Danish Polymer Centre DPC.DTU
Annual report 2003

KEY DEVELOPMENTS IN 2003

New organization

The Danish Polymer Centre (DPC) was created in October 1999 as a formal cooperation between Risø National Laboratory and the Technical University of Denmark (DTU). In connection with the creation of the DPC, first class polymer laboratories were established in Building 423 on the DTU campus. Equipped with state of the art instrumentation for polymer characterization, these laboratories provide a common ground for polymer chemists, polymer physicists, chemical engineers and mechanical engineers. The DPC was headed by Professor Klaus Bechgaard from Risø National Laboratory from January 2002 to September 2003.

In September a reorganization of the DPC construction was implemented. At the DTU, the Department of Chemical Engineering (KT) and the Department of Manufacturing Engineering and Management (IPL) created the DPC.DTU as a centre for polymer education and research. Located in the laboratories in building 423 at DTU, the DPC.DTU continues to provide a link between polymer activities at the DTU and Risø. Since its creation, the DPC.DTU has been headed by Professor Ole Hassager from KT at DTU.

International Master of Polymer Engineering and Science

In September 2003 the DTU created a two year M.Sc. program in polymer engineering and science for international students. The program is aimed at talented students who hold at least a Batchelor of Science degree in chemistry, chemical engineering, mechanical engineering or other relevant field.

A total of 7 active students are currently enrolled in the program, four of these with stipends provided by Danish industrial companies. The international students form an active group at the polymer centre. Measured in terms of student activity the polymer students are rated among the best within the 13 DTU international M.Sc. programs.

Graduate School of Polymer Science

Initiated ultimo 2003, the Graduate School of Polymer Science is a research education network between DPC.DTU, the Department of Chemistry at Aarhus University and Risø National Laboratory. Associated industrial companies include Coloplast A/S, Novo Nordisk A/S, NKT Research & Innovation A/S, and Elektro-Isola A/S. The school is supported by the Danish Research Training Council.
This school provides a logical framework for continuation of the joint activities of the Danish Polymer Centre initiated in 1999. Beginning 2004, the graduate school has 15 Ph.D. students, 3 of which are partly supported by the grant from the Danish Research Training Council.

STATUS DECEMBER 2003

Staff

In December 2003 the DPC.DTU included 10 scientific staff members, 2.6 technical staff and 9 Ph.D. students. This level is reduced compared to the situation that existed during the STVF-grant to the Danish Polymer Centre that ended in September 2003 . However, primarily due to the implementation of the Graduate School of Polymer Science, the total DPC.DTU staff is expected to increase in the years ahead. At the same time, the composition of the staff will reflect the strong emphasis on education of researchers inherent in the Graduate School.

	ult. 2001	ult. 2002	ult 2003	ult. 2004	ult.2005
Scientific staff					
DTU funded	8	8	7	6	7
Externally funded	4	4	3	2	1
Technical staff					
DTU funded	3.6	3.6	2.6	2.6	2.6
Externally funded	1	1			
Ph.D. Students	9	11	9	12	14
Total:	25.6	27.6	21.6	22.6	24.6

Table 1: DPC.DTU staff in December 2003 (ult. 2003). For comparison, numbers for 2001 and 2002 as well as estimates for are included

Research

In 2003 a total of 16 articles have been published in international journals with peer review. Also 6 reviewed conference proceedings and one book chapter have been published. The fields range broadly within polymer chemistry, polymer physics, polymer materials science and polymer processing. In order to relate the field of polymers to the Danish society, 4 articles have been prepared for publication in popular science related journals (in Danish) and accepted.

Two key stories that exemplify ongoing areas of research are included in this report. One story concerns the considerations involved in the replication of surface microstructures in injection moulding. Another story reports on new developments in the design, synthesis and characterization of nano-porous materials.

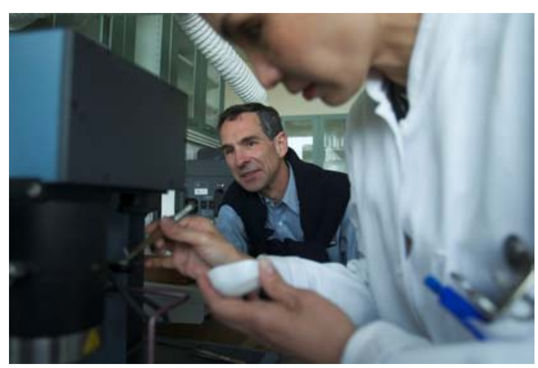

Figure 1: Laboratory technician Kim Chi Szabo preparing differential scanning calorimetry. (photo by Klaus Holsting).

Education

19 candidates have finished their education in 2003. These are distributed with 11 B.Sc. theses, 6 M.Sc. theses and 2 Pd.D. theses. An increase in especially M.Sc. theses is expected from 2005 due to the full implementation of the International Master of Polymer Engineering and Science program.

The courses are organized within the two departments as follows:

Department of Chemical Engineering:

- 28212 Polymer Chemisty (35)
- 28213 Polymer Technology (27)
- 28315 Colloid and Surface Science (35)
- 28414 Rheology (8)
- 28811 Polymers in Processes and Products (16)

Department of Manufacturing Engineering and Management

- 42230 Polymer Processing (20)
- 42232 Plastic design (11)
- 42234 Experimental plastic design (11)
- 42940 Form construction (5)
- 42946 Polymer extrusion (9)
- 42937 Experimental polymer processing (9)

The numbers in parentheses indicate the student participation (at exams).

Figure 2: Professor Martin E. Vigild in class room action. (photo by Klaus Holsting)

Editor

The report has been edited by Professor Ole Hassager, Department of Chemical Engineering, DTU.

Steering group

The activities in the DPC.DTU are administered by a steering group consisting of the two department heads.

Professor Kim Dam-Johansen, head Department of Chemical Engineering Technical University of Denmark Building 229 DK 2800 Kgs. Lyngby DENMARK	Professor Leo Alting, head Department of Manufacturing Engineering and Management, Building 424 Technical University of Denmark DK 2800 Kgs. Lyngby DENMARK

Replication of micro surface topography in injection moulding

Micro injection moulding and injection moulding with specific surface microstructures are novel and important research areas that have received substantial focus over the last decade. This interest is among other factors rooted in the emergence of new technologies for mould manufacturing and characterisation/visualisation of micro parts and features. However, injection moulding micro technology is in fact an issue that has been around for as long as the injection moulding process itself. The appearance of the surface is important for most plastic parts, and for some, the surface topography is a critical quality parameter. Surface topography has an important functional impact for products such as medical implants, and an aesthetical significance for many high-end consumer products like TV sets. Hence, the replication of a rough tool surface topography onto the plastic part surface can be regarded as micro technology with scope for analysis and optimisation. Conceptually this study of "random" microstructure replication is similar to the study of replication of specific surface microstructures, but a different approach to characterisation and analysis is appropriate.

A research project at The Technical University of Denmark, The Polymer Centre and Department of Manufacturing Engineering and Management investigate the mechanisms that determine the mould-to-part surface micro topography replication quality in injection moulding. A primary objective of the project is to understand how the choice of plastic material and the various injection moulding process parameters in concert affect replication. Such an understanding will provide the basis for optimisation of the surface topography of the injection-moulded components. The project also addresses specific metrological challenges pertinent to the injection moulding surface replication problem.

The main experimental work is based on mould surfaces manufactured with EDM (Electrical Discharge Machining) which is a process commonly found in the mould making industry. In EDM an electrical spark between an EDM tool and the work piece melts off droplets of material in the work piece surface, which are then flushed away. The process creates tool surfaces with varying degrees of roughness depending the roughness of the EDM tool itself and EDM process conditions. Injection-moulded plastic parts produced from moulds with EDM surfaces are widely found in such industries as medical devices, consumer electronics, and technical components.

In principle many techniques are available for 3D topographical surface characterisation; these include mechanical stylus characterisation, laser focus detection, scanning electron microscopy, confocal microscopy, interference microscopy, and atomic force microscopy. A comparative study in the context of rough plastic surfaces has been carried out for these instruments. The study pointed at the laser focus detection method as the most appropriate for the case and hand, exhibiting qualifying characteristics such as non-contact characterisation and large ranges both laterally and in the height dimension (figure 1).

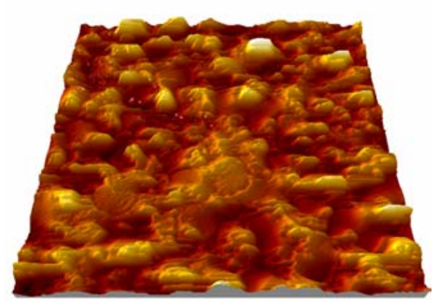

Figure 1: 3D topography image of PS part.
Sq = 4.3 µm; area: 1 x 1 mm

At the most rudimentary level the surface topography replication quality can be evaluated by applying established 3D topography parameters. Specifically, the ratio between a 3D topography parameter for an injection moulded plastic part surface and the corresponding parameter for the inverted surface of the mould can be used as an indicator of replication quality. Strictly speaking, given the nature of topography parameters, such a replication quality index may not actually describe replication in the sense of geometrical similarity very well. However, the wide industrial dispersion of the established 3D topography parameters in itself makes the "parameter transformation" from mould to plastic part and important scope of study.

Not surprisingly, it has been shown that replication quality depends on both plastic material and injection moulding process conditions. In general, the choice of plastic material can have a somewhat stronger effect on replication than process conditions – even at extreme points in the process window (figure 2, 3).

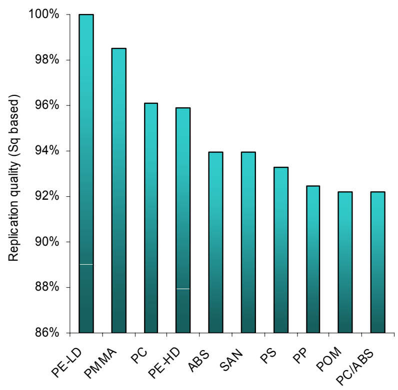

Figure 2: Replication quality for different materials (typical process conditions).

The practical implication of this is that given a certain plastic material, replication quality can only be controlled within a relatively tight range, while it may be possible to obtain larger changes by using a different plastic material. It has been found that the developed area ratio, *Sdr* most profoundly indicates changes in process conditions for a given plastic material. Between different materials, the density of summits, *Sds*, is the parameter that best captures topographical changes. For both process condition induced and material induced replication changes, the widely used RMS deviation, *Sq* reveals topographical changes with statistically significance.

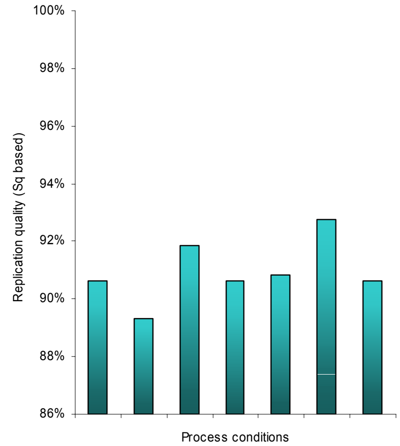

Figure 3: Replication quality for PP at different process conditions

Replication quality appears to be determined by a combined effect of material deformation in the surface and shrinkage. A complicating factor is that the topography itself also affects the shrinkage through a mould restraint mechanism at the micro level. The deeper analysis of process parameter effects on replication quality is assisted by the use of process simulation with commercial software. The simulation does not yield direct results on replication, but does provide important information on physical conditions like frozen layer build-up, that cannot practically be determined experimentally.

Currently the project focuses on more advanced measures of replication and on more extensive statistical analysis of the relationship between process parameters and replication quality.

Further information: Uffe Arlø Theilade

Nano-porous Materials Based on Polymer Self-assembly

Introduction

Microphase separated structures in block copolymers are very interesting in the light of nano-technological applications. Structural characteristics can be controlled via the chemical synthesis of the block copolymer molecules. In diblock copolymer systems the two chemically different constituents segregate into domains, where either one or the other block dominates the domian composition. These structures can be alternating lamellae for polymers with similar block volume fractions, or cylindrical or spherical domains of the minority blocks in a matrix of the majority blocks for asymmetrically composed polymers. Removing one domain of the diblock self-assembled structure will give a nano-porous material, which is a central first step towards future applications of this class of novel materials. Here we report on the quantitative etching of the polydimethylsiloxane block in a polystyrene-polydimethylsiloxane (PS-PDMS) block copolymer. The method is very accurate for analytical determination of the PDMS content in the samples. Several morphologies (templated from self-assembled diblock copolymer structures) can be conserved in the resulting glassy PS-matrix [1], as ascertained by small angle X-ray scattering. We report especially on films of milimeter thickness containing secluded spherical cavities of nano-meter diameter.

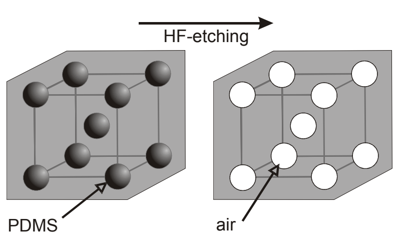

Figure1: Spherical cavities are created from the nano-phase separated structure of the block copolymer.

Making spherical cavities

The etching method is based on the removal of PDMS by the reaction with an excess of anhydrous hydrogen fluoride (HF). Please notice precautions [2]! The reaction scheme - illustrated in Figure 2 - works well for the etching of bulk samples. Percolation of the etched microphase to the outer surface is not required. Therefore this method permits - for the first time - to prepare bulk nanoporous polymers of secluded spherical voids. The use of anhydrous HF is known as an analytical tool for determining the composition of alkylsiloxanes, but it is not previously reported in the context of block copolymers. The reaction products as well as the excess HF were removed afterwards by applying vacuum overnight. Here we present the results of a non pre-oriented block copolymer, PS-PDMS-2, of mass fraction of PDMS $w_{PDMS} = 0.05$, number average molar mass $M_n = 40$ kg/mol, and polydispersity index PDI = 1.08.

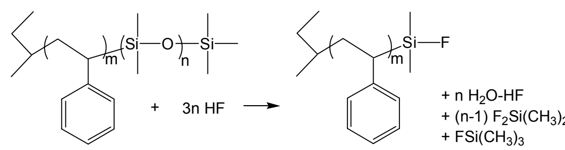

Figure 2: The expected reaction between PS-PDMS and HF.

Observing spherical cavities

Small Angel X-ray Scattering (SAXS) is a powerful technique to analyze for mesoscopic and nanoscopic structures [3]. It renders the symmetry of the sample, but also probes the whole bulk macroscopically. Figure 3 shows background corrected and normalized SAXS profiles for sample PS-PDMS-2 - before and after etching. In both cases the SAXS data gives undisputable evidence that the structure of the PS matrix remains in the HF etched sample. The scattering of the HF treated sample reproduces the features of the scattering from the original diblock, but it is intensified dramatically. A scattering intensity enhancement of about two orders of magnitude is expected from estimating the enhanced contrast factor between PS and air as compared to PS and PDMS. The spherical cavities in the etched sample are observed directly via

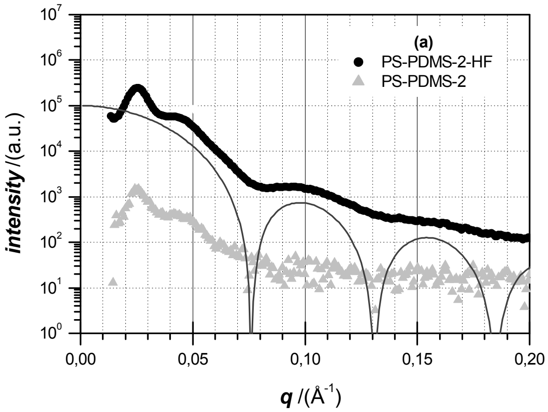

Figure 3: Scattering profiles before and after HF-etching, which are consistent with a morphology of spherical domains, as expected from the volume fraction. The full line is the spherical form factor.

Scanning Electron Microscopy (SEM), as illustrated in Figure 4. The SAXS and the SEM results are in agreement with respect to the cavity diameter of 12 nm, as recorded by the two techniques.

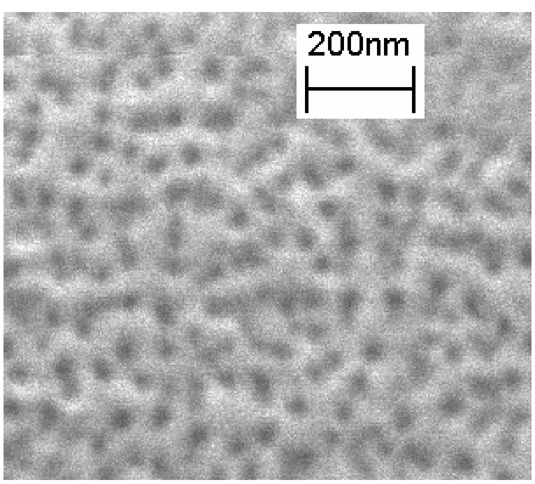

Figure 4: SEM micrograph of the nano-porous material, showing spherical cavities.

Conclusion

We have presented a new method for the preparation of porous nano-structures of polystyrene. The spherical cavities originate from domains of PDMS in self-organized PS-PDMS block copolymers. The morphology of PS is fully conserved after etching of PDMS, as ascertained by SAXS. The method is well suited for preparing samples of macroscopic dimensions; a 0.5 mm thick film of PS with secluded spherical voids was thus prepared for the first time. The method has potential to be applied to other materials containing alkylsiloxane moieties. A polydiene component would be highly desirable in many situations, because of the possibility to introduce functional groups by subsequent reactions on the double bonds. Preliminary experiments with polydiene-PDMS block copolymers are showing encouraging results.

Acknowledgement

We thank the Danish Technical Research Council (STVF) for supporting the Danish Polymer Centre. MEV thanks the Hempel Foundation for financial support. We acknowledge Martin M. Nielsen (Risø/POL, Denmark) for his help with the SAXS measurements. We thank Pia Wahlberg from Danish Technological Institute for helping with scanning electron microscopy (SEM) imaging.

References

[1] Ndoni, S., Vigild, M.E., Berg, R.H. *J Amer Chem Soc*, 125, 44, 13366-7 (2003)

[2] Anhydrous HF (b.p. 19°C) is an extremely toxic liquid. Inhalation of HF can cause serious injuries to the respiratory system and even death. Extreme care should always be exercised whenever it is handled.

[3] A rotating anode lab-source at Risø, was used with x-ray of λ = 1.54 Å.

Further information: Martin E. Vigild, (Department of Chemical Engineering, Danish Polymer Centre, DTU) and Sokol Ndoni and Rolf H Berg (Danish Polymer Centre, Risø)

PUBLICATIONS

Reviewed journal publications

Lars Poulsen, I. Zebger, Pentti Tofte, Markus Klinger, Ole Hassager, and Peter R. Ogilby: Oxygen Diffusion in Bilayer Polymer Films, Journal of Physical Chemistry B, 107, 13885-13891, 2003

Ingo Zebger, M. Rutloh, U. Hoffmann, J. Stumpe, Heinz W. Siesler, and Søren Hvilsted: Photoorientation of a Liquid-Crystalline Polyester with Azobenzene Side Groups: Effects of Irrradiation with Linearly Polarized Red Light after Photochemical Pretreatment, Macromolecules, 36, 9373-9382, 2003

Anne Ladegaard Larsen, Kim Hansen, Peter Sommer-Larsen, Ole Hassager, Anders Bach, Sokol Ndoni, and Mikkel Jørgensen:
Elastic properties of nonstoichiometric reacted PDMS networks, Macromolecules, 36 (26), 10063-10070, 2003

Sokol Ndoni, Martin E. Vigild, and Rolf H. Berg:
Nano-porous Material with Spherical or Gyroid Cavities Created by Quantitative Etching of Polydimethylsiloxane in Polystyrene-Polydimethylsiloxane Block Copolymers, Journal of the American Chemical Society, 125 (44), 13366-13367, 2003

L. Nedelchev, Avtar S. Matharu, Søren Hvilsted, and P. S. Ramanujam:
Photoinduced Anisotropy in a Family of Amorphous Azobenzene Polyesters for Optical Storage, Applied Optics, 42 (29), 5918-5927, 2003

Christian Müller, Kim Hansen, Peter Szabo, and Jens Nielsen:
Effect of deletion of chitin synthase genes on mycelial morphology and culture viscosity in Aspergillua oryzae, Biotechnology & Bioengineering, 81 (5), 525-534, 2003

Jørgen Lyngaae-Jørgensen and Leszek Utracki:
Structuring Blends with Bicontinuous Phase Morphology. Part II: Tailoring Blends with Ultralow Critical Volume Fraction, Polymer, 44 (5), 1661-1669, 2003

Anders Bach, Henrik Koblitz Rasmussen, and Ole Hassager:
Extensional viscosity for polymer melts measured in the filament stretching rheometer, Journal of Rheology, 47 (2), 429-441, 2003

Chengzhi Chuai, K. Almdal, and Jørgen Lyngaae-Jørgensen:
Phase Continuity and Phase Inversion in Polystyrene/Polymethylmetacrylate Blends, Polymer, 44 (2), 481-493, 2003

Katja Jankova and Søren Hvilsted:
Preparation of Poly(2,3,4,5,6-pentafluorostyrene) and Block Copolymers with Styrene by ATRP, Macromolecules, 36 1753-1758, 2003

Carlos Sánchez, Rafael Alcalá, Søren Hvilsted, and P.S. Ramanujam: Effect of Heat and Film Thickness on a Photo-induced Phase Transition in Azobenzene Liquid Crystalline Polyesters, Journal of Applied Physics, 93 (8), 4454-4460, 2003

Michael S. Hansen, Martin E. Vigild, Rolf H. Berg, and Sokol Ndoni:
Nanoporous Crosslinked Polyisoprene from Polyisoprene-Polydimethylsiloxane Block Copolymer, Polymer Bulletin, 2003

Anders Bach, K. Almdal, Henrik Koblitz Rasmussen, and Ole Hassager:
Elongational viscosity of narrow molar mass distribution polystyrene, Macromolecules, 36 (14), 5174-5179, 2003

Masaaki Sugiyama, M Annaka, K Hara, Martin E. Vigild, and George D. Wignall:
Small-Angle Scattering Study of Mesoscopic Structures in Charged Gels and Their Evolution on Dehydration, Journal of Physical Chemistry B, 107 (26), 6300-6308, 2003

Peter Szabo and Gareth H. McKinley:
Filament stretching rheometer: inertia compensation revisited, Rheologica Acta, 42 (3), 269-272, 2003

Jesper Neergaard, Ole Hassager, and Peter Szabo:
Molecular model for solubility of gases in flexible polymers, Journal of Polymer Science Part B - Polymer Physics, 41 (7), 701-706, 2003

Reviewed conference proceedings

Søren Hvilsted and P. S. Ramanujam:
Azobenzene Polyesters for Optical Information Storage and Other Optical Applications, 9th International Conference on Radiation Curing 2003, Yokohama, 21-24, 2003

Søren Hvilsted and Katja Jankova:
Novel Fluoropolymer Architectures Fuelled by Atom Transfer Radical Polymerization, 8th Pacific Polymer Conference 2003, 57, 2003

Ismaeil Ghasemi, Peter Szabo, and Henrik Koblitz Rasmussen:
Rheological Behaviour of polyethylene with peroxide crosslinking agent, Annual Transactions of the Nordic Rheology Society, 11 133-136, 2003

Katja Jankova, Patric Jannasch, and Søren Hvilsted: Ion Conducting Solid Polymer Electrolytes Based on Polypentafluorostyrene-b-poly(ethylene oxide-co-propylene oxide)-b-polypentafluorostyrene) Prepared by ATRP, Europolymer Congress 2003, Stockholm, 2003

Søren Hvilsted and Katja Jankova:
Novel Fluorine Polymer Architectures by ATRP, Europolymer Congress 2003, Stockholm, 2003

Søren Hvilsted, Sachin Borkar, and Katja Jankova:
Design of Novel Materials with Varying Fluorine Content Through Polymer Engineering, 16th Winter Fluorine Conference 2003, 16, 2003

Chapters in books

Søren Hvilsted, Sachin Borkar, Heinz W. Siesler, and Katja Jankova: Novel Fluorinated Polymer Materials Based on 2,3,5,6-Tetrafluoro-4-methoxystyrene.
In: *ACS Symposium Series* **854***: "Advances in Controlled/Living Radical Polymerization",* K. Matyjaszewski (Ed.), American

Chemical Society, Washington, DC, 2003. Chapter 17, 236-249.

Other publications

Martin E. Vigild, Rüya Eskimergen, and Kell Mortensen: Polymerer under lyset, Dansk Kemi, 107 (26), 35-37, 2003

Søren Hvilsted: Kontrolleret Fri Radikal Polymerisation - En Verden af Muligheder, Dansk Kemi, 84 (3), 38-39, 2003

Ole Hassager: Vi trækker tråde af polymerer, Dansk Kemi, 2003

Kim Lefmann, Lise Arleth, Martin E. Vigild, Kell Mortensen, and Bente Lebech: ESS: Nyt kæmpe forskningscenter til Øresundsregionen?, Naturens Verden, 86 (1), 2003

Melania Bednarek, Katja Jankova, and Søren Hvilsted: Star Polymers of Styrene and Acrylates by ATRP, Proc. Nordic Polymer Days 2003, 2003.

Sachin Borkar, Katja Jankova, Heinz W. Siesler, and Søren Hvilsted: Novel Polymeric Low Surface Energy Materials Based on Highly Fluorinated Monomers, 39th IUPAC Congress 2003, Ottawa, 2003.

Katja Jankova and Søren Hvilsted: Novel Block Copolymer Architectures Containing Pentafluorostyrene Prepared by ATRP, Proc. Nordic Polymer Days 2003, 2003.

Carina Koch Johannson, Afshin Ghanbari-Siahkali, Søren Hvilsted, and K. Almdal: Characterization of Chemical Degradation of Commercial Grade Polymers, Proc. Nordic Polymer Days 2003, 2003.

Katja Jankova, Sachin Borkar, Heinz W. Siesler, and Søren Hvilsted: Novel Polymeric Low Surface Energy Materials Based on Highly Fluorinated Monomers. Proc. Nordic Polymer Days 2003, 2003.

Susanta Mitra, K. Almdal, and Søren Hvilsted: Chemical Degradation of Cross-Linked EPDM in an Acidic Environment, Proc. Nordic Polymer Days 2003, 2003.

Anne Kathrine Kattenhøj Overgaard, Hanne Everland, Jacob Vange, and Søren Hvilsted: Synthesis of Biodegradable PLGA Polymers Initiated by Hydrophilic Macro Initiators, Proc. Nordic Polymer Days 2003, 2003.

Charlotte Juel Nielsen, Kristoffer Hansen, and Søren Hvilsted: Synthesis of a Variety of Low Molecular Weight Block Copolymers and Their Applications as Plasticizers for Polystyrene, Proc. Nordic Polymer Days 2003, 2003.

EDUCATION

B.Sc. theses

Modesto Javier Mora Benito, Needlefree sample Port for medical Devices, (2003) Advisor: Torben Lindemark

Jørn Lilleaas, Sammenføjning af plastemner med diodelaser, (2003) Advisor: Torben Lindemark

Laila Jensen, A Comparison between the surface of catheters and its processing, (2003) Advisor: Torben Lindemark

Frederik Daniel Hjort, Lægetaske, udvikling og konstruktion af, (2003) Advisor: Torben Lindemark

Morten Murmann, Insoucing af komponenter hos GN ReSound, (2003) Advisor: Torben Lindemark

Claus Würfel, Insoucing af komponenter hos GN ReSound, (2003) Advisor: Torben Lindemark

Nicolas Kiener Jensen, Produktudvikling af forflytningshjælpemiddel, (2003) Advisor: Torben Lindemark

Omid R Hosseinian, Anti vakuum projekt, (2003) Advisor: Torben Lindemark

Himmawan Arianto, Udvikling af ITE høreapparat, (2003) Advisor: Torben Lindemark

Sivert Øvretveit, Udvikling af ITE høreapparat, (2003) Advisor: Torben Lindemark

Kasper H Kristiansen, Udvikling af øreprop til Canta 760, (2003) Advisor: Torben Lindemark

Julie Öblom Poulsen:
Karakterisering af polymerer med snæver molvægtsfordeling, (2003). Advisor: Ole Hassager in collaboration with Sokol Ndoni, Risø National Laboratory.

M.Sc. theses

Anne Kathrine Kattenhøj Overgaard:
Preparation and Functionalization of PLGA-PEG Block Copolymers, (2003)
Advisor: Søren Hvilsted in collaboration with Coloplast Research A/S.

Mia Vengel Nielsen:
Glukosebiosensorer baseret på ledende polymerer, (2003) Advisors:
Ole Hassager and Keld West, Risø National Laboratory.

Charlotte Juel Nielsen:
Switcable Plasticizers, (2003) Advisor: Søren Hvilsted in collaboration with Coloplast Research A/S.

Signe Lagoni:
Optimerede acrylatgummier og præpolymerer ved styring af polymerisations kinetik, (2003). Advisor: Søren Hvilsted.

Michael Lei:
Syntese og opløsningsegenskaber af blokcopolymerer fremstillet ved atom transfer radikal polymerisation, (2003). Advisor: Jørgen Kops.

Ph. D. Theses:

Chengzhi Chuai:
Structure and Properties of Polymer Blends, Department of Chemical Engineering, DTU (2003)

Anders Bach:
Elongational viscosity for polymer melts, Department of Chemical Engineering, DTU (2003)

Holger Spanggaard:
A mechanical strain sensor for polymeric materials and photochemical investigations of large molecules, Department of Chemical Engineering, DTU (2003)