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Superconductivity of Ti–Zr–Ni alloys containing quasicrystals

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Abstract

Superconductivity of rapidly quenched ribbons $Ti_{53}Zr_{27}Ni_{20}$ at 1.94 K and the beginning of the transition to the superconductivity in ribbons $Ti_{45}Zr_{38}Ni_{17}$ below 1.5 K were found. X-rays diffractometry measurements showed that the icosahedral quasicrystal phase is dominant in all samples.

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Quasicrystals are solids which have ordered structure but without the translation invariance [1]. The investigation of electron transport in such systems, in particular superconductivity, is therefore a question of great interest. It is known [1–3] that icosahedral quasicrystal phases *i*-Al–Cu–Li and *i*-Al–Mg–Zn are superconductors at 1.5 K and 0.4 K, respectively. In the present Letter we report about the superconductivity in rapidly quenched ribbons of Ti–Zr–Ni alloys containing mainly icosahedral quasicrystal phase.

Ingots for the preparation of quasicrystal ribbons were made from ultra-pure components in a protective high-purity argon atmosphere. Ribbons were obtained by quenching of the melt on the copper rolling disc. Samples had the length ~ 0.05 m, the widths of about 10^{-3} m and the average thickness about 4×10^{-5} m. We investigated samples of two compositions: $Ti_{53}Zr_{27}Ni_{20}$ and $Ti_{45}Zr_{38}Ni_{17}$. The analysis of the chemical composition was made by X-rays fluorescent analyzer and showed that mean variations of the chemical composition of samples were about 0.5%. The structure and phase composition of samples were analyzed by means of X-rays diffractometry (XRD) in the filtered Cu–K_α radiation. The identification of phases was based on the JCPDS [4] and on the references [1,5–7]. Measurements of the electrical resistivity were made by the four-probe method. All contacts were glued by the electrically conductive silver epoxy EPO-TEK H20E. Electrical resistivity measurements were made in the temperature interval 1.4–4.2 K.

The typical XRD pattern of the sample with the composition $Ti_{53}Zr_{27}Ni_{20}$ is shown in Fig. 1. Index-

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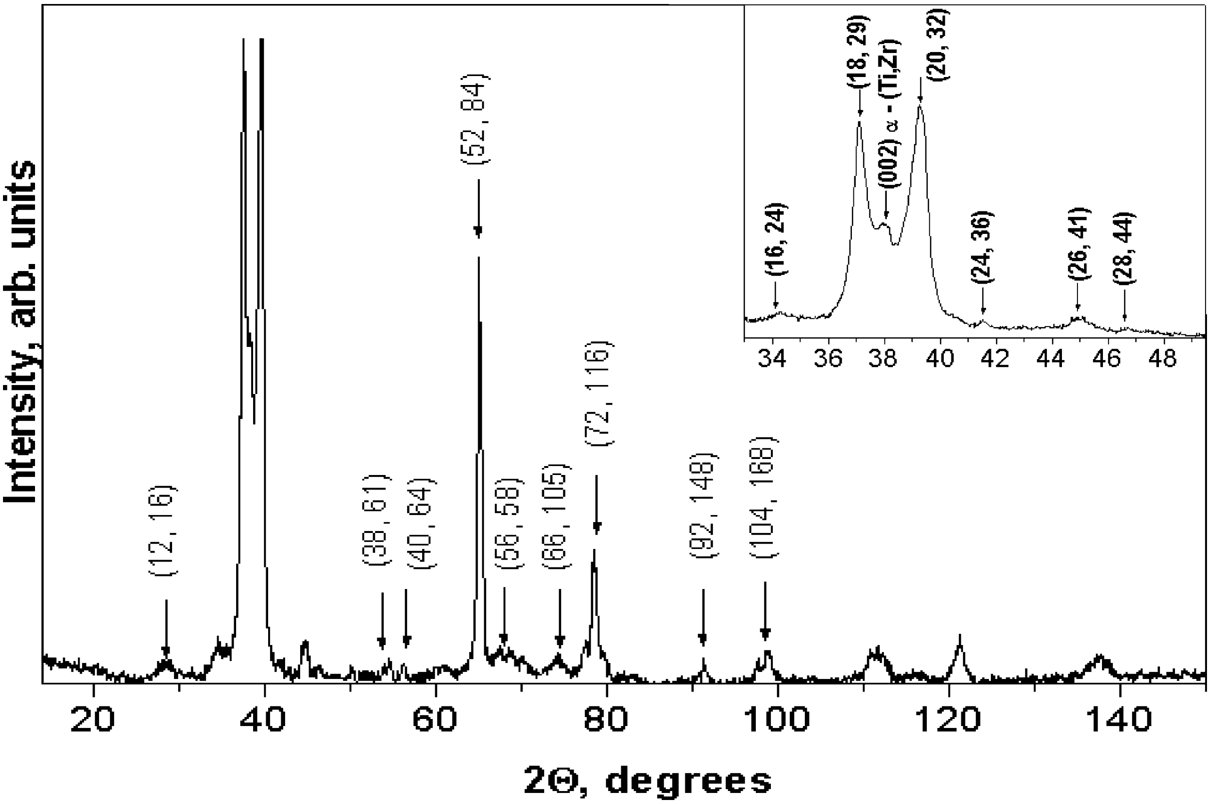

Fig. 1. XRD pattern of the $Ti_{53}Zr_{27}Ni_{20}$ icosahedral quasicrystal. In the inset the interval $33° \leqslant 2\theta \leqslant 49°$ is shown.

ing of lines was made on the scheme which was proposed in Ref. [10]. All the maxima in Fig. 1, excluding one at $2\theta \approx 37.4°$, belong to icosahedral quasicrystal i-phase. The parameter of quasicrystal of i-phase obtained by means of extrapolation of maxima at $2\theta > 60°$, is $a_q = 0.5164$ nm. This value coincides with the one for the i-phase which does not contain impurities [1,4,5,8]. The single reflection at $2\theta \approx 37.4°$ may correspond to the solid solution α-(Ti, Zr) which contains nearly of 30% (atomic) of zirconium.

XRD patterns of ribbons $Ti_{45}Zr_{38}Ni_{17}$ contain mainly strong and narrow maxima of i-phase reflections with the parameter $a_q = 0.5191$ nm and with the coherent length about 25 nm. The part of reflections with low intensity belong to the Laves phase C^{14} with such periods of the crystal cell: $a = 0.5262$ nm and $c = 0.8511$ nm. There is no amorphous phase in any of the samples of both of $Ti_{53}Zr_{27}Ni_{20}$ and $Ti_{45}Zr_{38}Ni_{17}$ compositions. The phase composition of our rapidly quenched samples is very close to the phase composition of the equilibrium samples obtained by the annealing of massive ingots (see Ref. [9]).

All investigated samples for both compositions ($Ti_{53}Zr_{27}Ni_{20}$ and $Ti_{45}Zr_{38}Ni_{17}$) have high electrical resistivity $\sim 2 \times 10^{-6}$ Ohm·m (Fig. 2) and rather small positive temperature coefficients of resistivity $\alpha \sim 10^{-4}$ K^{-1}.

The sample with the composition $Ti_{53}Zr_{27}Ni_{20}$ revealed a superconducting transition at 1.94 K (Fig. 2a). The width of the transition is about 0.07 K. The decrease of the resistivity with the decrease of the temperature from 3 to 2 K can be explained by a transition of the solid solution Ti–Zr to the superconducting state [11]. However, the influence of superconducting fluctuations [12] cannot be excluded entirely.

There are two steps on the temperature dependence of resistivity of the as-quenched sample $Ti_{45}Zr_{38}Ni_{17}$ (Fig. 2b, curve 1). We believe that these steps are

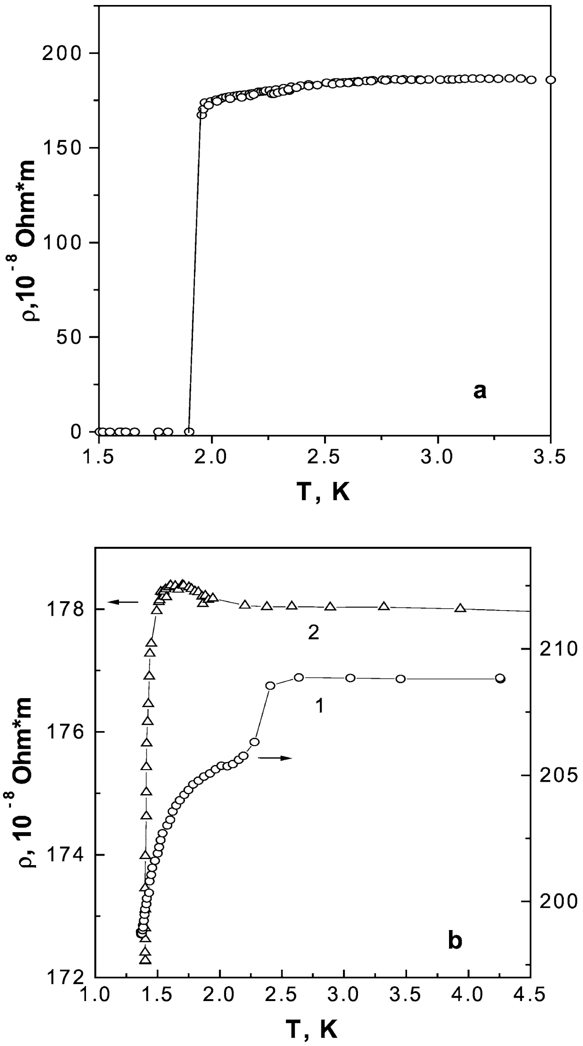

Fig. 2. Superconducting transitions in Ti–Zr–Ni icosahedral quasicrystals. (a) The $Ti_{53}Zr_{27}Ni_{20}$ composition; (b) The $Ti_{45}Zr_{38}Ni_{17}$ composition: as-quenched (curve 1) and annealed (curve 2).

connected with the existence of two superconducting phases in the as-quenched sample: C^{14}-like Laves phase which transits to the superconducting state in the interval 2.2–2.4 K and the icosahedral quasicrystal phase which transits to the superconducting state at $T < 1.4$ K (Fig. 2b, curve 1). We annealed the other sample of this composition in a vacuum of 10^{-7} Pa at a temperature of 823 K during 3 hours. According to our XRD data, annealing caused an increase of the proportion of the quasicrystal phase, its purity, and a decrease of the quantity of the Laves phase. Therefore the high-temperature step vanishes at annealing (Fig. 2b, curve 2), the width of the superconducting transition decreases and there appears the maximum of the resistivity just before the beginning of the superconducting transition (Fig. 2b, curve 2). This maximum is caused by the localization of electrons [1].

In conclusion, we have investigated the electrical resistance of rapidly quenched ribbons of $Ti_{53}Zr_{27}Ni_{20}$ and $Ti_{45}Zr_{38}Ni_{17}$ in the range 1.4–4.2 K. The icosahedral quasicrystal phase is dominant in all investigated samples. The parameters of quasicrystals are $a_q = 0.5164$ nm and $a_q = 0.5191$ nm, respectively. The comparison of our XRD data with the literature data shows that the phase compositions of both investigated systems are very close to those of equilibrium state.

It was found that the icosahedral quasicrystal phase $Ti_{53}Zr_{27}Ni_{20}$ has a superconducting transition at 1.94 K. The width of the transition is 0.07 K. The temperature of the superconducting transition of the icosahedral quasicrystal phase $Ti_{45}Zr_{38}Ni_{17}$ is obviously below 1.4 K. The difference of critical temperatures of quasicrystals can be caused by the differences in quasicrystal parameter of these two compositions.

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