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ZEEMAN SPLITTING OF GROUND AND EXCITED IMPURITY STATES IN ZnTe

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The selective pair luminescence of donor-acceptor pairs in ZnTe has been investigated in an external magnetic field. A detailed study of the polarization-dependent absorption and emission of photons by donor-acceptor pairs yields simultaneously the Zeeman g-values of ground and excited states of donors and acceptors. The selection rules for absorption and emission of photons by the axial donor-acceptor complex are discussed.

The Zeeman g-values for the 1S-ground and the 2S-excited state of the Li-acceptor in ZnTe are determined with selective pair luminescence (SPL). In an SPL-experiment, neutral donor-acceptor pairs with one partner in an excited state are created by absorption of monoenergetic photons of energy $\hbar\omega_p < E_{gap}$. The carriers in the excited states relax to the impurity ground state, and after a time τ, the donor-acceptor pairs recombine radiatively. The energy $\hbar\omega_\ell$ of the luminescence photons depends on the binding energies of the donor and the acceptor, and on the pair separation R_{DA} [1].

An external magnetic field causes a splitting of the impurity levels according to the symmetries of the electron and hole wave functions. If a pair with separation R_{DA} is excited, $\hbar\omega_\ell$ is given by

$$\hbar\omega_\ell = E_{gap} - E_{A^m} - E_{D^n} + \frac{e^2}{\varepsilon R_{DA}} , \qquad (1)$$

where E_{X^i} represents the i-th state of the impurity X. If a magnetic field is present, E_{X^i} corresponds to one of the subcomponents of a ground or excited state. In Fig.(1a), the energy $\hbar\omega_p$ necessary for the creation of a donor/excited acceptor pair is drawn as a function of pair separation R_{DA}. The Coulomb term in Eq.(1) leads to an increase of this energy with decreasing pair separation. In Fig.(1a), $\hbar\omega_p$ is chosen such that donor-acceptor pairs can be created, with the acceptor hole excited to the 2S-state. Due to the Zeeman splitting of the donor state into two components (symmetry Γ_6) and of the acceptor state into four components (symmetry Γ_8), Eq.(1) is fulfilled for eight pair separations R^i_{DA}, i=1,..,8, as indicated in Fig.(1a) by filled

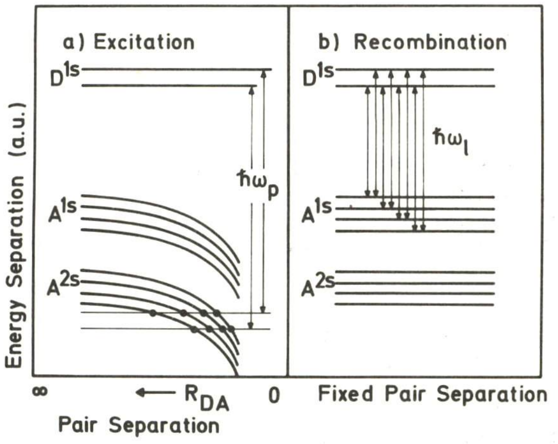

Fig.1 Schematic of the SPL process in an external magnetic field: (a) illustrates the absorption process of a photon by a donor-acceptor pair, (b) the recombination of a pair by emission of a photon

circles. The holes relax to the 1S-acceptor ground state in a short time compared to τ . Electrons and holes thermalize between the subcomponents of the donor and acceptor ground states. After the pair lifetime τ , recombination takes place between the ground states. Eight transitions $\hbar\omega_{\ell}{}^{i,j}$, $j = 1,..,8$, are possible for any given donor-acceptor pair separation R^{i}_{DA} , as shown in Fig.(1b).

A total of $64 = 8 \times 8$ luminescence energies $\hbar\omega_{\ell}{}^{i,j}$ result from the eight values R^{i}_{DA} in the pair excitation process, and from the eight possible transitions in the recombination process. This number is reduced if selection rules for the absorption and emission of photons by the donor-acceptor pair are taken into account. Dipole selection rules have been found to describe optical transitions in the vicinity of a single impurity center [2,3], e.g. free-to-bound transitions and bound exciton recombination. Figure (2) demonstrates that selection rules are also strictly valid for the recombination of an electron bound to a donor with a hole bound to an acceptor. A large field-dependent difference in the intensities between the σ^+ and σ^- components in the Faraday configuration ($\vec{k} \perp \vec{B}$) is observed. The spectra in Fig.(3) show that the selection rules are

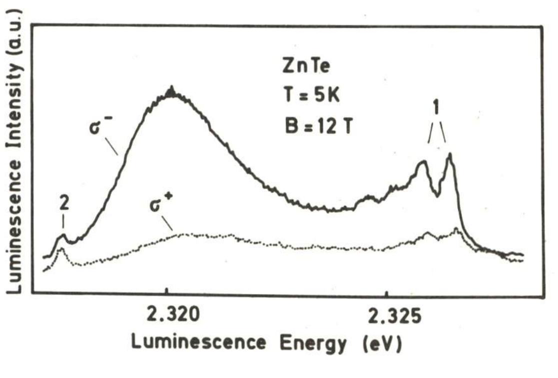

Fig.2 SPL-spectra in ZnTe at 12 T: The two circular polarizations of the luminescence light in the Faraday configuration are shown. "1" corresponds to the 1S-2S transition of the Li-acceptor. "2" is the 2 LO phonon replica of the laser line. In this measurement, the pump photons are unpolarized

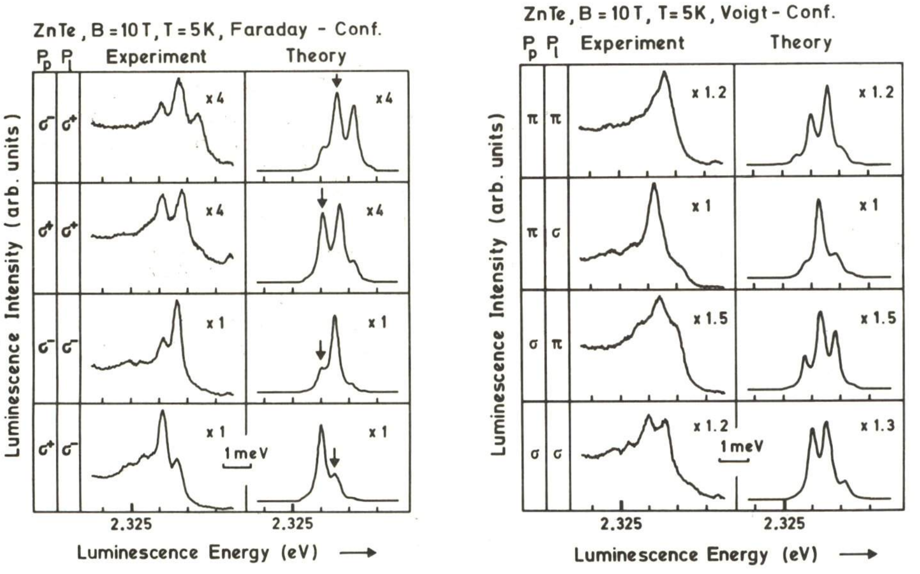

Fig.3 Comparison of experimental and theoretical SPL-spectra of the 1S-2S transition of the Li-acceptor in Faraday configuration (left picture) and Voigt configuration (right picture): P_p and P_ℓ indicate the polarizations of the pump photons and of the luminescence photons. The excitation energy is 2.370 eV. Arrows in the theoretical spectra mark peaks which are due to mixing

also valid in the pair excitation process, since the spectra depend on the polarizations of both the pump photons and the luminescence photons.

Experiments have been performed on the SPL-line of the Li-acceptor 1S-2S transition in the Faraday ($\vec{k} \perp \vec{B}$) and Voigt ($\vec{k} \parallel \vec{B}$) configurations. The results for different circular and linear polarizations for both configurations are shown in Fig.(3) for a magnetic field of 1o T. One observes a splitting of the SPL-line that depends linearly on the applied field. At high magnetic fields, the intensity of the σ^+ Faraday lines is much lower than the intensity of the σ^- lines. The intensity of the pairband is found to depend on the polarization of the luminescence photons in the same way as the SPL-lines, as can be seen in Fig.(2).

The SPL-spectra in the presence of a magnetic field have been calculated to obtain the Zeeman g-values from a comparison between measured and calculated spectra. On the basis of dipole selection rules for the absorption and emission of photons, the luminescence energies $\hbar\omega_\ell^{i,j}$ and the corresponding intensities of the components have been deduced. The theory of acceptor states in a magnetic field is derived in Refs.[4-6]. The g-value of the donor-bound electron is treated as an input parameter. We use g_e = +o.4

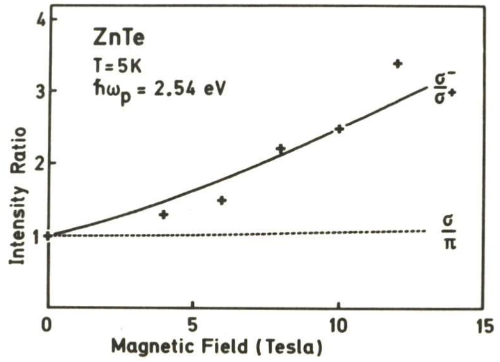

Fig.4 Intensity ratio of the σ^+ and σ^- components of the luminescence light of the Li-pairband in Faraday configuration, and between the π and σ components in Voigt configuration: Crosses are experimental results in Faraday configuration. In Voigt configuration, no difference between π and σ could be detected

from Ref.[7]. The sign of g_e is discussed in Ref.[8]. With this g-value for the donor electron the following parameters for the Li-acceptor in ZnTe have been obtained:

1S-state: $g_{3/2} = +0.56 \pm 0.05$
$g_{1/2} = +0.52 \pm 0.10$
2S-state: $g_{3/2} = +0.42 \pm 0.05$
$g_{1/2} = +0.43 \pm 0.10$

The diamagnetic splitting was found to be negligible. This result is similar to results found in GaP [6] and GaAs [2]. Best agreement between experimental and theoretical spectra was obtained for a mixing of approximately 20 % between different substates.

A photoluminescence experiment with excitation above the band gap is a test for the correctness of the derived parameters. In this experiment, the luminescence photons record the Zeeman properties of the ground states of donor and acceptor. Figure (4) shows a comparison between measured and calculated intensity ratios of the pair band maxima of different photon polarizations as a function of the magnetic field. Good agreement is found between experimental results and theoretical curves calculated on the basis of the parameters from the SPL measurements.

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