Magnetospectroscopy of the C line of Be in GaAs

R. A. Lewis[a], Y.-J. Wang[b] and M. Henini[c]

[a] *Institute for Superconducting and Electronic Materials, University of Wollongong,*
Wollongong NSW 2522, Australia
[b] *National High Magnetic Field Laboratory, Tallahassee, Florida 32310, USA*
[c] *School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, UK*

Photothermal ionization spectra (PTIS) of the C line of Be acceptor impurity in GaAs permit the full determination of the splitting of the field-induced components of the ground state and of the third excited state. This enables the g factors g_1, g_2 and g^C to be determined reliably. At high magnetic field a new feature appears in the vicinity of the C line. This moves in energy rapidly with field and is thought to originate in valence band Landau levels.

1. Introduction

The optical transition from the ground state of the Be acceptor impurity in GaAs to the third excited state of odd parity, denoted $1\Gamma_8^+ \rightarrow 1\Gamma_7^-$, is known as the C line and has energy of 22.6 meV [1]. The final state of the C line is particularly interesting in the case of the GaAs host as it is separated by a large amount, 0.44 meV [2], from the next nearest final state, $3\Gamma_8^-$. This relatively wide separation of adjacent states considerably simplifies the spectrum compared to that of other impurity systems. For example, for Zn^- acceptors in Ge the C-line manifold involves at least components of final states $1\Gamma_7^-$, $3\Gamma_8^-$, $3\Gamma_8^+$ and $4\Gamma_8^+$, as deduced from piezospectroscopy [3]. Examination of the transitions from the four-fold initial state to the relatively simple two-fold final state allows detailed information to be obtained on both initial and final states. We have used photo-thermal ionisation spectroscopy to obtain spectra with the electric field of the radiation both perpendicular to and parallel to the magnetic field, which completely determine the magnetic-field splitting of the initial and final states. This information is valuable in the interpretation of other spectral features, for example the G and the D lines, and their dependence on magnetic field. At much higher fields (> 15 T) new features emerge in the region of the C line that are tentatively attributed to the transitions conventionally labelled (8,7), (7,8), (5,8) [4], and to a new transition.

2. Experimental details

Samples used in these experiments were 4 μm thick and grown by molecular-beam epitaxy on 450-μm–thick <100> GaAs substrates. The acceptor Be was introduced at a concentration of 1.5×10^{15} atoms cm^{-3}. The samples were wedged to suppress optical interference between the front and back faces. Detailed far-infrared absorption spectra for these samples have been published previously [1]. Measurements were made using two Fourier spectrometers equipped with globar light sources and liquid-helium-cooled Si bolometer detectors. For low magnetic fields (< 7 T) a split-pair superconducting magnet was employed in the Voigt configuration which permitted data to be collected for both $\mathbf{E} \parallel \mathbf{B}$ and $\mathbf{E} \perp \mathbf{B}$. The temperature was adjusted during the PTIS experiment and was found to be optimum in the range 16-18 K. Measurements at high magnetic field were made in both a 17.5 T superconducting magnet and a 30 T resistive magnet. The light was conducted to the sample at field centre by a metal light pipe and a condenser cone. Measurements were made with the magnetic field parallel to the direction of light propagation (Faraday configuration) using nominally unpolarized radiation; in this geometry, $\mathbf{E} \perp \mathbf{B}$.

3. Results and discussion

The chief results of this study are presented in Fig. 1. Transitions are labelled as in Ref. [4].

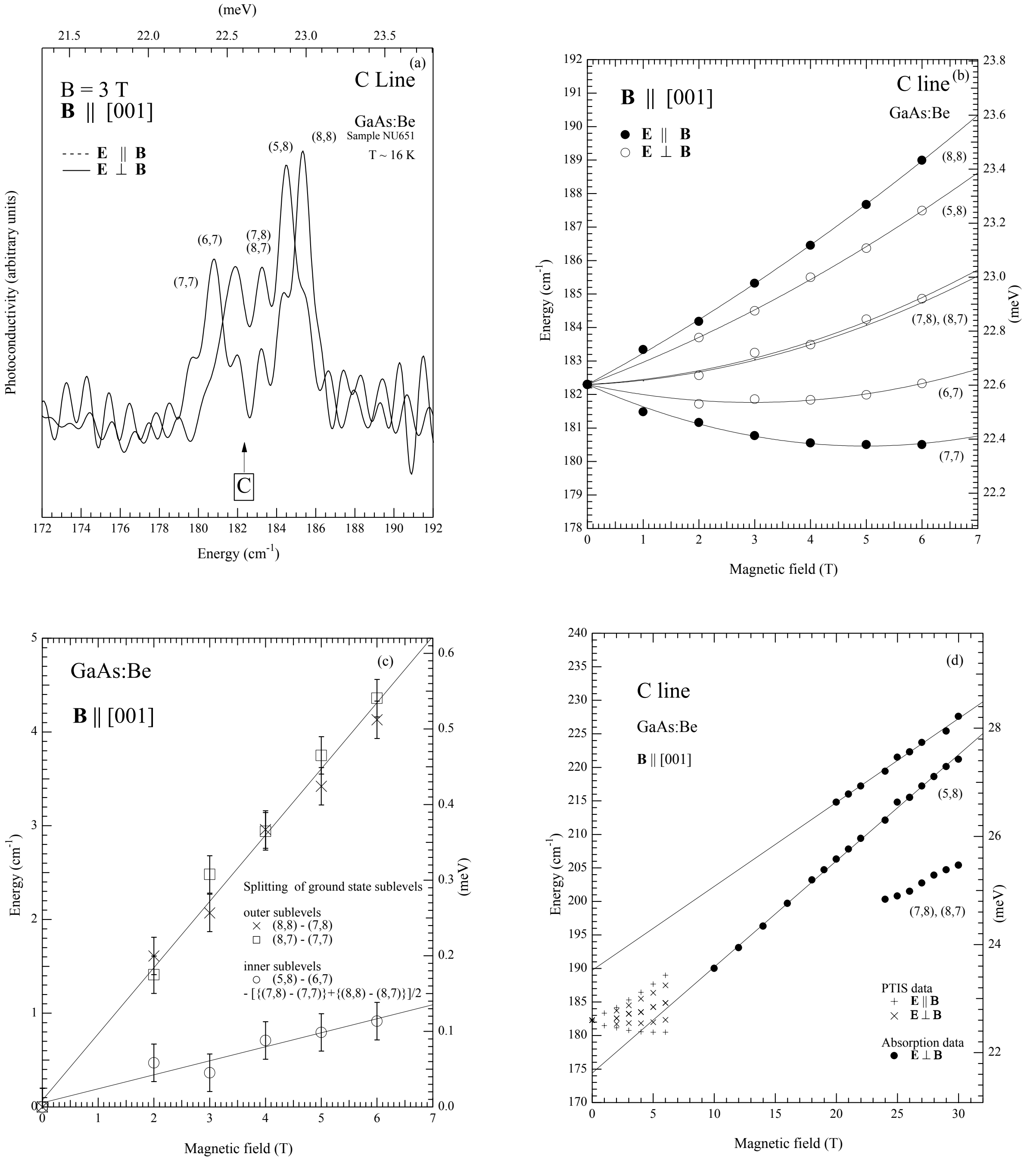

Fig. 1. Spectroscopy of Be impurity in GaAs. (a) PTIS for two orientations of the electric field vector of the radiation. (b) Fan diagram showing splitting of the C line. (c) Magnetic-field splitting of the ground and excited states as deduced from the data in (b). (d) High-field absorption data (with low field PTIS data for reference).

The selection rules in this case permit two transitions for **E** || **B** and four for **E** ⊥ **B**. All but one of these transitions is resolved, and the disposition of the observed transitions allows a reliable determination of the splitting of both the ground state and the excited state.

Fig. 1(a) shows the PTIS spectra. For all fields 1 T < B < 6 T, the **E** || **B** spectra exhibit two components, as expected. For **E** ⊥ **B** and 2 T < B < 6 T, three components only are consistently observed, whereas the selection rules permit four.

The positions of the peaks are plotted against magnetic field in Fig. 1(b). The data are well described by second-order polynomials with B, as indicated. The two transitions expected on the basis of the selection rules for **E** || **B** are the highest and the lowest energy transitions. In attempting to locate the missing **E** ⊥ **B** transition, it is noted that the average energy of sublevels that differ only in quantum number m will be the same. The average energy of the **E** || **B** transitions should coincide with the average energy of the **E** ⊥ **B** transitions at any given field. The average energy of the two **E** || **B** transitions is indicated by the dashed line and is seen to coincide with the intermediate of the three transitions observed for **E** ⊥ **B**. This immediately suggests that the observed intermediate energy transition for **E** ⊥ **B** is the superposition of two unresolved transitions. The symmetric disposition of the higher and lower energy transitions for **E** ⊥ **B** is also consistent with the "missing" fourth transition coinciding with the intermediate-energy transition observed. Two transitions will coincide in the way proposed if two of the sublevels of the ground state separate with magnetic field at the same rate as do the two sublevels of the excited state. Given this interpretation we may now obtain the splittings of all the components of the ground state and the excited state, as shown in Fig. 1(c).

Absorption measurements at high magnetic fields are presented in Fig. 1(d). The most prominent transition is the line identified as the (5,8) transition. This identification is on the basis of the low field PTIS data, also shown in the figure. The second most prominent transition is identified as the coincident lines (8,7) and (7,8). Even at high field these two transitions are not separated. Another distinctive line appears at high energy. The slope of the line position plotted against magnetic field, and the identification of the transitions made above, mean it is unlikely to arise from the C line. It is presumed to arise from the next state, $3\Gamma_8^-$. The g factors deduced from this data are given in Table 1.

Table 1. g factors for the states associated with the C line for Be in GaAs.

state	g factor	value
$1\Gamma_8^+$	g_1	+0.30±0.05
$1\Gamma_8^+$	g_2	+0.09±0.03
$1\Gamma_7^-$	g^C	+1.51±0.03

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