MARTENSITIC TRANSFORMATIONS IN Ti$_{0.5}$Ni$_{0.5-x}$Fe$_x$

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The role of premartensitic softening of the lattice in the realization of martensitic transformations is currently being widely studied and discussed [1, 2]. This is explained by its obvious scientific significance, leading to a deeper understanding of the nature of phase transitions, and by the practical interest in martensitic transformations, which impart to alloys the unique properties of shape memory which have novel technical applications [3, 4]. In addition, alloys exhibit special properties not only with martensitic transformations, but also in premartensitic states [1, 2].

The tendency toward the loss of structural stability in premartensitic states is manifested in anomalous diffraction patterns, electrical resistance, shear moduli, and other physical and mechanical properties [1, 2]. The softening of the elastic constants of the lattice (dC$_{ij}$/dT > 0) is a reliable experimental indicator of the development of structural instability.

In this work, the methods of x-ray structural analysis, and measurements of the shear modulus and electrical resistance are used to investigate the premartensitic state and martensitic transformation in the system of alloys Ti$_{0.5}$Ni$_{0.5-x}$Fe$_x$. It is well known that premartensitic anomalies in the properties and structure are distinctly manifested in titanium nickelide [1, 2], while alloying with iron sharply decreases the temperature of martensitic transformations [5]. The decrease in the transition temperature could be a result of the increase in the rigidity and stability of the starting B2 structure. The purpose of this work is to check this proposition experimentally.

The alloys were obtained by repeated arc melting. The losses in weight accompanying melting did not exceed 0.1%. The compositions of the alloys investigated are shown in Table 1. We performed the final annealing at T=1073 K for one hour.

RESULTS AND DISCUSSION

1. Structural Transitions

In all the alloys investigated, the starting structure is a bcc structure. The presence of superstructural lines and the absence of secondary phases confirms the isomorphous nature of TiNi and TiFe. The concentration dependence of the starting lattice parameters deviates from the linear law in the region of low Fe (Fig. 1). It is in this region of compositions that TiNiFe undergoes a chain of martensitic transformations (Fig. 2):

\[ B2 \rightarrow R(\omega) \rightarrow B19' \rightarrow B19'' \]

where R(\omega) is the rhombohedrally deformed \( \omega \) phase, B19' and B19'' are rhombic martensite with additional monoclinic and triclinic distortions, respectively. We previously obtained analogous data on the structural transformations in TiNiFe [5]. For this reason, here, we shall only consider the new results concerning the martensite-martensite transformation B19' \( \rightarrow \) B19''.

Figure 3 shows fragments on the diffraction pictures for alloy No. 2 at 248 and 123 K. The (022) and (111) lines of the monoclinic phase B19' are broadened below 153 K (unresolved splitting). The half-width of other

| TABLE 1 |
|-----|-----|-----|-----|-----|-----|-----|-----|
| Ti  | 50  | 50  | 50  | 50  | 50  | 50  | 50  |
| Ni  | 50  | 49  | 48  | 47  | 46  | 45  | 43  |
| Fe  | --  | 1   | 2   | 3   | 4   | 5   | 7   |

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Fig. 1. Dependence of the starting B2 lattice parameter on the composition \( T_{0.5}Ni_{0.5-x}Fe_x \). \( T=295 \, \text{K} \). The lattice parameter of the alloy No. 2 was measured at \( T=318 \, \text{K} \).

Fig. 2. Diagram of structural transitions in \( Ti_{0.5}Ni_{0.5-x}Fe_x \).

Fig. 3. Fragments of diffraction patterns of alloy No. 2 at different temperatures.

Fig. 4. Temperature dependence of the shear modulus \( (1/G \times dG/dT) \) (1, 2, 3) and of the electrical resistance \( (1', 2', 3') \) for alloys Nos. 9, 8, and 2, respectively.

lines remains unchanged. This indicates the triclinic distortion of the lattice, i.e., B19'→B19''. The parameters of the triclinic structure can be found assuming that \( a, b, c, \) and \( \beta \) lattices of B19' do not change with the transition B19'→B19'' [6]. However, during the distortion of the B19' structure, the linear parameters of the lattice can undergo strong changes [7]. For this reason, the parameters \( \alpha, \gamma \) of the triclinic lattice are found from the deviations of the angles \( \alpha \) and \( \gamma \) of the fictitious monoclinic lattice, corresponding to the temperature of the calculation, from 90°. In this case, it is assumed that the (111) line of the fictitious monoclinic lattice coincides with the center of gravity of the (111) and (111) lines of the triclinic lattice. The parameters of the B19' structure of alloy No. 2 at \( T=248 \, \text{K} \) are: \( a=2.89 \, \text{Å}, b=4.12 \, \text{Å}, c=4.65 \, \text{Å}, \beta=97.6° \). The parameters of the fictitious monoclinic structure at \( T = 123 \, \text{K} \) are: \( a = 2.89 \, \text{Å}, b = 4.11 \, \text{Å}, c = 4.66 \, \text{Å}, \beta = 97.8° \). It follows from the condition that the (111) and (111) lines are not split that

\[
a \cos \alpha = c \cos \gamma,
\]

while from the condition that the lines (111) and (111) are split, we find

\[
1/a \cos \gamma + 1/c \cos \alpha = b/4 (\pm 1/d_{h1}^2 + 1/d_{h1}^2).
\]

Solving (1) and (2) simultaneously, we find:

\[
\cos \gamma_{1,2} = \pm ab/8 [1/d_{h1}^2 - 1/d_{h1}^2];
\]

\[
\cos \alpha_{1,2} = \pm cb/8 [1/d_{h1}^2 - 1/d_{h1}^2].
\]

Substituting the numerical values of the parameters of the fictitious monoclinic lattice, we obtain, correspondingly

\( \gamma_1 = 89.8°; \gamma_2 = 90.2°; \alpha_1 = 89.7°; \alpha_2 = 90.3° \)