FINE CRYSTALLINE AND MAGNETIC STRUCTURES OF IRON-NICKEL INVARS

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Submitted 15 April 1971
ZhETF Pis. Red. 13, No. 11, 600 - 603 (5 June 1971)

To study the fine crystalline structure of iron-nickel invars by neutron diffraction, we used samples enriched with the isotopes Fe^{54}, Ni^{58}, and Ni^{62}, which ensure large differences between the scattering amplitudes of the iron and nickel. The table lists the contents of nickel and the scattering amplitudes of the components of the alloys.

Polycrystalline samples of cylindrical form were subjected to stepwise annealing in accordance with the equilibrium diagram of state of the nickel-iron system [1] in the γ-region, with subsequent quenching in water. The annealing times and temperatures are given in the table.

Sample number	C_{Ni}, at.%	$b_{Ni}\cdot 10^{12}$ cm	$b_{Fe}\cdot 10^{12}$ cm	Annealing		α_1	α_2
				T, °C	time, hr		
1	30	1.40	0.45	500	73	-0.010	0.029
2	32	-0.603	0.96	480	108	-0.017	0.052
3	35	-0.216	0.96	450	370	-0.023	0.069
4	40	-0.603	0.96	410	580	-0.076	0.225

Debyegrams of the annealed samples were taken in the angle interval $5° \leq 2\theta \leq 40°$ using a neutron diffractometer tuned to the wavelength $\lambda = 1.07$ Å.

The small-angle scattering of the neutrons was investigated with a diffractometer at $\lambda = 1.59$ Å in the interval from room temperature to 1000°C. In addition to isotopically-enriched samples, we investigated samples with natural isotope mixture, making it possible to study only magnetic small-angle scattering of the neutrons.

The neutron-diffraction patterns of samples 1 - 4 are shown in Fig. 1. All four patterns reveal atomic ordering. Extrapolation of the Kurnakov temperatures of the Ni_3Fe superstructure [2] into the invar region makes it possible to propose the existence of long-range order in alloy 4 and short-range order in alloys 1 - 3 at the given heat treatment. The diffusion maxima at the locations of the superstructure reflections (100) and (110) indicate a correlation of the distribution of unlike atoms in the invar alloys. The values of the short-range parameters α_1 and α_2 in the table have been roughly estimated from the reflection (100), using the formulas relating the long-range and short-range order parameters [3].

Figure 2 shows the intensities of the small-angle scattering of the neutrons of the non-enriched samples obtained at temperatures with equal values of $(T_c - T)/T_c = 0.21$. The neutron-diffraction patterns a and 4 were taken on the sample with 40% Ni at 1000 and 230°C, respectively. Analogous patterns were obtained with the samples of the table.

The small-angle scattering intensities obtained from enriched and non-enriched samples agree within the limits of measurement error. That is to say, the small-angle scattering is mainly of magnetic origin.

Figure 2 shows a growth of the small-angle scattering intensities with decreasing Ni

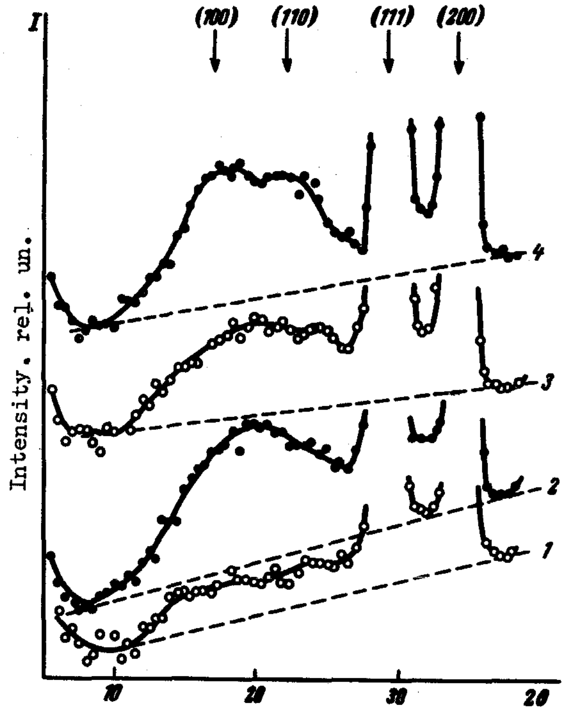

Fig. 1. Neutron diffraction patterns of invar alloys: 1 - 30% Ni, 2 - 32% Ni, 3 - 35% Ni, 4 - 40% Ni.

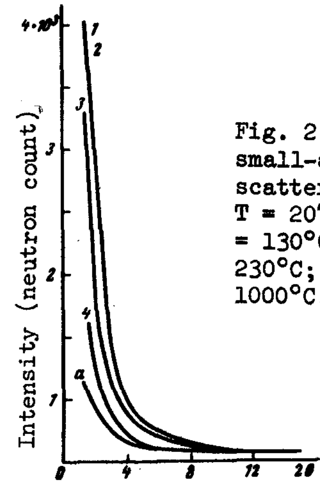

Fig. 2. Intensities of small-angle neutron scattering: 1 - 30% Ni, T = 20°C; 3 - 35% Ni, T = 130°C; 4 - 40% Ni, T = 230°C; a - 40% Ni, T = 1000°C.

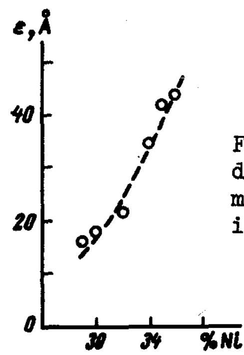

Fig. 3. Concentration dependence of the dimensions of the magnetic inhomogeneities ε.

concentration, in spite of the corresponding lowering of the measurement temperatures. Consequently, besides the magnon and critical scattering of the neutrons, which occur at $(T_c - T)/T_c = 0.21$, there occurs in invar alloys an additional small-angle magnetic scattering, which can be ascribed to scattering by magnetic inhomogeneities.

The contribution of the magnon scattering decreases appreciably in measurements at angles limited to the range $4\pi(\sin\Theta/\lambda) \geq 0.1$. Temperature measurements have shown that the effects of magnon and critical scattering are negligibly small at 20°C for alloys having $T_c \geq 200$°C, and were therefore not taken into account for $C_{Ni} \geq 34$ at. %.

Figure 3 shows the concentration dependence of the dimensions of the magnetic inhomogeneities ε at 20°C. Estimates of the dimensions obtained from the angular variation of the scattering intensity and from the radii of inertia of the inhomogeneities [4] assuming spherical regions. Both methods give close values of ε, which agree with the dimensions of the antiphase domains of ordering, equal to 20 Å for alloy 4.

Thus, the present results show that in invars there are produced ferromagnetic regions with short-range atomic order, of the type Ni_3Fe, in which the magnetic moment of Fe has a value close to $2.2\mu_B$ ($\mu_{Fe} = (2.32 \pm 0.24)\mu_B$ for alloy 3 [5]). These regions are distributed in a paramagnetic matrix that can be ferromagnetic below 60°K, with $\mu_{Fe} = 0.75\mu_B$ [6].

The numbers of the Ni atoms in the first and second coordination spheres (n_1 and n_2), calculated from α_1 and α_2, differ from the statistical distribution in tenths of an atom. In the ferromagnetic regions we have $n_1 > 3$, and in the paramgentic regions $n_1 \leq 3$. Therefore even after quenching from high temperatures there are possible formations with non-statistical distribution of the Ni atoms, leading to coexistence of the ferromagnetic and antiferromagnetic phases, in analogy with [7].

The proposed magnetic two-phase model of the invars differs from the model of concentration fluctuations [8] in the presence of correlation in the distribution of the Fe and Ni atoms. At the same time, alloyed invars can be analyzed within the framework of the proposed model with allowance for the influence of the alloying elements on the Ni_3Fe superstructure [9].

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OBSERVATION OF SELF-FOCUSING OF ELECTROMAGNETIC WAVES IN A PLASMA

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Submitted 15 April 1971
ZhETF Pis. Red. 13, No 11, 693 - 697 (5 June 1971)

The possibility of self-focusing of electromagnetic waves in a plasma had been discussed already in the first papers on the theory of this phenomenon [1]. It was shown later that self-focusing effects can play an important role in the propagation of electromagnetic waves of moderate intensity in a laboratory or a cosmic plasma [2]. Insofar as we know, however, no direct experiments have been performed as yet on these effects under laboratory conditions. We report here observation of self-focusing of millimeter waves in a weakly-ionized plasma.

We used an experimental setup similar to that described in [3]. A vacuum cylindrical volume (length 100 cm and diameter 30 cm, working pressure 0.25 Torr) was filled with plasma with maximum concentration $N_e \approx 8 \times 10^{13}$ cm^{-3}. After the end of the work of the source (a coaxial injector), plasma decay began, with a characteristic time $\tau \approx 1$ msec and with $\omega_p < \omega$ (ω_p is the plasma frequency), and a microwave pulse of duration 0.4 msec was fed to the plasma. The microwave source was a maser at cyclotron resonance (MCR), capable of producing up to 15 kW power at $\lambda = 5$ mm. The radiator was a conical horn, and the receiving antenna consisted of five standard rectangular waveguides for the 4-mm band (1.8 x 3.6 mm). Four of them were arranged pairwise in the vertical and horizontal planes, at equal distances (15 mm) from the fifth central waveguide, which was tuned to the maximum of the field in the "cold" system (without the plasma). The distance between the radiator and the receiver was 21 cm and remained fixed during the course of the work. The received signals were detected and registered with a five-beam oscilloscope. In the data reduction, the amplitudes of the signals passing through the plasma were determined with allowance for the detector characteristics and were normalized to the amplitude of the maximal "cold" signal.