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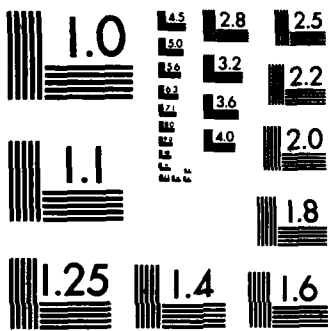
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Bolling Air Force Base, Washington, DC 20332  
Attention: Harry R. Haraldsen, Contracting Officer

from

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

IMPURITY AND DEFECT CHARACTERIZATION IN EPITAXIAL GaAs,  
InP AND THE TERNARY AND QUATERNARY COMPOUND SEMICONDUCTORS

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Mohammed N. Afsar, Co-Principal Investigator

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Introduction

We have observed the spin doublet of the  $1s+2p$  ( $m=+1$ ) transition of the hydrogen-like silicon donor in high-purity epitaxial n-GaAs at low temperature as a function of the intensity of the applied steady magnetic field. The splitting of the spin doublet increased with increasing magnetic field intensity. The data shows that the dependence of the spin splitting on magnetic field intensity was not only larger than linear but also larger than quadratic. The measurements were made in applied magnetic fields up to 14 Teslas (140 kilo-oersteds) in a Fourier transform spectrometer by observing the photoconductivity in the GaAs epitaxial layer. The photoconduc-

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) <b>The splitting of the spin doublet of the <math>1s^2 2p</math> (<math>m=+1</math>) transition of the hydrogen-like silicon donor in n-GaAs has been observed as a function of applied magnetic field at low temperature. The splitting of the spin doublet increased with increasing magnetic field intensity. The dependence of the splitting on magnetic field intensity was not only larger than linear but was also larger than quadratic dependence in agreement with the theory of David Larsen .</b>		

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tivity resulted from the photo excitation and subsequent thermal excitation of the bound donor electron to the conduction band. This experimental technique has been widely used (1-17). The spin doublet has apparently been observed in cyclotron resonance (18,19) but the magnetic field dependence was not investigated. The spin doublet has been observed in the  $1s \rightarrow 2p$  ( $m=+1$ ) transition of the bound electron by D.M. Korn, et al (unpublished) and probably by other pioneers in this specialty whose data is not yet published. The only theoretical treatment of this problem in GaAs has been carried out by Larsen (20) who compared his conclusions to the experimental data of Korn to prove that the doublet was indeed a spin doublet. Since the dependence of the splitting of the spin doublet on magnetic field intensity was not established by this comparison with experiment data, we are publishing these new results. These new results support the theoretical assertion of Larsen that the magnetic field dependence of the splitting is  $CH^2$  plus higher order terms in H, where H is the magnetic field intensity and C is a small positive constant for GaAs. Nevertheless, we cannot rule out the existence of a linear term in H because this could be observed directly only at low magnetic fields. The splitting is too small ( $g^* = 0.44$ ) to be observed at low fields.

### Results

The specimen was grown by the method of vapor phase

epitaxy<sup>†</sup> in which silicon is always the dominant donor and the (211)a face is the growth habit. Normally, GaAs grown by vapor phase epitaxy is contaminated by silicon from the quartz reactor and by sulfur from the arsenic compound used as starting material. We chose this specimen because the sulfur contamination was so low as to be almost undetectable and the room temperature  $N_D - N_A$  concentration of  $7 \times 10^{13}$  was unusually low. The mobility at room temperature is  $5330 \text{ cm}^2/\text{V-sec}$  and the epitaxial layer was  $100 \text{ }\mu\text{m}$  thick.

The higher field intensity increases the spin splitting. Table I contains a tabulation of the positions of the components of the spin doublet and the splitting for four different fields. A spectrometer resolution of  $0.07 \text{ cm}^{-1}$  was found to be sufficient to provide an accuracy in Table I of  $0.01 \text{ cm}^{-1}$ . The splittings listed in the Table have been plotted as a function of magnetic field intensity in Fig. 1 where the uncertainty is no larger than the plotted point. We have drawn a line through the points and extrapolated it to zero and note that it can not possibly be a straight line or any other simple function of magnetic field intensity. Note that

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<sup>†</sup>The specimen HP-C-12-1-25 was grown by Gary McCoy at the Electronics Research Branch of the Air Force Avionics Laboratory, Wright Patterson Air Force Base, Ohio.

TABLE I

SPIN SPLITTING IN n-GaAs

1s → 2p (m = +1)

Magnetic field Intensity H(Tesla)	1s → 2p(m=+1) $\tilde{\nu}$ (cm <sup>-1</sup> )	Splitting $\Delta\tilde{\nu}$ (cm <sup>-1</sup> )	Splitting $\Delta\tilde{\nu}/H$ (cm <sup>-1</sup> /Tesla)
7	131.84	0.44	0.0636
	132.28		
10	173.47	0.63	0.068
	174.15		
12	200.04	0.81	0.0675
	200.85		
14	225.20	1.07	0.0764
	226.27		

the point at 12 Teslas does not fall on the line. We have no explanation for this discrepancy but we have no reason to remove the point until we have taken enough data to establish a standard deviation.

In Fig. 2 we have shown a plot of the spin splitting divided by H. If the field dependence of the spin splitting were largely quadratic at high magnetic field intensity, this should yield a straight line. We have no justification for

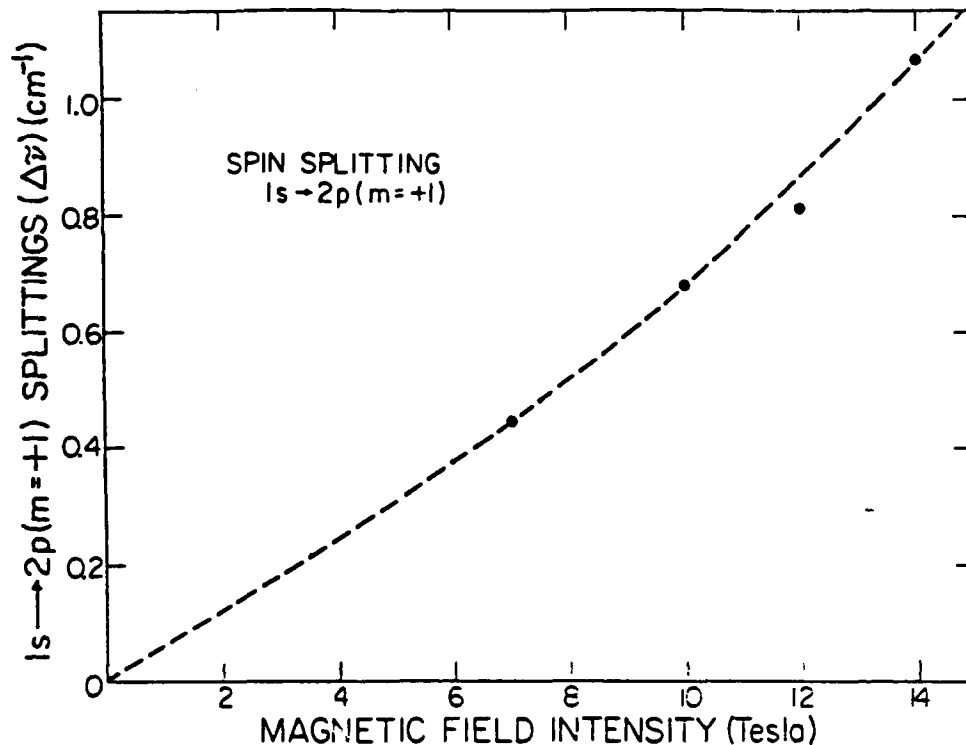


Figure 1. A plot of the magnitude of the splitting of the spin doublet as a function of applied magnetic field. The points represent the observed energy difference between the two spin states (See Table I).

drawing a straight line through the points in Fig. 2. Therefore, the possibility that higher terms in H may contribute to the magnetic field dependence cannot be ruled out.



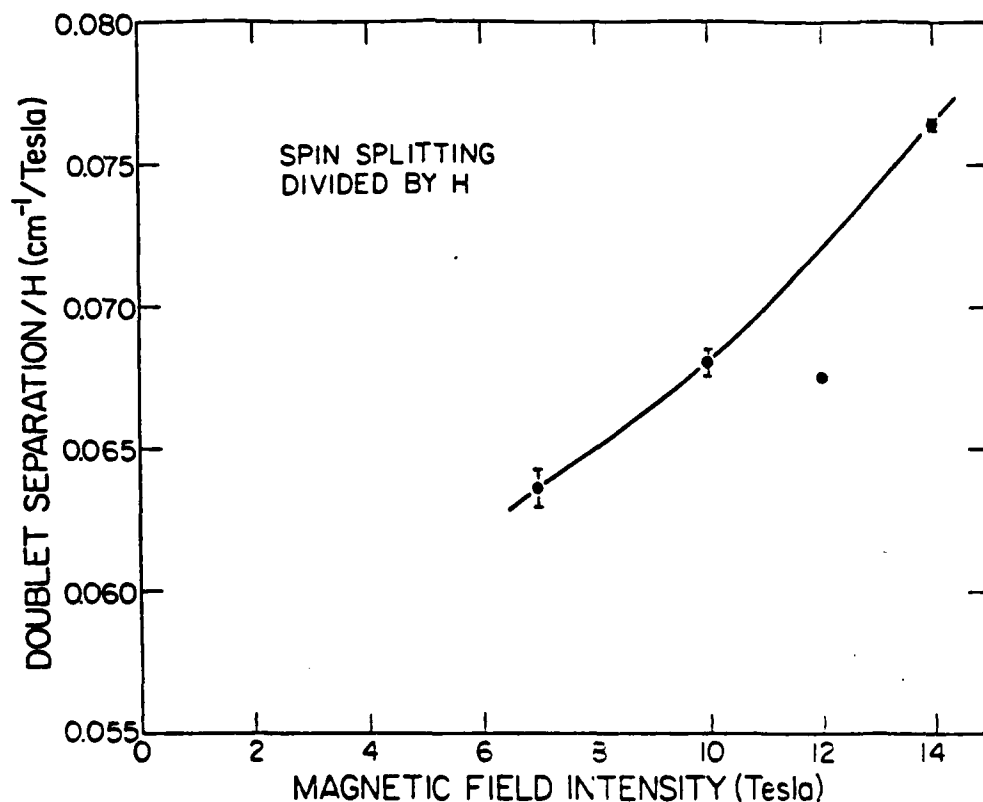


Figure 2. The points represent the spin splitting divided by H. If the curve were a straight line, the magnetic field dependence of the splitting would have to be accepted as purely quadratic. Since the data does not force us to accept such a simple interpretation, we must admit the possibility of higher order terms in H.

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