacity

1. Introduction

The occurrence of superconductivity in compacted platinum powders [1] is an interesting phenomenon since bulk platinum, in contrast, has not been found to superconduct even at the lowest accessible temperatures of solid matter ($T \simeq 1.5\,\mu$K) [2]. It was experimentally observed for various transition metal alloys that the transition temperature into the superconducting state T_c decreases rapidly with increasing values of the electronic susceptibility χ and the Sommerfeld coefficient γ, which lead to the conclusion that the spin fluctuations compete with the formation of conventional Cooper pairs and may even completely prevent superconductivity in palladium and platinum [3]. It is important to note, however, that the recent discovery of the ferromagnetic superconductors UGe_2 [4] and $ZrZn_2$ [5] supports the idea that strong ferromagnetic spin fluctuations of itinerant electrons might also *mediate* (spin-triplett) superconductivity.

2. Results and Discussion

Superconductivity of compacted platinum powders was previously reported for two different commercially available high purity platinum powders with average grain sizes in the micrometer range ("μPt"). A common onset of intragranular superconductivity was observed at $T_c \simeq 1.9$ mK [6], with an intragranular critical field $B_c \simeq 70\,\mu$T .

We have extended our studies to platinum powders with average grain sizes in the *sub*micrometer range ($300 \gtrsim d \gtrsim 100$ nm, "nPt"). The (intragranular) superconducting transition temperature T_c and critical magnetic field B_c as determined from ac susceptibility and dc magnetization are as high as 20 mK and 18 mT

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for one "nPt1"-sample, while $T_c \simeq 12\,\mathrm{mK}$ and $B_c \simeq 17\,\mathrm{mT}$ were observed for a second sample. Samples with higher content of paramagnetic impurities (corresponding to ≥ 50 ppm Fe) were not superconducting.

The lattice structure as well as the phononic and electronic properties of the samples with submicrometer grain size differ significantly from the properties of bulk platinum. Fig. 1 shows exemplary results of X-ray diffraction, static magnetic susceptibility and specific heat measurements.

The broadened diffraction peaks of all powders with submicrometer grain size arise from the small size of the crystalline domains and from a relatively strong lattice strain η. The average lattice constant a agrees with the literature value of bulk platinum.

The reduced values of the Debye temperature Θ_D of the "nPt"-samples clearly imply a shift of the phonon spectrum towards lower frequencies, which might be a consequence of the observed strong lattice strain. The increased weight of long wavelength phonons is expected to increase the electron-phonon interaction and thus the transition temperature into the superconducting state. A lowering of the phonon frequencies and a T_c-enhancement is also expected in small particles due to the large surface to volume ratio, however, no T^2-contribution is observed in specific heat at $0.35 \lesssim T \lesssim 10\,\mathrm{K}$, which would be indicative for surface phonons.

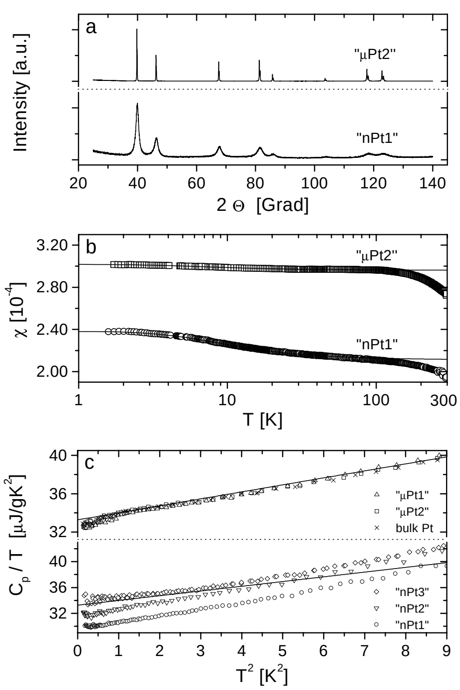

Fig. 1. (a) X-ray diffraction patterns (Cu-K$_\alpha$) for the platinum powders "μPt2" and "nPt1". (b) Temperature dependence of the static magnetic susceptibility χ of the platinum compacts "μPt2" (□) and "nPt1" (○) in a magnetic field of 3 Tesla. The solid lines are fits to the Brillouin function at $T \leq 30\,\mathrm{K}$. (c) Specific heat C_p divided by the temperature T as a function of T^2 for the samples "μPt1" (△), "μPt2" (□), "nPt1" (○), "nPt2" (▽), "nPt3" (◇) and a bulk platinum sample (×). The straight line in the upper and lower panels represents the literature data for bulk platinum [7].

On the other hand, the reduced values of the magnetic susceptibility χ_0 and the Sommerfeld coefficient γ of the "nPt" compacts indicate a partial quenching of the electronic spin fluctuations which might in turn favour the occurrence of superconductivity. The qualitative correlation between χ_0, γ and the lattice strain η suggests that the large η might be responsible for the reduction of χ_0 and γ. In analogy, the superconductivity of ion-irradiated palladium films [8] was also explained in terms of lattice disorder which caused the quenching of spin fluctuations due to a reduction of $N(E_F)$.

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