Final Report

WISSMC

Access to the Braun Submicron Center for Research On Semiconductor Materials Devices and Structures

Transnational Access

implemented as

Specific Support Action

Contract number: RITA-CT-2003-506095

Project coordinator: *Dr. Hadas Shtrikman – Weizmann Institute of Science*

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A. ACTIVITY REPORT

Final Report on the European TA program

Contract No. RITA-CT-2003-506095

We regard the past five year of the transnational access (TA) program as a great success. The reason for it is the large variety of participants' expertise, the interactions that were formed, the use of the sub-micron center (SMC) facilities, and the multitude of locations the participants arrived from. To be more specific, one can find that there was a healthy and constructive blend of theoreticians and experimentalists, as well as the variety of subjects dealt with, being of basic science nature and a more applied nature. Experimentalists spent time in the clean rooms of the SMC, high quality material was grown for some of them, electron beam lithography was used to miniaturize their structures, they were taught how to use the software needed to design their physical structures, etc. Many of them left with the fabricated samples to be measured back home in their laboratories. The theoreticians that visited interacted with the SMC experimentalists, on the feasibility of their ideas, as well as with the theoreticians on the condensed matter physics department, and, in some cases, with scientists from different faculties. All participants gave an oral presentation (a seminar or a colloquium) in the faculty of physics, and summarized their work and subsequent accomplishments after their visit. The program allowed a large number of visitors not only to accomplish their goals, but to acquaint themselves with our modern facilities and the people who conduct research here. This as lead, and still continues to lead, to tightening of the interpersonal relations between scientist here and in the EU.

The total number of projects supported – 77 projects.

The total number of users given access – 77 users.

The total quantity of access provided – 2100 days.

The average number of days per visit - 27 days.

Total number of publications and write-ups produced – 42.

The visitors came from 13 different countries: Poland, Italy, Netherlands, Germany, Turkey, Romania, Lithuania, Spain, France, Hungary, Sweden, United Kingdom and Switzerland.

Below we provide a summary of individual projects, worth mentioning, which have been funded during the five years of the project.

First year

Prof. Jurgen Smet - Germany

During the reporting year we continued to investigate the properties of ultra-high quality two-dimensional electron systems. These efforts disclosed a novel zero-resistance effect, which occurs when such devices are exposed to quasi-monochromatic microwave radiation. These so-called zero-resistance states unleashed an enormous interest in the scientific community, as they relate to fundamental physical phenomena such as superconductivity and the quantum Hall effect. To make further progress in our understanding of this phenomenon, likely requires the use of more sophisticated experimental probes such as local probe methods as they have been extensively explored by the group of Amir Yacoby at the Braun Submicron Research center. The transnational access program has enabled us to start a concerted action in this area in which the microwave photoconductivity expertise and the expertise of local probe methods of the Yacoby group are combined. Key contributions of the Weizmann Institute are the e-beam technology, the fabrication procedures to produce SETs on top of GaAs/AlGaAs heterostructures in a reliable and robust manner with high yield and the measurement procedures. Also the capability of producing state of the art two dimensional electron systems with electron mobilities exceeding the 10 million cm^2 /Vs mark has been very valuable. All of these are important prerequisites for our studies. Preliminary microwave results are very promising. We are now extending the measurements to higher frequencies and to samples that allow carrier density tuning. We do not doubt that this joint effort made possible through the TA-program will enable us to excel on an international level.

Yuriy Makhlin and Alexander Shnirman - Germany

The Berry Phase (BP) is a central concept in quantum mechanics. It is related to major themes such as adiabatic variation of parameters and pumping. More recently the BP has been addressed in the context of quantum computing. Given the importance of the subject we began our project (also in collaboration with R. Whitney at the University of Geneva) by posing the following question: “is it possible to define a BP (hence, to consider the adiabatic limit) for a system coupled to a reservoir made of an infinite number of degrees-of-freedom?” Once we have answered this question in the affirmative, we went ahead establishing the conditions for adiabaticity, as well as calculating environment-induced corrections to the BP. It turns out that the latter has a geometric interpretation. Moreover, the environment-induced imaginary part of the BP gives rise to geometric dephasing, a concept whose experimental ramifications are currently under investigation.

Mikhail Kiselev - Germany

Electron-electron interactions play an important role in confined geometry conductors, “zero-dimensional quantum dots (QDs)” being an important example. The “universal Hamiltonian” employed to describe the physics of QDs accounts inter alias, for the charging and exchange terms of the interaction. We analyze this Hamiltonian going beyond the mean-field limit (and accounting for quantum fluctuations). The fluctuations in the spin channel renormalize the spin susceptibility, but also affect the conductance in the charge channel.

Algirdas Suÿiedÿlis and Valerij Petkun - Lithuenia

Objective of the project was to develop the design of planar microwave detectors on the base of asymmetrically shaped mesoscopic semiconductor structures that can operate in submillimeter wavelength range of electromagnetic radiation:

a) planar diodes with upper contact layer;

b) microwave diodes on the base of 2DEG structures with thinner spacer and the delta-doped layer;

c) gated microwave diodes on the base of 2DEG structures;

d) to develop the design of the microwave diode on the b ase of thin semiconductor mesa placed onto thin polyimide film;

f) the design of planar microwave diode on the base of GaAs/AlGaAs isotype heterojunction

Analysis of the experimental results of the planar submicrometric microwave diodes fabricated during last visit at Braun Submicron Research Center let us to make adequate change in the design of the planar microwave detectors:

An upper contact layer in MBE grown semiconductor structures was introduced. The upper contact layer made it possible to fabricate microwave diodes on the base of non-degenerated *n*-GaAs MBE grown layer. The presence of the contact layer solved the problem of fabrication of high quality microwave diodes with submicromectric dimensions of the neck of asymmetrically shaped semiconductor structure. In this case the metallic contacts of the diode are apart from the active part of the diode avoiding any contact phenomena that are undesirable in operation of the microwave diodes. Moreover the appropriate regimes of UV lithography as well as chemical treatment were found that resulted in repeatable fabrication of the diodes with 0.5 mkm dimension of it active region. Testing of the planar microwave diodes in DC regime revealed high value of the asymmetry of their linear I-V characteristics for the diodes with submicrometric size of the neck of the asymmetrically shaped semiconductor layer that promises high voltage sensitivity of the diodes.

The asymmetrically shaped microwave diodes on the base of 2DEG structures with thinner spacer and the delta-doped sheets of AlGaAs instead of the doped n-AlGaAs layers of finite thickness were fabricated. Such design of the 2DEG structure should result in more sensitive and reliable microwave diodes for wide frequency band application. DC measurements of the asymmetrically shaped modulation doped 2DEG structures with various spacer dimensions revealed greater I-V characteristics asymmetry of the diodes with narrower spacer. The lower value of the asymmetry of I-V characteristics was intrinsic for the microwave diodes with asymmetrically shaped delta-doped layers, however lower electrical resistance of these structures promises higher operational speed of these microwave diodes. First experiments in microwave electric field were performed using asymmetrically shaped modulation-doped 2DEG layers with broader spacer. Monotonic manner of the dependence of detected voltage on microwave power was observed at room temperature, while at liquid nitrogen temperature sharply nonmonotonic character of the voltage-power characteristic was observed. The change of polarity of the detected voltage we relate with the Gunn domains formation under influence of strong microwave electric field, since at lower temperature this phenomenon is more pronounced due to stronger dependence of electron mobility on electric field strength.

The design of asymmetrically shaped 2DEG structure is, actually, the version of non-gated HEMT. Therefore, it is a certain interest to study the properties of the gated microwave diode. The gate was formed extending the anode contact of the diode over its active region. Thus, the detected voltage arising over the ends of the diode when it is placed in microwave electric field as well as external voltage should bias the gate controlling the voltage sensitivity of the microwave diode.

The design of “filmy” microwave diodes was implemented. This design represents thin (of micrometric dimensions) semiconductor mesas integrated with dielectric, mechanically robust polyimide film. The “filmy” diodes were successfully used for detection of electromagnetic radiation from microwaves up to infrared and are more versatile in wide frequency band application. The final stage of the fabrication of the “filmy” diodes was performed at the technological facility of Semiconductor Physics Institute in Vilnius.

Design of technological steps and photo masks for the fabrication of planar microwave diode on the base of GaAs/AlGaAs isotype heterojunction was done. The GaAs/AlGaAs heterostructures were designed and MBE grown at Braun Center for Submicron Research. Design of the photomasks was done with the possibility of prospective back-thinning of the substrate to achieve the planar heterojunction microwave diode on an elastic polyimide film.

Paulina Plochocka - Poland

Raman scattering from a single molecule, which is contacted by two metal nano particles was investigated. Single molecule spectroscopy is an emerging field that provides detailed information on molecular response, which is inaccessible in ensemble averaged measurements. The obvious problem, however, in implementing most spectroscopic techniques is the very weak signal which is obtained from a single molecule. Inelastic light (Raman) scattering is an example for that. The direct access to the vibration degrees of freedom of the molecule provided by this technique makes it very attractive for studying the response of a single molecule to external forces and its interactions with the environment. Unfortunately, the typical cross sections per molecule are extremely weak, of the order 10^{-30} cm^{-2}, yielding a practically undetectable signal. A way out of this was suggested by using the enhancement of Raman scattering near metal surfaces. It is well known that a dramatic signal increase may occur if the molecule is adsorbed to metal particles of sub-wavelength dimensions. This technique, known as surface enhanced Raman scattering (SERS), was recently was demonstrated to enhance the effective Raman cross section by a staggering 14–15 orders of magnitude. This huge enhancement has proven enough for successful single molecule spectroscopy.

In this project we investigated Raman scattering from a small aromatic molecule in a novel *dimer* structure, consisting of two metal nanoparticles connected by a *single* molecule. We have recently shown that this structure may serve as an efficient tool for conducting electrical transport measurements of the molecule. In this project we have shown that the Raman enhancement in this dimer structure is extremely large, yielding an easily detectable signal.

Second year

Prof. Jurgen Smet - Germany

Microwave induced zero resistance: local probe methods:

The recent discovery of zero resistance induced by microwave radiation in ultra-clean two-dimensional electron systems over extended regions of an applied perpendicular magnetic field has revived the general interest in microwave photoconductivity and has triggered a remarkably large and diverse body of theoretical works. The majority of theoretical accounts sub divides the argumentation to explain the zero resistance into two main points. First some mechanism produces an oscillatory photoconductivity contribution that may turn the overall dissipative conductivity negative near the minima. Examples of proposed mechanisms include for instance spatially indirect inter-Landau-level transitions based on impurity and phonon scattering and the establishment of a

non-equilibrium electron distribution function. Second, it is argued that negative values of the dissipative conductivity render the initially homogeneous system unstable and an inhomogeneous domain structure develops instead, which results in zero resistance in experiment.

Based on these theoretical predictions, the use of local probe methods seems potentially rewarding. By placing a single electron transistor it is possible to measure the local electrostatic potential of the two-dimensional electron system as well as its compressibility. If the electron distribution functions undergoes drastic changes we anticipate that this can be detected with an SET. The local character of this method also is appealing in view of the predicted formation of domains. First tests of the operation of SETs under microwave radiation were performed in collaboration with B. Verdene and A. Yacoby from the Submicron Center and revealed a number of interesting signals that suggest a response of the two-dimensional electron system when the microwave frequency is commensurate with a multiple of the electron cyclotron frequency. Unexpectedly, our experiments also disclosed signals that seem to be closely related to collective plasmon modes. Apparently the SET serves as an extremely sensitive probe for such excitations.

Microwave induced zero resistance: circular polarization dependence:

In collaboration with V. Umansky from the Submicron Center we have investigated the influence of the polarization of the incident radiation on these recently discovered microwave induced resistance oscillations in state-of-the-art highest-purity two-dimensional electron systems. A quasi-optical setup allowed us to tune in-situ between different circular as well as linear polarization states. We conclude from these experiments that the microwave photoconductivity is composed of two contributions: a bolometric and strong polarization dependent component associated with resonant heating at the cyclotron resonance and the polarization insensitive microwave induced oscillations. This immunity of the microwave induced oscillations to changes of the polarization direction of the microwave radiation contradicts the mainstream theories. This puzzling discrepancy will likely reinvigorate the controversy on their origin and there is clearly a strong need to analyze the polarization dependence of other proposed theoretical mechanisms.

Local Probe Studies on the spin transition of the 2/3 fractional quantum Hall state:

The mobility of charge carriers in good metals is directly responsible for their screening properties. Electric fields induced for example by charged impurities, are efficiently screened by local accumulation or depletion of charge. Of course screening is mostly associated with the charge of the electrons. The spin degree of freedom on the other hand cannot be trivially connected to screening.

In this work we followed the breakdown of screening across a spin phase transition that occurs at

filling factor 2/3 in the fractional quantum Hall regime by performing local compressibility measurements with the help of single electron transistor. In the presence of an increasing external magnetic field, a system of electrons confined to two dimensions undergoes a quantum phase transition from a fully unpolarized state, i.e. equal population of spin up and spin down electrons, to a fully polarized state. Using a single electron transistor, we followed the evolution of localized states across the spin phase transition. The appearance of localized states in the gapped phases of the integer and fractional quantum Hall effect is known to be directly linked to the breakdown of screening. Our measurements have shown that the underlying screened disorder potential changes across this transition on submicron length scales thereby emphasizing the role of spin in screening.

Roman Krahne - Italy

The research carried out in the Braun Center was intended to perform a series of transport measurements on a new class of nanocrystals. These nanocrystals consist of so called dimers, a $CoPt^3$- and a gold sphere linked by a common facet. The length of these dimmers is around 10 nm and we were interested in the conductivity at low temperatures and under external magnetic field. I brought with me a new type of electrode devices with a nanoscale gap and a close-by gate electrode that I tested at the Braun Center at low temperature. Then I positioned the nanocrystals by electrostatic trapping I obtained several devices which showed non-linear conductivity. The IV characteristics were measured in an external magnetic field at liquid helium temperatures. More than 50 % of the samples exhibited, apart from the Coulomb blockade features, a peculiar jump in conductance that has to be analyzed in further detail. I could not find any effect of a magnetic field on the current transport characteristics. The devices were also investigated by scanning electron microscopy. The obtained images confirm that the signal originates from single $CoPt^3$-Au dimers. Transport measurements at T=4K under external magnetic fields were carried out thanks to the excellent infrastructure at the Braun Center and the support of its staff.

Mickevicius Sigitas - Lithuenia

In the recent years, there has been an increasing interest in the fabrication of THz emitters and detectors. The given project covers just issue and it relies on usage of artificially grown semiconductor nanostructures as possible THz photo detector. Hence, we indent to extend the quantum well infrared detectors concept into THz frequencies employing quantum cascade laser structure.

In Semiconductor Physics Institute is no question of growth and processing such semiconductor nanostructure. For implementation this project we take advantage of the Braun Center for

Submicron Research, at the Weizmann Institute of Science by EU-Transnational Access program (EU project #RITA-CT-2003-506095) facilities. The Braun Center for Submicron Research is a unique facility enabling the design, material growth, fabrication, and characterization of small electronic systems.

During this project the sample was grown by molecular beam epitaxy on a semi-insulating GaAs substrate. On top of n-type GaAs contact and spacer layer was grown the 30 period repeating layers structure of active and injection regions of $Al_{0.15}Ga_{0.85}As$ barriers and GaAs wells. On the top of this structure were deposited another spacer and contact layer of n-type GaAs. Using photolithography technique and wet etching, the samples were processed into 900x900 m mesas. The bottom Ohmic contacts were made after metallization and successive annealing of Ge/Au (100/350 nm). The set of devices with different grating periods from = 10.2 to 11.6 m was fabricated when on top of the mesas were evaporated Ge/Au metallic grating and corresponding selective etching of n-GaAs contact layer were performed. The top contacts to enable wire bonding were prepare by evaporation of Ni/Au (10/200 nm) on the lateral stripes of the mesas and after successive annealing for 60s at about 320 C temperature.

The set of devices will be studied experimentally in the Semiconductor Physics Institute (Vilnius, Lithuania) by optically-pumped THz laser, Fourier spectrometer coupled with closed-cycle low temperature facilities.

Mikhail Kiselev – Germany

Spin and charge fluctuations in metallic quantum dots.

The goal of the project is the investigation of influence of charge and spin channels on a transport through the metallic quantum dots and system of coupled metallic mesoscopic grains. We proposed a new method for calculation of the Tunnelling Density of States and differential conductance as well as the dynamic longitudinal and transverse susceptibilities of metallic quantum dot in Coulomb valley regime. The magnetic (Stoner) instability and its influence on transport properties of the quantum dots have been investigated in details. The possibility of the interplay between Kondo effect and magnetic correlations is considered in the system of coupled quantum dots (quantum chains). The project benefited from EU-Transnational Access Program at the Braun Submicron Centre, Weizmann Institute.

Achievements:

- We calculated the tunneling density of states (TDoS) in a wide range of parameters of system.
- Non-monotonic behavior of TDoS as a function of energy is predicted. The proposal for experiment has been formulated.

- The influence of spin channel on transport through metallic dot has been investigated in the vicinity of Stoner Instability point. The magnetic instability manifests itself by strong enhancement in dynamic transverse susceptibility.
- A new method based on an analysis of stochastic equations has been developed for non-perturbative calculations of physical properties of metallic dots in different regimes. This method allows accessing the domain of physical parameters of the system (low temperatures) inaccessible by other methods used for investigation of such systems.
- The analysis of stochastic equations in the vicinity of magnetic instability point shed a light on a physics of mesoscopic grains possessing strong magnetic fluctuations.
- The effective theory of coupled nearly ferromagnetic grains has been developed.

Valerij Petkun - Lithuenia

Objective of the project was to develop the design of planar microwave detectors on the base of asymmetrically shaped mesoscopic semiconductor structures that can operate in submillimeter wavelength range of electromagnetic radiation:

a) planar diodes with upper contact layer;

b) microwave diodes on the base of 2DEG structures with thinner spacer and the delta-doped layer;

c) gated microwave diodes on the base of 2DEG structures;

d) in order to develop the design of the microwave diode on the b ase of thin semiconductor mesa placed onto thin polyimide film;

f) designing planar microwave diode on the base of GaAs/AlGaAs isotype heterojunction

The title of this project was: *"Planar microwave diode on the base of GaAs/AlGaAs heterojunction"*. The following steps of the implementation of the proposed project were envisaged: Design of photomasks for the fabrication of planar microwave diodes with 1 mkm dimension of the active part of the diode; Fabrication of the planar microwave diodes on the base of heterojunction; Discover a likely regimen of selective etching for removing the substrate; Semiconductor mesas place onto thin polyimide film; Elektron mobility measurement; Preliminary testing of the heterojunction diodes in dc regime. During the period of my visit I was no possibility to produce photo mask for the fabrication of the heterojunction diodes.. I couldn't do it because Department of Condensed matter Physics didn't have glasses for photo masks fabrication. This project is very important for our Institute and the topic of my dissertation. At our institute there isn't facility to implement this project.

Filmy sensor of electromagnetic radiation

Background

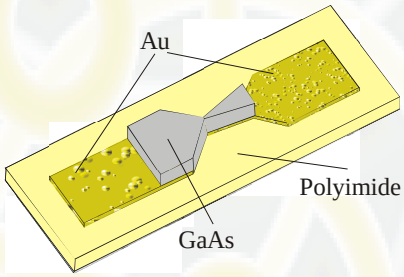
Electromotive force arises in nonhomogeneous asymmetrically necked semiconductor structure under carrier heating in microwave electric field

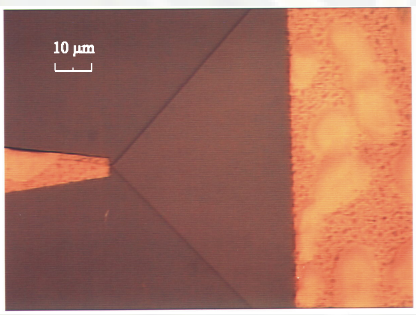
Application

The sensor can be used in microwave power-meters, for homogeneity control of materials, for faults detection in underground pipelines, , for mine detection, in archaeology, in search for victims buried in earthquakes, for early cancer and teeth decay diagnostics.

Parameters

- ***Frequency range 10 GHz – 30 THz***
- ***Voltage sensitivity (0.5÷50) V/W***
- ***Maximum power up to 1 W***
- ***Temperature range (4÷300) K***
- ***Width of the active region <1 μm***
- ***Dimensions (0.5×0.1×0.01) mm³***





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Enrique Diez - Spain

When electrons are constrained to move within a plane or a narrow line, strange things occur. For instance, they are expected not to conduct electricity at absolute zero of temperature. This lack of electrical conductivity in one- and two-dimensional systems at zero temperature has been one of the most striking effects in Solid State Physics. This result is based on extensive work on scaling theory pioneered by the 'gang of four': Anderson, Abrahams, Licciardello and Ramakrishnan. It has also received considerable numerical support. If we add the presence of a perpendicular magnetic field the integer quantum Hall (QH) regime emerges at low temperatures. The underlying physics is the

Anderson localization-delocalization quantum phase transition, and the experiment is sometimes regarded as a display of two-dimensional (2D) quantum critical phenomena.

While earlier works tend to concentrate on transitions between adjacent QH plateaus (PP), there is now also a great interest to focus on the transition from the last QH plateau to the high-magnetic field insulator (PI). In the framework of the scaling theory of the Quantum Hall effect the plateau transitions are interpreted as quantum phase transitions with an associated universal critical exponent?. The renormalization theory predicts that the PP and PI quantum phase transitions are the same and should have the same critical exponent.

Pioneering magneto transport in InGaAs/InP samples found a value of ? = 0,42 very close to the free electron value 7/3 obtained from numerical simulations. Some years ago Shahar et al. (at the Condensed Matter Physics Department at the Weizmann Institute of Science reported measurements for several samples that were inconsistent with this scenario. The controversy born after this work shown that further research was needed to clarify if the short range random potential due to the alloy potential dominates in these system above other scattering mechanisms and the role of macroscopic in homogeneities.

From a detailed characterization of the electronic properties of the two-dimensional electron gas (2DEG) confined in a series of 20 lattice matched In0.53Ga0.47As/In0.52Al0.48As/InP heterojunctions we have obtained a very good understanding of their transport properties showing that the alloy disorder completely dominates at low temperatures, with ratios very close to 1 between the transport and quantum lifetimes. Since many modern structures are now based on these materials, in many technologically important areas ranging from high speed electronics, optoelectronics and spintronics, such characterization is of fundamental and technological interest.

Third year

Sigitas Mickevicius - Lithuania

GaAs-based nanostructures for THz spectroscopy applications.

During this project the sample was grown by molecular beam epitaxy on a semi-insulating GaAs substrate. On top of n-type GaAs contact and spacer layer was grown the 30 period repeating layers structure of active and injection regions of Al0.15Ga0.85As barriers and GaAs wells. On the top of this structure were deposited another spacer and contact layer of n-type GaAs. Using photolithography technique and wet etching, the samples were processed into 900 x 900 micrometer

mesas. The bottom ohmic contacts were made after metallization and successive annealing of Ge/Au (100/350 nm). The set of devices with different grating periods from 10.2 to 11.6 micrometers was fabricated when on top of the mesas were evaporated Ge/Au metallic grating and corresponding selective etching of n-GaAs contact layer were performed. The top contacts to enable wire bonding were prepare by evaporation of Ni/Au (10/200 nm) on the lateral stripes of the mesas and after successive annealing for 60s at about 320 C temperature. The main difficulties were encountered by etching such deep mesas (3.8 micrometers) using wet etching down to n+-GaAs layer on which was deposited bottom contact. Were made test with different mordant solvents and have been chose citric acid/hydrogen peroxide volume concentration ratio between 8.0 and 10.0.

The sample was grown by molecular beam epitaxy on a semi-insulating GaAs substrate. On top of n-type GaAs contact and undoped GaAs spacer layer was grown the 32 period repeating layers structure of active and injection regions of Al0.15Ga0.85As barriers and GaAs wells. On the top of this structure were deposited another undoped GaAs spacer and contact layer of n-type GaAs. Using photolithography technique and wet etching with citric acid / hydrogen peroxide (volume ratio 10:1) at room temperature, the samples were processed into 900x900 microns mesas with 3.7 microns depth .

The bottom ohmic contacts were made after metallization of Ni/Au/Ge/Ni (100/200/100/60 nm) and successive annealing for 60s at 400 C. The set of devices with different grating periods from 10.2 to 15 microns was fabricated when on top of the mesas were evaporated Ni/Au/Ge/Ni metallic grating and successive annealing for 40s at about 320 degC. The corresponding selective etching of n-GaAs contact layer was performed. The top contacts to enable wire bonding were prepare by evaporation of Ti/Au (40/2 00nm) on the lateral stripes of the mesas. The samples were soldered with silver epoxy on holders and top and bottom contacts were bonded to Au-coated pads of holders. The set of devices will be studied experimentally by optically-pumped THz laser, Fourier spectrometer coupled with closed-cycle low temperature facilities.

Brent Wacaser - Sweden.

Study of fundamental growth aspects of semiconductor nanowires.

1) We were able to verify the correlation between the seed particle and the stacking faults. When the wires grew in a <112> direction they had stacking faults parallel to the growth direction, these stacking faults always correspond to irregularities in the particle/wire interface. In the areas without stacking faults the particle/wire interface was flat, but where stacking faults where present there is always an area of high curvature corresponding to the stacking fault. It is still unknown if the high curvature causes the stacking fault or if the fault causes the interface to reorganize .

2) The growth parameters greatly effect the stacking fault formation. There is a tendency to form both the Zincblende and Wurtzite crystal structures in the nanowires. The full parameter space needs to be more fully explored, but the general tendency seems to be that at lower substrate temperatures the Zincblende is more prevalent and a higher the Wurtzite is more prevalent. In between, there are many stacking faults in the wires as it switches between the two similar crystal structures.

3) When wire growth in the <110> direction they where seen to lack stacking faults or have very few. The problem is that the <111>B directions are the more preferential growth directions. We attempted unsuccessfully to obtain wire growth in directions other than the <111>B directions, but only a small percentage of the wires where found to grow in other direction. We attempted many different surface modifications and preparations, but none seem to work in the MBE growth system. The next step may be to try using different seed particles like Au-In alloy or Ag. These would have different properties that may make it possible to change the preferential growth direction of the wires and thus achieve wire growth without stacking faults.

Wiktor Maslana - Poland.

Study of optical properties of semiconductor materials.

In order to enable measurements of absorption special semiconductor structure was designed and grown by molecular beam epitaxy. The structure, in which GaAs quantum well was embedded in half microcavity structure allowed us to increase the absorption ratio of quantum well excitons up to 80% from 3% observed in typical structures. The optimization of sample parameters allowed us to obtain excellent quality of absorption spectra. The structures were grown on n+ layer. Through additional processing ,ohmic contacts to the quantum well and the back gate was obtained. This enabled us to independently control the density of electron gas in the quantum well by applying bias voltage. Therefore, we were able us to investigate the influence of electron density on the absorption. In the low density limit we were able to trace the many body effects evolving with the carrier density change.

We were also interested in comparing the absorption and emission energies of two dimensional electron gas under magnetic field. Here we stumbled upon major difficulty due to a slightly different effect of photo generated carriers on the density of electron gas. Despite special care taken to ensure that illumination power was the same in both photoluminescence and reflectivity measurements we were not able to obtain comparable experimental conditions. This is due to the fact that the photo carriers generated by laser used for photoluminescence excitation deplete the quantum well more

efficiently than the light from tungsten lamp used in reflectivity experiment. However, we were able to obtain similar carrier densities in reflectivity and photoluminescence experiments for different gate voltages. Photoluminescence measurements of ultra high mobility (above 20*10^6) 2DEG were perfomed.

Perla Kacman - Poland

1) The main purpose of my visit was to meet the Weizmann's outstanding specialists in the theory of coherent transport and discuss with them our calculations of spin-dependent tunneling in modulated structures of ferromagnetic semiconductor GaMnAs, which were undertaken to describe effects like spin injection in GaMnAs-based Esaki-Zener diode or TMR in such trailers. Our point was that in contrast to the metallic layered heterostructures based on classical ferromagnetic materials in these semiconductor devices the assumptions required for using spin diffusion equation are not valid and that the spin dependent tunneling has to be described within the coherent transport regime.

2) In parallel I had the possibility to discuss with Dr. Shtrikman her very interesting results obtained in the MBE growth of GaAs nanowires, in particular intriguing dependence of this growth on the orientation of the substrate. The several questions raised during these discussions stimulated a new direction of theoretical studies in our group in the Institute of Physics in Warsaw. Namely, with my new PhD student we try to asses the properties of nanowires using the first-principle DFT methods - we have just started with the calculation of the band structure of GaAs nanowires and its dependence on the crystallographic direction. The effects of different growth directions on the atom positions inside the wire and at the surface and on the perfection of the material were studied. Although in the calculation the simulated thickness of the whiskers is limited to values much smaller (the diameters ca 10A) than that of wires grown at Weizmann, these calculation lead to results of mutual interest and formed a basis for collaboration in the studies of this challenging topic which is of great importance for the field of nanowire electronic and optical devices.

Fourth year

Halit Altuntas - Turkey

There has been interest in the study of metal-semiconductor (MS) and metal-insulator-semiconductor (MIS) Schottky diodes, primarily for their superior performance as microwave mixers and also because they are increasingly being used to improve the fast switching of high frequency transistors. The study of the dependence of the Schottky diode characteristics on ambient and temperature

dependence is important for practical applications and for understanding the current conduction mechanism involved.

Also, high level radiation on semiconductor materials produces quasi-stable changes in the characteristics of materials. Radiation produces interface traps. Interface trap is one of the important parameters that strongly influence the device performance.

Five samples were produced at Braun Submicron Research Center at Weizmann Institute of Science to explain SiO_2 insulating layer and ^{60}Co gamma-ray irradiation how effects the electrical properties of metal-semiconductor (MS) and metal-insulator-semiconductor (MIS) Schottky diodes. Produced five samples are:

1) Au/ n-GaAs
2) Au/ SiO_2/n-GaAs , SiO_2 thickness= 67 Å
3) Au/ SiO_2/n-GaAs , SiO_2 thickness= 200 Å
4) Au/ SiO_2/n-GaAs , SiO_2 thickness= 500 Å
5) Au/ SiO_2/n-GaAs , SiO_2 thickness= 1200 Å

We checked the surface of n-GaAs by Atomic force Microscope and surface looked perfectly smooth. This is very important to make good Schottky devices. Current-Voltage measurements of the samples as a function of temperature were very good. That's means is produced samples are very quality. So we carried out the measurements of the samples easily, and we determined current conduction mechanisms and interface states in the produced samples.

Perla Kacman, Malgorzata Bukala and Marta Galicka - Poland

The growth of thin GaAs and InAs nanowires (NWs) was studied both theoretically and experimentally. Using *ab initio* methods, we studied the stability of the structure of the NWs; in particular the Wurtzite, Zinc-Blende competition, taking into account the reconstruction of the NW surfaces. Modelled NWs were constructed using bulk atomic positions along six different crystallographic directions of either Zinc-Blende or Wurtzite structures.

We found that for the diameters of up to 50Å the most stable NWs adopt the Wurtzite <0001> structure. In thin Zinc-Blende NWs along any crystallographic axis, the free energy is much larger than that of the Wurtzite <0001>. However, for Zinc-Blende NWs thicker than 30Å, the ones <111> oriented are energetically favourable, with the free energy difference from that of the Wurtzite <0001> diminishing with diameter. We note that on <0001> Wurtzite NW surfaces atoms are positioned in a 3-fold coordination, similar to the surface of the bulk material. Thus, in this case the

free energy can be well approximated by the sum of bulk and bulk surface values. In contrast, the <111> Zinc-Blende surface contains in addition some 2-fold coordinated atoms with dangling bonds, which are situated at the edges of the hexagonal NW cross-section. The density of these atoms, and thus their contribution to the total energy decreases with diameter, and for diameters larger than 50 Å the free energy of Zinc-Blende NWs can be approximated in the same way as the Wurtzite. Using this simple model, we predict that for NWs with the diameter larger than 100Å the free energies of Wurtzite and Zinc-Blende become nearly equal, which explains the occasional occurrence of stacking faults observed in as grown NWs.

The surface 2-fold coordinated As atoms (with extra dangling bonds) do not change only the excess energy, but also have an impact on the electronic structure of the NWs. For <111> Zinc-Blende NWs we observe additional states located in the band gap with the Fermi level pinned at these states. The calculated density of charge, generated by these states, shows an accumulation of the charge around the 2-fold coordinated As atoms. For the <0001> Wurtzite NWs such band-gap states were not found, hence the Fermi level is pinned at the top of the valence band, as expected when no extra electrons are introduced.

At the Braun Center InAs and GaAs NWs were grown in a solid source Molecular Beam Epitaxy (MBE) system by the Vapour Liquid Solid (VLS) method using a heated thin layer of Gold to form the metal droplets. GaAs and InAs NWs were grown on <111>B GaAs and InAs substrates, respectively. The NWs were studied by a high resolution transmission electron microscope (HRTEM). It has already been shown before that, in contrast to the bulk materials, the Wurtzite structure is normally dominant in such wires with occasional stacking faults resulting from the intermixing of Zinc-Blended stacking. Growth direction is <0001> and <111> for the Wurtzite and the Zinc-Blende type sections of the NW, respectively. Nevertheless, we find that for InAs NWs, thinner than 100Å, the Wurtzite/Zinc Blende stacking faults do not appear, and the whiskers have the Wurtzite structure. We also find GaAs wires to be free of stacking faults when their diameter is less than 100Å, though the structure is either Zinc-Blende or Wurtzite depending on the growth conditions.

This project comprised a unique collaboration between the polish group headed by Prof. Perla Kacman and the group at the Braun Center dealing with one dimensional nanowires. Together both groups submitted an abstract to the upcoming International Conference on Physics of Semiconductors.

Algirdas Suziedelis and Andzej Lucun - Lithuenia

Development of sub-micrometric planar microwave detectors for wide frequency band application.

The objective of the project was threefold: i) the verification of the idea to fabricate planar microwave diodes minimizing the quantity of photolithography operations with avoidance of precise alignment step; *ii)* investigation of microwave currents flow in asymmetrically and symmetrically shaped semiconductor structures of nanometric dimensions for different crystallographic directions; *iii*) investigation of possibility to create in homogeneity in the structure of planar diodes using a gate introduced over modulation doped structure. In case of success of one step diode fabrication, the possibility to fabricate the microwave diodes with nanometric dimensions of active region appears. The fabrication of microwave diodes on the base of symmetrically and asymmetrically shaped semiconductor structure let us expect the improvement of parameters of microwave diodes for wide frequency band application. Introduction of the gate over the part of two dimensional electron gas should improve f detection properties of the microwave diodes.

Implementation of the project was performed using MBE grown structures and photomasks that were fabricated during previous visits of our group at Braun Center for Submicron Research. The operation of our microwave diodes is based on carrier heating phenomena in mesoscopic semiconductor structures when microwave electric field is applied. The design of the microwave diodes is the asymmetrically and symmetrically shaped planar homogeneous and inhomogeneous semiconductor structures. The shape of the diode's mesas was defined using wet chemical etching. Therefore the dimensions of the active region of the diode could be controlled in micrometric range. Following step of metallization yet more complicates the situation due to not ideal alignment of metallization photomask with the defined semiconductor mesa-structure. In the frame of this project we eliminated the definition of semiconductor mesa-structure with chemical etching and define the shape of the microwave diode using only metallization procedure. This simplified fabrication process of the microwave diodes opens the way to minimize the dimension of the active region of the diode down to nano-scale in future that should improve substantially sensitivity of the microwave diodes. Another part of the project was devoted to the investigation of microwave properties of our microwave diodes depending on to the crystallographic orientation of the asymmetrically shaped semiconductor structures. The gated diodes that were fabricated under this project we intend to use for the detection of electromagnetic radiation at higher frequencies. A planar design of the microwave diodes on the base of thin polyimide film must be implemented for high frequency application. .A month of scientific activity at Braun Submicron Research Center let us to fabricate planar variant of asymmetrically and symmetrically shaped microwave diodes: *i*) using single

technological operation (metallization); *ii*) samples of the microwave diodes having different orientation of their longitudinal axis with respect to crystallographic orientation of the semiconductor substrate; *iii*) planar microwave diodes with a gate introduced over a part of two dimensional electron gas near one of the contacts of the diode .

Preliminary testing of the fabricated samples in dc regime has shown asymmetry of current voltage characteristic of the microwave diodes that were fabricated using single fabrication step. Low value of electrical resistance of the fabricated microwave diodes in the range of several hundreds Ohms promises perfect matching of the diodes with waveguide. Therefore, the proximity of the electrical resistance of the diodes to the wave resistance of the waveguide promises the value of voltage sensitivity of the microwave diodes in the order of one volt per watt at room temperature due to the greater amount of the microwave power that the diodes absorb. This outcome will soon proved experimentally in microwaves after finishing the fabrication process of the diodes at Semiconductor Physics Institute. The semiconductor mesa of several micrometers thick will transferred onto an elastic polyimide film during the last fabrication step.

The values of asymmetry of current voltage characteristics of the planar microwave diodes with symmetrically and asymmetrically shaped semiconductor structures were measured in dc regime. The preliminary testing of the microwave diodes revealed the dependence of the asymmetry of the IV characteristics on the orientation of the longitudinal axis of the diodes with respect to the crystallography axis of semiconductor wafer. In case of selectively doped semiconductor structure the sign of the asymmetry of IV characteristics of the asymmetrically shaped diodes corresponded to the polarity of the electromotive force of hot carriers in the asymmetrically shaped n-n^+ junction when the longitudinal axis of the diode was parallel to the basic off-cut of the substrate. The value of the IV asymmetry depended on the width of the neck of the asymmetrically shaped microwave diode. When the longitudinal axis of the diodes was perpendicular to the basic off-cut of the substrate no correlation between the size of the neck of the diodes and the value of the IV Asymmetry was observed.

The experimental study of the gated selectively doped structures in microwave frequency range revealed that the symmetric shape of 2DEG layer have preference against the microwave diodes with asymmetric shape. This experimental finding let us to expect the possibility to detect electromagnetic radiation in sub-millimetre wavelength range using symmetric gated SD structures that was stated experimentally detecting microwave radiation up to 120 GHz frequency as well as in THz frequency range.

Fifth year

Janusz Sadowski - Poland

GaMnAs is a canonical ferromagnetic semiconductor with carrier induced ferromagnetism. Nowadays the spintronic nanostructures fabricated from GaMnAs by means of e-beam lithography are extensively investigated. An alternative approach for formation of GaMnAs based nanostructures is the self-assembled growth of nanostructures (nanowires). This however faces sever difficulties due to the low temperatures of epitaxial growth of ternary GaMnAs alloy.

GaAs:Mn nanowires grown by molecular beam epitaxy by J. Sadowski at MAX-Lab Lund University, Sweden were studied at Weizmann Institute by scanning electron microscopy and transmission electron microscopy. Samples were grown at different conditions, on GaAs substrates with different orientations: (100), (111)A and (111)B. NWs have conical, needle-like shapes, typical for GaAs NWs grown at temperatures below 400 ^{o}C. It was verified if the NWs were formed due to the catalyzing properties of MnAs nano-islands. In some samples, especially these with short NWs, the MnAs catalyst was identified at the top. Since during the NW growth new MnAs catalyst particles can be formed at NW sides, GaAs:Mn nanowires typically have branches. Sample with the longest NWs were investigated by TEM. The chemical composition of NWs was determined by energy dispersive X-ray spectroscopy. It was found that the top parts of all investigated NWs are Mn rich (containing from 10 to 30% of Mn), the main part of NWs contains about 0.8% Mn. This corresponds well to the Mn composition of 1%, which was assumed in the MBE growth process. The 1% Mn content in GaMnAs ternary compound is close to the minimum for ferromagnetic phase transition to occur. However so far it was not determined if the as-grown GaMnAs NWs exhibit ferromagnetic properties. This can be investigated by the advanced TEM methods, and magnetotransport measurements. This is one of the tasks specified in the 7th Framework Marie Curie Initial Training Network for Semiconductor Spintronics (SemiSpinNet).

Appendix 1 – Science and society reporting questionnaire

Science and Society Reporting Questionnaire

Introduction

FP6 was designed to focus, integrate, structure and strengthen the European Research Area (ERA). The influence of science and technology on society was acknowledged when the ERA was established and the importance of having a healthy dialogue between science and society was recognised. This area now forms part of the policy to structure the ERA under the heading Science and Society. It incorporates ethical, gender and communications issues together with issues affecting education and youth and governance.

This questionnaire has been compiled for FP6 Project Coordinators. It has been designed to help coordinators respond to contractual reporting requirements (Article II.10.3 of the contract states that consortia must engage with actors beyond the research community) and to facilitate the monitoring of the science and society dimension in FP6.

The information gathered through this exercise will be confidential and will not be disclosed to any third parties or used in any way that could be linked to individual projects.

Please complete the questionnaire by ticking boxes or filling out information where requested. It would be appreciated if as many questions as possible could be completed.

Please note that Part A will be completed automatically when the contract number is entered.

A General Information on Contractor

1	**Contract Number:**	RITA-CT-2003-506095
2	**Instrument:**	Specific Support Action
3	**Thematic Priority:**	Transnational Access
4	**Title of Project:**	Access to the Braun Submicron Center for Research On Semiconductor Materials Devices and Structures
5	**Name and Title of Coordinator:**	Dr. Hadas Shtrikman
6	**Period Covered, Start Date:**	*1/3/2004* **End Date:** *28/2/2009*
7	**EC Contribution to project:**	€ 1,600,000

B Ethics

8 Which (if any) of the following does your research project involve?

- q Human beings
- q Human biological samples
- q Personal data
- q Genetic information
- q Animals
- q Human embryos or human embryonic stem cells
- q Non human primates and other animals

X q None of the above

9 To what extent do you believe ethical issues are relevant to your research project?

X ¡ Not relevant
¡ Minor relevance
¡ Significant relevance
¡ Critical

10 Do you have Ethicists or others with considerable ethics experience involved in the project?

¡ Yes
X ¡ No

11 Did your project have a separate EC ethical review?

¡ Yes
X ¡ No

12 How much (including the value of time spent, as well as paid-out costs) do you estimate your project (when it is completed) will have spent on considering and dealing with ethical issues?

€ **none**

C Gender

13a Did you undertake Gender Equality Actions in your research project?

¡ Yes
X ¡ No

13b If no, why not?

¡ Not relevant
¡ Team not gender aware
¡ No budget
¡ Not supported (no will)
X ¡ Other: The question is quite irrelevant since projects were judged by there scientific quality. Women scientists are always encouraged to take part in our research based on their qualifications.

13c If yes, which of the following actions did you carry out and how effective were they?

			Not at all effective				Very effective
X	q	Design and implement an equal opportunity policy	¡	¡	**X**	¡	¡
	q	Implement mentoring schemes for women	¡	¡	¡	¡	¡
	q	Family friendly working conditions	¡	¡	¡	¡	¡

14 Was there a gender dimension associated with the research content?

¡ Yes. If yes, please specify
X ¡ No

15 How much (including the value of time spent, as well as paid-out costs) do you estimate your project (when it is completed) will have spent on considering and dealing with gender issues?

€ **none**

D Science Education, Training and Career Development

16a Does this project anticipate having a direct impact on the local economy?

¡ Yes
X ¡ No

16b If Yes, is the project:

q Stimulating employment
q Retaining highly trained personnel
q Creating possible spin-out/start-up companies

17 Does your partnership employ and train researchers?

X ¡ Yes
¡ No

---

18 Does your project involve working with young people at schools?

¡ Yes
X ¡ No

---

19 Is there any education material being produced directly or indirectly by your project?

¡ Yes
X ¡ No

---

20 How much (including the value of time spent, as well as paid-out costs) do you estimate your project (when it is completed) will have spent on considering and dealing with Science Education, Training and Career Development issues? €

It is a negligible part of the budget since it was never a main target of the project.

E Engaging With Actors Beyond the Research Community

20a Is the project likely to generate outputs (expertise or scientific advice) which could be used by policy makers?

¡ Yes
X ¡ No

20b If Yes, is this a primary or secondary objective of the project?

¡ Primary
¡ Secondary

21a Did your project engage in significant communication with the public before research commenced?

¡ Yes
X ¡ No

21b Was the focus or methodology of your project modified in response to any communication with the public?

¡ Yes
X ¡ No

---

22 Does your project involve someone whose role is solely to communicate with the public?

X ¡ Yes
¡ No

F Use and dissemination

23 How many articles were published ?

In refereed journals: 31 Other journals: 11

24 How many patents have been applied for ?

none

25 How many other Intellectual Property Rights were applied for?

none

26 How many spin-offs were created? None

27 Have you issued press releases related to your project (and if so, how many)?

¡ Yes, number:
X ¡ No

28 Have you held media briefings? If so, how many, and on average roughly how many journalists attended?

¡ Yes, number of briefings: average number of journalists:
X ¡ No

29a Roughly how many items covering your project in the printed press, on radio or television can you identify?

none	Press:		Radio:		Television:	

29b Roughly how many items were:

none	Specialist Press:		Non-specialist Press:	
none	National Press:		International Press:	

30a Was there on-line information about the project?

¡ Yes

X ¡ Specific web site http://www.weizmann.ac.il/physics/wissmc/

¡ No

30b Roughly how frequently has it been updated?

Once in two years

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31 Do you have an e-mail mailing list to send news about the project? If so, how many subscribers to the list are there?

¡ Yes, number of subscribers:

X ¡ No

32a Have you created or participated in an event (e.g. workshop, conference, information day) in order to communicate with the public (not just other researchers or the press)?

¡ Yes

X ¡ No

32b Roughly how many people attended these events and learned about your project?

none

33a Have you produced a video or DVD film about your project?

¡ Yes
X ¡ No

33b If so, how effective do you believe it has been in communicating with the public?

¡ Unable to assess

¡ Completely ineffective
¡ Mostly ineffective
¡ Partially effective
¡ Significantly effective
¡ Extremely effective

34a Have you produced posters, flyers or brochures about your project?

X ¡ Yes
¡ No

34b If so, how effective do you believe they have been in communicating with the public?

¡ Unable to assess

¡ Completely ineffective
¡ Mostly ineffective
X ¡ Partially effective
¡ Significantly effective
¡ Extremely effective

35 In how many different languages were these products (video/DVD, posters, flyers, brochures) produced?

X Only English

36 How have you distributed these products (video/DVD, posters, flyers, brochures)? Please tick all methods you have used.

q Sent on request
X q Sent to schools/academic institutions
q Distributed through government agencies/public buildings/libraries etc.
q Sent to potentially interested non-governmental bodies (NGOs, citizen's associations etc)
q Other: Occasional distributed in conferences and occasional visits to EU laboratories

G Total Communication Spend

37 How much (including the value of time spent, as well as paid-out costs) do you estimate your project (when it is completed) will have spent on communication activities (engaging with the public, use and dissemination) as described in the current questionnaire?

€ Negligible amount of money

H Comments

38 If you have any comments about your experience of meeting the Science and Society objectives within your project, or any suggestions of improvements to the programme please add them here:

Thank you for your help!

Appendix 2 – final reporting questionnaires on workforce statistics