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Abstracts

Spin-flip Raman Scattering from Donors in Diluted Magnetic Semiconductors.*

D. L. PETERSON,** U. DEBSKA, D. U. BARTHOLOMEW, A. K. RAMDAS and S. RODRIGUEZ, Purdue Univ.

The spin-flip Raman line associated with the transition of an electron in the 1s ground state of an "effective mass" donor in a diluted magnetic semiconductor exhibits striking features caused by the presence of the large number of magnetic ions (Mn^{2+}) within its Bohr orbit. We report the results of our studies on the diluted magnetic semiconductor $Cd_{1-x}Mn_xTe$ doped with Ga with a range of composition $0.01 \leq x \leq 0.3$. The polarization characteristics of the Raman line convincingly demonstrate that it is due to an electron bound to a donor. The very large spin-flip Raman shift is due to the strong e^- - Mn^{2+} exchange coupling and is strongly dependent on both the magnetic field and temperature.[1] We have investigated the behavior of this line in the temperature range 1.8 - 40 K with external fields up to 60 kG.

For low Mn^{2+} concentrations ($x \sim 0.01$), this alloy is paramagnetic and the temperature and magnetic field dependence of the Raman shift follows a Brillouin function. As x is increased, the antiferromagnetic coupling among the Mn^{2+} ions comes into play and manifests itself in the behavior of the Raman shift.

For a sufficiently large Mn^{2+} concentration ($x \geq 0.03$), the Raman feature exhibits a 'zero field shift'; this can be attributed[2] to the 'bound magnetic polaron (BMP)' arising from the mutual spin-correlation of the bound electron and Mn^{2+} and effects of thermodynamic fluctuations of the magnetization. In $Cd_{1-x}Mn_xTe$ the BMP energy is observed to increase (decrease) with decreasing temperature for compositions less than (greater than) x = 0.05. Work on higher composition alloys is in progress. Results in $Cd_{1-x}Mn_xSe$ for $x \leq 0.25$ will also be presented and compared.

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MODEL OF PHOTOTHERMAL IONIZATION SPECTROSCOPY IN HIGH PURITY GaAs

T. S. Low*, B. Lee, and G. E. Stillman

University of Illinois at Urbana-Champaign
Urbana, IL 68101

A model of far-infrared (FIR) absorption by shallow semiconductor impurities has been developed and is presented for the specific case of shallow donors in GaAs. The dielectric response function $\varepsilon(\omega)$ was calculated for the 1s-2p donor transitions using impurity concentrations typical of high purity epitaxial GaAs. The resulting complex refractive index $N(\omega)$ was then used to calculate the reflectance, transmittance, and absorptance spectra of epitaxial layers both with and without the presence of a semi-insulating substrate. Since the photoconductivity due to photothermal ionization should be proportional to the corresponding absorptance, sequences of calculated absorptance spectra were compared with sequences of experimental photothermal ionization spectra in which various sample parameters were systematically varied. These parameters included the neutral donor concentration, the epitaxial layer thickness, and the inhomogeneous width of the donor transition. The calculated spectra compare quite favorably with the experimental spectra. The model of donor dielectric response accounts for many of the peculiar features that are sometimes observed in photothermal ionization spectra, including the notched peak phenomenon, which was the cause of several erroneous donor identifications in the first controlled doping experiments in GaAs. The model also corrects some commonly held misconceptions concerning photothermal ionization peak widths and amplitudes, and their relationships to donor and acceptor concentrations. These corrections are of particular relevance to the proper interpretation of photothermal ionization spectra in the study of shallow impurities and their incorporation in high purity semiconductors.

*Present address: Hewlett Packard Laboratories, Palo Alto CA 94304

ELECTRON PARAMAGNETIC RESONANCE ON SHALLOW ACCEPTOR IMPURITIES IN SILICON

R. van Kemp and C.A.J. Ammerlaan

Natuurkundig Laboratorium, Universiteit van Amsterdam, Valckenierstraat 65, 1018 XE Amsterdam, The Netherlands

The shallow acceptor impurities boron, aluminum, gallium and indium in silicon were investigated by electron paramagnetic resonance (EPR) using a K-band superheterodyne spectrometer. The EPR spectra of these impurities were observed at low temperatures ($1.4K < T < 4.2K$) under conditions of zero and small values of external uniaxial stress.

The observed angular dependence of the resonance lines can be analysed using the effective spin Hamiltonian $\mathcal{H} = \mathcal{H}_B + \mathcal{H}_\varepsilon$ with $J = 3/2$ [1],

$$\mathcal{H}_B = \mu_B\{g_1'(J_xB_x+J_yB_y+J_zB_z) + g_2'(J_x^3B_x+J_y^3B_y+J_z^3B_z)\} ,$$

$$\mathcal{H}_\varepsilon = b'\{J_x^2\varepsilon_{xx}+J_y^2\varepsilon_{yy}+J_z^2\varepsilon_{zz}\} + \frac{2}{\sqrt{3}}d'\{[J_xJ_y]\varepsilon_{xy}+[J_xJ_z]\varepsilon_{xz}+[J_yJ_z]\varepsilon_{yz}\} .$$

By making a least squares fit to the experimental data, the g-values g_1' and g_2' and the deformation potential parameters b' and d' were obtained.

Under a variety of conditions peculiar line shapes and widths were observed. We considered the following mechanisms to explain the observed characteristics of the resonance lines: double and triple quantum transitions, linear and quadratic effects of strain, dynamic Jahn-Teller distortion, transition probabilities and the effect of relaxation time on spin dynamics.

Double and triple quantum transitions can occur in this system because $J = 3/2$. They can be recognized because their intensity is proportional to the square and the cube, respectively, of the microwave power. However, in the experiment no such dependence on the microwave power was found. The effects of linear and quadratic strain were calculated using second order perturbation theory. The expressions thus obtained can account qualitatively for the line widths and asymmetry when it is assumed that the strain distribution in the crystal is approximately Gaussian. These effects can not account for a peculiar narrow dip that is present in the centers of the resonance lines with $\Delta M_J=1$ and $\Delta M_J=2$ [2].

A dynamic Jahn-Teller distortion of the acceptor atoms would have the result that there are no sites with strain zero. Together with the random strains present in the crystal, the effect will be a shift of intensity away from the magnetic field at which the center of the line occurs.

Calculation of the transition probabilities for the $\Delta M_J=1,2,3$ transitions showed that these do not become very small in any of the cases.

An explanation of the dip in the center of the resonance line can be offered in the following way [3]. The broad resonance lines for the $\Delta M_J=1$ and $\Delta M_J=2$ transitions are a superposition of spin packets which are shifted due to the random internal strains. For small values of the strains, packets will overlap, allowing a form of cross-relaxation to occur. This results in broadening of the homogeneous width and smaller intensity at the center of the resonance line.

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FOUR-WAVE PIEZO-MAGNETOSPECTROSCOPY OF SHALLOW DONORS IN SILICON AND GERMANIUM*

C. Jagannath, R.L. Aggarwal,
E.R. Youngdale and D.M. Larsen

Francis Bitter National Magnet Laboratory
Massachusetts Institute of Technology†
Cambridge, Massachusetts 02139

Four-wave mixing spectroscopy has proven to be a powerful technique for studying energy differences between levels for which there is a Raman-allowed transition. We have applied this technique to the investigation of the valley-orbit split 1s manifold of donor levels in Si and Ge under stress and magnetic field. By measuring the transition energy between the $1s(A_1)$ donor ground state and effective-mass-like excited 1s states in As and P donors in Ge as functions of magnetic field,[1] we have been able to deduce the mean square radius of the envelope functions associated with the $1s(A_1)$ level. Application of stress along [110] in Ge brings the conduction band edge of the two stress-deepened valleys closer to the donor ground state energy. Applying, in addition, a magnetic field, we have measured with increasing stress the expansion in size of the ground state envelope functions associated with the stress deepened valleys. Measurements on P donors in Si under stress have yielded the effective deformation potential constants for various levels of the 1s manifold.[2] Preliminary experiments on As donors in Ge under stress suggest that heating of the electrons by the strong optical pulses employed populates excited levels in the 1s manifold, allowing observation of transitions starting from the excited states even when the initial lattice temperature is very low.

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TEMPERATURE DEPENDENCE OF DONOR LINESHAPES BROADENED BY ELECTRIC FIELDS IN COMPENSATED SEMICONDUCTORS

David M. Larsen

Francis Bitter National Magnet Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

It is well known that donor absorption lines in high purity partly-compensated n-type semiconductors can be significantly broadened by the electric fields and field gradients of surrounding donor and acceptor ions. Recently reported computer experiments have shown that at $T = 0$ these fields are strongly quenched compared to fields generated by placing electrons on donor sites at random, provided that the compensation ratio K ($K = N_A/N_D$) is not too close to 1. Thus, for $K = 0.5$ it is found that the distribution of the square of the electric field, ε^2, seen by neutral donors has a FWHM which is less than 1/10 of that for the random ion system! Although this result suggests that in partly-compensated semiconductors the linewidths of donor transitions which are inhomogeneously broadened by the quadratic Stark effect might be strongly temperature sensitive, it seems that the temperature dependence of the field broadening of donor transitions in compensated semiconductors has not been studied previously. This paper describes a numerical simulation devised for the purpose of calculating the temperature