HL 91: Poster Session: Spintronics / Magnetic Semiconductors / Transport

Time: Thursday 16:00–19:00 Location: Poster D

HL 91.1 Thu 16:00 Poster D

Microwave influence on the electroluminescence of single InGaAs quantum dots — •Benjamin Wolter, Andreas Merz, Robert Schittny, Robin Schwerdt, Gunter Wüst, Pablo Asshoff, Michael Hetterich, and Heinz Kalt — Karlsruhe Institute of Technology (KIT) and DFG Center for Funtional Nanostructures (CFN), 76131 Karlsruhe, Germany

We investigate the effects of high-frequency microwave radiation (53 GHz) in different intensity regimes on the emission of single quantum dots in spin-injection light emitting diodes (spin-LEDs). A specially prepared spin-LED is placed in a microwave cavity and is exposed to the microwave radiation with different powers and frequencies. At low microwave powers an enhancement of the electro-luminescence emission was detected whereas at higher power the emission quenches due to thermal heating. Furthermore the influence at high static magnetic fields is investigated to proceed towards spin manipulation of single electron spins in InGaAs quantum dots.

HL 91.2 Thu 16:00 Poster D

Time-resolved spectroscopy of a three-terminal semiconductor structure for electrical spin-storage and read-out — •Helge Wurst, Andreas Merz, Johannes Zeller, Robert Schittny, Benjamin Wolter, Christoph Krämmer, Heinz Kalt, and Michael Hetterich — Karlsruhe Institute of Technology (KIT) and DFG Center for Funtional Nanostructures (CFN), 76131 Karlsruhe, Germany

In recent years, spin light-emitting diodes have become well-established devices in the spintronics community. In this contribution, we present time-resolved measurements performed at a transistor-like structure aiming at spin-injection, prolonged spin storage and spin-readout with all of these processes controlled individually and all-electrically. This structure consists of a diluted magneti semiconductor as spin-injector and quantum dots which are selectively loaded with electrons and holes, respectively.

HL 91.3 Thu 16:00 Poster D

Temperature dependence of the spin relaxation length in spin quantum dot LEDs — •Carola Fritsche[1], Henning Höpfner[1], Arne Ludwig[2], Astrid Ebbing[2], Frank Stromberg[3], Heiko Wende[3], Werner Keune[3], Dirk Reuter[2], Andreas D. Wieck[2], Nils C. Gerhardt[1], and Martin R. Hofmann[1] — [1]Photonics and Terahertz Technology, Ruhr-University Bochum, Germany — [2]Applied Solid State Physics, Ruhr-University Bochum, Germany — [3]Faculty of Physics and Center for Nanointegration Duisburg-Essen, University of Duisburg-Essen, Germany

Over the last two decades remarkable progress has been seen in the field of spintronics and spin-optoelectronics in particular. Spin injection into spin light-emitting diodes (LEDs) using ferromagnetic contacts has greatly improved, resulting in higher polarization of the emitted light.

Here we present an investigation of the spin relaxation length in actual spin-LED devices. Our devices consist of self-assembled InAs quantum dots in the active region and a Fe/Tb multilayer spin injector with a MgO tunnel barrier for improved injection efficiency. Operation of our devices in magnetic remanence enables measurements without the influence of external magnetic fields (Appl. Phys. Lett. 99 (5), 051102 (2011)).

Although our devices implement spin injection both in magnetic remanence and at room temperature, we performed a systematic study of the spin relaxation length as a function of device temperature. Additionally, we study the homogeneity of our samples and influences of diode current on spin polarization.

HL 91.4 Thu 16:00 Poster D

Higher order correlation spectroscopy: Theoretical foundation and application — •Sebastian Starosielec, Jörg Rudolph, and Daniel Hägele — AG Spektroskopie der kondensierten Materie, Ruhr-Universität Bochum, Germany

Fluctuation spectroscopy and spin noise spectroscopy in specific have opened a growing research field [1,2]. Recently, we implemented higher order correlation spectroscopy up to radio frequencies, significantly extending the usual determination of the (only second order) noise power spectrum [3]. There are recent proposals for identifying physical properties from higher order spectra [4]. As opposed to usual power spectra, the implication of finite frequency resolution (temporal windowing) and finite measurement time to higher order spectra are no longer trivial. Here, we present first steps towards a mathematical framework for practical higher order noise spectroscopy and show a few examples of its application.

[1] M. Oestreich *et al.*, Phys. Rev. Lett. **95**, 216603 (2005)
[2] S. Starosielec *et al.*, Appl. Phys. Lett. **93**, 051116 (2008)
[3] S. Starosielec *et al.*, Rev. Sci. Instr. **81**, 125101 (2010)
[4] R.B. Liu *et al.*, New J. Phys. **12**, 013018 (2010)

HL 91.5 Thu 16:00 Poster D

Electron spin dynamics in wurtzite GaN — Jan Heye Buss, Jörg Rudolph, Arne Schaefer, •Jago Döntgen, and Daniel Hägele — AG Spektroskopie der kondensierten Materie, Ruhr-Universität Bochum, Germany

The semiconductor GaN is well established in modern optoelectronics and is considered a candidate for semiconductor spinelectronics due to its small spin-orbit splitting. However, electron spin lifetimes were found to hardly exceed 50 ps at room temperature [1, 2] whereas GaAs with its larger spin-orbit splitting shows RT lifetimes of about 200 ps. The symmetry of wurtzite GaN is found to cause a k-linear dependence of the effective magnetic field (effective Rashba field) in the conduction band whereas cubic semiconductors show a k^3-dependence. As a direct consequence of the linear Rashba field we observe by time-resolved Kerr-rotation spectroscopy an anisotropic spin relaxation tensor [3], and a weaker dependence of spinlifetimes on temperature [2] and doping density [4] as compared to e.g. cubic GaAs. All results are quantitatively explained without any fitting parameter by a newly derived analytic expression for Dyakonov-Perel spin relaxation in wurtzite semiconductors [3,4].

[1] B. Beschoten *et al.*, Phys. Rev. B **63**, 121202 (2001)
[2] J. H. Buß *et al.*, Phys. Rev. B **81**, 155216 (2010)
[3] J. H. Buß *et al.*, Appl. Phys. Lett. **95**, 192107 (2009)
[4] J. H. Buß *et al.*, Phys. Rev. B **84**, 153202 (2011)

HL 91.6 Thu 16:00 Poster D

Evidence for an efficient dynamical nuclear polarization process in a high-mobility (110)-grown two-dimensional electron system — •M. Griesbeck[1], B. Erbe[1], M. Glazov[2], E. Sherman[3], T. Korn[1], D. Schuh[1], W. Wegscheider[4], J. Schliemann[1], and C. Schüller[1] — [1]Department of Physics, Regensburg University, Germany — [2]Ioffe Physical-Technical Institute, St. Petersburg, Russia — [3]Department of Physical Chemistry, The University of the Basque Country, Bilbao, Spain — [4]Solid State Physics Laboratory, ETH Zürich, Switzerland

As a consequence of the limited electron spin lifetime, the intensively studied concept of dynamical nuclear polarization (DNP) using two-dimensional electron gases still lacks an experimental implementation [1]. Recently, the spin dephasing time along the growth direction in (110)-grown zinkblende-based heterostructures, especially in symmetrically grown and doped two-dimensional electron systems, has been demonstrated to reach extremely high values [2]. By means of the all-optical resonant spin amplification technique [3], we study the anisotropic spin dynamics. Our sample consists of a 30 nm wide double-sided δ-doped single quantum well with a very high mobility of about 3 million cm^2/Vs. At low temperatures, we find evidence for a very efficient DNP process. We clearly map the expected strong dependence of the DNP on the initial spin polarization of the electron system.

[1] I. Ţifrea and M. Flatté, Phys. Rev. B 84, 155319 (2011)
[2] M. Griesbeck et al., preprint: http://arxiv.org/abs/1111.5438
[3] J. M. Kikkawa et al., Phys. Rev. Lett. 80, 4313 (1998)

HL 91.7 Thu 16:00 Poster D

Spin dynamics and anomalous spin diffusion in high-mobility (110) GaAs-based quantum wells — •R. Völkl[1], T. Korn[1], S.A. Tarasenko[2], M. Griesbeck[1], M. Schwemmer[1], D. Schuh[1], W. Wegscheider[3], and C. Schüller[1] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Germany — [2]A. F. Ioffe Physical-Technical Institute, Russian Academy of Sci-

ences, St. Petersburg, Russia — [3]ETH Zurich, Switzerland

Here, we present a study of electron spin dynamics in symmetrical, high mobility (110)-grown, GaAs-based quantum wells, focusing on spin lifetimes and the motion of spin-polarized electrons in the sample, as well as creating spin polarization due to a nonzero electron drift velocity. The Hanle-MOKE method is used to determine the spin lifetime and for mapping the motion of spin-polarized electrons. Spin lifetimes up to 54 ns are found for weak optical pumping, for stronger pumping the lifetime decreases rapidly. High excitation intensity entails an ascent of the hole-density, which leads to a faster decay of electron spin via the Bir-Aronov-Pikus mechanism, as well as to more recombination. Spin diffusion is studied by moving the pump beam using a motorized mirror. A maximum of the net spin polarization is observed a few microns away from the pump spot, due to a reduced influence of photo generated holes. An applied electric field yields a nonzero electron drift velocity. Due to the spatial dependence of the Dresselhaus field, an out-of-plane spin polarization is observed while an electric current runs along [1-10] direction. Financial support by the DFG via SFB 689 and SPP 1285 is gratefully acknowledged

HL 91.8 Thu 16:00 Poster D

Effects of low temperature annealing on the magnetic properties of (Ga,Mn)As/GaAs core-shell nanowires — •Alexander Eckrot[1], Christian Butschkow[1], Elisabeth Reiger[1], Andreas Rudolph[1], Dieter Schuh[1], Werner Wegscheider[2], and Dieter Weiss[1] — [1]Universität Regensburg, Germany — [2]ETH Zürich, Switzerland

We investigate the effect of low temperature annealing on the magnetic properties of GaAs/(Ga,Mn)As core-shell nanowires. The nanowires are grown via the vapor-liquid-solid (VLS) mechanism with gold as catalyst and molecular beam epitaxy (MBE). Depending on the growth parameters we achieve either wurtzite or zinc-blende core-nanowires. When the (Ga,Mn)As shell is grown axially on the side facettes of the nanowires at low temperatures it adopts the crystal structure of the core. The nanowires are contacted electrically using E-beam lithography (EBL) in order to monitor the resistance during the annealing process. The Curie-Temperature (T_C) and the magnetic anisotropies are determined by magnetotransport measurements. For annealing temperatures between 160°C and 230°C and an annealing duration of up to 350 hours we observe a resistance decrease of up to 20%. The annealing procedure can affect significantly the magnetic hysteresis of a single nanowire.

HL 91.9 Thu 16:00 Poster D

Ground-state properties of Kondo-lattice from spin dynamics — •Alexander Baral and Hans Christian Schneider — Physics Department, University of Kaiserslautern, 67653 Kaiserslautern, Germany

We present theoretical results on the spin dynamics in a Kondo-Lattice using an equation-of-motion approach for one and two-particle correlation functions. We use a s(p)-d model, which describes the exchange interaction between localized magnetic moments and itinerant electrons, in a parameter range typical of the magnetic semiconductor GaMnAs[1]. We set up dynamical equations for the relevant distributions and (spin) correlation functions, and employ different approximations, i.e., truncations of the equation-of-motion hierarchy, up to the level of scattering between correlations and distributions. To keep the numerics tractable, we employ a virtual-crystal approximation and investigate the properties of this system in one dimension. We obtain information on the correlation function between itinerant and localized spins in the ground state by evolving the dynamical equations starting from an uncorrelated initial state. We find long-range spin correlations at low temperatures, with a Kondo-like maximum of the correlation length at finite temperatures. Further, for very low temperatures, Cooper-pair like correlations between different spins and momenta emerge.

[1] L. Cywinski and L. J. Sham, Phys. Rev. B 76, 045205 (2007)

HL 91.10 Thu 16:00 Poster D

Cobalt-vacancy complexes and ferromagnetism in $\mathbf{Zn_{1-x}Co_xO}$ — •Paola Alippi[1], Gianluca Ciatto[2], Antonio Di Troilo[1], and Aldo Amore Bonapasta[1] — [1]CNR-ISM, Rome, Italy — [2]Synchrotron SOLEIL, Gif-sur-Yvette, France

The field of dilute magnetic semiconductors has gained increasing interest in the past decade both for the potential technological applications of spintronic devices and from a fundamental viewpoint due to the controversial mechanism that are at the basis of ferromagnetic ordering in these materials. Co- and Mn-doped ZnO are especially appealing materials, as they seem to exhibit ferromagnetism (FM) at room temperature (RT) and have low toxicity. Experimental and theoretical studies have attributed RT FM in these systems to a variety of origins including intrinsic defects, non-homogeneity of the dopant spatial distribution, formation of secondary phases. In particular, the role of oxygen vacancies V_O on the magnetic properties of $Zn_{1-x}Co_xO$ has been debated. We investigate the local structure of ferromagnetic $Zn_{1-x}Co_xO$ by coupling polarization- dependent x-ray absorption spectroscopy with Density Functional Theory calculations of selected defect structures. We give clear evidence of the presence of V_O located close to Co atoms in a specific complex configuration with the Co-V_O direction aligned along the wurtzite c axis. We also establish the upper concentration limit of metallic parasitic nanophases and their contribution to magnetism. Our results lead to the conclusion that oxygen vacancies play a major role in originating the high temperature ferromagnetism of $Zn_{1-x}Co_xO$.

HL 91.11 Thu 16:00 Poster D

Antiferromagnetic semiconductors of I-Mn-As type — •Stepan Svoboda[1], Vit Novak[1], Miroslav Cukr[1], Zbynek Soban[1], Helena Reichlova[1], Xavier Marti[1], Peter Wadley[1,2], Richard Campion[2], and Tomas Jungwirth[1,2] — [1]Institute of Physics AS CR, Prague, Czech Republic — [2]School of Physics and Astronomy, University of Nottingham, UK

Antiferromagnetic materials offer an alternative to ferromagnetic or multiferroic materials utilized so far in spintronic applications [1]. Compounds of the I-Mn-V family have been theoretically predicted to exhibit simultaneously semiconductance and room-temperature antiferromagnetism which makes them particularly appealing for spintronics. Although some of these compounds were chemically synthesized already thirty years ago, there has been virtually no experimental data on their electronic properties, mainly due to the limited quality of the material. Here we report on investigation of structural, electronic and magnetic properties of LiMnAs and CuMnAs. Both materials have been prepared in form of high-quality monocrystalline thin films by molecular beam epitaxy. Crystal structure of LiMnAs grown on InAs corresponds to that of the known cubic bulk material. Crystal structure of CuMnAs grown on GaAs substrate shows tetragonal symmetry with lattice parameters consistent with the strained bulk material.

[1] B.-G. Park et al., Nature Materials 10, 347-351 (2011)

HL 91.12 Thu 16:00 Poster D

Interference in single quantum Hall point contacts — •Martin Treffkorn, Timo Hyart, and Bernd Rosenow — Institut für Theoretische Physik, Universität Leipzig, Germany

Recent experiments on quantum Hall interferometers have shown evidence of resistance oscillations that originate from partitioning a wave packet at a quantum point contact (QPC), letting the two partial waves propagate along different one-dimensional channels, and interfering them at a second QPC. A further miniaturization of devices is possible if one achieves interference within a single QPC. While this possibility is absent in a QPC modeled be a harmonic saddle point potential as suggested in [Phys. Rev. B, 1987, 36, 7969-7976], anharmonicities in the potential result in the appearance of backscattering paths in the open quantum system. These give rise to an interference area and explain the observed resistance oscillations [Phys. Rev. B, 1988, 38, 10162-10165]. In order to study resitance oscillations of a realistic QPC, we use a potential that is calculated self-consistently from the electrostatics of a semi-conductor heterostructure with top gates and numerically calculate the magnetoresistance of such a device.

HL 91.13 Thu 16:00 Poster D

Magneto Thermopower Measuremtents on Rolled-Up 2DEGs — •Gunnar Schneider, Matthias Schmidt, David Sonnenberg, Christian Heyn, and Wolfgang Hansen — Institut fuer Angewandte Physik, Universitaet Hamburg, 20355 Hamburg, Germany

We present magneto thermopower measurements on an evenly curved two-dimensional electron gas (2DEG). The 2DEG is confined in a rolled-up GaAs/AlGaAs high electron mobility heterostructure (HEMT). The HEMT is grown by molecular beam epitaxy and, after a suspension step, it rolls up by the relaxation of strain that is intentionally introduced in the HEMT during the growth. Under a magnetic field, the 2D electronic density of states condensates into the Landau levels (LL). The number of filled LLs depends on the strength of the magnetic field component perpendicular to the 2DEG plane. Thus in a rolled-up 2DEG, where the field component is sinusoidally modulated, the density of states changes along the perimeter of the roll. We rotate the rolled up structure in the magnetic field and show the dependence of the diagonal and the off-diagonal (Nernst-Ettinghausen) magneto thermopower on the rotation angle.

HL 91.14 Thu 16:00 Poster D

Spin-splitting and g-factor of confined hole states in differently strained Ge quantum dots — •Alexei B. Agafonov, Kai-Martin Haendel, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, D-30167 Hannover, Germany

In this work we have investigated experimentally hole transport through vertical resonant tunneling structures of different lateral dimensions of the order of 1 micron using resonant magnetotunneling spectroscopy at low temperatures. The studied samples were prepared from the same double-barrier Si/Ge heterostructure containing Ge quantum dots sandwiched between two Si tunnel barriers.

For a smaller sample a considerable shift in the voltage position of current resonances arising in its current-voltage characteristic (IVC) at high bias in comparison with the position of the correspondent resonances in the IVC of a bigger one was found. This shift indicates a partial relaxation of the built-in strain in Ge layer of the smaller sample caused by the decrease of its lateral dimensions.

It was also found that the downscaling of the sample lateral size gives rise to a noticeable variation of g-factor of heavy hole states confined in quantum dots. The g-factor values were obtained from the splitting of the differential conductance peaks under the influence of the static homogeneous magnetic field. This splitting reflects the Zeeman spin-splitting of the above mentioned states and turned out to be field orientation dependent. The observed difference in g-factor is attributed to the partial strain relaxation in Ge layer of the samples as well.

HL 91.15 Thu 16:00 Poster D

Spin Injection from Ferromagnetic Contacts into InAs Nanowires — •Isabel Wehrmann[1,2], Sebastian Heedt[1,2], Torsten Rieger[1,2], Kamil Sladek[1,2], Daniel Bürgler[2,3], Detlev Grützmacher[1,2], and Thomas Schäpers[1,2,4] — [1]Peter Grünberg Institut -9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology — [3]Peter Grünberg Institut -6, Forschungszentrum Jülich, 52425 Jülich, Germany — [4]II. Physikalisches Institut, RWTH Aachen, 52056 Aachen, Germany

InAs nanowires grown either by MBE (molecular beam epitaxy) or by MOVPE (metalorganic vapour phase epitaxy) are contacted by two ferromagnetic strips (Co) to inject a spin-polarized current into the semiconducting nanowire. Because of the "conductivity mismatch" (difference in carrier concentration of InAs NW and Co contacts), a tunnel barrier, e.g. a thin layer of MgO or Al_2O_3, is required. In order to obtain a well-defined axis of magnetization and to achieve a continuous ferromagnetic contact area, the structure has to be planarized by using HSQ (hydrogen silsesquioxane) resist before Co is deposited. To prepare a defined thickness of the tunnel barrier, the native oxide is removed by in situ sputtering before the oxide layer is deposited by MBE. The ferromagnet-insulator-semiconductor junctions are characterized electrically. To prove whether spin injection has occurred, spin-valve measurements are performed in a non-local measurement geometry as well as the measurement of the spin dephasing in a Hanle setup.

HL 91.16 Thu 16:00 Poster D

Transport measurements on individual selective-area grown MnAs nanoclusters — •Martin Fischer[1], Matthias T. Elm[2], Shinjiroh Hara[2], Christian Heiliger[1], and Peter J. Klar[1] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, Deutschland — [2]Research Center for Integrated Quantum Electronics, Hokkaido University, Sapporo, Japan

Selective-area grown MnAs nanoclusters are promising components for applications in highly miniaturized future information storage devices. Due to the tuneability of parameters such as size, shape and arrangement of the clusters, their magneto-electronic behaviour can be widely tuned. As a starting point for the investigation of microscopic ordered cluster arrangements, we have studied the transport behaviour of single clusters of different shapes and sizes. For the contacting of the clusters, we used Au contacts structured by electron-beam lithography. The clusters were grown by selective-area MOVPE on GaAs (111)B substrates.

HL 91.17 Thu 16:00 Poster D

Hall effect in Cu-doped GaN films grown by molecular beam epitaxy — •Michael Maschek[1], Philipp R. Ganz[2], Christoph Sürgers[1], Hilbert v. Löhneysen[1,2], and Daniel M. Schaadt[2,3] — [1]Karlsruhe Institute of Technology, Physikalisches Institut, D-76049 Karlsruhe — [2]Karlsruhe Institute of Technology, Center for Functional Nanostructures, D-76049 Karlsruhe — [3]Institut für Energieforschung und Physikalische Technologien, TU Clausthal, D-38678 Clausthal-Zellerfeld

Group-III nitride semiconductors are attractive for spintronic device applications. A possible candidate for a nitride-based spin-aligner is Cu-doped GaN which exhibits ferromagnetic behavior at room-temperature, although Cu is an intrinsic non-magnetic material. However, the origin of the ferromagnetic behavior is not clear. Here we report on measurements of the Hall effect, resistivity, and magnetoresistance for temperatures $T = 2$ - 300 K and in magnetic fields up to 1 T performed on GaN:Cu films grown by plasma-assisted MBE. Films prepared under different growth conditions and of different thickness were investigated. With increasing Cu-to-Ga beam equivalent pressure (BEP) ratio the charge carrier density increases and the Hall mobility decreases due to defects introduced by Cu. Remarkably, samples with BEP ratio close to 1% show a strongly reduced charge carrier density and deviate from the general behavior. This suggests that Cu, which is preferentially substituted on Ga sites, acts as an acceptor up to a BEP ratio of 1%, whereas for higher concentrations Cu precipitates in Cu-Ga islands at the surface.

HL 91.18 Thu 16:00 Poster D

Ballistic Hall voltage in an asymmetric cross junction — •Michael Szelong[1], Ulrich Wieser[1], Michael Knop[1], Ulrich Kunze[1], Dirk Reuter[2], and Andreas Wieck[2] — [1]Lehrstuhl für Werkstoffe und Nanoelektronik, Ruhr-Universität Bochum — [2]Lehrstuhl für angewandte Festkörperphysik, Ruhr-Universtät Bochum

We are interested in the influence of asymmetry of a cross junction on ballistic Hall voltage in linear and nonlinear transport regime. The junction consists of a straight 200 nm wide stem and two 140 nm wide branches which merge into the stem at an angle of 30° (60°, 90°) and serve as voltage probes. Devices with different stem widths are processed on a high-mobility GaAs/AlGaAs heterostructure with a two-dimensional electron density and mobility of $n_{2D} = 3.6 \cdot 10^{11}$ cm^{-2} and $\mu_n = 8 \cdot 10^5$ cm^2/Vs, respectively, resulting in a mean free path of about 8 μm at $T = 4.2$ K.

A current driven through the stem induces a Hall voltage which is expected to be dependent on the current polarity, larger where electrons flow easier into the tilted probes, smaller in the opposite case. Linear and nonlinear transport regimes as well as the transition are to be considered and compared to theoretical simulations, which are based on time-resolved propagation of electron wave packets.

HL 91.19 Thu 16:00 Poster D

Shubnikov-de Haas oscillations and quantum Hall effect in Gd-implanted $Al_xGa_{1-x}N$/GaN heterostructures — •Stepan Shvarkov[1], Dirk Reuter[1], Yvon Cordier[2], and Andreas D. Wieck[1] — [1]Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany — [2]CRHEA-CNRS, F-06560 Valbonne, France

We present a study of the magnetotransport properties of $Al_xGa_{1-x}N$/GaN heterostructurs. The samples were grown by molecular beam epitaxy on Si(111) substrates. The transport properties of the samples doped with Gd and undoped samples are compared. The Gd ions were introduced by focused ion beam implantation with fluences from 8×10^{10} cm^{-2} to 1×10^{12} cm^{-2} . As-grown samples reveal quantum interference effects such as weak localization and electron-electron interactions in low magnetic fields. At high magnetic fields B > 6 T, Shubnikov-de Haas (SdH) oscillations and quantum Hall effect (QHE) were observed. In analyzing the measured data, elastic and inelastic scattering times, mobility, carrier concentration and effective mass of the electrons in unimplanted and implanted samples were determined. The implantation strongly affects the quality of the heterostructures, causing strong decrease in carrier mobility at low temperatures. Nevertheless, SdH-oscillations and the QHE are still well pronounced in samples implanted with a fluence of 1×10^{11} cm^{-2}.