

singlets and triplets is the result of splitting in the crystal field ( $C_{3v}$ ) and spin-orbit interaction. The former is close to 8 meV and the latter is about 1.3 meV.

It is interesting that in the luminescence spectrum of  $\alpha$ -SiC (6H) it is possible to observe besides the A line also five lines that increase gradually in intensity with increasing temperature [7]. The form of these lines at 77°K is shown in Fig. 1 (curve IV). In the absorption spectrum, the  $\alpha$  lines also have a fine structure. The presence of a fine structure in luminescence and absorption is in good agreement with the scheme of Fig. 2, where the relative position of the levels is shown on the basis of the experimental data.

It must be assumed that the intercombination transitions become partially allowed because of the spin-orbit interaction. The ratio of the oscillator strength of the dipole-allowed transitions to the oscillator strength of the intercombination transitions is equal in order of magnitude to the ratio of the square of the exchange splitting to the square of the spin-orbit splitting. We have measured directly the damping time of the A series upon excitation in the absorption  $\alpha_2$  line. It turned out that  $\tau = 8 \times 10^{-5}$  sec. This agrees well with the corresponding values of the splitting, if it is assumed that for dipole-allowed transitions  $\tau \sim 10^{-8}$  sec.

Thus, the spectroscopic manifestations of singlet and triplet exciton-impurity states in semiconductors were found for the first time, with  $\alpha$ -SiC (6H) crystals as the example. The nature of these states is due to the exchange electron-hole interaction, which turns out to be sufficiently large for small-radius complexes.

- [1] D.G. Thomas and G.G. Hopfield, Phys. Rev. 128, 2135 (1962).
- [2] D.G. Thomas and G.G. Hopfield, Phys. Rev. 150, 680 (1966).
- [3] C.H. Henry, P.G. Dean, and G.D. Cuthbert, Phys. Rev. 166, 754 (1968).
- [4] E.I. Rashba, Zh. Eksp. Teor. Fiz. 36, 1697 (1959) [Sov. Phys.-JETP 9, 1209 (1959)].
- [5] G.E. Pikus and G.L. Bir, *ibid.* 60, 195 (1971) [33, No. 1 (1971)].
- [6] W.G. Choyke and Lyle Patrick, Phys. Rev. 127, 1868 (1962).
- [7] D.R. Hamilton, W.G. Choyke, and Lyle Patrick, Phys. Rev. 131, 127 (1963).
- [8] I.S. Gorban' and A.P. Krokhmal', Fiz. Tverd. Tela 11, 775 (1969) [Sov. Phys.-Solid State 11, 623 (1969)].
- [9] E.I. Rashba and G.E. Gurgeishvili, *ibid.* 4, 1029 (1962) [4, 759 (1962)].
- [10] W. Kohn and G.M. Luttinger, Phys. Rev. 98, 915 (1955).

#### DIRECT OBSERVATION OF FLUCTUATIONS OF DEUTERIUM DISTRIBUTION IN ( $Nb_{0.33}Ti_{0.66}$ ) $D_{0.33}$

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The values of the equilibrium dissociation pressure calculated for hydrides of group-IV metals by the model of statistically distributed hydrogen do not agree with the experimentally obtained values. Libowitz proposed [1] that this disparity is due to the presence of fluctuation inhomogeneities of the hydrogen distribution in these hydrides. Insofar as the authors know, no experimental observation of hydrogen fluctuations in hydrides was ever reported.

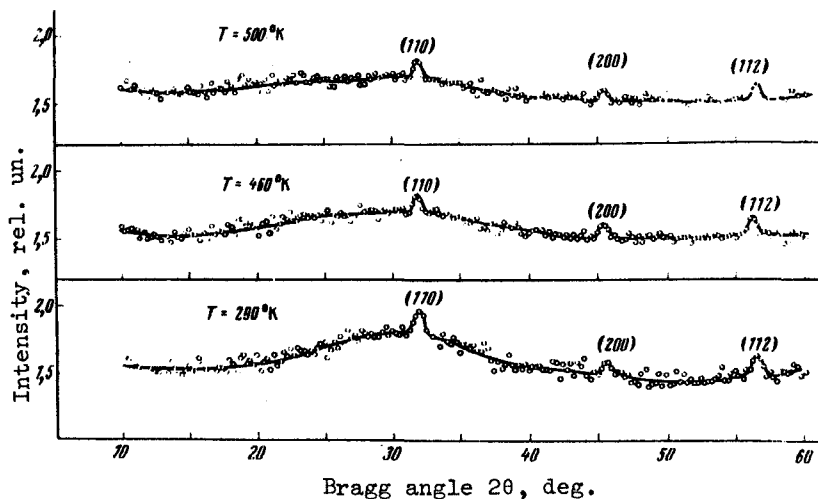
The most direct and effective method of determining the concentration inhomogeneities of light atoms is diffraction of slow neutrons. As was shown, for example, by Krivoglaz [2], in the scattering of x-rays in slow neutrons by materials having an inhomogeneous distribution of the components, noticeable diffuse maxima can appear on the diffraction pattern, besides the coherent peaks due to the "average" crystal lattice, as a result of the fluctuations of the concentration of the components in the lattice.

We have carried out an x-ray diffraction and neutron diffraction investigation of a deuteride of composition  $(\text{Nb}_{0.33}\text{Ti}_{0.66})\text{D}_{0.33}$ , which has made it possible to reveal experimentally the existence of concentration fluctuations of the deuterium atoms. The choice of the components of the initial alloy was determined by the following circumstances, which simplify the observation of this phenomenon: first, with such a composition the alloy (assuming the atoms have a statistical distribution) should have a close to zero amplitude of elastic coherent nuclear scattering of slow neutrons; second, above the temperature of the  $\alpha$ - $\beta$  phase transition, titanium forms with niobium a continuous series of solid solutions, making it possible to ensure, by suitable heat treatment, a statistical distribution of the components.

The  $\text{Nb}_{0.33}\text{Ti}_{0.66}$  alloy was prepared by melting niobium (99.9% pure) with titanium iodide in an electric-arc furnace (argon atmosphere) on a water-cooled copper sole. Ingots of the alloy were annealed at 600°C for 100 hr and subsequently quenched in water. An x-ray diffraction investigation has shown that the alloy is a homogeneous solid solution with a BCC lattice with parameter  $a = 3.30 \text{ \AA}$ . The absence of diffraction maxima on the neutron diffraction pattern confirms the statistical distribution of the metallic atoms.

Chips of the alloy were deuterated with apparatus of the Sieverts type, by adding fixed volumes of deuterium up to a concentration  $D/\text{Me} = 0.33$  with subsequent cooling together with the oven to room temperature. According to the x-ray diffraction data, the deuteride  $(\text{Nb}_{0.33}\text{Ti}_{0.66})\text{D}_{0.33}$  retained the BCC arrangement of the metallic atoms ( $a = 3.31 \text{ \AA}$ ). This is evidence of formation of a solid solution of deuterium in the initial alloy.

The neutron diffraction patterns of cylindrical briquettes of the deuteride, obtained at three temperatures (20°C (a), 180°C (b), and 220°C (c)) are shown in the figure. In the first of them (a) there is present, besides the weak-intensity reflections at angles  $\theta$  corresponding to the BCC lattice with



Neutron diffraction patterns of the deuteride  $(\text{Nb}_{0.33}\text{Ti}_{0.66})\text{D}_{0.33}$  ( $\lambda = 1.27 \text{ \AA}$ ), obtained at temperatures 20°C (a), 180°C (b), and 220°C (c).

parameter  $a = 3.31 \text{ \AA}$ , also an intense diffuse maximum in the interval of  $2\theta$  from  $20$  to  $40^\circ$ . In the second (b) and third (c), the intensity of the diffuse peak drops considerably. The coherent peaks remain unchanged and their relative intensities agree well with those calculated for a model in which a statistical arrangement of the deuterium atoms over the tetrahedral voids is assumed. A repeated analysis of the composition of the samples with respect to deuterium has shown that its concentration remained the same as before.

The diffuse reflection cannot be interpreted as a result of scattering of neutrons by inhomogeneities of the distribution of the metallic atoms, since the x-ray diffraction patterns show neither diffuse nor superstructure reflections. Consequently, it is the result of scattering by the fluctuations of the distribution of the deuterium atoms. This is confirmed also by the decrease of the intensity of the diffuse peak with increasing temperature, which can be readily explained as being due to equalization of the concentration of the deuterium atoms. Such an equalization is natural because of the increase of the mobility of the deuterium, which according to the NMR data, increases noticeably even at slight temperature rises [3].

Thus, the results allow us to draw the following conclusions: a) the light atoms in  $(\text{Nb}_{0.33}\text{Ti}_{0.66})\text{D}_{0.33}$  are distributed over the tetrahedral voids of the metallic matrix, b) the distribution of the deuterium deviates from the uniform-statistical one, forming concentration waves.

- [1] G.G. Libowitz, *The Advances in Chemistry* **39**, 66 (1963).  
 [2] M.A. Krivoglaз, *Teoriya rasseyaniya rentgenovskikh luchei i teplovykh neutronov real'nyimi kristallami* (Theory of Scattering of X Rays and Thermal Neutrons by Real Crystals), Nauka, 1967, pp. 137 - 150.  
 [3] K.M. McKay, *Hydrogen Compounds of Metallic Elements* (Russian translation), Mir, 1968, p. 115 [Barnes & Noble, 1966].

#### ANTIFERROMAGNETIC RESONANCE AND PHASE TRANSITION IN COBALT FLUORIDE IN A PERPENDICULAR MAGNETIC FIELD

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As shown in [1], the symmetry of antiferromagnetic cobalt fluoride (space group  $D_{4h}^{14}$ ,  $T_N = 37.7^\circ\text{K}$ ) admits of the following expansion of the free energy:

$$\Phi = \frac{B}{2} m^2 + \frac{a}{2} (\ell_x^2 + \ell_y^2) + e(m_x \ell_y + m_y \ell_x) - mH,$$

where  $\vec{\ell} = \vec{M}_1 - \vec{M}_2$ ,  $\vec{m} = \vec{M}_1 + \vec{M}_2$ ;  $\vec{M}_1$  and  $\vec{M}_2$  are the magnetizations of the sublattices.

The presence in the Hamiltonian of the term  $e(m_x \ell_y + m_y \ell_x)$  causes a spontaneous magnetic moment directed perpendicular to the z axis to appear when the antiferromagnetism vector  $\ell$  is inclined to the z axis, and antiferromagnets in which the indicated situation is realized without an external magnetic field are called antiferromagnets with weak ferromagnetism [2]. Since in the absence of an external magnetic field the magnetic moments in  $\text{CoF}_2$  are directed along the z axis, it does not have a weak ferromagnetic moment. When a field  $\vec{H} \parallel [100]$  is applied, the vector  $\vec{\ell}$  is deflected from the z axis and forms a