

Effective masses and g factors for 2-D light holes in InSb\*

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J.E. Schirber, C.P. Tigges, L.R. Dawson, H.P. Hjalmarson and I.J. Fritz

Sandia National Laboratories, Albuquerque, NM 87185

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## ABSTRACT

The light holes in InSb are characterized using a Shubnikov-de Haas technique by exploiting the Type II band offset of an  $\text{InAs}_{.15}\text{Sb}_{.85}/\text{InSb}$  strained layer superlattice. The data are analyzed to determine the effective masses and g factors as a function of carrier concentration.

## INTRODUCTION

Shubnikov-de Haas (SdH) data have been used effectively for many years in bulk semiconductors to determine band parameters, effective masses and g factors. In two dimensional (2 D) systems these oscillatory phenomena are extensively studied in the high field integral<sup>1</sup> and fractional<sup>2</sup> quantum Hall effect regime primarily in lattice matched superlattice systems. Purposely lattice mismatched structures,<sup>3</sup> called strained layer superlattices (SLS) offer an additional variable, strain, which allows the bandstructure to be tailored in a controlled fashion. The SdH technique can be applied to the study of these systems, in particular, the new features introduced by the strain.<sup>4</sup>

The  $\text{InAsSb}/\text{InSb}$  SLS structure is showing considerable potential as a long wavelength IR detector candidate.<sup>5</sup> In the  $\text{InAs}_{.15}\text{Sb}_{.85}/\text{InSb}$  SLS, the InAsSb has the smaller bandgap and also has a smaller lattice constant than InSb. This results in having the InSb layer under biaxial compression. It is well documented<sup>6</sup> that such a stress configuration removes the gamma-point valence band degeneracy and raises the light hole band in energy relative to a heavy hole band. As a result, the transport in the plane of the InSb layer is dominated by light holes.

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If the system had a Type I band offset, the conduction (valence) band of the InAsSb is lower (higher) than that of the InSb. In this situation, n-type doping will result in the usual light ( $m^* \sim .015$ ) carriers and p-type doping will give rise to heavy ( $m^* \sim .3$ ) holes. Our work shows that the InAs<sub>.15</sub>Sb<sub>.85</sub>/InSb system is Type II such that the valence band of InSb is higher in energy than InAs<sub>.15</sub>Sb<sub>.85</sub>. Our result is consistent with optical studies by Kurtz et al<sup>7</sup> and a tight binding calculation.<sup>8</sup> Under these conditions n-type doping again gives carriers in the smaller bandgap InAsSb channel but now the p-type doping results in creating light holes in the InSb. Thus, we have a unique opportunity to study in detail the properties of light holes in InSb. In this report we present direct measurements of the effective mass of the light holes in 2D InSb as a function of carrier concentration and an attempt to determine the  $g$  value of these carriers.

## EXPERIMENTAL

Samples were grown on [100] InSb low p-type ( $10^{12}$  carriers/cm<sup>3</sup> at 77K) substrates. A step composition-graded strain-relief buffer layer followed by alternating 200 Å thick InSb and 200 Å thick InAs<sub>.15</sub>Sb<sub>.85</sub> layers were doped with Be at  $5 \times 10^{17}$  cm<sup>-3</sup>. Structures with 15-100 periods were grown, varying the Be doping. The carrier concentration and mobility were measured for each structure by standard Van der Pauw techniques. Some of the structures suffer from parallel conduction paths so that carrier concentrations determined from the transport and from the SdH frequency do not agree. The values for our best samples to date are shown in Table I.

The mobilities achieved are disappointingly low for such low mass carriers. These mobilities may be attributed to the low carrier densities necessitated by the shallow confinement in the InSb channel for the holes (estimated to be 60 meV).<sup>7</sup>

Table I. Characteristics of light hole SLS structures studied in this investigation

Sample number	Carrier conc. per channel $P/(10^{10} \text{ cm}^{-2})$	Mobility $\mu/(V/\text{cm}^2 \text{ sec})$	SdH frequency F/kG	$m^*$
VL 648	13	12000	21	.05
VL 695	8	16000	11	.03
VL701	12	16000	19	.04
VL673	11	21000	46	.08

## RESULTS

Our results to date are tabulated in Table I. The values of  $m^*$  were determined as a function of carrier concentration by measurement of the temperature dependence of the amplitude of the Shubnikov de Haas oscillations at fields low enough that the oscillations were primarily the fundamental contributions to the series in the standard Lifshitz and Kosevich expression.<sup>9</sup> The measured  $m^*$  as a function of the carrier concentration determined from the observed SdH frequency is shown in Fig. 1. As this figure clearly shows the measured effective mass increases significantly as the carrier concentration is increased.

An attempt has been made to extract the Landau level broadening, and  $g^*$  by modeling the angular dependence of the oscillatory  $\rho_{xx}$  for two of the samples (VL695 and VL701). In each case, the lowest Landau level is clearly spin resolved. However, the oscillation amplitudes and extrema are generally angular dependent and consistent unambiguous fits have not been obtained. This behavior of  $\rho_{xx}$  can be seen for sample VL695 in Fig. 2. In this case, it appears that the second Landau level is partially resolved for  $\theta=0$  and is increasingly resolved as the magnetic field is tilted with respect to the plane of the 2D gas.

At present the apparent amplitude dependence of the oscillations is not understood but may be due to a near, though accidental equivalence of the Landau level and spin splittings. Such a coincidence is consistent with the effective  $g \sim 70$  values determined by Seiler et al and Littler.<sup>10</sup>

## CONCLUSIONS

The Type II band offset of the  $\text{InAs}_{.15}\text{Sb}_{.85}/\text{InSb}$  strained layer superlattice structure has been exploited in order to study for the first time the properties of two dimensional light holes in InSb. Analyses of Shubnikov-de Haas data yields effective masses of the light holes as a function of carrier concentration and an estimate of the  $g$  factor for these

carriers. At the lowest carrier concentration,  $m^* = .030$  but the band is highly non parabolic (at zone-center,  $m^* \leq 0.02$ ).

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FIG. 1.

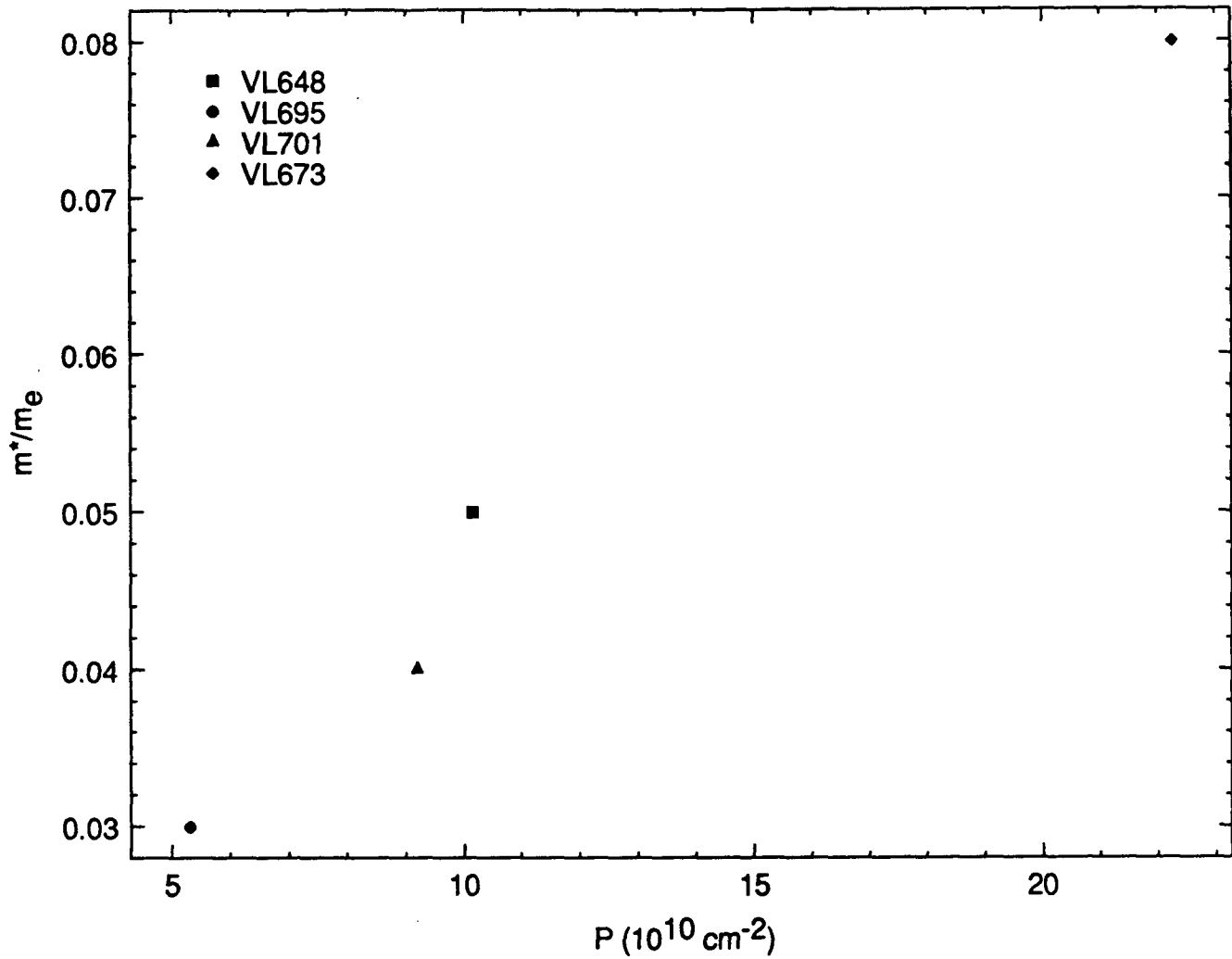


Fig. 1 The light hole effective mass ( $m^*$ ) as a function of the hole carrier concentration determined from the SdH frequencies in Table I. The light hole mass is clearly sensitive to carrier concentration and increases by more than a factor of two over the range of measured concentrations.

FIG. 2(a)

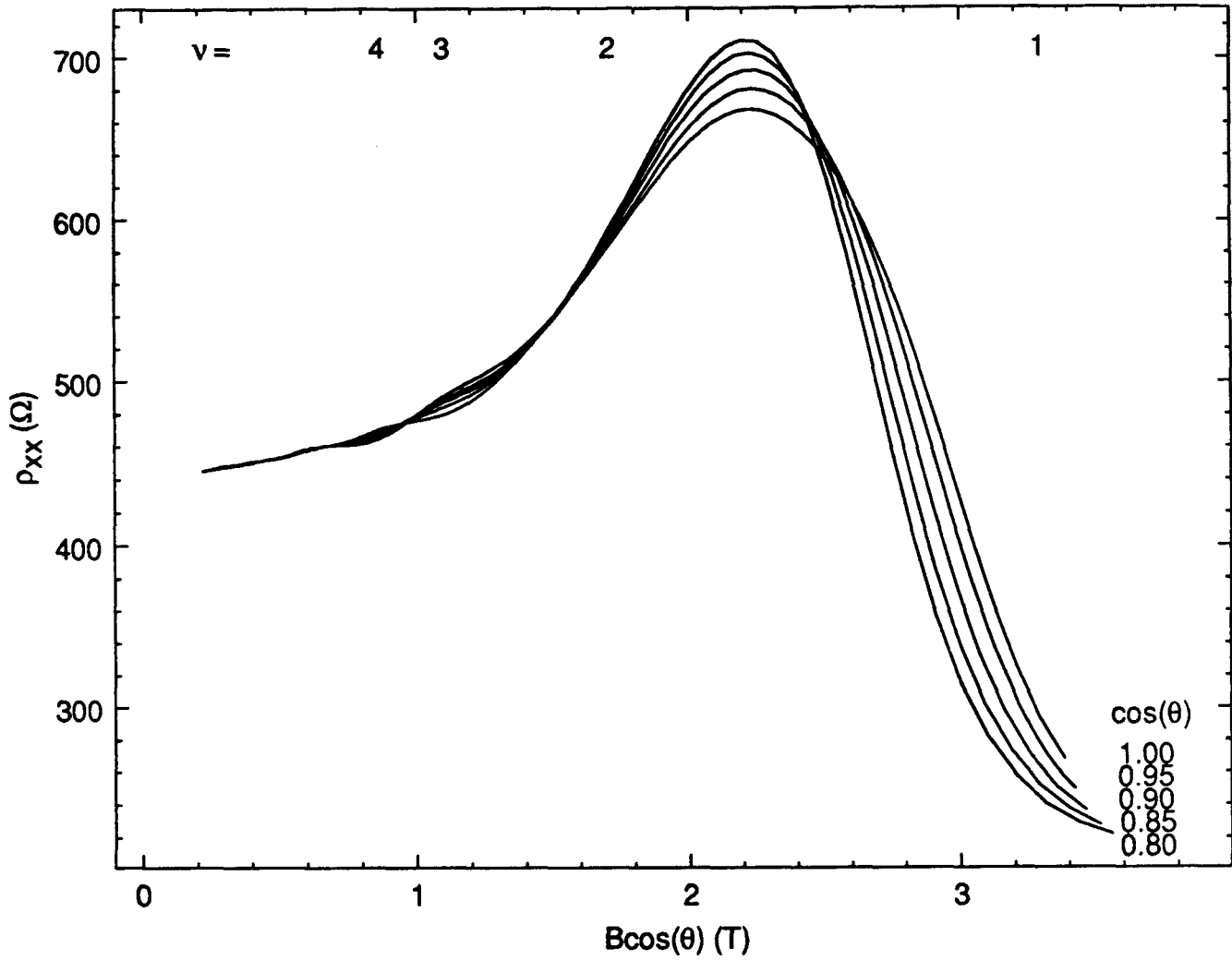


Fig. 2(a) The magnetoresistance as a function of the magnetic field perpendicular to the 2D hole gas for  $\cos\theta = 1.0-0.8$ . In this arrangement the Landau level splittings remain fixed while the spin splittings are increased as  $\cos\theta$  decreases. Integral filling factors are shown for a frequency of 1.65T.

Fig 2(b)

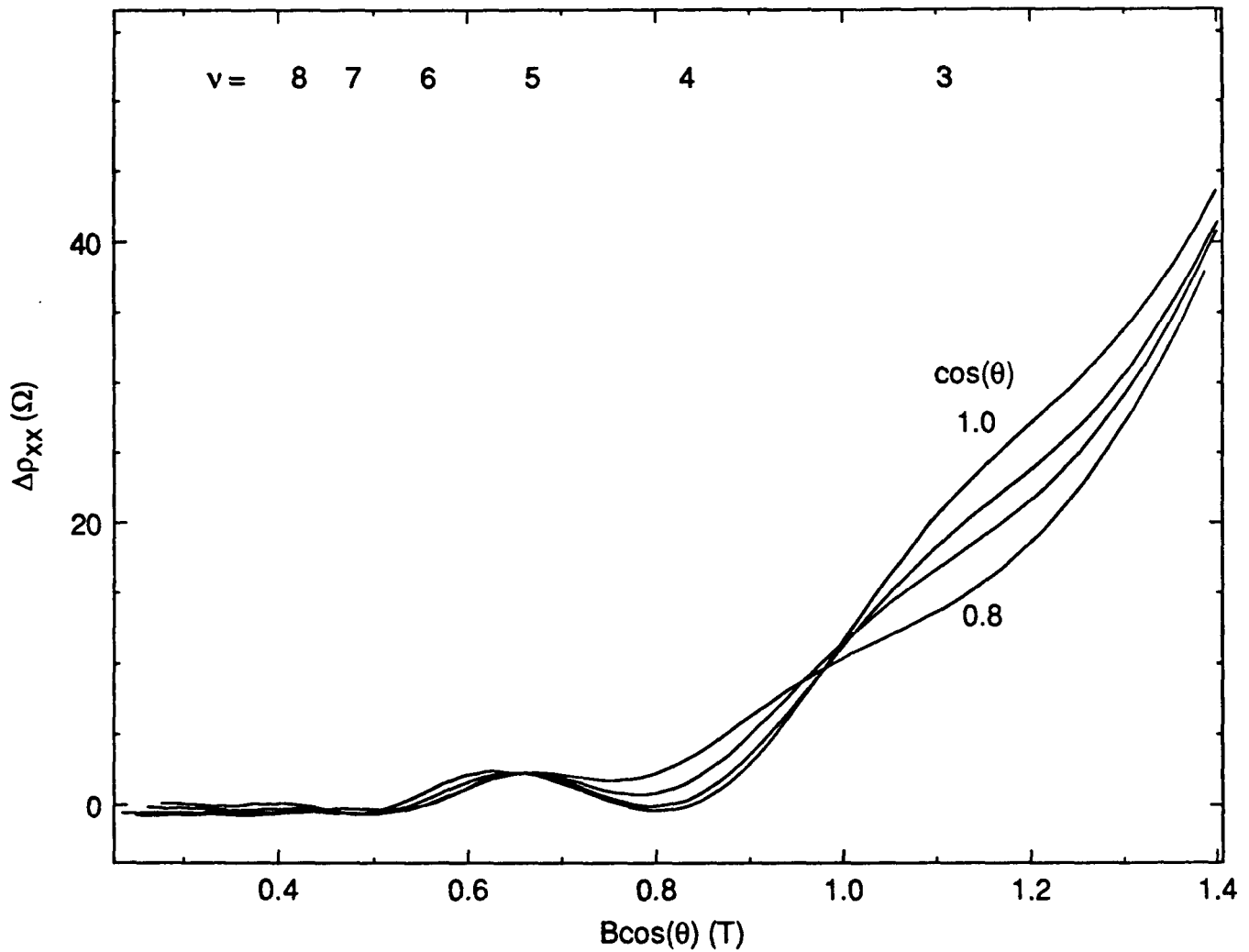


Fig. 2(b) Low field detail. Note the emergence of an oscillation near 1.0T. The  $\Delta\rho_{xx}$  minimum of 1.1T,  $\cos\theta = 0.8$ , corresponds to the  $\nu = 3$  filling factor.

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