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MAGNETIC ANOMALIES OF THE THERMAL EXPANSION OF CHROMIUM

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The great attention paid presently to the electric and magnetic properties of chromium is connected mainly with a number of features of its electron configuration. Thus, from the point of view of the band structure, the electron configuration d^5s^1 corresponds to the region of the transition from Pauli paramagnets (BCC metals of subgroups IVa and Va of the periodic system) to antiferromagnets (BCC metals of subgroup VIIa). The fact that chromium is actually in the transition region is evidenced, for example, by the relatively small magnetic moment per atom ($\sim 0.4\ \mu_B$) and the strong sensitivity of the Neel point to impurities [1], namely, small admixtures of vanadium decrease T_N sharply, and the presence of less than 0.5 at.% Mn in chromium leads to a sharp increase of T_N from 311 to 475°K. It is interesting that manganese contributes in this case to stabilization of the antiferromagnetic structure of chromium [2].

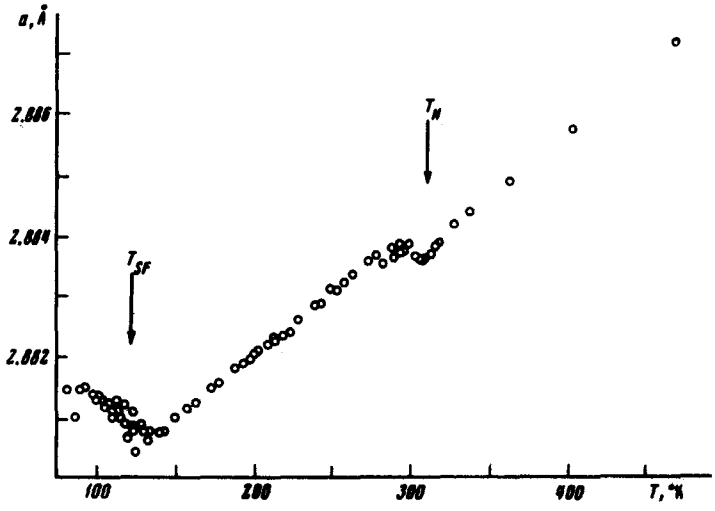
A number of recent papers offer evidence of the existence of anomalies in the variation of the parameters of the crystal lattice of chromium (and of the macroscopic dimensions of the sample as a whole) when magnetic ordering sets in [3 - 5]. We have therefore undertaken a direct x-ray structure determination of the dependence of the chromium lattice parameters on the temperature.

Chromium has a cubic body centered lattice assumed to have orthorhombic distortions in the temperature region $120 < T < 311$°K and tetragonal distortions at $T < 120$°K [6]. Carefully performed x-ray diffraction investigations have shown, however, that the relative magnitudes of these distortions $\Delta a/a$ does not exceed 10^{-5}, so that they cannot be observed by ordinary x-ray methods [7]. (We note that this result agrees with the results of a study of the shapes of the diffraction maxima at different temperatures in our investigation.)

The investigations were carried out with a sample containing not more than 0.018% of impurities (not more than 0.010 and 0.008% of nitrogen and oxygen, respectively); the sample was relieved of mechanical stress by electrochemical etching.

During the measurements, the temperature of the sample was maintained automatically with accuracy not worse than 0.05°. Prior to the measurement, the sample was held at each temperature not less than 2 - 3 hours. To increase the calculation accuracy, the (112) diffraction peak was plotted point by point (in steps of 2' - 3').

The results of the calculation of the lattice parameter a at the different temperatures are shown in the figure. It is seen from the figure that there are two regions of anomalous variation of the chromium lattice parameters: when magnetic ordering appears (near T_N) and below the temperature T_{SF} of the phase transition connected with the change in the character of the magnetic order. It is obvious that both anomalies on the a(T) plot are due to the appearance of



Temperature dependence of the parameters of the crystal lattice of antiferromagnetic chromium.

positive spontaneous striction λ_s below the temperatures T_N and T_{SF}. The large value of the spontaneous magnetostriction can be attributed to the strong dependence of the exchange interactions on the interatomic distances, as is evidenced by the strong pressure dependence of the temperatures T_N and T_{SF} [4, 8, 9].

The sign of the spontaneous striction upon appearance of magnetic ordering at T_N can likewise be explained on the basis of rather simple considerations. It is easily seen that in the case when the exchange energy E_{ex} depends on the interatomic distances we have for the magnitude of the volume spontaneous magnetostriction

$$\Delta V_s \sim -\frac{\partial E_{ex}}{\partial V} \sim \frac{\partial E_{ex}}{\partial p}.$$

Employing now the usual connection between the volume energy and T_N, we obtain

$$\lambda_s = \frac{\Delta a_s}{a} = \frac{1}{3}\frac{\Delta V_s}{V} = -\beta\frac{\partial T_N}{\partial p} \quad (\beta > 0).$$

Thus, the magnitude and the sign of the spontaneous magnetostriction are determined by the magnitude and sign of the derivative $\partial T_N/\partial p$. For chromium, $\partial T_N/\partial p < 0$, so that the transition into the region of magnetic ordering should be accompanied by the appearance of positive spontaneous striction.

Nonetheless, the character of the $\lambda_s(T)$ dependence near T_N apparently offers evidence that near the Neel temperature we are dealing with a first-order phase transition. This statement agrees with the results of neutron-diffraction investigations [10, 11] and with the results of x-ray diffraction determinations of the temperature dependence of the intensity of the diffraction maxima in chromium [12].

We note that at room temperature the magnitude of the anomaly Δa, due to the appearance of magnetic ordering (and equal to $\sim 1.0 \times 10^{-3}$ Å) is in good agreement with the analogous value that can be obtained from the investigation

of the a(p) dependence at the same temperature ($\Delta a \simeq 1.3 \times 10^{-3}$ Å).

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PHOTOCONDUCTIVITY OF GERMANIUM IN A HIGH-FREQUENCY ELECTRIC FIELD

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The use of a high-frequency electric field for the study of the photoconductivity of semiconductors has a number of advantages over other methods, since it combines the possibility of obtaining sufficiently strong fields with satisfaction of the requirement that the drift length of the non-equilibrium carriers be much smaller than the length of the sample. In this case, however, when the non-equilibrium carriers are excited by intense optical generation, non-trivial phenomena arise in the investigated germanium samples, and the present paper is devoted to their description.

We used for the investigations a pulse-modulated high-frequency voltage with carrier frequency 9.0 MHz and pulse duration 10 - 100 μsec. The output resistance of the pulse generator was 15 ohms; the voltage amplitude could range from zero to 350 V, with the envelope of the radio pulses maintained rectangular.

In the investigation of the current-voltage characteristics of p-Ge samples with antibarrier contacts it was observed that in a wide range of temperatures (20 - 300°K) at sufficiently large illumination and voltage, a reversible breakdown occurred when the current increased jumpwise by 10 - 20 times compared with its value prior to the breakdown (see Fig. 1). Such a phenomenon was observed in the investigation of p-Ge with different acceptor concentrations from 1×10^{12} to 7×10^{14} cm^{-3}. In the present study we investigated germanium with $p = 1.2 \times 10^{14}$ cm^{-3} at room temperature. The antibarrier contacts were obtained by fusing indium on the end surfaces of the samples; the samples were etched in H_2O_2 prior to the measurements.

Pre-breakdown regime. For a more detailed investigation of the aforementioned phenomenon we studied the distribution V(x) of the high-frequency potential along the samples. Figure 2 shows such distributions obtained by moving a metallic probe over the polished side face of one of the samples. Similar distributions were obtained also by other methods, namely using a moving capacitive probe and using direct measurement of the high-frequency potential on the sample with several stub probes. It is seen from Fig. 2 that the