STAND-ALONE PROJECT - FINAL REPORT

Project number	P 18316-N13
Project title	**Makroskopische Transportmodelle Hoeherer Ordnung**
Project leader	**Grasser Tibor**

1. Summary for public relations work

Simulation of the electrical behavior of semiconductor devices enables device engineers and manufacturers to estimate electrical characteristics prior to the finished production cycle. Highly expensive test runs can be efficiently eliminated by deepening the understanding of the physical behavior. Using this knowledge enables also to optimize the devices in an early phase. In order to master these simulation tasks, sophisticated software tools are required, commonly referred to as technology computer aided design (TCAD) tools. A particularly challenging problem in any TCAD environment is the accurate modeling of carrier transport in modern semiconductor devices. This project dealt with the development of an advanced transport model suitable for this problem. The new model was demonstrated to have considerable advantages compared to existing models.

From a theoretical point of view, the charge carriers in a semiconductor can be treated like a classical particle gas, the properties of which are described by Boltzmann's transport equation. Being a seven-dimensional integro-differential equation, the Boltzmann equation is extremely challenging to solve but provides a wealth of information on the spatial and energetic distribution of the particles. For engineering applications such a level of detail is often not required and approximate solutions are commonly sought. As an example, the current flowing through a device is obtained from the velocity moment of the distribution function. Thus rather than first calculating the distribution function and then averaging it for the moment calculations, it is much more efficient to directly formulate equations for the moments themselves. This is known as the method of moments and the accuracy of the model depends on the number of moments considered. Commercially available TCAD tools offer models based on the first two and the first four moments only, which have been shown to become inaccurate for deca-nanometer sized devices.

In this project, a six moments model was developed with a strong focus on deca-nanometer MOS transistors, the commercially most important devices. A particular aspect was the inclusion of quantum-mechanical effects in the channel of the transistor, which not only affects the electrostatics but also the transport parameters such as the mobility. Various theoretical and practical difficulties had to be resolved in order to obtain a numerically stable and accurate model. In a detailed study the new model was compared to existing models and their range of applicability clearly stated. As expected, for the reference case of long channel technologies, all models give similar predictions for the terminal currents. However, particularly for modern ultra-small MOS transistors, convincing benefits of the new model were identified, both in terms of predicted terminal currents as well as transit frequencies.

2. Brief project report

2.1 Report on the scientific work

2.1.1 Information on the development of the research work

Macroscopic transport models used for the analysis of modern semiconductor devices are normally derived from the semi-classical Boltzmann transport equation which is often used to describe carrier transport in contemporary MOS transistors down to gate-lengths as small as 10 nm. Quantum-mechanical effects perpendicular to the transport direction have to be considered in an accurate description. While the classic drift-diffusion model begins to loose its accuracy for gate-lengths smaller than about 500 nm, energy-transport models give an improvement only down to about 100 nm. Research results available at the start of the project indicated that the important window of gate-lengths from 100 down to about 25 nm could be covered by a six moments model. Various challenges on the road to the practical applicability of such an approach had to be covered in this project.
In particular, the aim of this project was the formulation of a robust, fit parameter free higher-order model which can be used for predictive simulations down to a still-to-be-determined minimum feature size. In order to achieve this, transport parameters such as the carrier mobility and the energy relaxation time have to be expressed as a function of the driving field, normal field, average carrier energy, doping concentration, and temperature, just to name the most important ones. Conventionally, this is done using semi-empirical analytical expressions which contain a number of ill-defined fit parameters. However, as these transport parameters essentially determine the overall quality of the model prediction, assessment of the general model properties becomes difficult if no clear theoretical or at least practical guidelines on these parameters are available.
In order to avoid these fit parameters, the transport parameters were extracted from Monte Carlo solutions of the homogeneous Boltzmann transport equation. Such an approach guarantees the consistency of the model. In particular, the impact of quantum-mechanical quantization in the channel on the transport parameters had to be assessed. This was done in close collaboration with Prof. Esseni's group in Udine, who provided their subband Monte Carlo simulator for that purpose. In addition, the much more efficient macroscopic model could thus be evaluated against the more rigorous subband Monte Carlo solution.
Overall, the ideas expressed in the proposal could be followed to a large extent. However, even with the improvements introduced into the numerical scheme, the six-moments model remained very sensitive to the mesh. Consequently, efforts where directed into studying and correctly capturing the impact of quantization rather than extending the model to even higher orders. This decision was also taken in accordance with the reduced funding as compared to the proposal.

2.1.2 Most important results and brief description of their significance

In a first step, higher-order transport models were reformulated using the method of moments [1, 2] and discretized using a generalized Scharfetter-Gummel type scheme [3, 4]. Basic physical concepts such as the microscopic relaxation time approach after Stratton and the macroscopic relaxation time approach after Bløtekjær were compared. Due to its better extendibility to higher order models, particularly from a numerical perspective, Bløtekjær's approach was then followed. Numerical issues were investigated until a stable implementation was available. In order to tackle the problem of the increasing number of transport parameters, which in the conventionally used approach are handled by analytical models with a considerable number of fit parameters, a rigorous extraction from homogeneous Monte Carlo (MC) simulations was performed. The initial version of the six moments model relied on data extracted from a bulk full-band MC simulator, thereby lacking information on surface scattering and quantization in the channel. Since it was *a priori* not clear how these effects impact the higher-order transport parameters, a self consistent

Schrödinger-Poisson subband Monte Carlo (SMC) simulator was developed. Using the information obtained from the SMC code, it was decided not to correct the bulk transport parameters for surface scattering and quantization effects, but rather to directly extract them from homogeneous SMC simulations.
Thus, as a next step, a two dimensional subband six moments model was developed. In order to maintain its efficiency, the subband transport is handled as an effective single band model with transport parameters pre-calculated by a homogeneous solution of the SMC problem. The transport model can thus be divided into two parts: in the microscopic part the transport parameters are self-consistently extracted from tabulated homogeneous SMC data, and a macroscopic part coming from the method of moments. In order to capture the influence of inversion layer effects like quantization, surface roughness scattering, and non-parabolic bands for high fields on higher-order transport parameters, we extract the parameters for different perpendicular and driving fields, doping concentrations, material compositions, temperatures, etc. The macroscopic part was implemented into the device simulator MINIMOS-NT [5]. Our device simulator MINIMOS-NT is then used to calculate the normal field through the channel of a whole device and to interpolate higher-order transport parameters from the SMC tables. This approach allows for an efficient modeling of the transport parameters in the inversion layer.
In the next step the 2D higher-order transport models were compared against other transport models, like subband drift-diffusion and energy-transport models, and eventually against reference device SMC simulations. Compared to full-band MC codes, device SMC simulations are computationally even more demanding, making the benefits of macroscopic models even more obvious. In order to guarantee consistency between the models, the subband drift-diffusion and energy-transport models follow as special cases from the general higher-order model developed in the course of the project and use the same homogeneous SMC tables for the transport parameters. As a result, in long channel MOS transistors, where non-local effects are negligible under normal operating conditions, all macroscopic models reproduce the results of the reference SMC simulation. Then, the channel length of the transistor was gradually decreased until the limit of the models became obvious. It is important to highlight that not a single fit parameter is available in the models. As a consequence, this procedure reveals the real physical limit of the various models. This issue is often obscured in other studies in the literature since even the very simple drift-diffusion model can be ‘adjusted’ in such a way to reproduce MC results in ultra-short devices. However, these adjustments are unphysical, violating fundamental principles like the maximum (saturation) velocity obtainable under homogeneous conditions. As a result, such an ‘adjusted’ drift-diffusion model can no longer reproduce for instance currents in a homogeneous sample or long-channel transistors. This severely limits the predictability of the model which is avoided in our approach.
Based on the above, the goal of the final phase of the project was to give guidelines regarding the validity of macroscopic transport models. As a consistency check, for long channel devices (about 1000 nm) all models converge to the same results. With decreasing channel lengths down to 100 nm, the drift-diffusion model increasingly underestimates the current compared to the reference SMC simulation. This is due to the fact that the drift-diffusion model cannot capture non-local effects, thus does for instance not allow to predict the velocity overshoot in the channel. On the other hand, at these gate lengths the energy transport and the six moments model can accurately reproduce the reference results. The error in the drain current predicted by the energy transport model increases rapidly below a channel length of 80 nm and becomes even larger than the error of the drift-diffusion model at 40 nm. This was identified as being due to the assumption of a displaced and heated Maxwellian distribution for the calculation of the closure relation of the energy transport model. As a consequence, the high-energy tail of the distribution function is dramatically overestimated compared to the thermal tail seen in the SMC simulations, which results in a considerable overestimation of the velocity overshoot and other non-local effects.
The error of the six moments model, on the other hand, increases to about 17% for a critical channel length of 30 nm. In comparison, at this range of gate-lengths the errors in the drift-diffusion and the energy transport models in the maximum drain currents are already as high

as -20% and 55%, respectively. While a -20% error in the drift-diffusion model appears not that serious, a closer analysis reveals that this is due to a lucky coincidence, namely the cancellation of two errors: at low drain voltages, the drift-diffusion model overestimates the conductivity by a factor of two [6], which roughly cancels with the underestimated velocity profile at the maximum drain voltage, resulting in a reasonable drain current. Thus, a drain current criterion was found to be insufficient for the evaluation of the models. A better evaluation thus needs to consider non-local or hot carrier effects. The prime example would be impact ionization, which is notoriously difficult to model using macroscopic models as it requires detailed knowledge of the carrier energy distribution function. However, impact ionization models used in drift-diffusion, energy-transport and six moments models are difficult to compare rigorously, as they are based on different approximations. They also result in differences of many orders of magnitude, two issues which might cloud the comparison. A quantity which can be calculated using only quantities directly provided by the transport model is the transit frequency, which is very sensitive to the details of the velocity profile. A comparison of the transit frequencies calculated by the various models shows that the error of the drift-diffusion, energy transport, and the six moments model is at −40%, 40%, and 18% for a channel length of 30 nm, respectively. The inaccuracy of the drift-diffusion model in the transit frequency is twice as large as in the current. The developed six moments model for carrier transport in inversion layers yields very accurate results through the whole scattering dominated regime and outperforms the energy transport and the drift-diffusion model in deca-nanometer channel length devices.
In order to use higher-order macroscopic transport models in semiconductor alloys such as GaAs or SiGe, detailed investigations concerning the behavior of macroscopic transport parameters in these materials were carried out. Accurate investigations of higher-order macroscopic transport parameters in the bulk regime as well as the important closure relation for the six moments model for these semiconductor alloys were carried out using bulk Monte Carlo data. It was also found that the same empirical closure relation as used for the six moments model in Silicon can be used in GaAs and SiGe as well.
At the end of the project we have attained our goal of having a robust, fit parameter free higher-order model, which can be used in a quantized system of an inversion layer or in a three-dimensional bulk regime of deca-nanometer channel length devices.

2.1.3 Information on the running of the project, use of the available funding

Since the permitted funding did not allow the funding of both a PostDoc and a Ph.D. over the course of three years, the available funding was mostly used to support the dissertation of Dr. Martin Vasicek, who successfully defended his Ph.D. thesis in October 2009 and was supported for 45 months (Online version is available at http://www.iue.tuwien.ac.at/phd/vasicek). In 2008, Dr. Stanislav Tyaginov worked on the project as a PostDoc for the 5 months. During the last year of the project, DI Karl Rupp contributed for 12 months. In total, 57 PhD months and 5 PostDoc months were spent during the project duration of 4 years.

References

[1] K. Blotekjaer, "Transport Equations for Electrons in Two-Valley Semiconductors," vol. ED-17, pp. 38–47, Jan. 1970.
[2] T. Grasser, R. Kosik, C. Jungemann, H. Kosina, and S. Selberherr, "Nonparabolic macroscopic transport models for device simulation based on bulk Monte Carlo data," *J. Appl.Phys.*, vol. 97, no. 9, pp. 093710–1 – 093710–12, 2005.
[3] T.-W. Tang and M.-K. Ieong, "Discretization of Flux Densities in Device Simulations Using Optimum Artificial Diffusivity," vol. 14, no. 11, pp. 1309–1315, 1995.
[4] W.-S. Choi, J.-G. Ahn, Y.-J. Park, H.-S. Min, and C.-G. Hwang, "A Time Dependent Hydrodynamic Device Simulator SNU-2D With New Discretization Scheme and Algorithm," vol. 13, no. 7, pp. 899–908, 1994.
[5] http://www.iue.tuwien.ac.at/software/minimos-nt, "Minimos-NT 2.0 User's Guide, IμE." Institut für Mikroelektronik, Technische Universität Wien, Austria, 2002.

[6] C. Jungemann, T. Grasser, B. Neinhüs, and B. Meinerzhagen, "Failure of Moments-Based Transport Models in Nanoscale Devices Near Equilibrium"; IEEE Transactions on Electron Devices, 52 (2005), 11; 2404 - 2408.

2.2. Personnel development – importance of the project for the scientific careers of those involved (including the project leader)

Martin Vasicek finished his PhD study during this project. Furthermore, during the extensive collaboration with Prof. Esseni's group at the University of Udine, he was involved in an exchange program. He currently holds a PostDoc position at the Wolfgang Pauli Institute in Vienna. Dr. Stanislav Tyaginov gained his first experience as a postdoctoral researcher and was able to further deepen his expertise gained in his previous PhD project. Finally, Karl Rupp, who holds a masters degree in electrical engineering as well as in mathematics, was able to obtain deep insight into macroscopic transport modelling. Particularly his input has enabled us to successfully apply for the 'Graduate School PDETech', a joint graduate school for engineers, mathematicians and physicists at TU Wien (for details see http://pdetech.tuwien.ac.at/).
As a consequence of the results obtained in the project, the project leader received various invitations for presentations at conferences, workshops, summer schools as well as book contributions, more than could be accepted.
Finally, the results obtained in the project form the backbone of the hot carrier degradation modeling activities now taking place in Tibor Grasser's group (Christian Doppler Laboratory for TCAD, FP7 ATHENIS, ENIAC MODERN).
International collaborations built up or strengthened during the course of the project are with Prof. Esseni's group in Udine, Prof. Jungemann's group in Munich, as well as Prof. Jüngel and Prof. Arnold's groups at TU Wien.

2.3 Effects of the project outside the scientific field

The results obtained in this project shaped and extended the contents of the lecture 'Modelling of Semiconductor Devices' given by the project leader as part of the compulsory curriculum for the 'Microelectronics' master program at TU Wien.

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			diploma students		
PhD students	2	20	PhD students	2	57
post-doctoral co-workers	1	2	post-doctoral co-workers	1	5
co-workers with “Habilitation” (professorial qualifications)			co-workers with “Habilitation” (professorial qualifications)		
professors	1	4	professors		

4. Attachments

(lists may be as long as required)

List 1

1.a. scientific publications[1]

All publications are available from the website of the Institute for Microelectronics at http://www.iue.tuwien.ac.at (Former Staff/Martin Vasicek)

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

Journals

[J1] M. Vasicek, P. Palestri, D. Esseni, T. Grasser: *"Advanced Macroscopic Transport Models for Submicron MOSFETs "*; (2010), (journal version of the most important project results, in preparation)

[J2] M. Vasicek, J. Cervenka, M. Wagner, M. Karner, T. Grasser: *"A 2D Non-Parabolic Six-Moments Model"*; Solid-State Electronics, 52 (2008), 1606 - 1609.

[J3] M. Vasicek, J. Cervenka, M. Wagner, M. Karner, T. Grasser: *"Parameter Modeling for Higher-Order Transport Models in UTB SOI MOSFETs"*; Journal of Computational Electronics, 7 (2008), 3; 168 - 173.

[J4] M. Karner, A. Gehring, S. Holzer, M. Pourfath, M. Wagner, W. Gös, M. Vasicek, O. Baumgartner, Ch. Kernstock, K. Schnass, G. Zeiler, T. Grasser, H. Kosina, S. Selberherr: *"A Multi-Purpose Schrödinger-Poisson Solver for TCAD Applications"*; Journal of Computational Electronics, 6 (2007), 179 - 182.

[J5] M. Wagner, M. Karner, J. Cervenka, M. Vasicek, H. Kosina, S. Holzer, T. Grasser: *"Quantum Correction for DG MOSFETs"*; Journal of Computational Electronics, 5 (2007), 397 - 400.

Contributions to Books

[B1] M. Vasicek, D. Esseni, C. Fiegna, T. Grasser, "Chapter 8: Modeling and Simulation Approaches for Drain Current Computation," Bookchapter in *Innovative materials, modelling and characterization for Nanoscale CMOS* (Ed. F. Balestra), p. 253-279, ISTE-Wiley/London, UK , 2010 (in press).

[B2] M. Karner, S. Holzer, W. Gös, M. Vasicek, M. Wagner, H. Kosina, S. Selberherr: *"Numerical Analysis of Gate Stacks"*; in: "Physics and Technology of High-k Gate Dielectrics 4, Vol. 3 No. 3", issued by: The Electrochemical Society; ECS Transactions, 2006, ISBN: 1-56677-503-5, 299 - 308.

[1] The publication list must mention for each work: all authors; full title; series/journal title; year; volume; and page numbers. Furthermore, if publications are freely available in the internet, please add the URL of the publication.

Talks and Poster Presentations

[C1] M.Vasicek, V. Sverdlov, J. Cervenka, T. Grasser, H. Kosina, S. Selberherr: *“Transport in Nanostructures: A Comparative Analysis Using Monte Carlo Simulation, the Spherical Harmonic Method, and Higher Moments Models“*, 7th International Conference on "Large-Scale Scientific Computations" (LSSC), Sozopol; 04-06-2009 – 08-06-2009; in: „Large-Scale Scientific Computing“, (2009), (lecture)

[C2] M. Vasicek: *"Advanced Macroscopic Transport Models"*; Quantum Systems and Devices: Analysis, Simulations, Applications, Beijing; 04-20-2009 - 04-24-2009; in: "Quantum Systems and Devices: Analysis, Simulations, Applications", (2009), 32. (invited lecture)

[C3] M. Vasicek, J. Cervenka, M. Karner, T. Grasser: *"Consistent Higher-Order Transport Models for SOI MOSFETs";* International Conference on Simulation of Semiconductor Processes and Devices (SISPAD), Hakone; 09-09-2008 - 09-11-2008; in: "International Conference on Simulation of Semiconductor Processes and Devices 2008", (2008), ISBN: 978-1-4244-1753-7; 129 - 132. (poster)

[C4] M. Karner, O. Baumgartner, M. Pourfath, M. Vasicek, H. Kosina: *"Investigation of a MOSCAP Using NEGF"*; International Semiconductor Device Research Symposium (ISDRS), Maryland; 12-12-2007 - 12-14-2007; in: "2007 International Semiconductor Device Research Symposium", (2007), ISBN: 978-1-4244-1892-3; 2 pages. (lecture)

[C5] M. Vasicek, J. Cervenka, M. Wagner, M. Karner, T. Grasser: *"A 2D-Non-Parabolic Six Moments Model"*; International Semiconductor Device Research Symposium (ISDRS), Maryland; 12-12-2007 - 12-14-2007; in: "2007 International Semiconductor Device Research Symposium", (2007), ISBN: 978-1-4244-1892-3; 2 pages. (lecture)

[C6] M. Vasicek, J. Cervenka, M. Karner, M. Wagner, T. Grasser: *"Parameter Modeling for Higher-Order Transport Models in UTB SOI MOSFETs"*; International Workshop on Computational Electronics (IWCE), Amherst; 10-08-2007 - 10-10-2007; in: "12th International Workshop on Computational Electronics", (2007), 96 - 97. (poster)

[C7] M. Vasicek, M. Karner, E. Ungersböck, M. Wagner, H. Kosina, T. Grasser: *"Modeling of Macroscopic Transport Parameters in Inversion Layers"*; International Conference on Simulation of Semiconductor Processes and Devices (SISPAD), Wien; 09-25-2007 - 09-27-2007; in: "International Conference on Simulation of Semiconductor Processes and Devices 2007", T. Grasser, S. Selberherr (ed.); Springer-Verlag Wien New York, 12 (2007), ISBN: 978-3-211-72860-4; 201 - 204. (lecture)

[C8] M. Karner, S. Holzer, M. Vasicek, W. Gös, M. Wagner, H. Kosina, S. Selberherr: *"Numerical Analysis of Gate Stacks"*; Meeting of the Electrochemical Society (ECS), Cancun; 10-29-2006 - 11-03-2006; in: "Meeting Abstracts 2006 Joint International Meeting", (2006), ISSN: 1091-8213; Paper ID 1119, 1 pages. (lecture)

[C9] M. Karner, A. Gehring, M. Wagner, R. Entner, S. Holzer, W. Gös, M. Vasicek, T. Grasser, H. Kosina, S. Selberherr: *"VSP-A Gate Stack Analyzer"*; Workshop on Dielectrics in Microelectronics (WODIM), Catania; 06-26-2006 - 06-28-2006; in: "WODIM 2006 14th Workshop on Dielectrics in Microelectronics Workshop Program and Abstracts", (2006), 101 - 102. (lecture)

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

[W1] T. Grasser, M. Vasicek, M. Wagner: *"Higher-Order Moment Models for Engineering Applications"*; Equadiff, Wien; 08-05-2007 - 08-11-2007 (invited lecture)

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

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)

List 2 project-related participation in international scientific conferences
(with an indication of the conference date) – 4 subunits:

2.1. Conference participations - invited lectures

[C2] M. Vasicek: *"Advanced Macroscopic Transport Models"*; Quantum Systems and Devices: Analysis, Simulations, Applications, Beijing; 04-20-2009 - 04-24-2009; in: "Quantum Systems and Devices: Analysis, Simulations, Applications", (2009), 32. (invited lecture)

[W1] T. Grasser, M. Vasicek, M. Wagner: *"Higher-Order Moment Models for Engineering Applications"*; Equadiff, Wien; 08-05-2007 - 08-11-2007 (invited lecture)

2.2. Conference participations - lectures

[C1] M.Vasicek, V. Sverdlov, J. Cervenka, T. Grasser, H. Kosina, S. Selberherr: *“Transport in Nanostructures: A Comparative Analysis Using Monte Carlo Simulation, the Spherical Harmonic Method, and Higher Moments Models“*, 7th International Conference on "Large-Scale Scientific Computations" (LSSC), Sozopol; 04-06-2009 – 08-06-2009; in: „Large-Scale Scientific Computing“, (2009), (lecture)

[C4] M. Karner, O. Baumgartner, M. Pourfath, M. Vasicek, H. Kosina: *"Investigation of a MOSCAP Using NEGF"*; International Semiconductor Device Research Symposium (ISDRS), Maryland; 12-12-2007 - 12-14-2007; in: "2007 International Semiconductor Device Research Symposium", (2007), ISBN: 978-1-4244-1892-3; 2 pages. (lecture)

[C5] M. Vasicek, J. Cervenka, M. Wagner, M. Karner, T. Grasser: *"A 2D-Non-Parabolic Six Moments Model"*; International Semiconductor Device Research Symposium (ISDRS), Maryland; 12-12-2007 - 12-14-2007; in: "2007 International Semiconductor Device Research Symposium", (2007), ISBN: 978-1-4244-1892-3; 2 pages. (lecture)

[C7] M. Vasicek, M. Karner, E. Ungersböck, M. Wagner, H. Kosina, T. Grasser: *"Modeling of Macroscopic Transport Parameters in Inversion Layers"*; International Conference on Simulation of Semiconductor Processes and Devices (SISPAD), Wien; 09-25-2007 - 09-27-2007; in: "International Conference on Simulation of Semiconductor Processes and Devices 2007", T. Grasser, S. Selberherr (ed.); Springer-Verlag Wien New York, 12 (2007), ISBN: 978-3-211-72860-4; 201 - 204. (lecture)

2.3. Conference participations - posters

[C3] M. Vasicek, J. Cervenka, M. Karner, T. Grasser: *"Consistent Higher-Order Transport Models for SOI MOSFETs";* International Conference on Simulation of Semiconductor Processes and Devices (SISPAD), Hakone; 09-09-2008 - 09-11-2008; in: "International Conference on Simulation of Semiconductor Processes and Devices 2008", (2008), ISBN: 978-1-4244-1753-7; 129 - 132. (poster)

[C6] M. Vasicek, J. Cervenka, M. Karner, M. Wagner, T. Grasser: *"Parameter Modeling for Higher-Order Transport Models in UTB SOI MOSFETs"*; International Workshop on Computational Electronics (IWCE), Amherst; 10-08-2007 - 10-10-2007; in: "12th International Workshop on Computational Electronics", (2007), 96 - 97. (poster)

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

N	**E**	**D**	**Collaboration partner / content of the collaboration**
E	E3	D	1) Name: Prof. David Esseni Title: Institution: Univ. of Udine Content: Subband Monte Carlo Simulation
E	E3	D	2) Name: Prof. Christoph Jungemann Title: Institution: Univ. Bundeswehr/Munich Content: Fullband Monte Carlo/Spherical Harmonics Simulation
E	E1	T	3) Name: Prof. Ansgar Juengel Title: Institution: TU Wien Content: Mathematical and Numerical Modeling of Semiconductor Devices
			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
with an indication of the status (in progress / completed)

Note: it will not be possible to assign a "Habilitation" to a single project; what is required here is a mention of those "Habilitations" for which the project was important. A similar caveat applies to PhD and diploma theses: the FWF does not support thesis work but rather funds the scientific work that forms the basis for theses.

4.1. Professorial Qualifications

4.2. PhD Theses

Dr. Martin Vasicek, *Advanced Macroscopic Transport Models* (October 2009),
Online version available at http://www.iue.tuwien.ac.at

4.3. Diploma Theses

List 5 Effects of the project outside the scientific field (where appropriate)

Sections of the list:

5.1. Organization of scientific events

5.2. Particular honours, prizes etc.

5.3. Information on results relevant to commercial applications

5.4. Other effects beyond the scientific field

See 2.3

5.5. Relevance of the project in the organization of the relevant scientific discipline

See 2.2

List 6. Applications for follow-up projects
with an indication of the status (submitted / approved) and the funding organization.

6.1 Applications for follow-up projects (FWF projects)
(with an indication of the project type, e.g. stand-alone project, NFN, SFB, WK, fellowship, contribution to a stand-alone publication)

6.2 Applications for follow-up projects (Other national projects)
(e. g. FFG, CD Laboratory, a K-plus Centre, funding from the Austrian National Bank, the Federal Government, the provincial government or similar)

6.3 Applications for follow-up projects (International projects)
(eg. ERA project, ESF)