

University of Wollongong

Research Online

University of Wollongong Thesis Collection
1954-2016

University of Wollongong Thesis Collections

2004

Landau spectra of ZnH and neutral Zn in germanium

Keiichi Ishida

University of Wollongong

Follow this and additional works at: <https://ro.uow.edu.au/theses>

University of Wollongong

Copyright Warning

You may print or download ONE copy of this document for the purpose of your own research or study. The University does not authorise you to copy, communicate or otherwise make available electronically to any other person any copyright material contained on this site.

You are reminded of the following: This work is copyright. Apart from any use permitted under the Copyright Act 1968, no part of this work may be reproduced by any process, nor may any other exclusive right be exercised, without the permission of the author. Copyright owners are entitled to take legal action against persons who infringe their copyright. A reproduction of material that is protected by copyright may be a copyright infringement. A court may impose penalties and award damages in relation to offences and infringements relating to copyright material.

Higher penalties may apply, and higher damages may be awarded, for offences and infringements involving the conversion of material into digital or electronic form.

Unless otherwise indicated, the views expressed in this thesis are those of the author and do not necessarily represent the views of the University of Wollongong.

Recommended Citation

Ishida, Keiichi, Landau spectra of ZnH and neutral Zn in germanium, M. Sc. thesis, School of Engineering Physics, University of Wollongong, 2004. <http://ro.uow.edu.au/theses/536>

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

NOTE

This online version of the thesis may have different page formatting and pagination from the paper copy held in the University of Wollongong Library.

UNIVERSITY OF WOLLONGONG

COPYRIGHT WARNING

You may print or download ONE copy of this document for the purpose of your own research or study. The University does not authorise you to copy, communicate or otherwise make available electronically to any other person any copyright material contained on this site. You are reminded of the following:

Copyright owners are entitled to take legal action against persons who infringe their copyright. A reproduction of material that is protected by copyright may be a copyright infringement. A court may impose penalties and award damages in relation to offences and infringements relating to copyright material. Higher penalties may apply, and higher damages may be awarded, for offences and infringements involving the conversion of material into digital or electronic form.

Landau Spectra of ZnH and Neutral Zn in Germanium

A thesis submitted in fulfillment of the
requirements for the award of the degree

Master of Science (Physics)

from

University of Wollongong

by

Keiichi Ishida

School of Engineering Physics

2004

Abstract

Far-infrared absorption spectroscopy was carried out on samples of germanium cut from single-crystal ingots doped with zinc. The ingots were grown in a hydrogen atmosphere and hence also contained the axial complex ZnH. Landau studies were made in the Voigt configuration for both the acceptors neutral zinc, Zn^0 , and ZnH with **B** oriented along $\langle 100 \rangle$ crystallographic directions. Measurements were made in a super-conducting magnet with field strengths up to 6 T for both ZnH and Zn^0 using a modified slow-scan Polytec FTIR spectrometer. The incident radiation was plane polarised either parallel or perpendicular to the field. It was found that the main Landau features for both acceptors are the same as for the group III single-hole acceptor boron. The difference is in the fine-structure of the Landau lines which reflects the different natures of the acceptors boron, Zn^0 and ZnH.

Acknowledgments

I would like to thank both my supervisors, Professor Peter Fisher and Dr. Rodney E.M. Vickers for their guidance and encouragement.

I would like to thank the following people for their assistance:

Members of the Engineering Physics Department technical staff, especially Peter Anthony, Peter Ihnat and John Bourke.

Members of the Engineering Physics Department; academic and general staff.

Purdue University for supplying the samples.

Finally, I give special thanks to my family and friends for their support and encouragement.

Contents

Abstract.....	i
Acknowledgments.....	ii
Contents.....	iii
List of Figures.....	iv
List of Tables.....	v
1. Introduction.....	1
2. Theoretical	
2.1 Landau States for Free Electrons.....	3
2.2 Landau States for Electrons in Semiconductors.....	4
2.3 Landau States and Bound Hole States.....	10
2.4 Selection Rules for $B \langle 100 \rangle$	10
2.4.1 Zn-H in Ge.....	10
2.4.2 Neutral Zinc (Zn^0).....	11
3. Experimental Techniques	
3.1 Introduction.....	15
3.2 Polytec FTIR Spectrometer.....	16
3.3 Bomem FTIR Spectrometer.....	18
3.4 Sample Preparation.....	20
4. Results and Discussion	
4.1 ZnH.....	23
4.2 Neutral Zinc (Zn^0).....	37
5. Conclusions.....	47
References.....	48

List of Figures

2.1	Results of Landau's treatment of the behaviour of free electrons in a homogeneous magnetic field.....	5
2.2	Valence band Landau levels in germanium as calculated by Hensel and Suzuki.....	8
2.3	Energy states of group III and axial defects in Ge for $\mathbf{B} <100>$	12
2.4	Allowed Landau transitions for neutral zinc for $\mathbf{B} <100>$	14
3.1	Schematic of modified Polytec FTIR spectrometer.....	17
3.2	Schematic of Bomem FTIR spectrometer.....	19
3.3	The effect of different surface treatments for Ge(ZnH)394A#5.2.....	21
4.1	Unperturbed spectrum of the sample used for studying the Landau lines of axial defect ZnH in Ge for $\mathbf{B} <100>$	24
4.2	Unperturbed spectrum of the sample of Figure 4.1 in the range of $65 - 95 \text{ cm}^{-1}$	25
4.3	Set of spectra of ZnH in Ge for $\mathbf{E} \perp \mathbf{B}$. $T \approx 4.5 \text{ K}$. Unapodised resolution = 0.37 cm^{-1}	26
4.4	Set of spectra of ZnH in Ge for $\mathbf{E} \mathbf{B}$. $T \approx 4.5 \text{ K}$. Unapodised resolution = 0.37 cm^{-1}	27
4.5	Landau spectra of Ge(ZnH) $\mathbf{B} <100>$ for both polarizations. $T \approx 4.5 \text{ K}$. Unapodised resolution = 0.37 cm^{-1}	28
4.6	Series of Landau spectra of Ge(ZnH) for $\mathbf{B} <100>$ for both polarizations. Magnetic field strength from 4 T to 6 T. Unapodised resolution = 0.37 cm^{-1}	29
4.7	Two Lorentzian fits to Landau line I_a of Ge(ZnH), with magnetic field of 5 and 6 T for $\mathbf{E} \perp \mathbf{B}$. $T \approx 4.5 \text{ K}$. Unapodised resolution = 0.37 cm^{-1}	30
4.8	Two Lorentzian fits to Landau line I_a of Ge(ZnH), with magnetic field of 5 and 6 T for $\mathbf{E} \mathbf{B}$. $T \approx 4.5 \text{ K}$. Unapodised resolution = 0.37 cm^{-1}	31

4.9	Two Lorentzian fits to Landau line I_b of Ge(ZnH), with magnetic field of 5 and 6 T for $\mathbf{E} \parallel \mathbf{B}$. $T \approx 4.5$ K. Unapodised resolution = 0.37 cm^{-1}32
4.10	Field dependence of the energies of the Landau lines of ZnH in Ge for both polarizations and boron in Ge with $\mathbf{E} \perp \mathbf{B}$ for $\mathbf{B} \parallel \langle 100 \rangle$. Also shown are the results of Hensel and Suzuki for light hole Landau levels adapted to boron in Ge.....33
4.11	Landau splitting of I_a (ZnH) $\mathbf{B} \parallel \langle 100 \rangle$ for both polarizations.....35
4.12	Comparison of the splittings of Landau I lines with the those of the ground state of ZnH $\mathbf{B} \parallel \langle 100 \rangle$. The quadratic fit to the data points of the ground state splitting of ZnH.....36
4.13	Unperturbed spectrum of the sample used for studying the Landau lines of neutral zinc in Ge for $\mathbf{B} \parallel \langle 100 \rangle$39
4.14	Unperturbed spectrum of the sample of Figure 4.13 in the range of $65 - 95 \text{ cm}^{-1}$40
4.15	Set of spectra of neutral Zn in Ge for $\mathbf{E} \perp \mathbf{B}$. $T \approx 2.5$ K. Unapodised resolution = 0.37 cm^{-1}41
4.16	Set of spectra of neutral Zn in Ge for $\mathbf{E} \parallel \mathbf{B}$. $T \approx 2.5$ K. Unapodised resolution = 0.37 cm^{-1}42
4.17	Landau spectra of neutral Zn in Ge for $\mathbf{B} \parallel \langle 100 \rangle$ at $B = 6$ T for both polarizations.....43
4.18	Field dependence of the energies of the Landau lines of Zn^0 in Ge for both polarizations (See Fig. 4.17 for I_x 's) and boron in Ge with $\mathbf{E} \perp \mathbf{B}$ for $\mathbf{B} \parallel \langle 100 \rangle$. Also shown are the results of Hensel and Suzuki for light hole Landau levels adapted to boron.....44
4.19	Field dependence of the splitting of the I lines of Zn^0 and the ground state of Zn^0 in Ge $\mathbf{B} \parallel \langle 100 \rangle$46

List of Tables

4.1	Field dependence of Landau transitions of ZnH and boron in Ge. $\mathbf{B} \parallel \langle 100 \rangle$34
-----	---

4.2	Field dependence of Landau transitions of Zn^0 and boron in Ge.	
	$\mathbf{B} \parallel \langle 100 \rangle$	38