STAND-ALONE PROJECT - FINAL REPORT

Project title **Modeling of Nanoelectronic Semiconductor Devices**

Project leader **Ao. Prof. Dr. Hans Kosina**

P17285-N02 **Project number**

1. Summary for public relations work

Die Vielzahl der heutigen elektronischen Anwendungen, wie etwa Mobiltelefone, Notebooks oder digitale Kameras, wurde durch die kontinuierlichen Fortschritte in der Herstellung von Mikrochips ermöglicht. Im Zuge dieser Entwicklung werden die Abmessungen der Einzelbauelemente – hauptsächlich MOSFET Transistoren – laufend verkleinert und dadurch die Anzahl der in einem Mikrochip integrierbaren Bauelemente laufend vergrößert. Die Skalierung des MOSFET wird voraussichtlich bis zu Gate-Längen unter 20 nm voranschreiten. Im Rahmen dieses Projekts wurde ein Simulationsprogramm für nano-elektronische Halbleiter-Bauelemente entwickelt. Das Programm löst die Wigner-Gleichung, welche eine der möglichen Quantentransport-Formulierungen darstellt, mittels einer neuartigen Monte Carlo Methode. Die zu simulierenden Bauelemente können aus Silizium, Germanium oder einer Vielzahl von III/V Verbindungs-Halbleitern bestehen. Es wurden verschiedene numerische Methoden entwickelt, um die Robustheit und Effizienz der Simulationen zu steigern. Dazu zählt die spektrale Zerlegung der Potentialverteilung in einen klassischen und einen quantenmechanischen Anteil, sowie ein neuer Algorithmus zur Kontrolle der Teilchenzahl, welcher die Stromdichte exakt erhält. Die Anwendbarkeit des Simulators wurde für verschiedene Bauelemente demonstriert: Galliumarsenid-basierte resonante Tunneldioden, Silizium n-i-n Dioden und Doppel-Gate Feldeffekt-Transistoren. Durch das komplexe Modell des Simulators kann das Zusammenspiel von klassischen und quanten-mechanischen Effekten in einer Form untersucht werden, wie dies mit herkömmlichen Simulatoren nicht möglich ist. Zu diesen Effekten zählen Raumladungseffekte und Streuprozesse einerseits und Tunneleffekte und Quantisierung andererseits.

Der Transport von Elektronen in ultra-dünnen Silizium-Schichten wurde auf Grund seiner großen Bedeutung für zukünftige MOSFET Architekturen genauer untersucht. Dabei wurde festgestellt, dass die Zwischen-Subband-Streuung der Elektronen wesentlich ist, um bestimmte experimentelle Befunde über die Elektronen-Beweglichkeit in Einfach- und Doppel-Gate-Strukturen erklären zu können. Des Weiteren wurde der Einfluss von mechanischer Verspannung in der Silizium-Schicht auf die Elektronen-Beweglichkeit untersucht. Es wurde gezeigt, dass das Vorhandensein von Scherspannung zu einer Änderung der Transportmasse in der untersten Subband-Leiter und damit zu einer Erhöhung der Beweglichkeit führt. Gezielt eingesetzte Verspannungs-Effekte sind wesentlich für die Leistungssteigerung von zukünftigen integrierten Schaltungen.

The multitude of todays electronic appliances, such as mobile phones, notebooks, and digital cameras, has been enabled by a continuous progress in the fabrication of microchips. In the course of this development the dimensions of the single components – mainly MOSFET transistors – have been steadily reduced and thus the number of components that can be integrated in a Microchip steadily increased. Scaling of the MOSFET is expected to continue down to gate lengths below 20 nm. In this project a simulation program for nanoelectronic semiconductor devices has been developed. The program solves the Wigner equation, which represents one of the available formulations of quantum transport, by means of a novel Monte Carlo method. The device to be simulated may consist of silicon, germanium or various group III/V compound semiconductors. Different numerical methods have been developed to improve robustness and efficiency of the simulations, including a spectral decomposition of the potential profile into a classical and a quantum-mechanical part, and an algorithm for the control of the particle number, which conserves current exactly. Applicability of the simulator has been demonstrated for various devices: a gallium arsenide-based resonant tunneling diode, a silicon n-i-n diode, and double-gate field-effect transistors. The comprehensive model of the simulator allows the interplay of classical and quantum-mechanical effects to be studied in a way not feasible with established simulation tools. These effects are space charge effects and scattering processes on the one side, and tunneling and size-quantization on the other side.

Because of its importance for future MOSFET architectures, transport of electrons in ultrathin silicon layers has been studied in more detail. It was found the inter-subband scattering of electrons play an important role to explain certain electron mobility measurements in single and double gate structures.

Furthermore, the effect of mechanical strain on the electron mobility in the silicon layer has been investigated. The presence of shear strain changes the effective mass of the lowest subband ladder and thus can improve the mobility. Engineering of strain effects is an important measure to improve performance of future integrated circuits.

2. Brief project report

2.1 Report on the scientific work

2.1.1 Information on the development of the research work

The workplan laid out in the project propoal has been followed in essence.

2.1.2 Most important results and brief description of their significance (References refer to List 1.a.1 in the Attachments)

Following the project proposal, the first aim was the inclusion of quantum confinement in the Wigner function formalism. The problem of inclusion of size quantization of the carrier motion in ultra-scaled MOSFETs into the Wigner function approach was addressed in detail. It was found that an approach treating size quantization directly within the Wigner picture leads to a complicated set of integro-differential equations for complex valued quantities (i.e., the off-diagonal Wigner functions), which could hardly be handled without introduction of additional, restrictive approximations, such as, for instance, the projection operation technique. A practical approach found to be applicable to MOSFET simulations is based on the separation of the quantized motion in transverse direction from the motion in the direction of propagation, also known as the decoupled mode space approach. In this case the eigen-energy depends on the position along the propagating direction and plays the role of the position-dependent subband minimum. Carrier motion in different subbands may be considered decoupled only if the quantization potential is a smooth function of the longitudinal coordinate and transitions between different subbands are negligible. The electron motion within each subband is then described by the corresponding Wigner equation, with the potential energy determined by the corresponding quantization energy of the transverse motion. The subband decomposition has been shown to provide a good approximation for double-gate and triple-gate Silicon-on-Insulator FETs. To prove this, we expanded the density matrix in the subband related basis set and explicitely found the inter-subband coupling Hamiltonian. The inter-subband coupling elements were computed for different FET geometries and found to be much smaller than inter-subband energy, which allows to neglect them safely in practically relevant cases [22]. The role of scattering and inter-subband coupling in ultrathin body silicon-on-insulator MOSFETs was investigated in [6][22]. It was found that scattering is still affecting the transport in ultra-scaled MOSFETs, while intersubband coupling was found to be small [20]. Significant intersubband coupling in these devices emerges from the intersubband scattering processes, such as electron-phonon and surface roughness scattering. This effect will be discussed below.

The second aim of the proposal was band structure modeling. In the project we have actually focused on the effect of strain on the band structure. In [25] we present an efficient two-band k*p theory which accurately describes the six lowest conduction band valleys in silicon. By comparing the model with pseudo-potential band structure calculations we demonstrate that the model captures both the nonparabolicty effects and the stress-induced band structure modication for general stress conditions. It reproduces the stress dependence of the effective masses and the nonparabolicity parameter [26]. Analytical expressions for the valley shifts and the modifications of the transversal and longitudinal effective masses induced by uniaxial [110] stress are obtained and analyzed. The low-field mobility enhancement in the direction of tensile [110] stress in [001] SOI FETs with small body thickness is due to a modication of the conductivity mass and is shown to be partly hampered by an increase in nonparabolicity at high stress value [25]. In [27] the two-band k*p model has been employed to determine the subband dispersion relations for electrons in ultra-thin (100) silicon films. For the unprimed subbands the dependence of the nonparabolicity parameter on the film thickness is obtained. The two-band k*p model yields the thickness dependence of the effective masses of the primed subbands. The importance of the dependence of the nonparabolicity parameter on the film thickness for transport is demonstrated [27].

The third aim stated in the proposal was the augmentation of the Wigner Monte Carlo simulator by a self-consistent iteration loop. Such a loop has been implemented, allowing the simultaneous solution of the Wigner and the Poisson equation [3]. Quantum transport in a GaAs resonant tunneling diode has been simulated with space-charge effects taken into account. Scattering with polar optical phonons as well as Coulomb scattering in the highly doped contact regions is considered. A region of negative differential resistance common to transport via a resonant level is clearly visible after the resonance peak. A self-consistent solution of the Wigner and Poisson equation is mandatory for the correct determination of the resonance position [3]. To improve the numerical stability of the simulation method, a spectral separation of the potential along the channel into a classical and quantum mechanical part has been proposed [24]. The classical potential accommodates the voltage applied to the structure. The proposed potential separation allows Wigner function-based simulations of practically relevant double-gate SOI FETs [23].

The fourth aim was implementation and application. The Wigner Monte simulator was further developed and kept as an independent tool. The particle annihilation algorithm used in the Wigner Monte Carlo method to address the negative sign problem has to be improved [14]. A new algorithm which minimizes the weight stored on the annihilation mesh and intrinsically conserves the current through the device has been implemented and tested. A Monte Carlo algorithm to solve the Levinson equation, which takes into account the finite collision duration, was enhanced. It is shown that the collision duration is only important for extremely short times of the initial evolution of highly non-equilibrium distributions [7]. The state-of-the art of Monte Carlo methods applied to solve the Wigner equation is summarized in the review papers [4,5] and the invited talk [18].
The Monte Carlo simulator was coupled to MININMOS-NT via files to exchange potential profiles and subband energy profiles. For the purpose of validation of the Monte Carlo simulator we have carried out simulations of double-gate MOSFETs assuming the simplified

qunatum-ballistic case, where electron-phonon scattering is neglected. Results reproducing the current enhancement due to quantum-mechanical tunneling through the potential barrier are in good agreement with those obtained from a direct solution of the Schrödinger equation with open boundary conditions [4, 21]. The role of scattering and intersubband coupling in ultrathin body silicon-on-insulator MOSFETs is investigated in [6,22]. It is found that scattering is still affecting the transport in ultra-scaled MOSFETs. Significant intersubband coupling in these devices emerges from intersubband scattering processes, such as electron-phonon and surface roughness scattering. The subband structure was determined by solving Schrödinger and Poisson equation self-consistently.

Importance of inter-subband coupling [13] in single- and double-gate silicon-on insulator (SOI) MOSFETs was further investigated. It is demonstrated that degeneracy effects lead to higher occupation of upper subbands in a double-gate MOSFET, due to a twice as large carrier concentration than in a single-gate structure for the same gate voltage [16]. This leads to an increase in inter-subband scattering, which results in a mobility lowering observed experimentally [13]. Higher substrate occupation of higher subbands [12] due to degeneracy effects [19] is responsible for the mobility degradation in ultra-thin body double-gate MOSFETs with (100) body orientation [1]. The Monte Carlo simulator was used to study the mobility in MOSFETs under general stress conditions. It is shown that the effective mass change due to shear strain results in a substantial mobility enhancement in the direction of tensile stain [10, 11, 15].

The role of space charge effects on the current-voltage characteristics of resonant tunneling diodes has been investigated [3]. Self-consistent Wigner simulations of nano-scaled Si n-i-n structures with realistic scattering mechanisms reveal the importance of electron-phonon scattering even for an intrinsic region length as short as 2.5 nm [5, 14].

3. Information on project participants

not funded by the FWF			funded by the FWF (project)		
co-workers	**number**	**Person-months**	**co-workers**	**number**	**Person - months**
non-scientific co-workers			non-scientific co-workers		
diploma students	1	4	diploma students		
PhD students			PhD students		
post-doctoral co-workers			post-doctoral co-workers	1	34
co-workers with "Habilitation" (professorial qualifications)	1	3	co-workers with "Habilitation" (professorial qualifications)		
professors			professors		

4. Attachments

List 1

1.a. scientific publications[1]

1.a.1. Peer-reviewed publications (journals, contribution to anthologies, working papers, proceedings etc.)

1) V. Sverdlov, E. Ungersböck, H. Kosina and S. Selberherr: "Volume inversion mobility in SOI MOSFETs for different thin body orientations"; *Solid-State Electronics, 51 (2007) 2, p. 299 – 305.*

2) V. Sverdlov, E. Ungersböck, H. Kosina:
"*Theoretical Electron Mobility Analysis in Thin-Body FETs: Dependence on Substrate Orientation and Biaxial Strain*";
IEEE Transactions on Nanotechnology, 6 (2007), 3; p. 334 – 340.

3) V. Sverdlov, T. Grasser, H. Kosina, S. Selberherr:
"*Scattering and Space-Charge Effects in Wigner Monte Carlo Simulations of Single and Double Barrier Devices*";
Journal of Computational Electronics, 5 (2006), p. 447 – 450.

4) H. Kosina:
"*Wigner function approach to nano device simulation*";
International Journal of Computational Science and Engineering, 2 (2006), 3/4; S. 100 - 118.

5) V. Sverdlov, H. Kosina, S. Selberherr:
"*Modeling Current Transport in Ultra-Scaled Field-Effect Transistors*";
Microelectronics Reliability (invited), 47 (2006), 1; p. 11 – 19.

6) V. Sverdlov, A. Gehring, H. Kosina, S. Selberherr:
"*Quantum Transport in Ultra-Scaled Double-Gate MOSFETs: A Wigner Function-Based Monte Carlo Approach*";
Solid-State Electronics, **49** (2005), 9; p. 1510 – 1515.

7) V. Sverdlov, H. Kosina, Ch. Ringhofer, M. Nedjalkov, S. Selberherr:
"*Quantum Correction to the Semiclassical Electron-Phonon Scattering Operator*";
in: "*Lecture Notes in Computer Science Vol. 3743*", Springer-Verlag, Berlin/Heidelberg, 2006, ISBN: 3-540-31994-8, p. 594 – 601.

8) E. Ungersböck, V. Sverdlov, H. Kosina, S. Selberherr:
"*Low-Field Electron Mobility in Stressed UTB SOI MOSFETs for Different Substrate Orientations*";
in: "*SiGe and Ge: Materials, Processing, and Devices, Vol. 3, Nr. 7*", published by: The Electrochemical Society; ECS Transactions, 2006, ISBN 1-56677-507-8, p. 45 – 54.

9) E. Ungersböck, V. Sverdlov, H. Kosina, S. Selberherr:
"*Modeling of Advanced Semiconductor Devices*" in: "*Microelectronics Technology and Devices SBMICRO2006 Vol. 4 Nr. 1*", publised by: The Electrochemical Society; ECS Transactions, 2006, ISBN 1-56677-512-4, p. 207 – 216.

10) E. Ungersböck, V. Sverdlov, H. Kosina, S. Selberherr:
"*Low-Field Electron Mobility in Stressed UTB SOI MOSFETs for Different Substrate Orientations*" in: "*Meeting Abstracts 2006 Joint International Meeting*", (2006), ISSN: 1091-8213 (CDROM); Paper-Nr. 1397, 1 p.

1 The publication list must mention for each work: all authors; full title; series/journal title; year; volume; and page numbers.

11) E. Ungersböck, V. Sverdlov, H. Kosina, S. Selberherr:
"*Strain Engineering for CMOS Devices*" in: "*2006 8th International Conference on Solid-State and Integrated Circuit Technology Proceedings (Part 1 of 3)*", (2006), ISBN: 1-4244-0160-7; p. 124 – 127.
12) V. Sverdlov, E. Ungersböck, H. Kosina:
"*Mobility Modeling in SOI FETs for Different Substrate Orientations and Strain Conditions*" in: "*NATO Advanced Research Workshop Conference Abstracts*", (2006), p. 77 – 78.
13) V. Sverdlov, E. Ungersböck, H. Kosina, S. Selberherr:
"*Orientation Dependence of the Low Field Mobility in Double- and Single-Gate SOI FETs*" in: "*Proceedings of the 36th European Solid-State Device Research Conference*", (2006), ISBN: 1-4244-0301-4; p. 178 – 181.
14) H. Kosina, V. Sverdlov, T. Grasser:
"*Wigner Monte Carlo Simulation: Particle Annihilation and Device Applications*" in: "*International Conference on Simulation of Semiconductor Processes and Devices 2006*", (2006), ISBN: 1-4244-0404-5; p. 357 – 360.
15) E. Ungersböck, V. Sverdlov, H. Kosina, S. Selberherr:
"*Electron Inversion Layer Mobility Enhancement by Uniaxial Stress on (001) and (100) Oriented MOSFETs*" in: "*International Conference on Simulation of Semiconductor Processes and Devices 2006*", (2006), ISBN: 1-4244-0404-5; p. 43 – 46.
16) V. Sverdlov, E. Ungersböck, H. Kosina, S. Selberherr:
"*Comparative Study of Low-Field Mobilities in Double- and Single-Gate Ultra-Thin Body SOI for Different Substrate Orientations*"; in: "*Abstracts IEEE 2006 Silicon Nanoelectronics Workshop*", (2006), p. 17 – 18.
17) V. Sverdlov, T. Grasser, H. Kosina, S. Selberherr:
"*Scattering and Space-Charge Effects in Wigner Monte Carlo Simulations of Single and Double Barrier Devices*";
in: "*11th International Workshop on Computational Electronics, Book of Abstracts*", (2006), ISBN: 0-9767985-8-1; p. 29 – 30.
18) V. Sverdlov, H. Kosina, S. Selberherr:
"*Current Flow in Upcoming Microelectronic Devices*";
in: "*Proceedings International Caribbean Conference on Devices, Circuits and Systems*", (2006), ISBN: 1-4244-0041-4; p. 3 – 8.
19) V. Sverdlov, E. Ungersböck, H. Kosina:
"*Mobility for High Effective Field in Double-Gate and Single-Gate SOI for Different Substrate Orientations*"; in: "*EUROSOI 2006 Second Workshop of the Thematic Network on Silicon On Insulator Technology, Devices and Circuits*", (2006), p. 133 – 134.
20) V. Sverdlov, H. Kosina, S. Selberherr:
"*Current Transport in Nanoelectronic Semiconductor Devices*";
in: "*Proceedings IEEE Conference on Emerging Technologies - Nanoelectronics*", (2006), ISBN: 0-7803-9358-9; p. 490 – 495.
21) V. Sverdlov, H. Kosina, S. Selberherr:
"*Modeling Current Transport in Ultra-Scaled Field Effect Transistors*";
in: "*Proceedings of the 2005 IEEE Conference on Electron Devices and Solid-State Circuits*", (2005), ISBN: 0-7803-9339-2; p. 385 – 390.
22) V. Sverdlov, A. Gehring, H. Kosina, S. Selberherr:
"*Tunneling and Intersubband Coupling in Ultra-Thin Body Double-Gate MOSFETs*" in: "*Proceedings of ESSDERC 2005*", CDROM ISBN: 0-7803-9204-3 (2005), ISBN: 0-7803-9203-5; p. 93 – 96.

23) A. Gehring, V. Sverdlov, H. Kosina, S. Selberherr:
"*Quantum Transport in Ultra-Scaled Double-gate MOSFETs: A Wigner Function-based Monte Carlo Approach*" in: "*EUROSOI 2005 First Workshop of the Thematic Network on Silicon On Insulator Technology, Devices and Circuits*", (2005), p. 71 – 72.

24) A. Gehring, H. Kosina:
"*Wigner Function-Based Simulation of Quantum Transport in Scaled DG-MOSFETs Using a Monte Carlo Method*";
Journal of Computational Electronics, **4** (2005), 1-2; S. 67 – 70.

25) V. Sverdlov, E. Ungersboeck, H. Kosina, and S. Selberherr:
"Effects of Shear Strain on the Conduction Band in Silicon: An Efficient Two-Band k p Theory" in: "*Proceedings of ESSDERC 2007*" (in print).

26) V. Sverdlov, G. Karlowatz, E. Ungersboeck, and H. Kosina:
"Influence of Uniaxial [110] Stress on the Silicon Conduction Band Structure: Stress Dependence of the Nonparabolicity Parameter" in: "*International Conference on Simulation of Semiconductor Processes and Devices 2007*", (in print).

27) V. Sverdlov, H. Kosina, and S. Selberherr:
"Electron Subband Dispersions in Ultra-Thin Silicon Films from a Two-Band k p Theory", in "2007 *International Workshop on Computational Electronics, Book of Abstacts"*, (in print).

1.a.2. Non peer-reviewed publications (journals, contribution to anthologies research reports, working papers, proceedings, etc.)

None

1.a.3. Stand-alone publications (monographies, anthologies)

None

1.b. publications for the general public and other publications

such as films, exhibitions, preparation of a home page etc. with an indication of the status (published, submitted / in preparation)

None

List 2 project-related participation in international scientific conferences

2.1. Conference participations - invited lectures

1) H. Kosina:
"*Nanoelectronic Device Simulation Based on the Wigner Function Formalism*";
International Workshop on Tera- and Nano-Devices: Physics and Modeling, Aizu-Wakamatsu (invited); 16.10.2006 – 19.10.2006.
2) H. Kosina:
"*Modeling of Electronic Transport Phenomena in Semiconductor Nanodevices*";
The 4th International Nanotech Symposium & Exhibition, Seoul (invited); 30.08.2006 - 01.09.2006.
3) E. Ungersböck, V. Sverdlov, H. Kosina, S. Selberherr:
"*Strain Engineering for CMOS Devices*";
International Conference on Solid State and Integrated Circuit Technology (ICSICT), Shanghai (eingeladen); 23.10.2006 – 26.10.2006.
4) V. Sverdlov, H. Kosina, S. Selberherr:
"*Current Flow in Upcoming Microelectronic Devices*";
International Caracas Conference on Devices, Circuits and Systems (ICCDCS), Playa del Carmen (invited); 26.04.2006 – 28.04.2006.
5) V. Sverdlov, H. Kosina, S. Selberherr:
"*Current Transport in Nanoelectronic Semiconductor Devices*";
IEEE Conference on Emerging Technologies - Nanoelectronics (NanoSingapore), Singapore (invited); 10.01.2006 – 13.01.2006.
6) V. Sverdlov, H. Kosina, S. Selberherr:
"*Modeling Current Transport in Ultra-Scaled Field Effect Transistors*";
Conference on Electron Devices and Solid-State Circuits (EDSSC), Hong Kong (invited); 19.12.2005 – 21.12.2005.
7) E. Ungersböck, V. Sverdlov, H. Kosina, S. Selberherr:
"*Modeling of Advanced Semiconductor Devices*";
Symposium of Microelectronics Technology and Devices (SBMICRO), Ouro Preto (invited); 28.08.2006 - 01.09.2006.

2.2. Conference participations - lectures

1) E. Ungersböck, V. Sverdlov, H. Kosina, S. Selberherr:
"*Low-Field Electron Mobility in Stressed UTB SOI MOSFETs for Different Substrate Orientations*";
Meeting of the Electrochemical Society (ECS), Cancun; 29.10.2006 – 03.11.2006.
2) V. Sverdlov, E. Ungersböck, H. Kosina:
"*Mobility Modeling in SOI FETs for Different Substrate Orientations and Strain Conditions*";
NATO Advanced Research Workshop Nanoscaled Semiconductor-On-Insulator Structures and Devices, Sudak; 15.10.2006 – 19.10.2006.
3) V. Sverdlov, E. Ungersböck, H. Kosina, S. Selberherr:
"*Orientation Dependence of the Low Field Mobility in Double- and Single-Gate SOI FETs*";
European Solid-State Device Research Conference (ESSDERC), Montreux; 18.09.2006 – 22.09.2006.
4) H. Kosina, V. Sverdlov, T. Grasser:
"*Wigner Monte Carlo Simulation: Particle Annihilation and Device Applications*";
International Conference on the Simulation of Semiconductor Processes and Devices (SISPAD), Monterey; 06.09.2006 – 08.09.2006.

5) E. Ungersböck, V. Sverdlov, H. Kosina, S. Selberherr:
"*Electron Inversion Layer Mobility Enhancement by Uniaxial Stress on (001) and (100) Oriented MOSFETs*";
International Conference on the Simulation of Semiconductor Processes and Devices (SISPAD), Monterey; 06.09.2006 – 08.09.2006.
6) V. Sverdlov, E. Ungersböck, H. Kosina, S. Selberherr:
"*Comparative Study of Low-Field Mobilities in Double- and Single-Gate Ultra-Thin Body SOI for Different Substrate Orientations*";
Silicon Nanoelectronics Workshop, Honolulu; 11.06.2006 – 12.06.2006.
7) V. Sverdlov, T. Grasser, H. Kosina, S. Selberherr:
"*Scattering and Space-Charge Effects in Wigner Monte Carlo Simulations of Single and Double Barrier Devices*";
International Workshop on Computational Electronics (IWCE), Wien; 25.05.2006 – 27.05.2006.
8) V. Sverdlov, E. Ungersböck, H. Kosina:
"*Mobility for High Effective Field in Double-Gate and Single-Gate SOI for Different Substrate Orientations*";
Workshop of the Thematic Network on Silicon on Insulator Technology, Devices, and Circuits (EUROSOI), Grenoble; 08.03.2006 – 10.03.2006.
9) V. Sverdlov, A. Gehring, H. Kosina, S. Selberherr:
"*Tunneling and Intersubband Coupling in Ultra-Thin Body Double-Gate MOSFETs*";
European Solid-State Device Research Conference (ESSDERC), Grenoble; 12.09.2005 – 16.09.2005.
10) H. Kosina, V. Sverdlov, Ch. Ringhofer, M. Nedjalkov, S. Selberherr:
"*Quantum Correction to the Semiclassical Electron-Phonon Scattering Operator*";
International Conference on Large-Scale Scientific Computations (LSSC), Sozopol; 06.06.2005 – 10.06.2005.
11) A. Gehring, V. Sverdlov, H. Kosina, S. Selberherr:
"*Quantum Transport in Ultra-Scaled Double-gate MOSFETs: A Wigner Function-based Monte Carlo Approach*";
Workshop of the Thematic Network on Silicon On Insulator Technology, Devices and Circuits (EUROSOI), Granada; 19.01.2005 – 21.01.2005.
12) V. Sverdlov, H. Kosina, Ch. Ringhofer, M Nedjalkov, S. Selberherr:
"*Beyond the Golden Rule in Electron-Phonon Scattering: an Advanced Monte Carlo Algorithm*";
DFG Workshop on Multiscale Problems in Quantum Mechanics and Averaging Techniques, Garching; 04.11.2004 - 05.11.2004.

2.3. Conference participations - posters

2.4. Conference participations - other

List 3 Development of collaborations

Indication of the most important collaborations (maximum 5), that took place (initiated or continued) in collaboration please give the name of the collaboration partner (name, title, institution) and a few words about the scientific content. Please also assign one of the following **categories** to each collaboration:

N			Nature: **N** (national); **E** (European); **I** (other international cooperation)
	E		Extent: **E1** **low** (e.g. no joint publications but mention in acknowledgements or similar); **E2** **medium** (collaboration e.g. with occasional joint publications, exchange of materials or similar but no longer-term exchange of personnel); **E3** **high** (extensive collaboration with mutual hosting of group members for research stays, regular joint publications etc.)
		D	Discipline: **D** within the discipline; **T** transdisciplinary

N	E	D	Collaboration partner / content of the collaboration
I	E2	T	1) Name: Christian Ringhofer Title: Prof. Institution: Arizona State University Content: Subband Coupling in Wigner picture, quantum extension to the classical scattering operator
E	E2	D	2) Name: Mihail Nedjalkov Title: Assoc. Prof. Institution: Bulgarian Academy of Science Content: Monte Carlo algorithms for the Wigner equation
N	E1	T	3) Name: Anton Arnold Title: Prof. Institution: TU Vienna Content: Mathematical properties of the Wigner equation, boundary conditions.
			4) Name: Title: Institution: Content:
			5) Name: Title: Institution: Content:

Note: general scientific contacts and occasional meetings should not be considered as collaborations in the above sense.

List 4 “Habilitations” (professorial qualifications) / PhD theses / diploma theses

4.1 Diploma Theses

1) Bernhard Höflechner:
"*A Random Number Generator Library for Monte Carlo Simulation*";
Supervisor: H. Kosina, E. Ungersböck; Institute for Microelectronics, 2006;
final examination: 06-22-2006.

List 5 Effects of the project outside the scientific field

5.1. Organization of scientific events

"11th International Workshop on Computational Electronics, IWCE- 11", Chairmen H. Kosina and S. Selberherr, TU Vienna, May 25 – 27, 2006.