



Characterization of deep impurities in semiconductors by terahertz tunneling ionization

S.D. Ganichev^{a,b,*}, E. Ziemann^a, I.N. Yassievich^b, V.I. Perel^b, W. Prettl^a

^a Institut für Exp. und Angew. Physik, Universität Regensburg, 93040 Regensburg, Germany

^b A. F. Ioffe Physicotechnical Institute of the RAS, 194021 St. Petersburg, Russia

Abstract

Tunneling ionization in high-frequency fields as well as in static fields is suggested as a method for the characterization of deep impurities in semiconductors. It is shown that an analysis of the field and temperature dependences of the ionization probability allows to obtain defect parameters like the charge of the impurity, tunneling times, the Huang–Rhys parameter, the difference between optical and thermal binding energy and the basic structure of the defect adiabatic potentials. Compared to static fields, high-frequency electric fields in the terahertz-range offer various advantages, as they can be applied contactlessly and homogeneously even to bulk samples using the intense radiation of a high-power pulsed far-infrared laser. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Deep impurities; Terahertz radiation; Tunneling

1. Introduction

Investigation of the effect of an electric field on thermal ionization and trapping of carriers has been widely used to probe deep impurities in semiconductors. The standard method for the characterization of deep centers is DLTS [1] which is applied in various modifications. Here we will show that the investigation of phonon-assisted tunneling in strong static or alternating electric fields, in particular of terahertz frequencies, can be used to obtain the parameters of multiphonon transitions determining the nonradiative recombination rate.

2. Tunneling ionization in alternating electric fields

The application of strong electric fields to semiconductors with deep centers leads to the stimulation of

ionization/capture processes due to the Poole–Frenkel effect, phonon-assisted tunneling and direct tunneling. The Poole–Frenkel effect occurs for charged impurities only and can be observed for relatively small electric field, whereas all types of impurities can be ionized by tunneling. The phonon-assisted tunneling in static electric fields was first studied numerically in [2]. In semiclassical approximation the ionization probability $\epsilon(E)$ of deep neutral centers due to phonon-assisted tunneling in an alternating electric field $E(t) = E \cos(\omega t)$ is given by [3]

$$\epsilon(E) = \epsilon(0) \exp \left[\frac{E^2}{(E_c^*)^2} \right] \quad \text{with} \quad (E_c^*)^2 = \frac{3m^* \hbar}{e^2 (\tau_2^*)^2}, \quad (1)$$

where m^* is the effective mass of the carrier and τ_2^* is an effective time:

$$(\tau_2^*)^2 = \frac{3}{4\omega^2} (\sinh(2\omega\tau_2) - 2\omega\tau_2). \quad (2)$$

The tunneling time τ_2 is given by

$$\tau_2 = \frac{\hbar}{2k_B T} \pm \tau_1, \quad \tau_1 = \frac{1}{2\omega \alpha_{\text{dis}}} \left| \ln \frac{\epsilon_T}{\epsilon_{\text{opt}} - \epsilon_T} \right|, \quad (3)$$

where T is the temperature, α_{dis} is the impurity vibration frequency, ϵ_{opt} and ϵ_T are the optical and

*Correspondence address: Institut für Exp. und Angew. Physik, Universität Regensburg, 93040 Regensburg, Germany. Tel.: +49-941-943-2050; fax: +49-941-943-4223.

E-mail address: sergey.ganichev@physik.uni-regensburg.de (S.D. Ganichev).

Deep Impurities In Semiconductors

Moshe Homyonfer



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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 handbook delivers in depth treatment of the field reflecting a combined experience spanning several decades as both researchers and educators Offering a unique perspective on many issues Semiconductor Physics is an invaluable reference for physicists materials scientists and engineers throughout academia and industry

The Physics of Submicron Semiconductor Devices (Nato Asi Series. Series B. Physics, Vol 180)
Harold L. Grubin, David K. Ferry, C. Jacoboni, 1988 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 CONTENTS MODELLING OF SUB MICRON DEVICES 1 E Constant BOLTZMANN TRANSPORT EQUATION 33 K Hess TRANSPORT AND MATERIAL CONSIDERATIONS FOR SUBMICRON DEVICES 45 H L Grubin EPITAXIAL GROWTH

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Solid State Physics Vimal Kumar Jain, 2022-10-07 The book has been designed as a textbook for graduate and postgraduate students of physics material science and engineering This is the third edition of the textbook that is updated to reflect recent works in the field In this edition some new topics have been introduced while some of the existing topics like phonons Drude Lorentz model Fermi levels electrons and holes etc are modified Moreover the book has complete information on semiconductor devices like tunnel diode Gunn diode photodiode photoconductive diode varactor diode solar cell LED semiconductor lasers and semiconductor detectors All the chapters have been supplemented by solved and unsolved examples Some of the chapters illustrate areas of current interest in solid state physics to give the student practical working knowledge of the subject text in a simple and lucid manner There is a fair amount of detail in the examples and derivations given in the text Each section of the book has exercises to reinforce the concepts and problems have been added at the end of each chapter The detailed coverage and pedagogical tools make this

an ideal textbook for students and researchers enrolled in graduate and postgraduate courses of physics material science and engineering

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Physics of Semiconductors, 1979

Semiconductor Micromachining, Fundamental Electrochemistry and Physics S. A. Campbell, H. J. Lewerenz, 1998-05-08 *Semiconductor Micromachining Fundamentals and Technology* is a two volume work in which for the first time the various disciplines associated with the theory and practice of device fabrication are brought together in one comprehensive reference source Volume 1 contains a detailed coverage of semiconductor electrochemistry and physics whilst Volume 2 describes the wide range of microengineering technologies with details of practical applications The authors for each chapter have been carefully selected for their expertise and are acknowledged leaders in their respective fields The purpose of this book is to enable workers in the area of semiconductor micromachining to have ready access to the basic literature essential to provide a solid basis for the many different aspects of physics chemistry electronics and engineering involved with this technology The main focus of the book is on structures based on silicon the most common and versatile of the current range of commercially available semiconductors but other materials such as III V semiconductors are also considered Together these two volumes provide an indispensable reference text for this fast growing area of applied science It will be of value to a wide range of academic and industrial scientists technologists and engineers who wish to expand their knowledge in this area of science and for whom thus far there has been no convenient reference work Volume 2 *Techniques and Industrial Applications*

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