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have been the object of intensive research, since these alloys exhibit a "memory" effect and are used in various areas of technology. However, an accurate picture of the structural transitions has not yet been obtained and the literature on the subject shows considerable disagreement,¹⁻⁴ including, in some cases, the publication of mutually exclusive results.^{1,3} In our opinion these disagreements are caused by the fact that in the interpretation of the experimental data the multiplicity of structural transformations in the alloys investigated was not taken into account. The present work is devoted to the determination of the character and the order of the structural transitions in Ti-Ni alloys as a function of composition and temperature.

Our preliminary work⁵ showed that the high-temperature phase, with the B2 structure (CsCl bcc structure), may, depending upon the composition, transform directly to a B19' structure (rhombohedral B19 structure with additional monoclinic distortion) or may instead transform to a rhombohedral phase R which, upon further cooling, transforms in turn to the B19' phase.

The work described here was carried out on binary Ti-Ni alloys and ternary Ti-Ni-Fe alloys with an equiatomic relationship Ti/(Ni + Fe). The alloys were smelted from titanium iodide and electrolytic nickel and subjected to multiple electric-arc melting. After forging, the castings were rolled into a strip of thickness 1.5 mm for x-ray diffraction studies or were drawn into a wire of diameter 1 mm for electrical-resistance measurements. The studies were carried out after annealing for one hour at 800°C without preliminary cycling in the range of the transformations.

It was observed that the monoclinic B19' phase formed directly from the B2 underwent triclinic distortion upon further cooling and transformed to a B19ⁿ structure, as

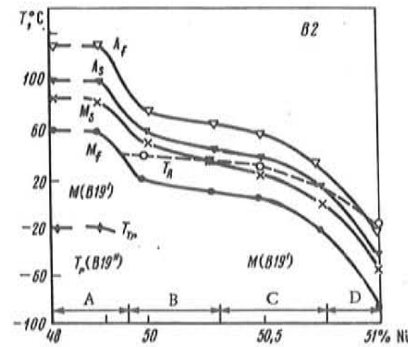


FIG. 1. Transformation diagram for the binary system Ti-Ni.

splitting of certain powder-pattern lines associated with the monoclinic structure as the temperature was lowered. The transformations $B19' \rightleftharpoons B19^n$, like $B2 \rightleftharpoons R$, cannot be distinguished experimentally from second-order transitions, while the transformations $B2 \rightleftharpoons B19'$ and $R \rightleftharpoons B19'$ are typical first-order martensitic transformations. In contrast, the B19' phase formed from R does not experience any transformations upon cooling to -196°C. Assuming that the B19' phases formed from B2 and from R are somewhat different in their parameter values, we may expect that both phases will coexist in some concentration interval. However, verification of these conjectures is difficult, since the difference between the phases is at the limit of sensitivity of the techniques employed.

The extent of the martensitic transformations $B2 \rightleftharpoons B19'$ and $R \rightleftharpoons B19'$ was estimated in two ways from the x-ray diffraction data: as the ratio of the peak intensity of the $(101)_{B19'}$ line to its maximum value below M_f , and as the ratio of the intensity of the $(110)_{B2}$ line to its maximum value in the absence of the martensitic phases. The two methods gave consistent results except when the temperature interval of the single-phase state R upon cooling was very wide. The temperature T_R of the transition $B2 \rightleftharpoons R$ was determined from the onset of the broadening of the upper part of the intensity profile of the $(110)_{B2}$ line; this broadening precedes the rhombohedral splitting of this line. The temperature T_{TR} of the transition $B19' \rightleftharpoons B19^n$ was determined from the onset of the regular broadening of the $(101)_{B19'}$ line.

Typical curves of the temperature dependence of the $(110)_{B2}$ peak intensity and the ratio c/a , corresponding to different regions of the transformation diagrams (Figs. 1 and 2), are shown in Fig. 3. The rhombohedral distortion c/a was determined for hexagonal close-packing. The cubic system corresponds to $c/a = 1.224$.

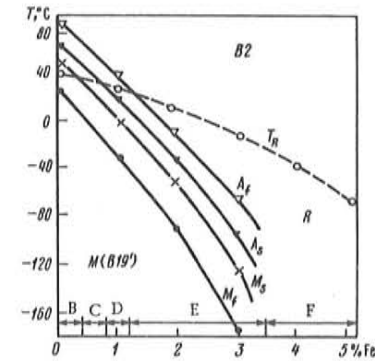


FIG. 2. Transformation diagram for the TiNi-TiFe system.

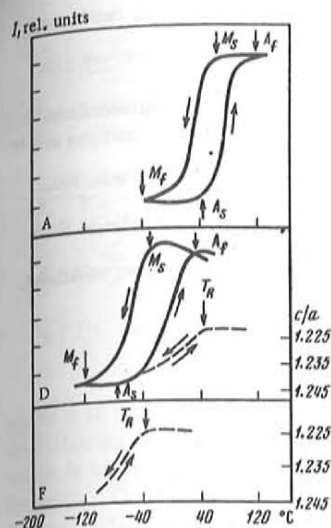


FIG. 3. Typical temperature dependences of the peak intensity of the $(110)_{B2}$ line (solid curves) and the degree of rhombohedral distortion c/a (dashed curves) in the range of the transformation in various regions of the transformation diagrams of Figs. 1 and 2.

The electrical resistance was measured by the ammeter-voltmeter method with careful stabilization of the current and direct recording on an xy automatic recording instrument. The martensitic points of the $B2 \rightleftharpoons B19'$ and $R \rightleftharpoons B19'$ transitions were determined in the usual way as parameters of the hysteresis loop, while the temperature T_R of the $B2 \rightleftharpoons R$ transition was determined as the temperature of the onset of the resistance increase accompanying the rhombohedral distortion of the cubic phase. Typical curves of the variation of the electrical resistivity upon cooling and heating in the range of the transformations are shown in Fig. 4.

The transformation diagrams for the binary system are shown in Fig. 1. For concentrations of nickel below 50% of the martensitic points are practically independent of composition, owing to the unavoidable two-phase character of the original material ($NiTi + NiTi_2$) and consequently of the constant (equilibrium) composition of the high-temperature phase (B2) of $NiTi$. The line T_R in Fig. 1 intersects the line M_S at 50.3% Ni, the line A_S at 50.7% Ni, and the line A_f near 51% Ni. For nickel contents below 46.75% the point T_R falls below M_f and the $B2 \rightleftharpoons R$ transition is not realized. As pointed out above, in alloys of this composition the $B19' \rightleftharpoons B19''$ transition occurs (at -20°C). We note that cycling in the temperature interval of the transformations lowers the points M_S , M_f , A_S , and A_f to a larger degree than the point T_R , with the result that the points of intersection of the T_R line with the corresponding curves are displaced to the left.

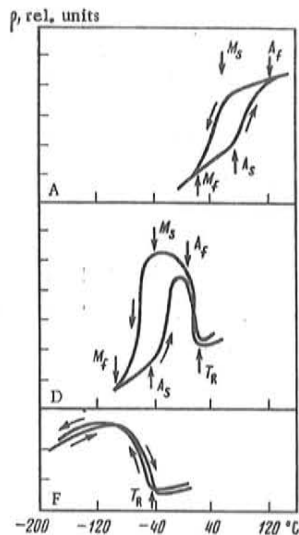
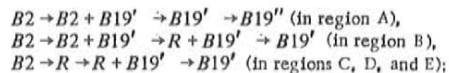
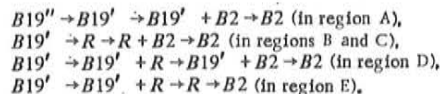


FIG. 4. Typical curves of the temperature dependence of the electrical resistance in the range of the transformations in various regions of the transformation diagrams of Figs. 1 and 2.

observed:



while the reverse transformations are:



In the transformation diagrams, regions with different positions of the line T_R with respect to the lines denoting the beginning and end of the martensitic transformations are distinguished: A ($T_R < M_f$); B ($M_f < T_R < M_S$); C ($M_S < T_R < A_S$); D ($A_S < T_R < A_f$); and E ($T_R > A_f$). In the region E the only transition observed above -196°C is $B2 \rightleftharpoons R$.

The multiplicity of diffusionless structural phase transitions in alloys with a specific chemical composition is a typical and, apparently, general characteristic of such transitions. This multiplicity of transitions and their products is not a manifestation of Ostwald's rule of stages, since the phases transform into each other not by a time-dependent process with constant external conditions, but rather by change of these conditions. The specifics of each diffusionless process, exhibiting all or some of the classical indications of martensitic kinetics,⁷ are such that the final state for a given set of external conditions is reached very rapidly and, in the absence of diffusion processes, will last for an indefinitely long period if the

Features of the heating of matter by specially profiled radiation

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The problem of the heating of matter by radiation is basically determined by the physics of the introduction of electromagnetic energy and by the mechanisms of transfer of energy from the electrons to the ions of the plasma of the substance.

In the present work we consider the mechanism of the heating of the ions of a dense plasma and of a metal lattice, and its dependence on the energy of the intense incident radiation.

We consider a metal in the "cold-plasma" model - i.e., we do not consider kinetic effects in the electron gas. The electron gas is assumed to be degenerate up to a temperature T_0 (T_0 is the degeneracy temperature). Hence we may restrict our attention, below this temperature, to electrons located near the Fermi level. The dispersion properties of the plasma and metal are not taken into account. We consider the spatially uniform formulation of the problem.

The electrons in the plasma or metal move in the field of a transverse wave of the form

$$E = E_0 \sin \omega t. \quad (1)$$

The motion of an electron in the light-wave field obeys the equation

$$\frac{\partial u_e}{\partial t} = \frac{eE_0}{m_e} \sin \omega t - \nu_{ei} u_e, \quad (2)$$

where ν_{ei} is collision frequency of electrons with the ions or with the metal lattice. In the general case, the collision frequency depends on the direction of the electron velocity.

Assuming that the time of action is small compared with the propagation time of the heating wave arising from

the heating of the electron gas, we can assume that the heating of the electrons and the metal lattice is described by the equations

$$c_e \frac{\partial T_e}{\partial t} = jE - \delta' \nu_{ei} (T_e - T_i), \quad (3)$$

$$c_i \frac{\partial T_i}{\partial t} = \delta' \nu_{ei} (T_e - T_i), \quad \delta c_e = \delta', \quad (4)$$

where δ is the elastic-collision coefficient of the electrons with the metal lattice or with the ions of the plasma. For metals¹

$$\delta = \frac{\pi^2}{6} \frac{m_e c_s^2 n}{c_e T} \gg 1,$$

where c_s is the speed of sound, while for a plasma²

$$\delta = \frac{m_e}{m_i} \ll 1.$$

Assuming that δ is a constant, i.e., is independent of the relative velocity of the electrons and ions, we obtain a solution of the system (1)-(4) in the form

$$T_e - T_i = a \sin^2 \omega t + b \sin \omega t \cos \omega t, \quad (5)$$

$$T_i = \delta \nu_{ei} \left(\frac{a+c}{2} t + \frac{B}{\omega} \sin^2 \omega t \right); \quad (6)$$

$$a+c = \frac{e^2 n E_0^2}{m_e c_e \delta (\omega^2 + \nu_{ei}^2)}, \quad (7)$$

where

$$b = \delta^2 \frac{\nu_{ei}}{\omega} \frac{e^2 n E_0^2}{\delta m_e c_e (\omega^2 + \nu_{ei}^2)} \times$$