Zeeman Spectra of Boron in Germanium at High Magnetic Fields

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Introduction

Previous Zeeman studies of group III impurities in Ge have been carried out at high resolution with magnetic fields up to 7 T [1 – 8]. All these observations were in the Voigt configuration using linearly polarised radiation and showed that the behaviour of the excited states is essentially the same for all five shallow acceptors (B, Al, Ga, In, Tl) while that of the ground states is different. Observations have been made with **B**||<100> and <111>; for aluminium, spectra with **B**||<110> were also examined [8]. Two definitive calculations have been made [9, 10], one [9] for **B**||<100> and <111>, up to 5 T and the other [10] for all three principal cubic directions (<100>, <110> and <111>) for B = |**B**| in the range 0 – 10 T. Reasonable

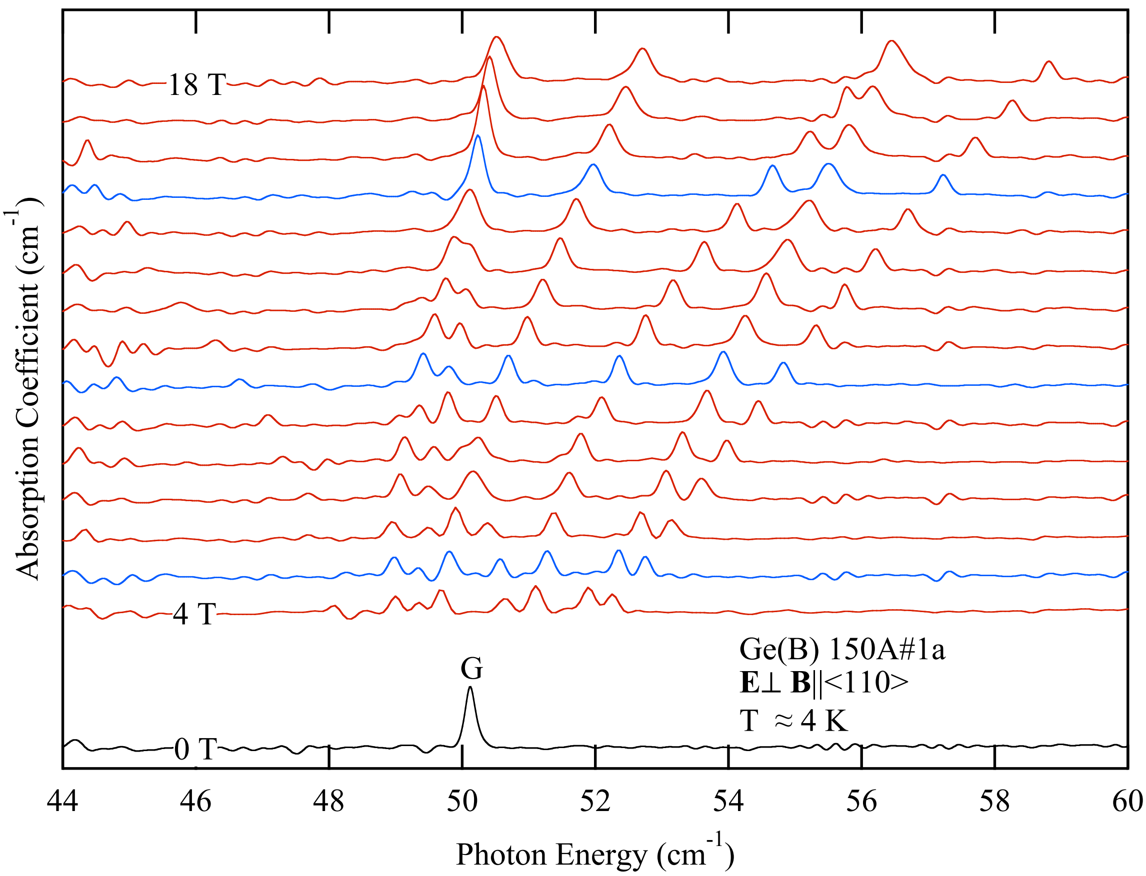

Fig 1. Zeeman spectra of the G line of Boron in Germanium in the Faraday configuration in intervals of 1 T. Unapodised resolution is 0.18 cm^{-1}.

agreement between theory and experiment has been obtained for the excited states but not for the ground states. We have now extended the experimental investigations for boron with **B**||<110> and B up to 18 T in the Faraday configuration.

Experimental Results and Discussion

The Zeeman components of the G line [11] of boron in Ge for **B**||<110> are shown in Fig. 1 for a number of values of B, while Fig. 2 gives the spectrum for B = 12 T on a magnified scale. These spectra were all obtained with an unapodised resolution of 0.18 cm^{-1}. In the Faraday configuration **E** is perpendicular to **B**, where **E** is the electric field of the far-infrared radiation. For **B**||<110>, the point group, O_h, of the unperturbed impurity reduces to C_{2h} and the irreducible representations of the fourfold degenerate impurity states, $\Gamma_8^{\pm}$, yield $2(\Gamma_3^{\pm} + \Gamma_4^{\pm})$ [9, 10], where the ± signs are parity labels. These two pairs of Zeeman states will be designated as 3.1, 3.2, and 4.1, 4.2. Transitions from the even-parity ground state to the odd-parity excited states are labelled by (i,f), where i, f = 3, 4 and the selection rules are i = f for **E**||**B** and i ≠ f for **E**⊥**B**. Thus eight components are allowed in the present case, all of which are observed. The labelling of the components in Fig. 2 follows the above notation, their identification being based on a comparison with the lower-field, higher-resolution studies for aluminium in Ge [8].

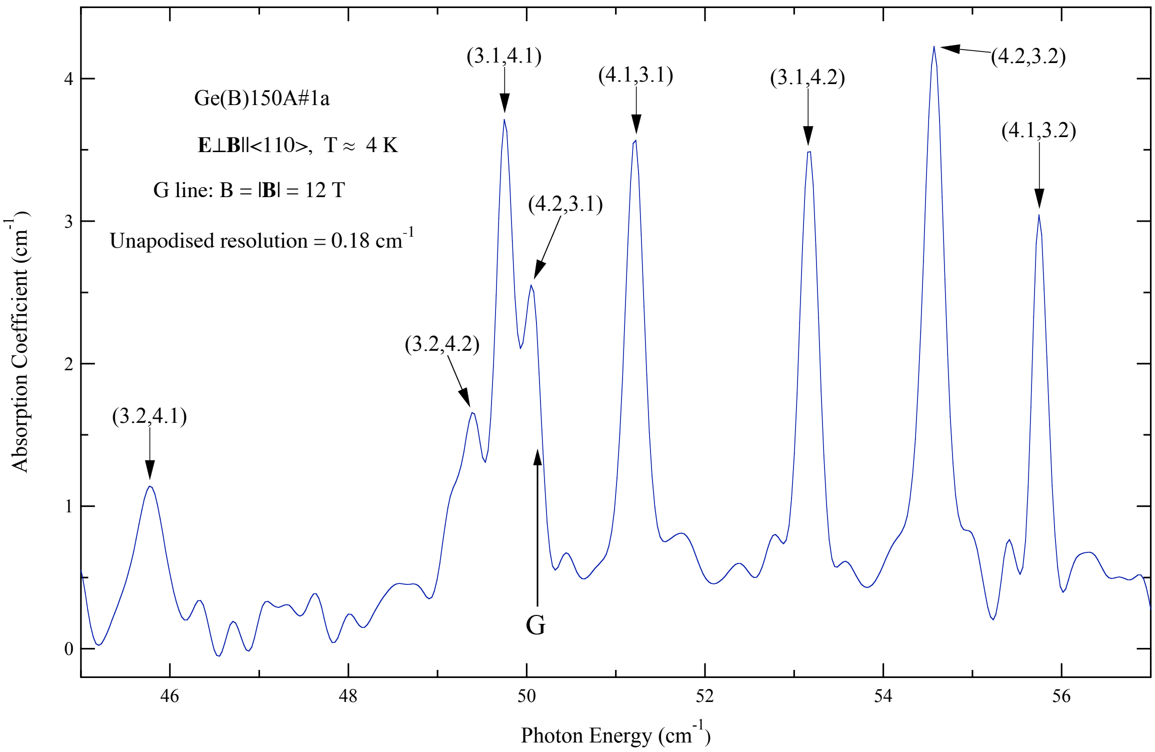

Fig 2. The Zeeman spectrum of the G line of Boron in Germanium at 12 T for **B**||<110> in the Faraday configuration.

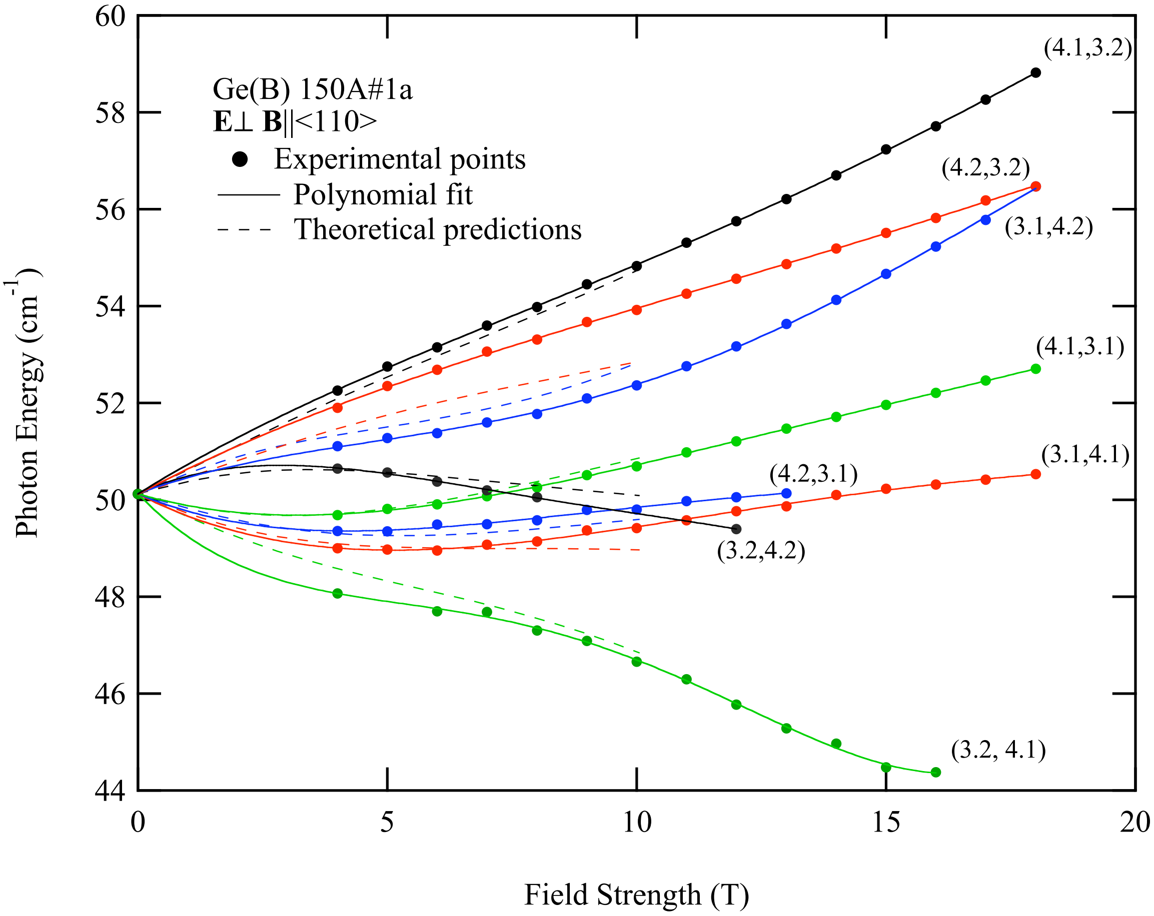

Fig 3. Dependence of the energies of the Zeeman components of the G line of Boron in Ge on magnetic field strength.

In Fig. 3 is given the dependence of the experimental energies of the G components on B. These results are represented by the data points through which the full curves are fitted. Also shown on this figure as dashed curves are the predictions of one of the calculations [10]. It is seen that qualitatively the predictions are in good agreement with the experimental results. However, quantitatively, the experimental and theoretical results for the transition (4.2,3.2) are significantly different.

Conclusions

The qualitative splittings of some of the states involved in the Zeeman spectrum of the G line can be recognised from the labels on the transitions in Figs. 2 and 3. Thus, it is seen that the splitting of the ground states $\Gamma_{3.1}^{+}$ and $\Gamma_{3.2}^{+}$ at large magnetic fields is comparable to the splitting of its excited-state counterparts $\Gamma_{3.1}^{-}$ and $\Gamma_{3.2}^{-}$ while this is not so for $\Gamma_{4.1}^{+}$ and $\Gamma_{4.2}^{+}$. The details of these splittings will be presented elsewhere along with the results of the analysis of the Zeeman data for the other lines obtained in the present studies.

Acknowledgements

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