Posters

Radius Dependent Shift of Surface Plasmon Frequency in Metallic Nanospheres: Theory and Experiment

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The theoretical description of oscillations of an electron liquid in metallic nanosphere is formulated within random-phase-approximation semiclassical scheme. The spectrum of plasmons in metallic nanospheres is determined including both surface and volume type excitations. The Lorentz friction of electrons due to irradiation of electro-magnetic (e-m) energy by plasmon oscillations is analyzed with respect to the sphere dimension. The resulting red-shift of resonance frequency due to plasmon damping turns out to be strongly sensitive to the sphere radius. The form of e-m response of the system of metallic nanospheres embedded in the dielectric medium is found. The theoretical predictions are verified by the measurements of light excitation in nanosphere colloidal water solutions, for Au and Ag with the radius of metallic components from 10 to 75 nm. Theoretical predictions and experiment data clearly agree in the radius dependence of the resonance red-shift and in the emergence of the first volume plasmon resonance in the e-m response of the system for big nanosphere radii.

Plasmons in Metallic Nanospheres in RPA-type Approach; Undamped Energy Transport by Collective Surface Plasmon Oscillations Along Metallic Nanosphere Chain

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The random-phase-approximation semiclassical scheme for description of plasmon excitations in metallic nanosphere is developed for a case of presence of dynamical electric field and a long chain of nanoparticles. It is demonstrated that only surface plasmons of dipole type can be excited by a homogeneous dynamical electric field. The irradiation-induced damping effects are analyzed with respect to the sphere dimension in near-field zone leading to Foerster type coupling between nanoparticles.. The collective sub-diffraction wave-type oscillations of surface plasmons in long chains of metallic spheres are described. The undamped region of propagation of plasmon waves along the chain is found in agreement with some previous numerical simulations.

Numerical Study of Metastable States in Type II Gaussian QDs

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The metastable states (with angular momentum L=0, for rotational symmetry) against dipole e-m transitions are analyzed by numerical methods in Gaussian QD type II confinement in 2D electron systems (dot for electrons, antidot for holes, or conversely). The verification of previous analytical Hartree calculus is performed. Wide range of parameters including external magnetic field, and different bare potentials for electrons and holes is considered in order to model experimental situations (electrically defined type II QDs, self-assembled type I QDs converted to type II by strain). Formation of exciton in type II QDs is described also in lateral electric field. Comparison of Gaussian with singular Coulomb-type confinement of ionized acceptor or donor in 2D quantum well is presented.

Coherent Emission and Phonon-Related Effects in Double Quantum Dots

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Double quantum dots (DQDs) are systems of two semiconductor quantum dots (QDs) placed close to each other, so that the carriers confined in each dot become coupled either by tunneling through the inter-dot barrier (the system is then referred to as a quantum dot molecule) or by Coulomb couplings. The state space of such a system is obviously richer than that of a single QD and allows, e.g., for entanglement between the dots. Also the recombination and relaxation processes in DQDs show many features which cannot appear in individual QDs. In the case of radiative recombination, these include collective (superradiant) effects in the coupling between the confined carriers and their electromagnetic environment (radiation vacuum) [1]. In the case of phonon-related decoherence, new relaxation and dephasing channels are opened due to, among others, inter-dot excitation transfer [2] or "localization"-like dephasing of non-local superpositions [3].

In this contribution, we will present our recent results related to the specific decoherence processes in double quantum dots. We will discuss the collective radiative effects in the occupation decay as well as in the linear and non-linear optical response of the system [1,4]. We will describe the decay of entanglement in coupled and uncoupled double-dot structures [5]. We will also discuss the phonon-assisted excitation transfer between the dots. In addition, we will propose a unified approach to the numerical simulation of the system evolution under the joint action of radiative and phonon-assisted dephasing. We will show some effects related to the non-trivial interplay of collective emission and phonon-induced decoherence [6].

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The Photoluminescence Studies of Many Body Interactions in Two Dimensional Hole Gas

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The experimental studies of low-temperature (T = 2 K), high-field ($B \leq 20$ T), polarization-resolved magneto-photoluminescence (PL) of an asymmetric w = 22 nm wide GaAs/GaAlAs quantum well are reported. The structure was fabricated by molecular beam epitaxy, and the two-dimensional hole gas was obtained by Carbon δ-doping in one of the barriers of the well. The sample was of a very good quality, with dark low temperature 2D hole concentration p = 1.92×10^{11} cm^{-2} and mobility μ = $1.71\times10^{5}cm^{2}/Vs$. The optical emission was excited above the barrier by an Argon ion laser. By increasing laser excitation power density we were able to slightly decrease the 2D hole concentration. The actual concentration was determined from parallel transport measurements in van der Pauw configuration. Recorded PL spectra (Fig. 1) reveal all three predicted [1] bound states of the positive trion (charged exciton): the singlet as well as both triplets ("bright" and "dark"). The neutral exciton peak was also identified, allowing an experimental determination of trion binding energies. At lower energies (below free excitons and trions) several lines attributed to the acceptor-bound excitons and trions were identified. The most intriguing of these lines emerges in the PL spectra only at sufficiently high fields ($B \geq 5$ T), initially below the singlet trion. When the field is increased, the line shifts linearly to higher energies (in contrast to the "shake-up" line [2]). In high fields, it crosses all trions and the exciton (Fig. 2). Its intensity decreases in lower temperatures (from T =4.2 K down to 50 mK in our experiment). Aided with the numerics, we attribute this transition to the combined exciton-cyclotron resonance (hole cyclotron replica of an acceptor-bound positive trion, $AX^{+}CR$). A similar effect was previously observed in PLE and reflectivity of a low-density electron gas [3].

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Fig. 1

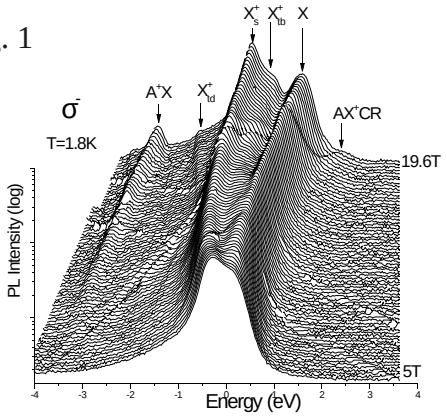
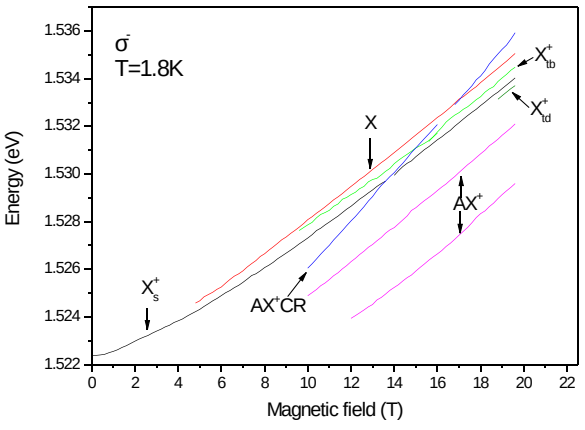


Fig. 2



Eight-band k•p Calculations of the Effects of the Composition Contrast on the Linear Polarization Properties of Columnar Quantum Dots

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We present eight-band **k·p** calculations of the electronic and polarization properties of columnar $In_yGa_{1-y}As$ quantum dots (CQD) with high aspect ratio embedded in an $In_xGa_{1-x}As$ /GaAs quantum well. Our model accounts for the linear strain effects, linear piezoelectricity and spin-orbit interaction. We calculate the relative intensities of transverse-magnetic (TM) and transverse-electric (TE) linear polarized light emitted from the edge of the semiconductor wafer as a function of the two main factors affecting the heavy hole - light hole valence band mixing and hence the polarization dependent selection rules for the optical transitions, namely i) the composition contrast *y*/*x* between the dot material and the surrounding well, and ii) the dot aspect ratio. The numerical results show that the main driving parameter for tuning the polarization properties is the composition contrast. This is explained based on an analysis of the integrated biaxial strain over the CQD volume, which is shown to be a good figure of merit to predict and explain the TM to TE intensity ratio.

Time and Spectrally Resolved Photoluminescence of In(N)As Quantum Dots Embedded in GaIn(N)As/GaAs Quantum Well

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It is expected that quantum dot (QD) based lasers can offer better perspectives in telecommunication applications than their QW-based counterparts. It is mostly due to theoretically predicted advantages like low threshold current, broad gain spectrum, high wavelength and temperature stability. A very good candidate for the laser application are self-organized InAs QDs grown on GaAs substrate, however in this materials system it is still difficult to achieve emission at 1.3 μm. An effective method to tune the emission from InAs QDs to longer wavelength is their overgrowth by GaInAs layer. It was also recognized that more controllable redshift of InAs QDs emission wavelength can be realized by the overgrowth of InAs QDs by GaInNAs, because incorporation of nitrogen into GaInAs simultaneously decreases the energy gap and reduces strains. We believe that similar effect can be achieved when N atoms are incorporated into the InAs QDs grown on the GaAs.

In this work we use time and spectrally resolved photoluminescence technique to study the influence of nitrogen incorporation into the InAs/GaInAs dots-in-the-well system. It is observed that the incorporation of a small nitrogen content into InAs/InGaAs system causes redshift of the ground state emission and changes in the intensity and broadening of the photoluminescence emission line depending on the growth process optimization. For the best growth parameter the ground emission of entire In(N)As/GaIn(N)As system is at 1.3 μm at room temperature and its intensity exceeds by about one order of magnitude the PL intensity from InAs/GaInAs system. Moreover, the temperature quenching of the PL emission line for optimized In(N)As QDs is much slower than for InAs QDs. The time resolved PL experiment shows that room temperature radiative recombination time for the optimized In(N)As QDs is ~500 ps, which is almost twice longer than for InAs/InGaAs system. It confirms that nitrogen inclusion does not necessarily deteriorate optical quality of the structure by introducing additional non-radiative recombination channels, which was expected in nitrogen containing structures. At low temperature it is observed that radiative recombination time is very similar for the optimized In(N)As QDs and InAs QDs (~1.25 ns) however for non-optimized In(N)As QDs it is ~1.6 ns and strongly varies with QDs emission wavelength. This difference is related with strain conditions under the QDs layer generated by the nitrogen presence in the structure but also growth condition. The strain conditions influence size and homogeneity of QDs ensemble which was additionally confirmed by the SEM picture.

Emission Properties of Strongly Asymmetric Single Quantum Dots Described by a Few Level Rate Equation Model

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Different kind of self-assembled quasi-zero-dimensional structures called quantum rods (InGaAs/GaAs) and quantum dashes (in two different material systems: InAs/InP and InGaAs/GaAs) were studied. Quantum rods are columnar quantm dots with the aspect ratio significantly larger than 1 which is obtained by a close stacking growth technique of a short period supperlattice (an alternate growth of very thin InAs and GaAs layers on a seed quantum dot layer). Quantum dashes are a form of quantum dots with one lateral dimension elongated (here in the direction [0-11]), which is a direct result of the anisotropic strain field in the substrate, present during the epitaxial growth process.

In these structures, spectral lines connected with different exciton complexes confined in a single quantum rod/dash have been resolved in microphotoluminescence spectra. In order to describe their excitation power dependence and determine the exciton (X) to biexciton (XX) lifetimes ratio τ_x/τ_{xx} a rate equation model was used, taking into account the possible occupation of the higher energy states. The inclusion of the latter and tuning of the τ_x/τ_{xx} influence mainly the high excitation part of the intensity versus generation rate functions for both X and XX. This allows fitting the experimental data in a very broad excitation level range and determining the dynamic properties indirectly. For instance, an unusually high τ_x/τ_{xx} of about 4 has been obtained for InGaAs quantum rods which can be connected with fast spin-flip relaxation rate in such structures [1]. In the case of InGaAs quantum dashes, the obtained lifetimes ratio indicated a rather short exciton lifetime (τ_x/τ_{xx} of about 1), compared to the typical values observed for self-assembled InAs or InGaAs quantum dots. The latter, together with the observation of the biexciton sideband [2], being a fingerprint of fast quantum dash recombination rate (i.e., close to the neighbouring wetting layer lifetime values), suggest a rather weak confinement regime and enhanced oscillator strength in these dashes.

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Electronic Structure and Optical Properties of InGaAs/GaAs Quantum Dot Based Tunnel Injection System: Experiment and Modelling

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The limited speed of the direct modulation due to relatively long times of the electron relaxation towards the quantum dots (QDs) ground state is a major drawback of the application of QD based lasers in fibre optics telecommunication. One of the most promising methods of alleviating this problem is the design of tunnel injection (TI) structures, where carries (in principle electrons) are injected by the means of tunnelling through a thin barrier from a quantum well (QW) directly to the QD ground state with the assistance of phonons. In this way not only the electrons reach the QD ground state much faster, but in larger numbers as well, since the QW collects carriers with much better efficiency, and thus the device has improved operating parameters.

We present the results of optical investigations of the properties of TI structures consisting of the $In_xGa_{1-x}As$ quantum well, being a reservoir of carriers and a layer of self-assembled $In_{0.6}Ga_{0.4}As/GaAs$ quantum dots, serving as the emitter. The application of various complementary spectroscopic techniques, supported by the calculations in 8-band **kp** formalism, has given a direct insight into the physical properties of the investigated structures. Photoreflectance spectroscopy as an enhanced sensitivity modulation technique has been used to determine the band structure and the carrier wavefunctions of this complex system. There has been studied the dependence on the emitter-injector energy levels separation, type of the well, and barrier height. The experimental results are verified by the calculations of energy levels and wavefunctions in a realistic 3D model, including strain and piezoeffect. That data is crucial for the determination of the possible channels of the carrier transfer, governing the properties of TI structures. The conclusions drawn from this technique have been tested by the photoluminescence excitation, which directly probes the carrier transfer processes, and the results confirmed the tunnelling of carriers from the well to the dots. Finally, the influence of the tunnelling on the emission properties is investigated by photoluminescence, performed at different temperatures, i.e. exciton and free carrier transfer regimes.

Contactless Electroreflectance of GaInNAsSb/GaAs Quantum Well Structures for Laser Applications

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Recently, the III-V-N compound systems with a small content of nitrogen (N<5%) have attracted a great attention due to both, its unusual fundamental properties and their potential for long wavelength optoelectronic device applications on GaAs substrates. Contactless electroreflectance (CER), is very powerful tool to investigate optical properties of semiconductor systems including the number of confined states and the bandgap lineup in QW structures (i.e., the conduction and valence band offsets) [1-3]. In this work this techniques has been applied to study the number of confined states and their energies for GaInNAsSb/GaAs single quantum wells (QWs) and step-like GaInAsSb/GaNAs/GaAs QW structures dedicated for laser applications at 1.3 μm and 1.5 μm. The experimental data have been compared with theoretical calculations which were performed in the framework of the electron effective mass approximation. In this way the energy level structure for GaInNAsSb QWs has been determined. In addition, the broadening of CER resonance, which corresponds to the quality of QWs, was investigated for various sets of QW samples annealed at different temperatures. The optimal annealing temperature has been found by analyzing the broadening of CER resonance and the intensity of photoluminescence from GaInNAsSb QWs.

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Contactless Electroreflectance of AlGaN/GaN Heterojunction Structures Capped by a Thin GaN Layer

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AlGaN/GaN heterojunction structures have emerged as attractive transistors suitable for high-power and high-temperature electronics. In this work, uncapped and GaN caped AlGaN/GaN structures are investigated by contactless electroreflectance (CER). This technique, due to its absorption and differential character is an excellent tool to study the energies of optical transitions (including the excited state ones) in quantum wells as well as energies of bulk-like QW barriers. Because of its high sensitivity to the Franz Keldysh effect, this technique can be also used to determine the value of built-in electric fields in semiconductor structures. In CER spectra, a strong AlGaN resonance followed the Franz-Keldysh oscillation have been clearly observed [1]. The built-in electric field in the AlGaN layer has been extracted from the FKO period to be in the range of 0.3-0.5 MV/cm. Below the AlGaN-related transition, a clear resonance at the energy of ~3.6-3.8 eV (i.e. at much higher energy than the GaN band gap energy) has been detected in CER spectra. This resonance has been attributed to the optical transition within the GaN cap layer which creates a surface quantum well [2]. The observed experimental data have been compared with theoretical calculations which were performed within the electron effective mass approximation. Strain effects as well as the effect of spontaneous and piezoelectric polarization have been included in these calculations. It has been shown that the presence of surface GaN quantum well changes the band bending in this structure and influences the 2DEG concentration at AlGaN/GaN interface.

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Photoluminescence and Photoreflectance of Mid- and Far-Infrared Low Dimensional Structures by Using Fourier Transform Spectrocrometer

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Modulation spectroscopy, due to its absorption and differential character, is an excellent tool to study the energies of optical transitions (including the excited state ones) in quantum well (QW) and quantum dots as well as energies of bulk-like QW barriers or intermediate layers. Such experiments have already been successfully employed to study GaSb-based QWs for infrared applications up to 2 μm [1,2] and including type II structures for even longer wavelengths [3]. Nevertheless, the standard modulation spectroscopy based on diffraction grating monochromators has some limitations due to several reasons like e.g. less sensitive detectors or less efficiency of the probing light sources in case of mid and far infrared (comparing e.g. to the tools used in the visible range) [4]. Because there is a growing interest and necessity to investigate structures designed for operation in mid and far infrared range (e.g. infrared detectors, quantum cascade lasers, etc.) it has been proposed to exploit modulation spectroscopy realized by using Fourier transformed spectrometer [4]. This approach has already been used to investigate mainly the bulk-like materials and layers. In this work we are demonstrating the application of FTIR modulation spectroscopy for investigation of low-dimensional structures like type I or II quantum wells designed for mid infrared spectral region (up to ~ 5 μm). High signal to noise ratio of the measured spectra shows that this approach might by very perspective for the characterization of electronic and optical properties of structures designed for longer wavelength QCLs at 10-15 μm and further into the infrared.

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Band Gap Discontinuities in GaInAsSb/Al(In)GaASb Quantum Wells Being the Active Region of Mid Infrared Lasers

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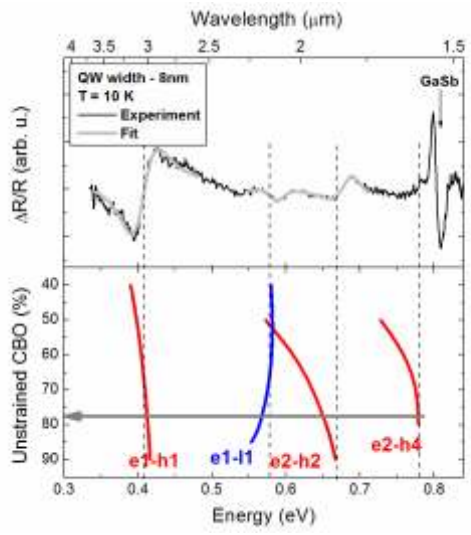
Semiconductor lasers with GaInAsSb/Al(In)GaAsSb quantum wells (QWs) on GaSb substrate operating in the wavelength region up to 3 μm and beyond are attractive light source for applications including remote sensing, pollutant detection, medical procedures or laser spectroscopy. In spite the room temperature cw operation has been demonstrated for such lasers the optimization of their performance is still limited by unfavourable band gap discontinuities ratio between the conduction and valence band, especially when going with the emission to longer wavelengths. Therefore, it is of crucial importance to be able to determine the band offsets (BO) in such structures reliably. We propose the use of modulation spectroscopy (in a form of photoreflectance) as a high sensitivity technique probing the higher order states in low-dimensional structures It is a method which combined with the energy level calculations offers unambiguous band offset determination in contrast to typically used PL studies. The latter detects usually the ground state transition only, which, as occurring between the relatively well confined electron and hole levels, is very weakly sensitive to the band offset ratio change. In contrast, the commonly observed in modulation spectra excited state related transitions and those involving the light holes give several experimental energies to be compared with the results of the calculations in which the BO ratio is treated as the only free parameter.

Figure shows an example of such a procedure performed for a quinary barrier $Ga_{0.35}In_{0.65}As_{0.32}Sb_{0.68}/Al_{0.25}Ga_{0.50}In_{0.25}As_{0.24}Sb_{0.76}$ QW. The top part is the low temperature photoreflectance spectrum whereas the bottom one is the result of calculations in a function of the BO in the conduction band thought for the unstrained materials (chemical band offset). The best agreement has been obtained for its value of about 78 %, which after including the strain (i.e. as in the real structure) recalculates into 65 % for the conduction band. The obtained BO values could be verified when determined for a QW of the same composition but different width, for which it expected to be the same. Similar studies have been performed for QWs with various quaternary and quinary barriers giving the insight on the BO dependence versus the change of the change of the well or barrier composition. The results have been confronted with the theoretical predictions based on the Van de Walle method. For instance, it has been obtained that the conduction band offset ratio (including the strain effect) would increase to about 90% for the same quantum well of $Ga_{0.35}In_{0.65}As_{0.32}Sb_{0.68}$ when the barrier is changed into quaternary $Al_{0.30}Ga_{0.70}As_{0.03}Sb_{0.97}$.



Optical Properties of GaSb-based Type II Quantum Wells Emitting in the Mid-Infrared Range

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Mid-infrared lasers find increasingly applications during last years including for instance gas sensing for detection and control of the presence or concentration of harmful gases like CO_2, SO_x, NH_3, and many others. The benefits of laser based methods have been limited mainly by the lack of suitable laser light sources, which have to provide the sensing wavelength in single mode and continuous wave (cw) in order to provide the required wavelength control and intensity. The performance of semiconductor laser emitters based on type I quantum wells operating in mid-wave infrared wavelengths beyond 3µm are restricted by fundamental limitations like unfavourable carrier confinement or small band gaps (comparable with split-off gaps). Therefore, the type II heterostructures employing InAs-GaSb-AlSb family have been proposed as an alternative. This eliminates Auger processes by removing the resonance between energy gap and split-off gap and enhances electronic confinement. Hereby, we present fundamental optical and electronic properties of a type II GaSb/AlSb/InAs/InGaSb/InAs/AlSb/ GaSb quantum well system potentially able to cover spectrally the range of 2 to 10 µm (when the thickness of InAs layer is tuned for instance), and possible to be integrated in a photonic sensor unit for gas detection. Spectroscopic experiments at low temperatures, like photoluminescence and photoreflectance, allowed us the detection of the optical transitions, including the spatially indirect ones, and their unambiguous identification after the comparison to the energy level calculations. Based on that, conclusions regarding the band gap discontinuities in such a complex system could also be drawn.

Additionally, photoluminescence thermal quenching was analyzed which on the one hand showed that the emission can still be effective at room temperature, and on the other hand that the temperature shift of the optical transitions is significantly smaller than for type I QW system and dependent on the InAs layer thickness. The latter does not follow the energy gap temperature dependence which could be explained when considered that electrons and holes are confined in separate layers.

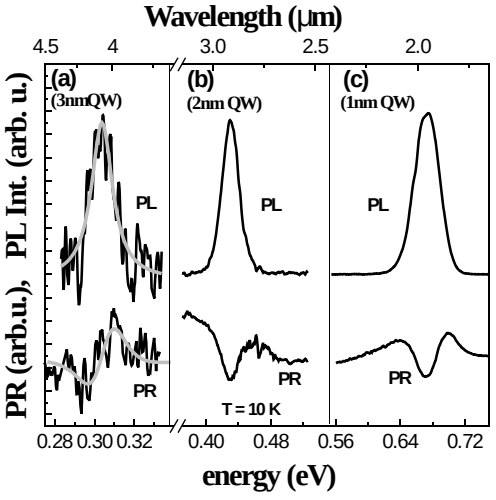

Fig. Low temperature (10K) PL and PR spectra for the GaSb/AlSb/InAs/GaInSb/AlSb/GaSb type II quantum wells with QW width equal to 3 nm (a), 2nm (b) and 1 nm (c).

Surface Photovoltage Spectroscopy of Low Dimensional Semiconductor Structures

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Surface photovoltage spectroscopy (a version with contacts) has been used for many years to study the properties of electronic states near the surface in bulk semiconductors. With the advent of crystal growth techniques, allowing the production of high quality semiconductor heterostructures, SPS spectroscopy found additional applications and it was used to study electronic states in heterostructures, quantum wells (QW's), quantum dots (QD's) and nanostructures.

We are using a contactless version of SPS. SPS, like electromodulation techniques (e.g. photoreflectance (PR) and contactless electroreflectance (CER), being nondestructive and contactless, but possesses some advantages over PR and CER.

The potential of contactless SPS we will show on three examples.

i) We will start with the results obtained from AlGaAs epitaxial layers with different Al content grown by MBE on GaAs substrate. We can show that using SPS technique it is possible to investigate direct bandgap in AlGaAs semiconductor up to 100% of Al.

ii) The need of realizing active layers for 1.3 μm lasers on GaAs substrate has recently led to intensive studies on long wavelength light emitting materials, e.g. GaAsSb. Several earlier studies have reported contradictory results on the value of GaAsSb/GaAs valence band offset. Here we present the optical studies of $GaAs_{1-x}Sb_x$/GaAs multiple quantum well structures with emission close to 1.3 μm. Under investigations were four structures which differ only with Sb content: 0.23, 0.26, 0.32 and 0.39. After detailed investigations we can show that the optical response of our structures shows weak type-I band alignment.

iii) As third ex ample we present a room temperature study of two 30-layer stacks of self-assembled InAs/GaAs quantum dots with different spacer layer thickness. Both PL and SPS spectra of stacked QDs structure with a thinner spacer layer in comparison to other structures show additional feature. QD features are more clearly visible in SPS spectra and show more features in comparison to PL ones.

Above studies demonstrate the considerable potential of SPS, PR and PL as complementary techniques for the contactless and nondestructive characterization of low dimensional structures at room temperature.

Influence of the Annealing Temperature on Excitation of Terbium Luminescence in Yttrium-Aluminum Oxide Films Deposited onto Porous Anodic Alumina

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In this work we investigate the excitation mechanism and influence of the annealing temperature on this process terbium-doped yttrium-aluminum oxide films fabricated by spin-on deposition onto porous anodic alumina. An interest in the synthesis of light-emitting materials in PAA arises from its unique tailor-made honey-comb structure, strong luminescence of the embedded impurities and great photonic density of states at direction along the channels of the pores. The samples were annealed at the temperatures from 400 to 1100°C, covering the range of the formation of the amorphous and crystalline phases of Al_2O_3 and $YAlO_3$. A strong terbium photoluminescence (PL) was observed for all samples revealing a spatial homogeneity of the PL intensity within 10%. An influence of the annealing temperature on the terbium PL related to $^5D_4 \rightarrow {}^7F_J$ (J = 3, 4, 5, 6) transitions of Tb^{3+} ions was studied using 2D photoluminescence excitation (PLE) and time-resolved spectroscopy. Moreover, a comparison of the thermal quenching data for the most intensive $^5D_4 \rightarrow {}^7F_5$ luminescence band of Tb^{3+} ions in the fabricated amorphous and crystalline matrices was performed for the temperature range of 10 - 300 K. Based on obtained data, mechanisms of Tb excitation and its dependence on the annealing conditions were proposed and discussed.

Direct Evidence of the Energy Transfer from Silicon Nanocrystals to Nd Ions and the Carriers Relaxation Pathways in Their Local Surrounding

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In this work a direct experimental evidence of the excitation energy transfer from the silicon quantum dots (Si-QD's) to Nd ions has been given based on photoluminescence and photoluminescence excitation measurements in the wide spectral range. Moreover, it has been shown that the excitation of Nd ions is possible and even more efficient from the higher energy levels in the vicinity of Si-QD's which lie close in resonance with the $^4I_{9/2} \rightarrow {}^4D_{3/2}$, $^4D_{5/2}$ absorption band of Nd ions. Moreover, it has been found that the excitation power density plays an important role in the temperature dependence of PL intensity both for Nd as well Si-QD's emission, where for high excitation fluxes emission intensity increases with the temperature up to 150 K. It has been proposed that this is due to the existence in relaxation mechanism additional processes related to recovery of the carriers captured at the defect states in the vicinity of Si-NC's.

Surface- and Volume-related Excitation Mechanism of Eu-doped GaN Nanocrystals

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Influence of the dopant position on the excitation mechanism of Eu^{3+} ions doped into nanocrystalline GaN powder has been investigated by using photoluminescence and photoluminescence excitation spectroscopy. It has been found, that depending on the grain sizes (surface to volume ratio in fact), different dopants excitation mechanisms can dominates. In the case of nanograins, it has been proposed that surface plays very important role and the dominant excitation of Eu^{3+} ions is via the local charge transfer from the oxygen atoms adsorbed post growth at the GaN nanocrystals surface.

Thick GaN Layers from Hydride Vapor Phase Epitaxy Examinated by Means Micro-Raman Spectroscopy

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Gallium nitride is a very attractive material for optoelectronic devices such as blue and ultraviolet light sources, UV detectors and for high temperature/power electronics. In the nature there are no native crystals of the gallium nitride, synthesis is very difficult and it is hard to obtain single crystals with good properties. Crystallization of freestanding GaN substrates can be made for example: by high-pressure synthesis, by sublimation method, ammonothermal method or flux method. However, the size of GaN crystals obtained in these methods is still too small for practical use. The current largest freestanding GaN substrate is obtained by growing a thick GaN layer on a sapphire substrate using Hydride Vapour Phase Epitaxy (HVPE) and separating the grown layer from the sapphire substrate. Since for gallium nitride devices manufacturing alternative substrates almost exclusively were used, dislocation and defects were generated. It results from mismatch lattices and thermal expansion coefficients of GaN and substrates crystals.

Raman scattering measurements are very sensitive, sophisticated and useful method for determination of materials parameters, especially gallium nitride GaN. This is a good method of qualitative and quantitative analyze of the matter, since the spectra of scattered light in a Raman mode (inelastic) are like fingerprints - are unique and allow to indentify the material (kind of atoms and molecules) and its parameters, for example residual strains (compressive and tensile) and doping. It is important especially for gallium nitride since nitrides devices, like laser diodes, high power and high temperature transistors, because their properties are very sensitive to stress. The need for use of alternative substrates, such a sapphire (Al_2O_3), silicon (Si) or silicon carbide (SiC), which have lattice parameters and thermal expansion coefficients different from GaN, leads to the formation of strains and defects in epitaxial GaN layers. The presence of residual strain can be important for yield of optoelectronic devices. Micro-Raman spectroscopy is one of the sensitive methods for giving information about the stress in epilayers.

From the measured Raman spectra modes intensity and shift the distribution of the residual strain, compressive stress - degree of epitaxial structures relaxation, homogeneity of the phonon mode emission lines as well as the presence of defects and quality of GaN crystals can be determined. Possibility of the microRaman spectroscopy applications in area of gallium nitride epilayers analyzes, especially determination of the stress and the stress distribution as well as strains in epitaxial structures. It can give information about the surface's crystal quality. Micro-Raman spectroscopy is one of the sensitive methods for giving information about the stress in epilayers. These huge possibilities of quality and quantity estimation arise from characteristic reaction of atoms and molecules - i.e. their vibrations and Raman spectrum intensity depends on the inelastic scattered photons quantity.

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Epitaxial Growth and Characterization of InGaAsN/GaAs Heterostructures Dedicated to Optoelectronic Devices

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Nitrogen incorporation into GaAs-based epilayers has received interest especially due to a band gap decreasing of resultant material. Small fraction of nitrogen makes (In,Ga)(As,N) alloys useful materials for optoelectronic devices grown on GaAs substrate. For photodetectors there is a possibility to extend the range of detectable wavelengths beyond the GaAs cutoff at 870 nm [1, 2]. Unfortunately, (In,Ga)(As,N) compounds suffer from deterioration of structural, optical and electrical properties with increasing nitrogen fraction in these semiconductor alloys [3, 4, 5, 6]. Therefore achieving the high quality of (In,Ga)(As,N)/GaAs heterostructures requires MBE (Molecular Beam Epitaxy) or LP-MOVPE (Low Pressure - Metalorganic Vapour Phase Epitaxy) techniques. Our work is focused on optical, electrical and structural properties of diluted nitrides. The technological parameters and characterization of epilayers with small nitrogen content obtained by Atmospheric Pressure MetalOrganic Vapour Phase Epitaxy (AP-MOVPE) are presented.

We investigated the influence of the growth temperature T_g and the III/V vapour phase ratio X_g= u-DMHy/ (u-DMHy + AsH_3) on fraction of the nitrogen in Ga(As,N) epilayers. The content of the InAs phase in (In,Ga)As layers grown at low temperatures was also determined for further elaboration of the AP-MOVPE growth of quaternary alloys (In,Ga)(As,N). The structural properties of the obtained Ga(As,N)/GaAs heterostructures were examined using the HRXRD. To determine the electrical properties of the structures the C-V and E-CV measurements were performed. Photovoltaic spectroscopy, photoluminescence and photoreflectance spectroscopy were used for optical characterization.

For the Ga(As,N)/(In,Ga)(As,N)/GaAs devices heterostructures the etching procedures, Schottky and ohmic contacts evaporation technique and the thermal treatment of the metal contacts were elaborated. Under our growth conditions we achieved Ga(As,N)/GaAs heterostructures suitable for photodetector MSM and PIN photodetectors fabrication. The dc I-V and spectral characteristics of these devices were measured and discussed.

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Investigation of Deposition Initial Step Influence on the Properties of Gallium Nitride Layers

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Gallium nitride is a semiconductor material widely applied for fabrication of electronic and optoelectronic devices, as well as chemical sensors. Despite of the devices commercial availability, the problem of good quality layers and substrates fabrication is still topical. Difficulties are caused by mismatch of thermal extension coefficients and lattice constants between GaN and applied alternative substrate. The most critical step of deposition is its initial stage. The nitridation mechanism of sapphire substrates and its influence on the growth and properties were investigated in Helicon wave plasma assisted technique [1]. GaN main layer properties are also dependent on buffer layer preparation. The decomposition of GaN nucleation layer [2] and influence of nitridation and buffer design on polarity were evaluated [3].

Gallium nitride layers were deposited on Al_2O_3 substrates, nitridated in the solution of ammonia and nitrogen in the proportions of NH_3:N_2 (1:10) at 1050 ^{o}C. Various times of nitridation were applied, in comparison purposes. Samples treated for 5, 10 and 15 minutes were chosen and named as sample #1, #2 and #3, respectively. Then layers were placed in 450 ^{o}C and nucleation layer (NL) was deposited. The duration of NL epitaxy was equal for all samples (6 min). HCl diluted in nitrogen (400 sccm/min) and ammonia flows were 8 and 400 sscm/min, respectively.

The morphology, crystalline quality and optical quality of HT-GaN layers were evaluated by application of Scanning Electron Microscopy imaging, High-Resolution X-Ray Diffractometry and photoluminescence, transmission, and reflectance measurements.

Time of sapphire substrate surface nitridation influenced the size of NL islands. The highest and smallest in diameter grains were remarkable for sample #1 but nitridation time of 5 min did not assure uniform preparation of sample surface. NLs of samples #1 and #2 were not continuous. The largest grains were observed for sample #2, islands of sample #3 NL had comparable sizes to that of sample #2 but were overgrown by smaller grains and formed continuous NL. Nitridation time of 15 min did not provide proper NL structure to obtain good quality of HT-GaN what could be observed in SEM images. Sample #3 exhibited extended surface morphology what indicated on its poor crystalline quality. SEM images of HT-GaN revealed terraces and artifacts on surfaces of sample #1 and #2, respectively.

XRD Θ/2Θ -patterns revealed preferred orientation in the 00.1 growth direction of HT-GaN (samples #1 and #2). Θ/2Θ -pattern of polycrystalline sample #3 consisted of additional peak from (10.1) GaN, additionally (00.4) peak was substantially weaker compared to patterns of other samples.

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Fabrication of Ohmic Contact Based on Platinum to *p*-type Compositionally Graded AlGaAs Layers

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AlGaAs/GaAs heterostructures are commonly applied for fabrication of semiconductor devices such as Heterojunction Bipolar Transistor, Monolithic Microwave Integrated Circuit, infrared light-emitting diode, laser diode, infrared photodetector and solar cell.

Stable and low-resistance ohmic contacts are critical for performance and reliability of the devices. Their preparation and characterization require many technological efforts. Ohmic contacts with low specific resistance to *p*-type AlGaAs are essential for microwave and optical devices such as bipolar transistors, *p-i-n* diodes and diode lasers. The metallization should have smooth surface and good interface morphology, very low contact resistance, sharp edges and good thermal stability to meet the demand of the modern devices. One of the most important criteria for an ohmic contact is its thermal stability which is usually assessed based on the test measurements performed at typical temperature for investigated material (400^{o}C for GaAs).

We focused on the development of low resistance ohmic contact based on platinum to *p*-type compositionally graded AlGaAs layer. Application of GaAs cap layer was unavoidable because it prohibits the oxidation of AlGaAs layer oxidation and improves the properties of the metallic contact to semiconductor. Previous works indicated that the use of low doped GaAs cap layer did not fulfil requirements for good quality contact fabrication. Thus, the heavy doped GaAs cap layers, with thickness of 20 nm, have to be applied.

Novel metallization scheme was proposed for ohmic contact formation to compositionally graded *p*-type AlGaAs. A metal multilayers of Ti/Pt/Au, Pt/Ti/Pt/Au and Pt/Ti/Ni/Au were deposited by thermal evaporation using electron gun and resistance heater. The contacts were sequentially annealed by rapid thermal annealing system in N_2 atmosphere at various temperatures (in the range from 350^{o}C to 550^{o}C). The duration of annealing step was 2 minutes. The as-deposited Pt/Ti/Pt/Au and Pt/Ti/Ni/Au multilayer metallizations had resistivities of $1.4 \cdot 10^{-5}$ $\Omega \cdot cm^2$ which have been gradually deteriorated after each subsequent annealing. The current-voltage characteristics of the ohmic contacts to compositionally graded *p*-type AlGaAs epitaxial layers were studied and discussed.

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