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SELECTIVE LASER EXCITATION SPECTROSCOPY OF GALLIUM AND PHOSPHOROUS IN GERMANIUM

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ABSTRACT

Shallow impurity states of donors and acceptors in Ge have been investigated by far-infrared laser magnetospectroscopy. The Zeeman splitting of the impurity states produces resonant absorption of the laser radiation at certain magnetic fields. The data are compared to measurements made using a conventional spectrometer and good agreement is found.

1. INTRODUCTION

The energies associated with transitions between the energy states of shallow impurities correspond to photons that are found in the far infrared (FIR) region of the electromagnetic spectrum and so FIR methods are ideal for probing such energy states. Much has been learned through the use of conventional spectrometers, either of diffraction grating or Fourier transform variety [1]. Typically the spectroscopy is combined with a perturbation such as by magnetic field (Zeeman spectroscopy), uniaxial stress (piezo spectroscopy), or both [2].

An alternative method of spectroscopy viable under the application of a perturbation is FIR laser spectroscopy. In the experiments described below, photons of a fixed energy are directed onto a sample and the magnetic field varied. At certain fields resonant absorption occurs.

Laser spectroscopy contrasts with conventional spectroscopy in several ways. First, the laser is capable of producing much more power in a narrow bandwidth than a conventional FIR source (e.g. a globar). Second, the monochromatic nature of the laser means unwanted excitations, such as optical pumping or induced photoconductivity, are eliminated from the experiment. Third, achieving resonance by sweeping magnetic field at constant photon energy permits FIR spectroscopy using a laser to be carried out in pulsed magnetic fields which is not possible using swept-frequency spectrometers [3]; to perform spectroscopy in high magnetic fields a laser is mandatory. Fourth, because of the higher power of the laser, pumping to higher excited states is much more feasible than when using broadband sources. The opportunity for selective photoexcitation, accompanied by subsequent photoluminescence, then arises.

In this paper we describe preliminary experiments in FIR laser magnetospectroscopy of bulk Ge doped with Ga acceptor, but also containing residual P donor.

2. EXPERIMENTAL DETAILS

The source of radiation was an Edinburgh Instruments FIRL laser [4]. This comprises a mid-infrared CO₂ laser (9-11 μm , 40 W) that optically pumps a FIR cavity producing FIR radiation in the range 40-500 μm at powers of up to 120 mW. In the experiments to be described the laser lines were tuned to either 84.2 cm^{-1} (118.8 μm) or 103.6 cm^{-1} (96.5 μm). The magnet employed was a split-coil 7 tesla Oxford Instruments superconducting magnet. The split coil permits measurements with the direction of propagation of the radiation either parallel or perpendicular to the magnetic field. In these experiments the former orientation ("Faraday geometry") was used. In this case, the electric field vector of the radiation \mathbf{E} is perpendicular to the magnetic field \mathbf{B} . The crystal sample was arranged so that the [100] axis was parallel to both the incident laser beam and direction of the magnetic field. A DTGS room-temperature FIR detector was used to make absorption measurements. A helium-cooled Infrared Laboratories Inc. bolometer was placed at right angles to the laser beam along the sample [010] axis with a view to detecting selectively-excited photoluminescence. Using another sample, furnished with electrical contacts, magnetospectra have been obtained by photoconductivity [5]. In principle absorption, photoluminescence and photoconductivity data can be collected simultaneously, although to date only two of the three data channels have been used in a single run.

3. RESULTS AND DISCUSSION

The laser line was brought into resonance with the shallow gallium acceptor levels by sweeping the magnetic field while absorption measurements were made. Zeeman absorption measurements have been made on many acceptors in germanium using conventional spectroscopy and the main features we observe can be identified on this basis.

With the laser tuned to 84.2 cm^{-1} the A, B and C gallium acceptor lines came into resonance with the laser source as the magnetic field was scanned (Fig. 1). When 103.6 cm^{-1} was used for the excitation radiation, P impurity lines dominate the absorption (Fig. 2). These could be interpreted by conventional spectra [6] given in Fig. 3.

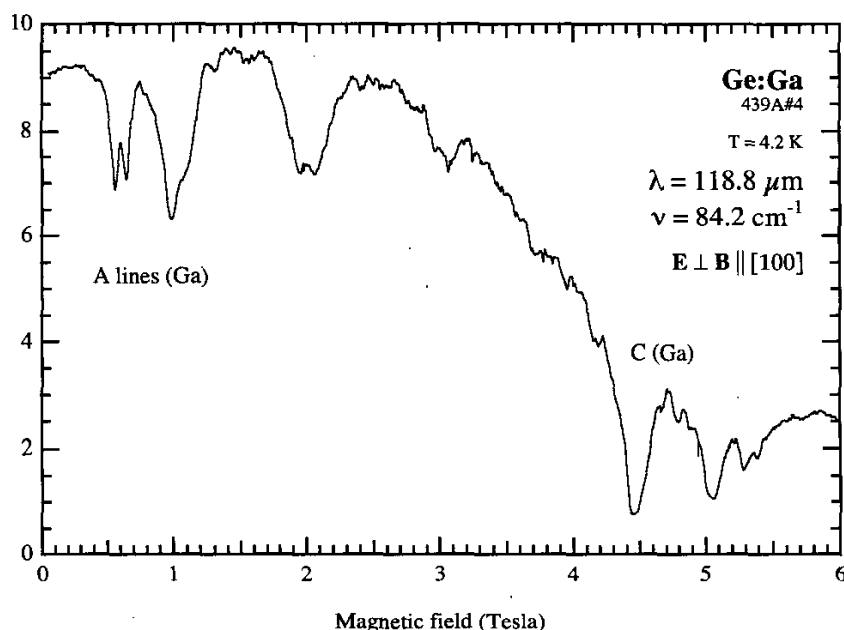


Fig. 1. Transmission (arbitrary units) of Ge:Ga 439A#4 at 4.2 K under laser radiation of 84.2 cm^{-1} (118.8 μm).

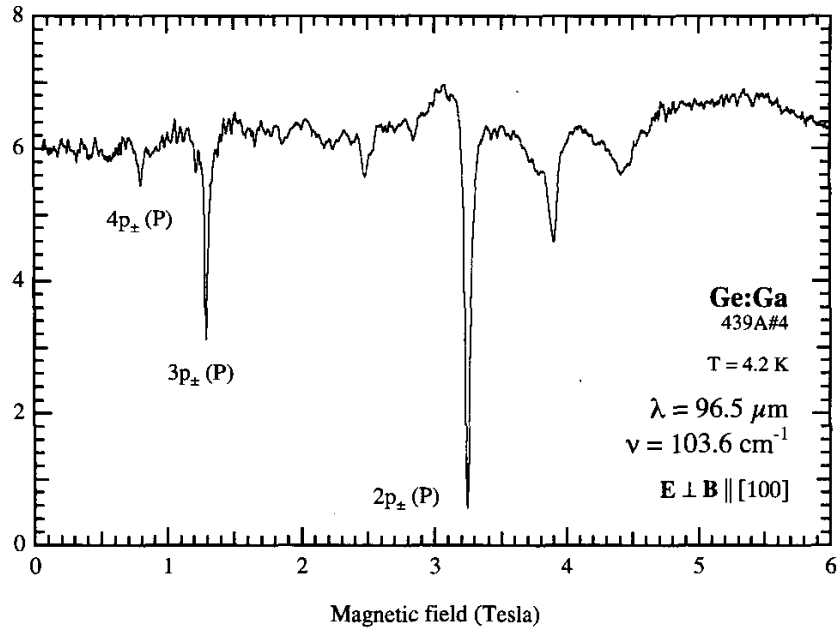


Fig. 2. Transmission (arbitrary units) of Ge:Ga 439A#4 at 4.2 K under laser radiation of 103.6 cm^{-1} ($96.5 \mu\text{m}$).

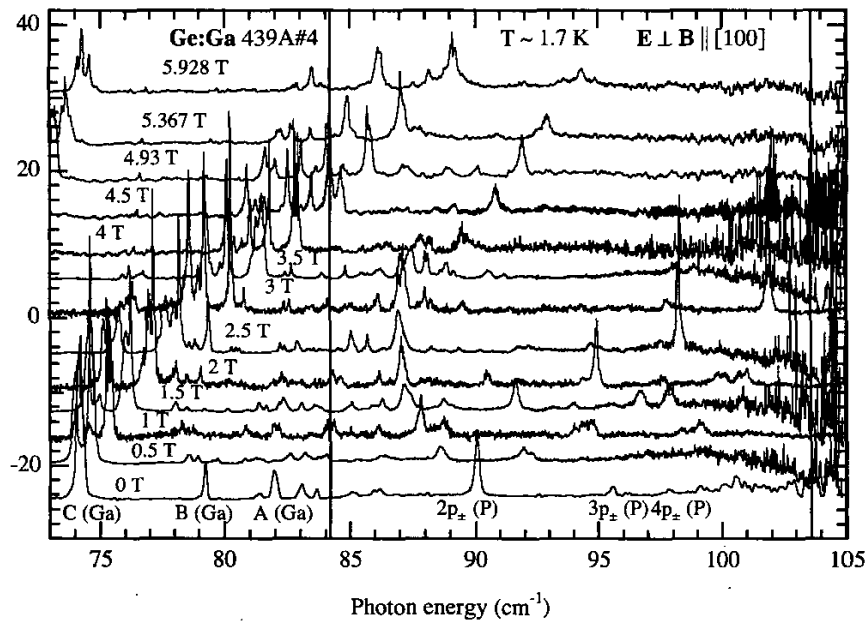


Fig. 3. Conventional spectroscopy of Ge:Ga over a range of magnetic fields. The vertical axis is absorption coefficient (cm^{-1}); successive curves are offset for clarity. The vertical lines indicate the laser energies used to collect the data in Figs. 1 and 2.

We combine results from two types of experiments on a fan chart in Fig. 4. Laser spectroscopy gives data on horizontal lines (equal energy). One set of conventional spectroscopy data is shown, for the complex C-line manifold. This intersects the 84.2 cm⁻¹ data near 4.5 T. Similar analysis of other Zeeman lines is still in progress.

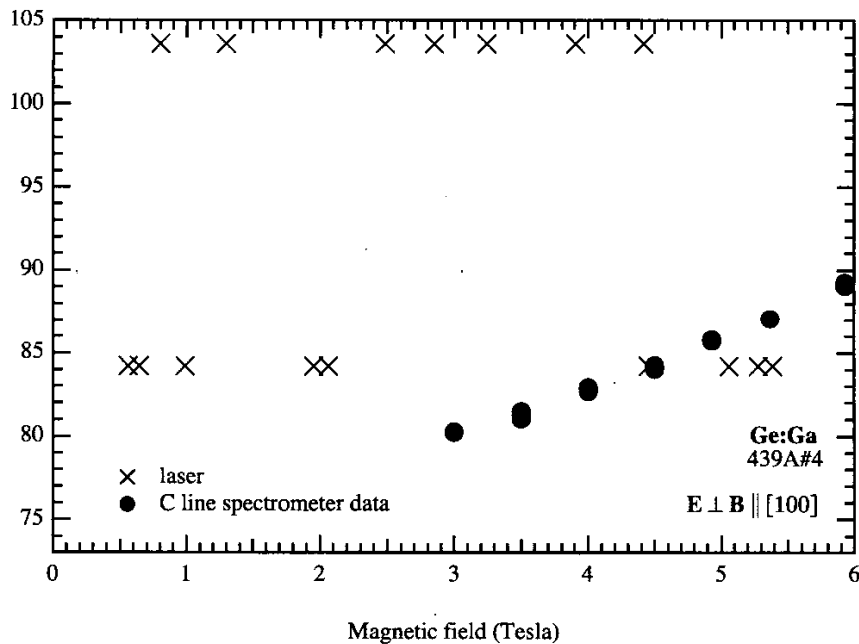


Fig. 4. Energy (cm⁻¹) of various transitions in Ge:Ga as a function of magnetic field.

4. CONCLUSION

Preliminary measurements using FIR laser spectroscopy are in agreement with measurements using conventional spectroscopy. It appears the laser spectroscopy exhibits superior signal-to-noise and may reveal hitherto unobserved transitions. Preliminary spectra taken at right angles to the laser beam had very much the appearance of the absorption spectra collected and no definite fluorescence spectral lines have yet been identified. It is believed that the reason for this is self-absorption of the photoluminescence by the sample. Modifications are being made to the experimental apparatus to analyse the signal orthogonal to the laser beam using a Fourier transform spectrometer.

ACKNOWLEDGEMENTS

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