up to a concentration $N_D = 7.2 \times 10^{17}$ cm^{-3} at which the hfs structure lines at the frequencies $\nu = \nu_0 \pm A/2$ practically disappear; the frequency ν_0 is determined from the relation $h\nu_0 = g\beta H$. The decrease of A following strong compensation is especially noticeable for $N_D \gtrsim 6 \times 10^{17}$ cm^{-3}, where strong exchange interaction exists, as is evidenced by the intense line at the frequency ν_0 [2]. The appearance of the hfs lines in a sample with $N_D = 7.2 \times 10^{17}$ cm^{-3} and K = 0.99 (sample 7 of the table) points unequivocally to the occurrence of localized states as a result of the compensation. This effect was observed for the first time in [3] and was explained theoretically in [4].

The decrease in the value of the hyperfine splitting in strongly-doped samples with strong compensation can be explained qualitatively on the basis of the theory of Takeyama et al. [5], who considered the electron states of isolated impurity pairs. Assuming that the pair interaction is strongest in the strongly doped crystals and that compensation leads to the formation of ionized pairs, we estimated the energy of the volume interaction at $N_D \gtrsim 6 \times 10^{17}$ cm^{-3} by extrapolating the data of [5] to higher concentrations. The obtained value, $\gtrsim 4 \times 10^{-3}$ eV is of the same order of magnitude as the valley-orbit splitting of phosphorus in n-Si, $E_{12} = 1.5 \times 10^{-2}$ eV [6]. In this case, according to [5], the ground states of the ionized pair become mixed with higher states that make no contribution to the hfs, thus leading to a decrease in A.

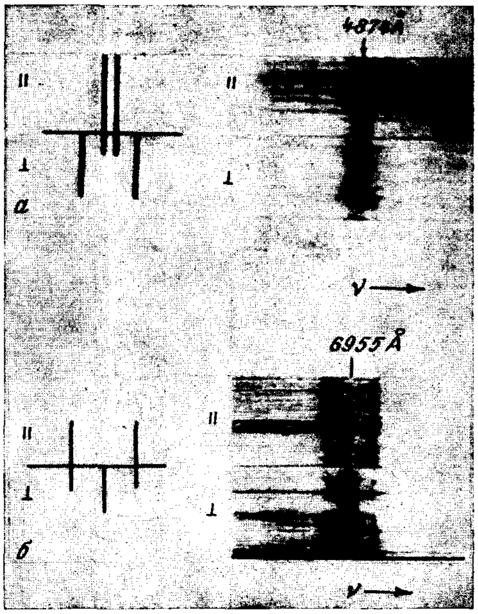
[1] R. C. Fletcher, W. A. Yager, G. L. Rarson, A. N. Holden, W. F. Read, and F. R. Merritt, Phys. Rev. 94, 1392
[2] B. G. Zhurkin and N. A. Penin, Fiz. Tverd. Tela 6, 1141 (1964) [Sov. Phys.-Solid State 6, 879 (1964)].
[3] B. G. Zhurkin and N. A. Penin, ibid. 7, 3204 (1965) [7, 2592 (1966)].
[4] L. V. Keldysh and T. G. Tratas, ibid. 8, 83 (1966) [8, 64 (1966)].
[5] K. Takeyama, M. Kawahito, M. Okazaki, and M. Kikuchi, J. Phys. Soc. Japan 22, 118 (1967).
[6] D. K. Wilson and G. Feher, Phys. Rev. 124, 1068 (1961).

LINEAR STARK EFFECT ON ZERO-PHONON LINES OF COLOR CENTERS IN LITHIUM FLUORIDE CRYSTALS

A. A. Kaplyanskii and V. N. Medvedev
A. F. Ioffe Physico-technical Institute, USSR Academy of Sciences
Submitted 28 July 1967
ZhETF Pis'ma 6, No. 10, 893-895 (15 November 1967)

If the point symmetry group of an impurity or a defect in a crystal does not contain an inversion, then the linear Stark effect is possible in their optical spectrum in an external electric field [1-3]. The first attempts to observe this effect in the spectra of complex color centers in alkali-halide crystals were made by Overhauser and Ruchardt [1] for the broad bands of M and R centers in KCl and NaCl. The observation of an electron-vibrational structure in the spectra of the color centers, including narrow zero-phonon lines [4], uncovers new possibilities for observing the linear Stark effect in spectra of inversionless color centers.

We have observed in an electric field a splitting, linear in the field, of a number of zero-phonon lines in the absorption spectra of complex electronic color centers of LiF. A constant field of intensity up to $\epsilon_0 \approx 300$ kV/cm was applied at 4.2°K to single crystals of γ-ray-colored LiF along the ⟨100⟩ axis. The absorption spectra were photographed in a direction transverse to $\vec{\epsilon}_0$, using a diffraction spectrograph with dispersion from 1.7 to 8.0 Å/mm.



The zero-phonon 4874 Å line of the ionized F_3^+ center [5] splits into a symmetric triplet, the outer components of which are polarized with $\vec{E} \perp \vec{\epsilon}_0$; the width of the triplet is $\delta \approx 2 \times 10^{-5}$ cm^{-1}/V/cm (Fig. a). The F_3^+ center, which includes three neighboring vacancies in the (111) plane, corresponds in symmetry to the trigonal inversionless group C_{3V}. The 4874 Å absorption line corresponds to a transition of the A → E type in this group [6]. According to [7], the nondegenerate A-level of C_{3V} is in general shifted in an electric field (shift $\Delta_A = A'\epsilon_{\parallel}$), and the doubly degenerate E level experiences, besides a shift, also a splitting ($\Delta_E^{\pm} = A''\epsilon_{\parallel} \pm B\epsilon_{\perp}$); here $\epsilon_{\parallel}$ and $\epsilon_{\perp}$ are the projections of the field on the trigonal axis of the center and on the plane normal to it, and A', A'', and B are proportionality coefficients.[*] Thus, the line of the A → E transition in an individual center should split into two in the field. Owing to the presence of eight groups of C_{3V} centers in the cubic lattice, with axes directed along several ⟨111⟩ directions (orientational degeneracy [8]), the summary spectrum from all the groups should yield a polarized quartet when $\epsilon_0 \parallel \langle 100 \rangle$ (Fig. a). The observed picture of the splitting of the 4874 Å line agrees qualitatively with the calculated "quartet" picture if it is assumed that the central component of the triplet is an unresolved doublet (this can occur when $|A' - A''| \approx \sqrt{2}B$).

One of the unidentified lines of the colored LiF, 6955 Å, splits into a symmetrical polarized triplet with $\delta \approx 3.8 \times 10^{-5}$ cm^{-1}/V/cm (Fig. b). The picture corresponds to that calculated for "pseudo-Stark" splitting [3] of the lines of inversionless noncubic centers with a constant dipole moment along ⟨110⟩.[**] The line splitting occurs here exclusively as a result of different shifts of the levels (and different transition frequencies) of the orientationally-degenerate centers having different momentum projections on the direction of an external field with $\epsilon_0 \parallel \langle 100 \rangle$. The orientation of the dipole moment along the ⟨110⟩ axis is characteristic [7] of centers of rhombic I or monoclinic I symmetry [8]. From the polarization of the pseudo-Stark triplet it follows that the linear electric oscillator corresponding to 6955 Å is directed in the center along $[1\bar{1}0]$, perpendicular to its constant dipole moment along [110].

Triplet symmetric splitting was observed also for the unidentified lines 6935 Å ($\delta \approx 1.0 \times 10^{-4}$ cm^{-1}/V/cm) and 4877 Å ($\delta \approx 1.4 \times 10^{-5}$ cm^{-1}/V/cm). The 6400 Å splits into an unpolarized doublet ($\delta \approx 8.3 \times 10^{-5}$ cm^{-1}/V/cm), the short-wave component of which vanishes with increasing field. For the linear Stark effect in O_h crystals, the picture of the splitting should be symmetrical relative to the line without the field (with all the splitting components appearing in the spectrum) [7]. The vanishing of part of the 6400 Å components, which leads to the asymmetry, can be due to Boltzmann quenching of the populations of the corresponding energy states. The latter probably explains also the peculiarities in the behavior of the zero-phonon 391 nm R_2 line of $R(F_3)$ centers in a field, namely that splitting into a poorly resolved asymmetric doublet is observed in fields $\epsilon_0 \approx 300$ kV/cm ($\delta \approx 2 \times 10^{-5}$ cm^{-1}/V/cm).[***]

The field exerts no influence on the zero-phonon 5234 Å line of N_1 centers [6]; this agrees with Pick's model [9] for these centers (an aggregate of four F centers in octahedron plane, the point group C_{2h} of F_4 center has inversion). Nor does the field act on the 3932 Å line, which belongs [6] to A → E transitions in centers of tetragonal symmetry.

[1] A. W. Overhauser and H. Ruchardt, Phys. Rev. 112, 722 (1958).
[2] N. Bloembergen, Science 133, 1363 (1961).
[3] W. Kaiser, S. Sugano, and D. L. Wood, Phys. Rev. Lett. 6, 605 (1961).
[4] D. B. Fitchen, R. H. Silsbee, T. A. Fulton, and E. L. Wolt, ibid. 11, 275 (1963).
[5] Y. Farge, G. Toulouse, and M. Lambert, J. de Phys. 27, 287 (1966).
[6] A. E. Hughes and W. A. Runciman, Proc. Phys. Soc. 86, 615 (1965).
[7] A. A. Kaplyanskii and V. N. Medvedev, Opt. Spektrosk. 23, No. 5 (1967).
[8] A. A. Kaplyanskii, ibid. 16, 602 (1964).
[9] H. Pick, Z. Physik 159, 69 (1960).

[*] A general phenomenological calculation of the characteristics of the linear Stark effect in spectra of inversionless local centers in O_h crystals is given in [7].

[**] The calculated picture [7] of these centers agrees also - in the number, polarization, and relative positions of the components - with the experimental splitting (incompletely resolved quartet) of 6955 Å when $\epsilon_0 \parallel \langle 110 \rangle$.

[***] It must be noted that deviations unrelated to quenching were observed for the lines for which the picture of the splitting was described above as "symmetrical"; the reasons for this call for an investigation.

COHERENT EMISSION FROM ELECTRON-HOLE PLASMA OF INDIUM ANTIMONIDE IN THE ABSENCE OF A MAGNETIC FIELD

A. P. Shotov, S. P. Grishechkina, and R. A. Muminov
P. N. Lebedev Physics Institute, USSR Academy of Sciences

Submitted 25 August 1967; resubmitted 6 October 1967
ZhETF Pis'ma 6, No. 10, 895-898 (15 November 1967)

Indium antimonide is the most complicated among the III-V compounds when it comes to generation of coherent emission by electric carrier injection [1,2].

When the coherent emission is generated with the aid of an electron-hole plasma produced in pure indium antimonide crystals [3-5], additional difficulties are caused by the pinch effect, since the contraction of the carriers into a pinch leads to a strong intrinsic absorption of the radiation in the remaining part of the crystal [6,7]. We have therefore used in [6,7] a longitudinal magnetic field to eliminate the pinch effect.

An examination of the conditions for the occurrence of the pinch effec leads to the conclusion that the pinch formation should be strongly influenced by the geometry of the cross section (form of the cross section and distance between contacts). By choosing crystals having a definite geometry, it is possible to shift the threshold of pinch formation into the