$$q+ue\varphi n=-nx\nabla T+nuT(^{5}/_{2}+r)+eun\varphi.$$

Transforming here to the nondimensional variable given in the body of the paper, and using the equality $n\approx n_0$, we obtain the condition (9b').

[1)]This method has been used in a number of researches (see, for example, Ref. 10).

[2)]Thus, although the ideological content of Ref. 1 and the statement of the problem given there are not subject to doubt, the result expressed by Eqs. (43) and (44) of this paper apparently does not have a region of applicability.

[3)]We note that the quantity v_1 could in principle turn out to be negative. As is easily shown, under certain conditions this circumstance can itself cause the instability of the static distribution of the electron temperature in the heated electron gas. In what follows, we shall nevertheless assume $v_1 > 0$.

[4)]This result should not produce surprise, because (55) is normally nothing other than the equation of transport of energy under conditions in which an external voltage is lacking and the kinetic coefficients do not depend on the temperature of the electrons.

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Translated by R. T. Beyer

Polarization of recombination radiation of multiparticle exciton–impurity complexes in silicon under uniaxial deformation

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(Submitted 18 December 1978)
Zh. Eksp. Teor. Fiz. **76**, 1727–1738 (May 1979)

The spectral distribution and the polarization of recombination radiation of free excitons and of multiparticle exciton–impurity complexes were investigated in silicon subjected to uniaxial compression and tension in the directions [111] and [001]. The agreement of the experimental and calculated degrees of polarization of all the exciton–emission bands was attained by choosing the values of two parameters that characterize the contributions of the different intermediate states in radiative recombination with participation of phonons. The degree of polarization of different emission lines of multiparticle exciton–impurity complexes is calculated on the basis of the choice of the symmetry of the initial and final electronic states in accordance with the shell model of the complexes and in accordance with the data on the polarization of the exciton radiation. A quantitative comparison of the results of this calculation with the experimental values of the degree of polarization of the phonon and no-phonon radiation components of complexes bound on phosphorus and boron atoms in silicon show that the shell model describes correctly the main properties of multiparticle exciton complexes.

PACS numbers: 78.60. – b, 71.35. + z, 62.20.Fe

1. INTRODUCTION

The substantial progress made recently in the investigation of multiparticle exciton–impurity complexes (MEIC)[1] are due to a considerable degree to the use of the "shell" model.[2,3] According to this model, the electrons and holes fill in succession the shells of the complexes in accordance with the Pauli principle. The cells are made up in this case of single-particle states and have the degeneracy multiplicity and the symmetry of a simple donor for electrons and of a simple acceptor for holes. The validity of this assumption has already been confirmed by the observation of new relatively weak lines in the emission spectra of complexes bound on donors of group V in silicon (the β series and some other lines[4-6]), as well as by the character of the splitting of the emission lines of the complexes in uniaxially deformed silicon[5-7] and in strong magnetic fields.

The polarization of the recombination radiation makes it possible to assess directly the symmetry of the initial and final electronic states in radiative decay of the

0038-5646/79/050878-07$02.40

complexes. In the present study we investigated quantitatively the polarization of a number of emission lines of MEIC in silicon doped with phosphorus or boron, resulting from uniaxial compression or tension of the crystals in the [111] and [001] directions. The experimental results are compared with the calculation performed under the assumption of the shell model. A comparison of the results of the calculation and of the experiment for the phonon components of the emission of the complexes called for a more detailed investigation of the polarization of the radiation of the free excitons, inasmuch as the selection rules for the phonon transitions are similar in both cases.

2. EXPERIMENTAL PROCEDURE

We investigated samples of pure silicon containing residual boron 1×10^{12} cm^{-3}, and of silicon doped with phosphorus at a concentration 7×10^{14} cm^{-3} and boron at a concentration 1×10^{15} cm^{-3}. To ensure homogeneity of the deformation, we used samples with dimensions $\approx1.8\times1.8\times20$ mm^3. The deforming force F was applied in the direction [111] or [001], along which the corresponding samples were cut. In the case of tension (Fig. 1a) the ends of the samples were glued with epoxy resin into vessels of copper foil with lugs to which the tensile force was applied. This construction made it possible to attain stresses $P\approx-10^3$ kg/cm^2. In compression (Fig. 1b) we used samples with hemispherical end faces, which were pressed at room temperature into plungers with cavities filled with an alloy of 50% Sn+50% Pb, which solidified at low temperatures. The absence of noticable broadening of the emission lines of the complexes, in either tension or compression, indicated that the deformations were sufficiently uniform.

The samples were placed in a helium bath of a cryostat and excited with modulated radiation from an argon laser focused in the form of a strip measuring 7×0.2 mm. The recombination radiation was analyzed with a grating monochromator MDR-2 and was registered with a cooled FÉU-62 photomultiplier. To analyze the polarization of the radiation we used a film polaroid placed directly past the exit window of the cryostat. Rotation of the polaroid through 90° to cancel the apparatus polarization, automatically changed the gain of the recording channel.[9]

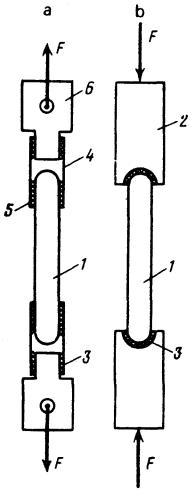

FIG. 1. Diagram of installation for uniaxial tension (a) and compression (b) of silicon samples: 1—sample, 2—plunger, 3—50% Sn + 50% Pb solder, 4—copper-foil vessels, 5—epoxy resin, 6—lugs.

In the quantitative investigation of the polarization of the recombination radiation, an important task is to decrease the depolarization effect due in particular to imperfection of the surfaces of the investigated crystals. For this purpose, the sample surface facing the spectrometer slit was polished mechanically, and the remaining surfaces were polished chemically to decrease the rate of surface recombination. In addition, the samples were placed in a metallic screen provided with windows for the entrance of the exciting and for the exit of the recombination radiation, thus preventing radiation emerging from the side faces of the sample from entering into the spectrometer slit. These measures made it possible to decrease the radiation depolarization factor to ≈1.5 and to ensure reproducibility of the results.

3. FREE EXCITONS

As will be shown below, there exists a definite connection between the polarization of the radiation of free excitons and the polarization of the phonon components of the MEIC radiation. We considered it therefore useful to investigate in greater detail the polarization of the exciton radiation under deformation both in the [001] direction[10] and in the [111] direction. In addition, the substantial decrease of the depolarization factor reached in the present study made possible a more accurate quantitative comparison of the experimental data with the calculation.

Uniaxial tension ($P<0$) or compression ($P>0$) of silicon crystals causes, generally speaking, a splitting of the valence band and the conduction band. The excitons can be produced in this case as the result of the binding of the electrons and holes belonging to different branches of the split bands. The schemes of the splitting of the exciton state upon compression and tension of silicon in the [001] and [111] direction are shown in Fig. 2. This figure shows also the spectral distribution of the components of the exciton radiation polarized parallel and perpendicular to the deformation direction. The degree of polarization was assumed equal to $[(I_\parallel-I_\perp)/(I_\parallel+I_\perp)]\times100\%$, where $I_\parallel$ and $I_\perp$ are the intensities of the radiation polarized along and across the direction of the deformation. The experimental values of the degree of polarization are given in Table I.

To calculate the degree of polarization and the ratio of the intensities of the *TO* and *LO* components of the different exciton radiation lines, we have used the results of calculations of the relative probabilities of the radiative transitions, performed in Refs. 10 and 11. The results of these calculations are given in Table I. The parameters c and d ($c=k_1^{1/2}=\alpha/\beta$, $d=k_3^{1/2}=\lambda/\eta$ in the notation of Refs. 10 and 11) depend here on the contributions of the different intermediate states in the annihilation of the excitons with participation of the phonons. The values of c and d were chosen to obtain optimal agreement between experiment and calculation. Only two parameters are chosen here to determine 18

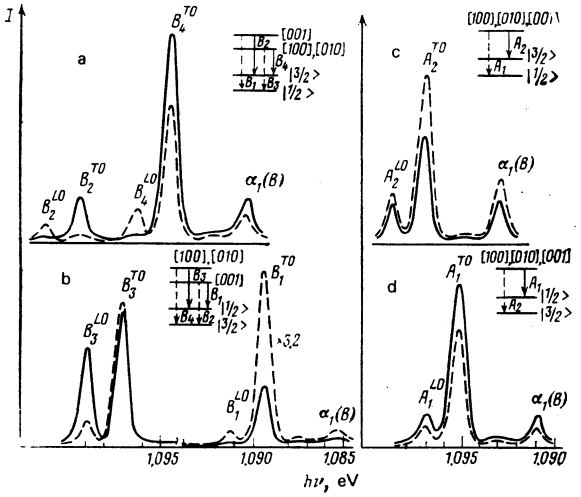

FIG. 2. Splitting of exciton levels in silicon and spectral distribution of *TO* and *LO* components of the emission of free excitons at 2 K, polarized parallel (solid line) and perpendicular (dashed) to the deformation; along the [001] axis: a—tension, $P=-690$ kg/cm^2, b—compression, $P=1000$ kg/cm^2; along the [111] axis: c—tension, $P=-280$ kg/cm^2, d—compression, $P=630$ kg/cm^2.

quantities (12 values of the degree of polarization and 6 values of the ratio of the intensities of the *TO* and *LO* components for different lines in the exciton spectrum). The ratio of the intensities of the lines in the *TO* and *LO* components of the exciton radiation was also calculated for different types of transitions in accordance with Refs. 10 and 11. A comparison of the calculated values of this ratio with the experimental ones is given in Table II. In both Table I and Table II the calculation was performed for $c=0.5$, $d=-0.2$. For these values of the parameters, the ratio of the calculated degree of polarization to the experimental one lies in the range 1.15–1.65, thus pointing to a small value and sufficient constancy of the depolarization factor attained in the present study. The agreement between the calculation and experiment remains satisfactory when c and d are varied in a range ±0.05. Thus, the choice of these parameters is far from arbitrary. The only deviation beyond the limits of the experimental and calculation accuracy is observed for the ratio of the intensities of the *TO* and *LO* components of the transition A_2 (Table II). The cause of this discrepancy is not clear to us.

When pure silicon was compressed in the [001] direction, radiation was observed connected with annihilation of the excitonic molecules marked in Fig. 3 by the symbol M_1^{TO}. However, besides this known molecular-radiation band[12] we observed a new radiation band M_3^{TO}, which appeared simultaneously with the M_1^{TO} band at temperatures below 2.2 K and shifted towards lower energies by approximately 2 MeV relative to the peak of the emission of the "hot" excitons.[12] In its spectral position, the band M_3^{TO} corresponds to annihilation of excitonic molecules in which at least one electron is coupled with the upper branches of the split conduction band. It is also seen from Fig. 3 that the intensity of the exciton radiation, which is proportional to their concentration, is approximately one-eighth as large for the hot excitons B_3^{TO} than for the "cold" excitons B_1^{TO}. Taking into account the bimolecular law of binding of excitons into molecules, one should expect the intensity of the M_3^{TO} to be smaller by a factor of 60–70 than the intensity of the M_1^{TO} band, if the hot molecules are produced only out of hot excitons. It is seen from Fig. 3, however, that the intensity of the M_3^{TO} and M_1^{TO} bands differ by not 20 times. From this we can conclude that the M_3^{TO} band is due at least in part to annihilation of the molecules produced on account of the binding of hot and cold excitons. Thus, the excitonic molecules in silicon can contain electrons belonging to different branches of the conduction band.[14]

TABLE I.

Transition	Degree of polarization, %			
	TO		*LO*	
	Calculation $c=0.5$	Experiment	Calculation $d=-0.2$	Experiment
$A_1(^1/_2)$	27	17	21	20
$A_2(^3/_2)$	−33	−23	−24	−15
$B_1(^1/_2)$	−78	−50	−72	−50
$B_2(^3/_2)$	100	76	−100	−70
$B_3(^1/_2)$	−6	−4	78	60
$B_4(^3/_2)$	23	20	−100	−70

TABLE II.

Transition	I_{TO}/I_{LO}	
	Calculation $c=0.5$ $d=-0.2$	Experiment
B_1	19	21
B_2	2.4*	2.4
B_3	2.3	2.3
B_4	15	12
A_1	6	5.5
A_2	5.7	3.5

*The value of the ratio was taken from experiment.

4. MULTIPARTICLE EXCITON-IMPURITY COMPLEXES BOUND ON PHOSPHORUS ATOMS

Under the assumptions of the shell model,[2,3] the lines of the α series of the radiation of the complexes, which are bound on a simple donor in silicon, occur when an electron in the state $|\Gamma_1\rangle$ combines with a hole in the state $|\Gamma_8\rangle$. Uniaxial deformation of the crystal lowers the symmetry and causes partial lifting of the degeneracy of the electron and hole states in the complexes (Fig. 4). Thus, the fourfold degenerate state $|\Gamma_8\rangle$ splits

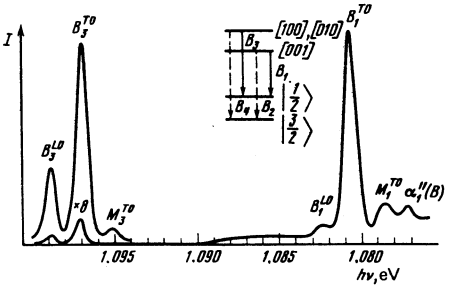

FIG. 3. Emission spectrum of pure silicon at 2 K compressed along the [001] axis, $P=2100$ kg/cm^2.

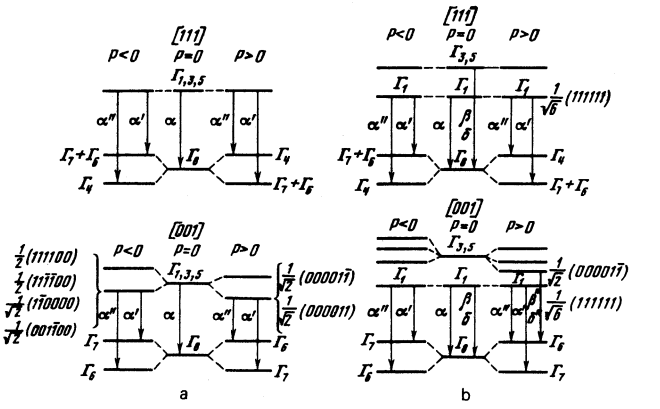

FIG. 4. Splitting of states of MIPC bound on a simple acceptor (a) and donor (b) in silicon under uniaxial tension ($P<0$) and compression ($P>0$) along the axes [111] and [001].

into two doublet states.[15] In the case of deformation in the [111] direction, the wave functions of these doublets are transformed in accordance with the representations Γ_4 and $\Gamma_6+\Gamma_7$. As the basis functions of these representations one can choose the wave functions of the holes at the vertex of the valence band, which is split by the deformation[15]:

$$|\psi_1\rangle=\frac{1}{\sqrt{6}}\left\{-(1+i)\left|\frac{3}{2}\right\rangle+\sqrt{3}\left|\frac{1}{2}\right\rangle+i\left|-\frac{3}{2}\right\rangle\right\},\quad \psi_2=K\psi_1 \text{ for } \Gamma_4;$$
$$|\psi_3\rangle=\frac{1}{\sqrt{6}}\left\{-(1+i)\left|\frac{3}{2}\right\rangle-\sqrt{3}\left|\frac{1}{2}\right\rangle+i\left|-\frac{3}{2}\right\rangle\right\},\quad \psi_4=K\psi_3 \text{ for } \Gamma_6+\Gamma_7. \tag{1}$$

Here K is the time reversal operator, and

$$|m\rangle=\begin{cases}|\pm 1/2\rangle\\ |\pm 3/2\rangle\end{cases}$$

is the Luttinger-Kohn basis. Analogously, in deformation in the [001] direction, the wave functions of the doublets are transformed accordance with the representations Γ_7 and Γ_6, and can be chosen in the form

$$|\pm 1/2\rangle \text{ for } \Gamma_7 \text{ and } |\pm 3/2\rangle \text{ for } \Gamma_6. \tag{2}$$

The form of the wave functions of the lower electronic states under the deformations is indicated in Fig. 4. At large deformations along [001], the state Γ_3 becomes mixed with the state Γ_1.[15]

The probability of phononless optical transitions from the state $|\Gamma_1\rangle$ into the states (1) and (2) is determined by matrix elements of the form

$$\langle\Gamma_i S_z|\mathbf{epK}|m\rangle,$$

where S_z is the projection of the electron spin on the [001] direction, **p** is the momentum operator, and **e** is the unit vector of the radiation polarization. Thus, $e_\perp=\{100\}$, $e_\parallel=\{001\}$ for deformation in the [001] direction and $e_\perp=6^{-1/2}\{11\bar{2}\}$, $e_\parallel=3^{-1/2}\{111\}$ for the [111] direction. After calculating these matrix elements, we calculated the degrees of polarization of the emission lines α'' (recombination of a hole in a state with angular momentum 1/2) and α' (recombination of a hole in a state with angular momentum 3/2), and also the intensity of the ratio of the lines α'' and α' for the doublets α_3 and α_4 with account taken of the populations of the hole states. The values calculated in this manner are listed in Table III.

TABLE III.

Direction	Sign of deformation	Line	Degree of polarization, %		Ratio of intensities $I(\alpha')/I(\alpha')$	
			Calculation	Experiment	Calculation	Experiment
[111]	$P>0$	α_1''	60	45	–	–
		α_2''	»	41	–	–
		α_3''	»	36	3.3	2.2–2.4
		α_4''	»	–	1.67	1.6
	$P<0$	α_1'	–100	–70	–	–
		α_2'	»	–70	–	–
		α_3'	»	–	0.83	0.9
		α_4'	»	–	1.67	1.4–1.6
[001]	$P>0$	α_1''	60	42	–	–
		α_2''	»	38	–	–
		α_3''	»	33	3.3	2.9–3.5
		α_4''	»	–	1.67	1.4–1.6
	$P<0$	α_1'	–100	–62	–	–
		α_2'	»	–58	–	–
		α_3'	»	–64	0.83	0.7–0.75
		α_4'	»	–	1.67	1.3–1.4

The spectrum and polarization of the radiation of MEIC bound on phosphorus atoms, in uniaxial tension and compression deformation of silicon, are shown in Fig. 5 for the [111] direction and in Fig. 6 for [001].[1)] It is seen from the figures that for each deformation the polarization of the no-phonon components (NP) of the lines α'' and α' is oppositely directed and is approximately the same for all doublets of the α series. The degree of polarization of the α'' lines increases somewhat with increasing compression in the [001] direction. For a comparison of the experimental values of the degree of polarization with the calculated ones, used only the intensities of the lines α_1, α_2, and α_3 for both polarization directions, since the accuracy with which the doublets α_4 were recorded was insufficient. In addition, we used data obtained in the region of relatively low deformations in the [001] direction, for in this case it is possible to neglect the "intermixing" of the state Γ_3 with the state Γ_1, which was not taken into account in the calculation of the NP component intensity. A comparison of the experimental values of the degree of polarization with the calculated ones is given in Table III. It is seen from the table that the experimental values are 1.3–1.6 times less than the calculated ones,

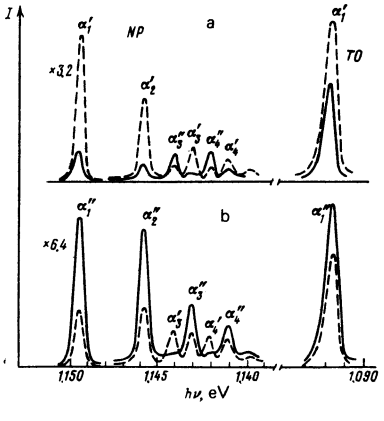

FIG. 5. Spectral distribution of *NP* and *TO* components of the emission of MEIC bound on atoms of phosphorus in silicon at 2 K, polarized parallel (solid line) and perpendicular (dashed) to the direction of deformation along the [111] axis: a—tension, $P=-275$ kg/cm^2, b—compression, $P=275$ kg/cm^2.

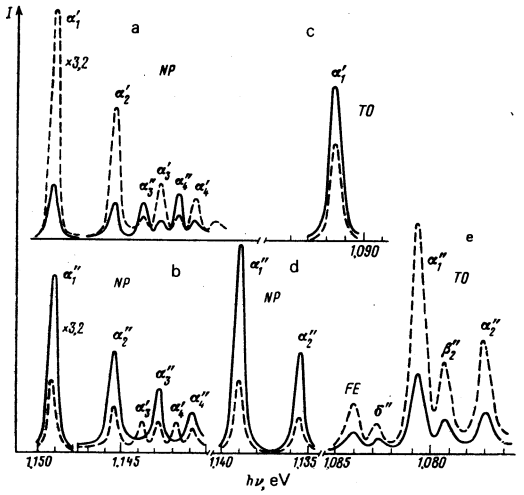

FIG. 6. Spectral distribution of the emission of MEIC bound on phosphorus atoms in silicon at 2 K, polarized paralled (solid line) and perpendicular (dashed) to the direction of deformation along the [001] axis: tension, $P=-250$ kg/cm^2, a) *NP* component, c) *TO* component; compression: b) $P=250$ kg/cm^2, *NP* component, $P=2000$ kg/cm^2, d) *NP* component, e) *TO* component.

i.e., the difference lies within the limits of the probable values of the depolarization factor of the radiation. In the same Table III are given the experimental values of the ratio of the intensities of the lines α'' and α' for the doublets α_3 and α_4. When account is taken of the populations of the hole states of the complexes, these values are also in satisfactory agreement with the calculated ones.

The influence of the population of the hole states on the intensity of the components α' and α'' is clearly demonstrated in Fig. 7. As seen from Fig. 4, the reversal of the sign of the deformation leads to a change in the angular momentum of the holes in the upper and lower states of the complexes. In the complex with four holes, $MEIC_4$, there are two holes in each state, while in the complex with three holes, $MEIC_3$, two holes are in the upper state and one in the lower. It is seen from Fig. 7 that the ratio of the intensities of the lines α_4' and α_4'' is close to unity and does not change when the sign

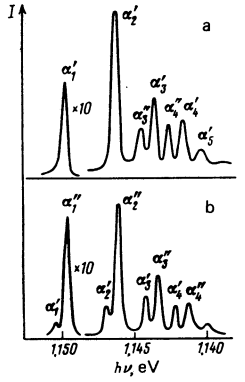

FIG. 7. *NP* component of the emission spectrum of MEIC bound on phosphorus atoms in silicon under uniaxial deformation along the [111] axis: a—tension, $P=-275$ kg/cm^2, 2 K; b—compression, $P=275$ kg/cm^2, 4.2 K.

of the deformation is reversed. On the other hand the ratio of the intensities of the lines α_3' and α_3'' is reversed when the sign of P is reversed. The intensity of the transition corresponding to the recombination of the holes from the upper state is approximately double the intensity corresponding to recombination of holes from the lower state. Such a redistribution of the intensities demonstrates the change of the populations of the hole states with different angular momenta with changing sign of the deformation.

In the case of recombination of the electrons and the holes in the complexes with participation of phonons, the situation turns out to be substantially different than in the no-phonon optical transitions. Emission of a definite phonon with quasimomentum corresponding to one of the valleys of the conduction band "selects" only those components of the wave function which describes the electronic state in the complex, which correspond to the same valley. Therefore in the calculation of the intensity of the phonon transition we summed the intensities (and not the matrix elements) corresponding to each component of the wave functions pertaining to a definite valley. This makes it possible to use the results of a transition-intensity calculation performed for free excitons.[10,11]

In the case of deformation along [111], the electronic states of the complexes are not split. The initial electronic state $|\Gamma_1\rangle$ for transitions of the α series includes in identical fashion the wave functions of all six valleys of the conduction band, which in the case of phonon transitions is perfectly analogous to the case of the free exciton. Therefore the *TO* components of the emission of the complexes α'' and α', which are produced in the case of recombination of the holes from the state (1), should be polarized in the same way as the *TO* components of the emission of the free excitons A_1 and A_2.[2)] A comparison of the so-calculated degree of polarization of the radiation of the complexes with the experimental values obtained from Fig. 5 is given in Table IV.

At small deformations in the [001] direction, when the admixture of the state Γ_3 to Γ_1 can be neglected, the intensity of the α'' lines can be represented as a sum of the intensities of the exciton transitions B_1 and B_3, while the intensity of the α' line can be represented as the sum of the intensities B_2 and B_4 (see Figs. 2 and 4). A comparison of the calculated and experimentally determined degree of polarization for this case is also given in Table IV.

With increasing deformation in the [001] direction, when the splitting of the conduction band is large enough,

TABLE IV.

Direction	Sign and magnitude of deformation		line	Degree of polarization, %	
				Calculation	Experiment
[111]	$P>0$		α_1''	27	20
	$P<0$		α_1'	−33	−23
[001]	$P>0$	small	α_1''	−43	−31
		large	α_1''	−78	−50
		large	β_2''	−78	−50
		large	δ''	−78	−50
	$P<0$		α_1'	33	22

the lower electronic state in the complex should include only the wave functions of the lower valleys. This qualitative reasoning is confirmed by the analogy with a simple donor in silicon,[15] when the admixture of the state Γ_3 to the state Γ_1 leads to formation of a wave function of the type $2^{-1/2}|000011\rangle$. Thus, at large deformations, the *TO* components of the radiation of the complexes α_1'' and α_2'' should be polarized in the same way as the *TO* component of the radiation of the free exciton B_1. The emission lines β_2'' and δ'' should be similarly polarized, since the initial electronic state for transitions of this type, even at small deformations, is the state with symmetry Γ_5 (Fig. 4). The degree of polarization of the lines α_1'', α_2'', β_2'' and δ'', calculated in this manner and determined from Fig. 6, is shown in the same Table IV.

It is thus clear from Tables III and IV that the experimental values of the degree of polarization of a number of emission lines of MEIC bound on phosphorus atoms, for both *NP* and *TO* components of the spectrum, agree with the calculated values accurate to the radiation depolarization factor 1.3–1.6. The ratio of the intensities of α'' and α' in the doublets are also in satisfactory agreement with calculation.

5. MULTIPARTICLE EXCITON-IMPURITY COMPLEXES BOUND ON BORON ATOMS

In MEIC bound on acceptors in silicons, the electron shells are located far enough from the impurity ion, so that the electronic states Γ_1, Γ_3, and Γ_5 in the absence of deformations should not be split.[2,3] This manifests itself in particular in the fact that the shift of the spectral emission lines of the MEIC bound on boron atoms depends linearly on the applied pressure for both the

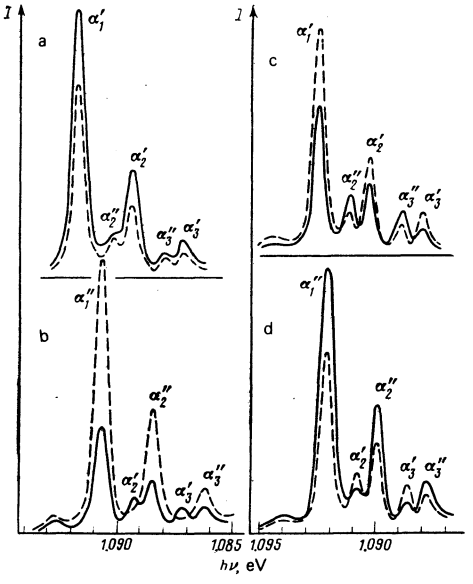

FIG. 8. Spectral distribution of *TO* component of the emission of MEIC bound on boron atoms in silicon at 2 K, polarized parallel (solid line) and perpendicular (dashed) to the direction of deformation along the [001] axis: a—tension, $P=-220$ kg/cm^2, b—compression, $P=220$ kg/cm^2; along the [111] axis: c—tension, $P=-260$ kg/cm^2; d—compression, $P=260$ kg/cm^2.

TABLE V.

Direction	Sign of deformation	Line	Degree of polarization, %		Ratio of intensities $I(\alpha_2'')/I(\alpha_3'')$	
			Calculation	Experiment	Calculation	Experiment
[111]	$P>0$	α_1''	27	19	1.2	1–1.2
		α_2''	»	17		
	$P<0$	α_2'	−33	−21		
		α_2'	»	−17		
[001]	$P>0$	α_1''	−78	−47	3	2.7
		α_2''	»	−41		
		α_2'	100	>50		
	$P<0$	α_1'	23	17	0.43	0.5
		α_2'	»	18		
		α_2''	−6	small		

[111] and [001] direction.[5,17]

The deformation of the crystals in the [111] direction does not lead to a splitting of the electronic states whose aggregate, in phonon transitions, is equivalent to the state Γ_1 (Fig. 4). Therefore the emission lines α'' should be polarized like the A_1 lines, and α' like the A_2 lines of the free electron. The spectrum and the polarization of the emission of MEIC bound on boron atoms are shown in Fig. 8. A comparison of the experimental and calculated values of the degree of polarization is given in Table V. In the same table are presented the experimental and calculated values of the ratios of the intensities of the lines α_3'' and α_3'. The table shows the sufficiently good agreement of the experimental values with the calculations.

In the case of deformations in the [001] direction, the electronic states of the complexes bound on the acceptors are split. Upon compression, the lower states are the electronic ones, which include the Bloch functions of only the lower valleys of the conduction band. Therefore the emission lines α'' and α' should be polarized like the B_1 and B_2 exciton lines, respectively. In the case of tension along [001], the aggregate of the wave functions of the lower electronic states also gives the relative transition probabilities equivalent to the excitonic ones, so that the polarization of the α' lines corresponds to the polarization of the B_4 line, while that of α'' corresponds to B_3. Comparison of the experimental values of the degree of polarization of the emission of MEIC bound on boron atoms in the case of deformations in the [001] direction (Fig. 8), with the results of the calculation, is given in Table V. The same table indicates the calculated and the experimental values of the ratios of the intensities of the emission lines α_3'' and α_3'.

We note that the circular polarization of the emission of MEIC bound on boron atoms in silicon in strong magnetic fields[18] is also explainable on the basis of general symmetry considerations.

6. CONCLUSION

The results of the present paper have made it possible to compare in sufficient detail the polarization of the MEIC emission lines bound on phosphorus and boron atoms in uniaxially deformed silicon, with the results of a calculation performed under the assumptions of the shell model of the complexes.[2,3] It must be emphasized that the polarization of the radiation is directly con-

nected with the symmetry of the wave functions of the initial and final electronic states. In turn, the choice of the symmetry of the electronic states is determined by the principle of the construction of the shell model of the complexes. We have therefore chosen in the calculation Bloch-function combinations analogous to the combinations that describe the electronic states in a simple donor or acceptor under uniaxial deformation of silicon,[15] in accordance with the assumptions of the shell model. We note also that the constants that determine the contribution of the different intermediate states in radiative decay of MEIC with emission of phonons were determined on the basis of an analysis of the polarization of the free-exciton radiation. Despite the approximate character of the assumptions on which the calculation is based, good agreement was obtained with experiment for practically all the emission lines of the MEIC both under compression and in tension of silicon in the directions [111] and [001]. We regard this agreement as an important confirmation of the validity of the shell model of multiparticle exciton-impurity complexes.

[1)]Owing to the authors' error, the sign of the polarization of the *NP* component of the radiation of MEIC bound on phosphorus and silicon atoms, deformed in the [001] direction, is given incorrectly in Ref. 16.

[2)]Naturally, an investigation of the polarization of the radiation of free and bound excitons for the same samples would make it possible to eliminate the lack of constancy of the depolarization factor. However, an analysis of the polarization of exciton radiation of samples of doped silicon is not reliable, since the intensity of this radiation is low. Therefore the comparison was made with the exciton radiation of pure silicon.

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Translated by J. G. Adashko