

Giant negative magnetoresistance in semiconductors doped by multiply charged deep impurities

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A giant negative magnetoresistance has been observed in bulk germanium doped with multiply charged deep impurities. Applying a magnetic field the resistance may decrease exponentially at any orientation of the field. A drop of the resistance as much as about 10000% has been measured at 6 T. The effect is attributed to the spin splitting of impurity ground state with a very large g-factor in the order of several tens depending on impurity.

71.55.-i, 71.70.Ej, 72.20.-i, 73.30.Vn

It is surprising that in well investigated transport properties of bulk semiconductors, particularly in the best known material germanium, until now new and previously not observed phenomena can be found. Here we report on a giant negative magnetoresistance in Ge which shows sizable effects already at very small magnetic field strengths. An exponential drop of the resistance with rising magnetic field, which may be more than two orders of magnitudes, occurs in a parallel as well in perpendicular orientation of current and magnetic field.

Negative magnetoresistance has attracted much interest in the last decades due to the large variety of physical phenomena causing a drop of the resistance of semiconductors in an external magnetic fields. One of the striking effects is the low temperature giant negative magnetoresistance observed in disordered structures in magnetic fields with a variable range hopping regime due to quantum interference leading to weak localization [1–6]. Other important mechanisms of giant negative magnetoresistance in semiconductors are magnetic field controlled metal-insulator transitions [7], removal of a minigap in a semiconductor superlattice [8], and magnetic field suppression of spin-disorder scattering [9,10]. The application of a magnetic field on magnetic perovskites aligns the spins in different magnetic domains thereby lowering the energy barrier for carriers and yielding a colossal negative magnetoresistance [11]. A negative magnetoresistance occurs also in carbon nanotubes which has been shown to exhibit ballistic electron transport [12], the increase of conductivity has been attributed to a magnetic field induced increase of the density of states in the vicinity of the Fermi level [13]. The giant negative magnetoresistance reported here has only been

observed in samples doped with multiply charged impurities and could not be detected in materials with only singly charged impurities.

The experiments have been carried out on Ge:Hg, Ge:Cu, and Ge:Ga. In germanium Hg and Cu are deep acceptors doubly and and triply charged, respectively, whereas Ga is a singly charged shallow acceptor. The binding energies of holes on Hg are 90 meV and 230 meV for detachment of the first and the second hole, respectively. From Cu three holes may be removed with the binding energies 40 meV, 320 meV, and $(E_g - 260)$ meV where E_g is the energy gap. The hydrogen-like shallow impurity Ga has an ionization energy of about 10 meV. The doping levels were in the range from 10^{14} to 3×10^{15} cm $^{-3}$. The typical size of the samples was $5 \times 3 \times 1$ mm 3 . One pair of ohmic contacts were prepared on opposite faces. The samples were fixed in a temperature variable cryostat. The resistance of the samples in the dark has been obtained from the low voltage ohmic range of current-voltage characteristics. A magnetic field B up to 6 T could be applied parallel and perpendicular to the current flow by a superconducting magnet.

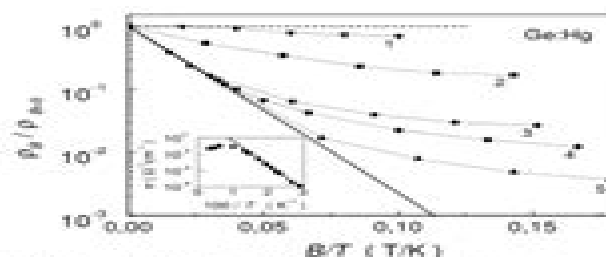


FIG. 1. A log-lin plot of the magnetoresistance $\rho_B/\rho_{B=0}$ of Ge:Hg as a function of the magnetic field strength B normalized by the temperature T in the range $B = 0 \dots 6$ T and for various temperatures: 1- 55 K, 2- 40 K, 3- 38 K, 4- 35 K, 5- 33 K. The full is a fit to $\exp(-\alpha B/k_B T)$ with $\alpha = 5.8$ meV/T. The inset shows an Arrhenius plot of the conductivity at zero B .

Deep Impurities In Semiconductors

**Matthew D. McCluskey, Eugene E.
Haller**



Deep Impurities In Semiconductors:

Deep Impurities in Semiconductors Arthur George Milnes, 1973 **Deep Impurities in Semiconductors** K. J. Blow, 1982 Semiconductor Material and Device Characterization Dieter K. Schroder, 2015-06-29 This Third Edition updates a landmark text with the latest findings The Third Edition of the internationally lauded Semiconductor Material and Device Characterization brings the text fully up to date with the latest developments in the field and includes new pedagogical tools to assist readers Not only does the Third Edition set forth all the latest measurement techniques but it also examines new interpretations and new applications of existing techniques Semiconductor Material and Device Characterization remains the sole text dedicated to characterization techniques for measuring semiconductor materials and devices Coverage includes the full range of electrical and optical characterization methods including the more specialized chemical and physical techniques Readers familiar with the previous two editions will discover a thoroughly revised and updated Third Edition including Updated and revised figures and examples reflecting the most current data and information 260 new references offering access to the latest research and discussions in specialized topics New problems and review questions at the end of each chapter to test readers understanding of the material In addition readers will find fully updated and revised sections in each chapter Plus two new chapters have been added Charge Based and Probe Characterization introduces charge based measurement and Kelvin probes This chapter also examines probe based measurements including scanning capacitance scanning Kelvin force scanning spreading resistance and ballistic electron emission microscopy Reliability and Failure Analysis examines failure times and distribution functions and discusses electromigration hot carriers gate oxide integrity negative bias temperature instability stress induced leakage current and electrostatic discharge Written by an internationally recognized authority in the field Semiconductor Material and Device Characterization remains essential reading for graduate students as well as for professionals working in the field of semiconductor devices and materials An Instructor s Manual presenting detailed solutions to all the problems in the book is available from the Wiley editorial department *Getting to Know Semiconductors* M. Levinshstein, G. S. Simin, 1992-09 Getting to Know Semiconductors is a simple introductory text on semiconductors First published in Russian 150 000 copies of the first edition were sold out immediately This translated English version by two of Russia s foremost scientists in the field of semiconductors is now available Clearly written in a simple and lively manner this book presents the most important phenomena of semiconductor physics and devices Dopants and Defects in Semiconductors Matthew D. McCluskey, Eugene E. Haller, 2012-02-23 Dopants and Defects in Semiconductors covers the theory experimentation and identification of impurities dopants and intrinsic defects in semiconductors The book fills a crucial gap between solid state physics and more specialized course texts The authors first present introductory concepts including basic semiconductor theory defect classifications crystal growth and doping They then explain electrical vibrational optical and thermal properties Moving on to characterization approaches

the text concludes with chapters on the measurement of electrical properties optical spectroscopy particle beam methods and microscopy By treating dopants and defects in semiconductors as a unified subject this book helps define the field and prepares students for work in technologically important areas It provides students with a solid foundation in both experimental methods and the theory of defects in semiconductors Doping in III-V Semiconductors E. Fred Schubert, 2015-08-18 This is the first book to describe thoroughly the many facets of doping in compound semiconductors Equal emphasis is given to the fundamental materials physics and to the technological aspects of doping The author describes various doping techniques including doping during epitaxial growth doping by implantation and doping by diffusion The key characteristics of all dopants that have been employed in III V semiconductors are discussed In addition general characteristics of dopants are analyzed including the electrical activity saturation amphotericity autocompensation and maximum attainable dopant concentration Redistribution effects are important in semiconductor microstructures Linear and non linear diffusion different microscopic diffusion mechanisms surface segregation surface drift surface migration impurity induced disordering and the respective physical driving mechanisms are illustrated Topics related to basic impurity theory include the hydrogenic model for shallow impurities linear screening density of states classical and quantum statistics the law of mass action as well as many analytic approximations for the Fermi Dirac integral for three two and one dimensional systems The timely topic of highly doped semiconductors including band tails impurity bands bandgap renormalization the Mott transition and the Burstein Moss shift is discussed as well Doping is essential in many semiconductor heterostructures including high mobility selectively doped heterostructures quantum well and quantum barrier structures doping superlattice structures and d doping structures Technologically important deep levels are summarized including Fe Cr and the DX center the EL2 defect and rare earth impurities The properties of deep levels are presented phenomenologically including emission capture Shockley Read recombination the Poole Frenkel effect lattice relaxation and other effects The final chapter is dedicated to the experimental characterization of impurities This book will be of interest to graduate students researchers and development engineers in the fields of electrical engineering materials science physics and chemistry working on semiconductors The book may also be used as a text for graduate courses in electrical engineering and materials science

Semiconductor Physics Karl W. Böer, Udo W. Pohl, 2023-02-02 This handbook gives a complete and detailed survey of the field of semiconductor physics It addresses every fundamental principle the most important research topics and results as well as conventional and emerging new areas of application Additionally it provides all essential reference material on crystalline bulk low dimensional and amorphous semiconductors including valuable data on their optical transport and dynamic properties This updated and extended second edition includes essential coverage of rapidly advancing areas in semiconductor physics such as topological insulators quantum optics magnetic nanostructures and spintronic systems Richly illustrated and authored by a duo of internationally acclaimed experts in solar energy and semiconductor physics this

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Modern Semiconductor Quantum Physics Ming-Fu Li, 1995-02-01 Modern Semiconductor Quantum Physics has the following constituents 1 energy band theory pseudopotential method empirical and ab initio density functional theory quasi particles LCAO method k p method spin orbit splitting effect mass and Luttinger parameters strain effects and deformation potentials temperature effects 2 Optical properties absorption and exciton effect modulation spectroscopy photo luminescence and photo luminescence excitation Raman scattering and polaritons photoionization 3 Defects and Impurities effective mass theory and shallow impurity states deep state cluster method super cell method Green's function method carrier recombination kinetics trapping transient measurements electron spin resonance electron lattice interaction and lattice relaxation effects multi phonon nonradiative recombination negative U center DX center and EL2 Defects 4 Semiconductor surfaces two dimensional periodicity and surface reconstruction surface electronic states photo electron spectroscopy LEED STM and other experimental methods 5 Low dimensional structures Heterojunctions quantum wells superlattices quantum confined Stark effect and Wannier Stark ladder effects resonant tunneling quantum Hall effect quantum wires and quantum dots This book can be used as an advanced textbook on semiconductor physics for graduate students in physics and electrical engineering departments It is also useful as a research reference for solid state scientists and semiconductor device engineers

Transistors Mikhail Efimovich Levinshtein, G. Simin, 1998 This new book by M Levinshtein and G Simin tells the readers about the design and work of the most important and most interesting semiconductor devices the transistors The book is written in a friendly and easy to read manner and is meant primarily for young people high school students freshmen and sophomores However the original approach to semiconductor physics makes this book attractive to physics teachers and professors as well The book consists of 3 parts Part I The section on semiconductors describes the main properties of semiconductors explains the difference between the semiconductors metals and dielectrics We find here the explanation of the appearance of those wonderful properties of semiconductors which underlie their numerous applications This part also contains a vivid and detailed description of the main types of motion of the charge carriers in semiconductors thermal motion motion in the electric field and diffusion Part II covers Barriers and Junctions In order to understand the principles of the work of the most important semiconductor devices it is not sufficient just to get to know the properties of semiconductors It

is also quite essential to study certain specific and interesting phenomena the so called junctions This part of the book contains a detailed and vivid description of those properties and in that view of the properties of the p n junctions and diodes photodiodes varicaps light emitting diodes solar cells and rectifier diodes Part III covers Transistors It describes the basis of the work of the Bipolar and Field Effect Transistors Without making use of rather complicated equations or notions of quantum mechanics the authors give a clear and simple explanation of the cause of ability of those devices to amplify and generate electric signals They tell the readers how transistors are manufactured and describe the work of the transistor s simplest circuits The last chapter of the book is devoted to the ideas underlying the transistors integrated circuits It is these integrated circuits which are the foundation of modern electronics from telephone apparatus to supercomputers from medical instruments to cosmic communication systems In conclusion the authors make an attempt to foresee and imagine together with the reader what other devices may come to substitute the transistor in the future

Defect and Impurity Engineered Semiconductors and Devices ,1998 **Problems Concerning the Spatial Distribution of Deep Impurities in Semiconductors** P.E. Gibbon,1968 *Basic Properties of Semiconductors* P.T. Landsberg,2016-04-19 Since Volume 1 was published in 1982 the centres of interest in the basic physics of semiconductors have shifted Volume 1 was called Band Theory and Transport Properties in the first edition but the subject has broadened to such an extent that Basic Properties is now a more suitable title Seven chapters have been rewritten by the original authors However twelve chapters are essentially new with the bulk of this work being devoted to important current topics which give this volume an almost encyclopaedic form The first three chapters discuss various aspects of modern band theory and the next two analyze impurities in semiconductors Then follow chapters on semiconductor statistics and on surfaces interfaces and band offsets as they occur in heterojunctions Chapters 8 to 19 report on newer topics though a survey of transport properties of carriers is also included Among these are transport of hot electrons and thermoelectric effects including here and elsewhere properties of low dimensional and mesoscopic structures The electron hole liquid the quantum Hall effect localisation ballistic transport coherence in superlattices current ideas on tunnelling and on quantum confinement and scattering processes are also covered

The Physics of Submicron Semiconductor Devices Harold L. Grubin,David K. Ferry,C. Jacoboni,2013-11-11 The papers contained in the volume represent lectures delivered as a 1983 NATO ASI held at Urbino Italy The lecture series was designed to identify the key submicron and ultrasubmicron device physics transport materials and contact issues Nonequilibrium transport quantum transport interfacial and size constraints issues were also highlighted The ASI was supported by NATO and the European Research Office H L Grubin D K Ferry C Jacoboni v

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Best Of Soviet Semiconductor Physics And Technology (1989-1990) Michael S

Shur, Michael E Levinstein, 1995-12-08 Each year a large number of first rate articles on the physics and technology of semiconductor devices written by Soviet experts in the field are published However due to the lack of exchange and personal contact most of these unfortunately are neglected by many scientists from the United States Japan as well as Western Europe Consequently many important developments in semiconductor physics are missed by the Western world This book is a serious attempt to bridge the gap between the Soviet and Western scientific communities Most of all it is an effort towards facilitating the communication and sharing of knowledge amongst people from different parts of the world Ultimately the aim is to contribute towards the building of a better world for all one where the knowledge of advanced technology and scientific discoveries is used to improve the quality of life and not the pursuit of selfish mutually destructive behavior For those in the field who wish to partake in this exchange of knowledge and as a gesture of support for their Soviet counterparts the reading of this book provides the first step

Proceedings of the Tenth International Workshop on the Physics of Semiconductor Devices : (December 14 - 18, 1999) [New Delhi]. 2(2000) ,2000 Advanced Materials '93 T Matsumoto, 2012-12-02

Computations Glassy Materials Microgravity and Non Destructive Testing is a compilation of the papers presented during the Third IUMRS International Conference on Advanced Materials International Union of The Materials Research Societies that discussed the concepts and methods behind glassy materials The book is divided into parts Part 1 tackles the progresses in sol gel science and technology the reaction mechanisms of ormosils and effects of ultrasonic irradiation and the preparation of different glasses and their properties Part 2 covers topics such as the neural network system for the identification of materials the use of computers for simulations of many body systems computer system for meeting the supercomputing needs of materials quality control of materials information by knowledge base and the development of knowledgebase system for computer assisted alloy design Part 3 deals with the properties of different materials the concepts and the techniques behind them and Part 4 discusses the non destructive evaluation The text is recommended for chemists and engineers in the field of materials science especially those who wish to know more about the progress in its field of research

Semiconductor Physics and Applications M. Balkanski, Richard Fisher Wallis, 2000-08-31 This textbook covers the basic physics of semiconductors and their applications to practical devices with emphasis on the basic physical principles upon which these devices operate Extensive use of figures is made to enhance the clarity of the presentation and to establish contact with the experimental side of the topic Graduate students and lecturers in semiconductor physics condensed matter physics electromagnetic theory and quantum mechanics will find this a useful textbook and reference work Proceedings of the First International Symposium on Electrochemical Microfabrication Madhav Datta, Keith Sheppard, Dexter D. Snyder, 1992 **SERI Photovoltaic Advanced Research and Development Bibliography, 1982-1985** ,1986

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