The influence of crystal structure defects on magnetic properties of superconductors

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It is well known the ideally pure tantalum, rhenium and indium are type-I superconductors. However, our results show that the nature of superconductors can be changed by introducing a high concentration of structural defects in metals matrixes. In particular, vacancies and dislocations cause a reduction of the mean free path of electrons. As a result, there is an increase of the Ginzburg-Landau parameter κ, which determines the type of superconducting material.

Experimental

The polycrystalline sample of Ta [1] was prepared by the arc-melting technique under a Ti-gettered purified argon atmosphere. After melting, the ingot was cold-rolled at room temperature to the final thickness of 0.2 mm and cut into rectangular pieces of 2 cm x 1 cm. This specimen will be referred to as the cold-rolled sample. In the next step, the cold-rolled sample was annealed in a furnace at 1270 K for 24 h under a vacuum of better than 10^{-4} Pa and after that, slowly cooled down to room temperature for 6 h. This sample will be referred to as the annealed sample. Re and In [2] foils were purchased from Alfa Aesar and cut to the same size. That samples will be referred to as annealed samples. In the next step, the foils were rolled at room temperature to the thickness of 0.2 mm and again cut into 2 cm x 1 cm pieces. These specimens will be referred to as cold-rolled samples. The measurements were performed using three experimental techniques and devices: Positron Annihilation Lifetime Spectroscopy (PALS), Superconducting Quantum Interference Device (SQUID) magnetometer and Physical Properties Measurement System (PPMS) platform.

PPMS results

The electrical resistivity measurements were performed using the four-point technique. Silver-wire contacts were mounted on the samples previously cut down in form of flat elongated cuboids. Resistivity as a function of temperature measured without applied magnetic field, near to critical temperature T_c is shown as an inset on Fig.1.

PALS results

Positron lifetimes were measured at room temperature. PALS spectra had about $3 \cdot 10^6$ counts each. The ^{22}NaCl positron source in a Hostaphan envelope was sandwiched between two identical samples under study. The mean implantation depth of positrons from a source for metals is much smaller than 0.2 mm, therefore all positrons entering the studied material will be trapped and annihilate inside it. The measured spectra were analysed into discrete components using the LT-9.0 [3] program, described by three exponential components, characterized by mean lifetimes τ, τ_{s1} and τ_{s2}, where the major component with an intensity close to 90% and shortest lifetime τ was considered as the mean lifetime of positrons in studied samples. Two components with longer mean lifetimes correspond to the positron annihilation in the Hostaphan foil. The values of major components for each spectrum are presented in Tab. 1.

	Cold-rolled	Annealed
Ta	τ = 164(5) ps	τ = 132(8) ps
Re	τ = 182(3) ps	τ = 109(4) ps
In	τ = 193(4) ps	τ = 187(4) ps

Tab. 1 Measured mean positron lifetimes of studied samples.

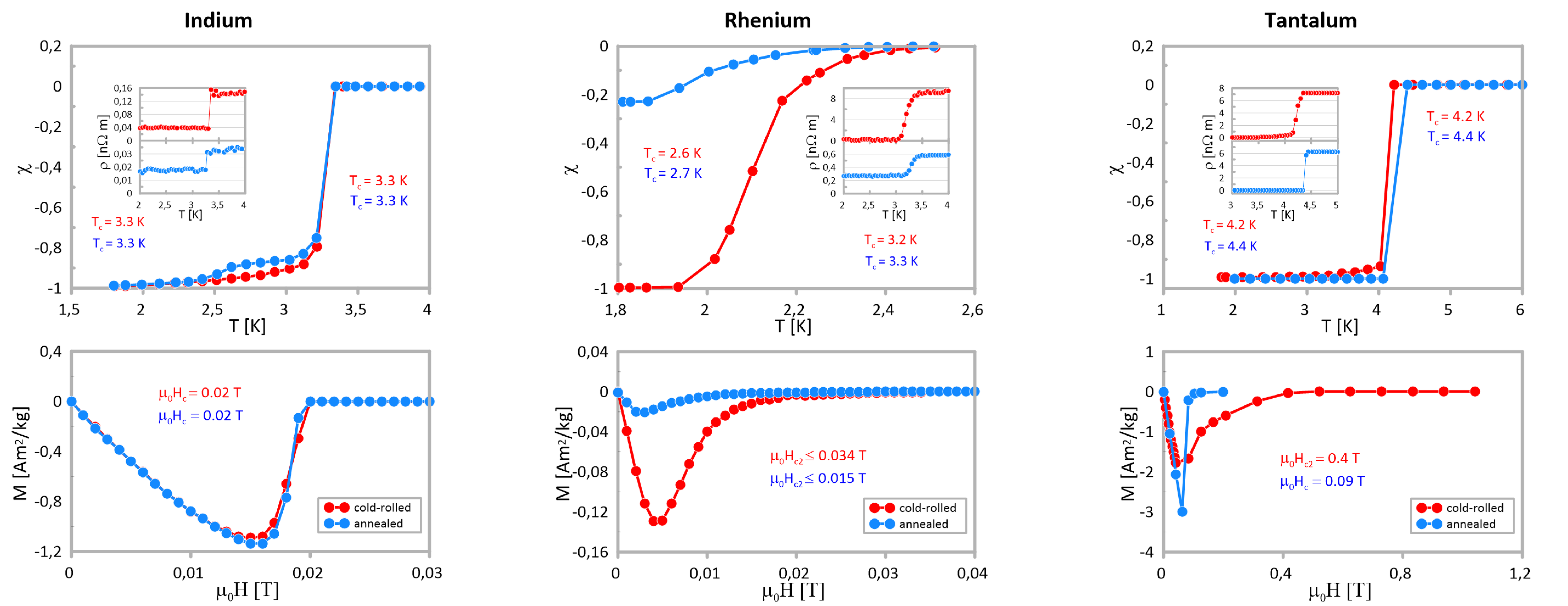

Fig. 1. The magnetic and electric dependencies for each sample under study.

SQUID results

The presented magnetic data were corrected for the demagnetization effect as well as for the background signal from the sample holder. All magnetic measurements were performed after zero-field cooling the samples to 1.8 K.

The upper row of Fig. 1 shows the susceptibility as a function of temperature with an applied field of about 0.002 T for each sample. Insets contain temperature dependencies of resistivity at 0 T. The lower row shows the magnetizations versus applied fields at 1.8 K.

Conclusions

The PALS measurements indicate that the cold-rolled samples of Re and Ta contain a high concentration of structural defects, while the annealed ones are almost free of any structural defects. In the case of In, both studied samples are practically identical. The reason is that the vacancy migration in this material takes place at around 100 K. The magnetic data reveals:

- the cold-rolled Ta sample exhibits type-II superconductivity while after annealing, the sample recovers type-I superconductivity,
- the annealed Re sample contains a volume fraction of impurities nevertheless, according to the cold-rolled sample, the superconducting properties can be enhanced by introducing structural defects,
- both samples of In are type-I superconductors with the same parameters of H_c and T_c. Plastic deformation practically does not affect the superconducting properties of this material.

The correlation between the PALS and magnetic data leads to the conclusion that structural defects are mainly responsible for changing the properties of superconductors.

References

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