Synthesis Report

Contract n^o: BRPR-CT97-0588
Project n^o: BE97-4371

Title: Fundamental Physical Chemistry of Ultraprecision Silicon Etching to Nanometer Dimensions (FUPUSET)

Reference Period: from 1.2.98 to 30.4.01

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1. Summary

Keywords: Silicon etching; Si(100); micro-machining; KOH; MEMS

The development of the FUPUSET project has proved successful in having achieved one of the main goals, i.e. **improved surface finish of micro machined components**. A novel process step has been developed which reduces the surface roughness without deteriorating the anisotropic ratio during etching. Several **methods to suppress the formation of pyramids** without reducing the etch rate of Si(100) have been developed. This can be realised by addition of oxidants to the etching solution (OCl^- seems to be ideally suited) or by controlling the electrochemical potential. It has been shown that the OCP of the KOH/Si(100) interface can be controlled when a **galvanic cell** is formed and hence pyramid formation can be suppressed during the etching of micro-machined components even without the use of an external electrical circuit.

Advances also have been made concerning the **improvement of anisotropic ratios**. It has been shown that the Si(100)/Si(111) junction in micro-machined components acts as a local electrochemical cell in which the anisotropic ratio is determined by the relative surface area of the different crystallographic orientations. These findings are a key to improve existing design rules in order to achieve the desired anisotropic ratios. For the case of p-silicon it was demonstrated, that the anisotropic ratio between Si(100) and Si(111) can be improved by the appropriate choice of the electrochemical potential during etching. Under industrial conditions, reliable and improved anisotropic ratios have been evaluated with the use of solution agitation, lower concentration solutions and the use of suitable tank materials.

A systematic study of surface finish and anisotropic ratios under industrial conditions has shown that the quality of the KOH and the water, used for anisotropic etching, influences the etching process significantly. However, it turned out that surface finish and anisotropic ratio of etched silicon are inversely related. That is to say the surface finish deteriorates when the anisotropic ratios are improving. For that reason a **compromise between anisotropic ratios and surface finish**, which can be tailored to the specific needs of the product, has to be tolerated during the anisotropic etching process. However, it has been shown that defects (micro-pyramids), which are formed to some degree under strongly anisotropic conditions, can be removed in the presence of oxidants at the end of the etch and hence the surface finish can be improved without the loss of the anisotropy during the etching process.

An in depth understanding of the **etching mechanism** has been gained from several *in-situ* methods, which were applied to the Si(100)/etchant interface (FTIR- and impedance-spectroscopy, transistor techniques, photo-luminescence ….). A surface state intermediate with an energy level high in the band gap is formed during etching. For both, p- and n-Si(100), the injection of electrons from this etching intermediate into the conduction band is the main source of the electrochemical current. Isotope exchange experiments have shown, that the rate-determining step in both, the chemical- and the electrochemical etching mechanism involves the breakage of an Si-H bond.

Video microscopy studies have demonstrated, that the **adhesion of hydrogen bubbles, which are formed during the etching process, is responsible for the formation of defects on Si(100)**.The bubble adhesion and hence the defect formation is extremely reduced at anodic potentials and at high KOH concentrations. This was explained by FTIR results, which have shown, that the hydrogen coverage of the Si(100) surface is reduced with increasing electrode potential and hence the surface is getting more hydrophilic at anodic potentials.

2. The Consortium

UNIVERSITY OF LIVERPOOL

The University of Liverpool is a major UK University, with over 10,000 students. The Department of Chemistry has 28 members of staff and a large research school, of over 200 researchers between research staff and research students. The Department has well established groups in Organic Synthetic Chemistry, Catalysis, Surface Science, Computational Chemistry and Electrochemistry. The electrochemistry group has at its disposal all modern instrumental techniques for electrochemical research, such as ellipsometry, FTIR and UV-vis modulated reflectance spectroscopies, AC Impedance spectroscopy, *in situ* electrochemical STM and AFM, and photocurrent spectroscopy. There are four academic members of staff with research interests in electrochemistry covering organic and inorganic electrochemistry, advanced surface probe microscopies, conducting polymers, nanostructured materials, electrocatalysis, liquid-liquid electrochemistry, corrosion, sensors, spectroelectrochemistry and silicon micromachining. Most of the work on Si etching has been carried out in collaboration with industry.

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UNIVERSITY OF LIMERICK

During the course of the project the Advanced Sensors Research Unit and the Electrochemistry Research Group of Dr. Vincent J Cunnane has become part of a larger institute at the University of Limerick. This institute is known as the Materials and Surface Science Institute (MSSI). The institute was formed in early 1998 to act as a focus for research in selected areas. The mission of the Materials and Surface Science Institute is to provide a world-class centre of excellence generating state-of-the-art fundamental research on topics of industrial significance in the fields of surface science and materials. The fundamental aims of the Institute are:

- The training of postgraduate and postdoctoral researchers
- The generation of high quality publications in basic and applied research
- The provision of world-class facilities in a small number of specialisms
- The generation of quality intellectual proprietary information of value to the Institute and to industrial collaborators

- The provision of significantly improved opportunities for research collaboration
- The provision of specialised training services in advanced topics within the core competence of the Institute
- To enable individual research groupings, now gathered within the Materials and Surface Science Institute, to be more competitive for contract research

The Materials and Surface Science Institute was established in 1998 by gathering together various research centres into a single large institute. It has received over 15 million euros in national funding since then to establish itself as a world class centre of research. The core competencies of the Materials and Surface Science Institute are based in four research themes:

Catalysis
Structural materials
Active materials
Interfacial science

Dr. Cunnane is the theme leader for 'interfacial science'. Dr. Cunnane is also leader of the Electrochemistry Research Group working on fundamental and applied aspects of electrochemistry. He started his career in electrochemistry as Works Chemist for a company engaged in the manufacture of printed circuit boards. As such he has some 16 years experience in the field. In 1990 Dr. Cunnane moved to the position as lecturer in Physical Chemistry at the University of Limerick (senior lecturer position since 1998). Presently there are 8 postgraduate students and 2 post-doctoral researchers in the Group.

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UNIVERSITY OF ST. ANDREWS

The University of St. Andrews was founded in 1411 and is the oldest in Scotland. Currently over 5000 students are enrolled at the University, of whom 600 are postgraduates. Chemical research has a long and distinguished history at St. Andrews. Nobel prize winners Sir Robert Robinson and Sir Norman Howarth spent some of their most important years at St. Andrews and, recently, four named prizes of the Royal Society of Chemistry were awarded to current members of the School as well as the ICI Research Award for contributions to Organic Chemistry.

In 1998, Prof. N.V. Richardson moved to St. Andrews to strengthen research in surface chemistry, in particular on the chemical and physical properties of organic compounds on metal and semiconductor (silicon) surfaces. The Surface Chemistry group is equipped with a wide range of state-of-the-art surface analytical instruments, such as X-ray photoelectron spectroscopy (XPS, ESCA), high resolution electron energy loss spectroscopy (HREELS) scanning tunnelling spectroscopy (STM), atomic force microscopy (AFM) and infra-red spectroscopy (FTIR). Current interdisciplinary research projects include the physics and chemistry of photonic materials, in which physics and chemistry departments of several universities in the U.K. participate.

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UNIVERSITY OF UTRECHT

The Department is a member of the Debye Institute of Utrecht University. In this Institute groups from the Faculties of Chemistry and of Physics and Astronomy participate in research in a broad field of materials science.

The Department has two main responsibilities

(i) **Research**. Here the emphasis is on solid state spectroscopy and the surface chemistry and electrochemistry of single crystal, porous and quantized semiconductors.
(ii) **Teaching**. Staff members are strongly involved in both undergraduate and postgraduate teaching (solid state chemistry, electrochemistry, spectroscopy).

The contribution of the Department to the present project centred mainly on using the facilities and expertise available in Utrecht in the field of semiconductor electrochemistry to (a) gain a better understanding of the mechanisms of anisotropic etching of Si; (b) to develop etchants and systems for practical applications. The main part of the research was carried out by Dr. Xinghua Xia.

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DRUCK PLC

Druck Ltd is the UK establishment of Druck Holdings PLC within premises at Groby in Leicestershire. The company is a major manufacturer of Aerospace and Industrial pressure sensors, and related pressure control and calibration equipment. Pressure measurement is based on silicon micro-machined pressure sensor elements manufactured at Druck Ltd. These elements all employ anisotrpoic wet etching techniques of the kind investigated by this project.
Druck Ltd employs around 600 people and has a turn-over in excess of 50M ecu.

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SIEMENS AG

Siemens is among the largest European manufacturers of electronic and electric equipment and components. Extensive efforts are invested in research and development in order to preserve this leading position. In addition to the development of new products Siemens has always put a strong emphasis on the development of advanced new production technologies which are then not only implemented in its own production lines but are also made available to other users through licence or joint ventures. Strong efforts have been concentrated for several years on the development of advanced communication equipment for use in long haul transmission, switching and dialling. Through long term internal development activities Siemens tries to anticipate the needs for future information technologies based on all optical data transmission with data rates in excess of 10 GBit/sec. A key role for this technology is the ability to fabricate optical components at low cost with up to now unparalleled fabrication accuracy. In contrast to components for copper- or radio-based systems fibre chip coupling requires sub-micron positioning accuracy which can be reached by ultra-precision silicon 3D structurization. For this purpose Siemens has great interest to improve Si micromachining towards a standard fabrication technology to a state of extremely high reproducibility and precision. Within the company there is no capacity and know-how such as that there will be available in the proposed consortium for understanding the mechanistic aspects of anisotropic etching. The company foresees that there will be exacting production requirements that the proposed work will fulfil.

The main efforts of Siemens towards ultra-precision micromachining are dedicated towards the next generation of micromachined optical and fluid devices. They will be produced by micromachining and related technologies (such as galvanoplastic replication of silicon) and submicron accuracy will be required. With the results of the project cost can be reduced and real low cost devices (but with nevertheless highest accuracy) can be envisaged to increase the volume of devices dramatically up to numbers which can be fabricated profitable. This is the (only) way to serve applications and niches with large leverage or strategic importance but low volume production, which normally can participate only as ‘free-riders’ at other product lines. To these fields belong almost all activities for medical applications (anaesthesia, even future hearing aids) or industrial measuring equipment (gas chromatography and environmental/car exhaust monitoring).

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3. Technical achievements

Introduction:

Anisotropic etching of Silicon is a ubiquitous process in silicon micro-machining. Complex micro-systems can be generated using the anisotropic properties of single crystals in an orientation dependant dissolution reaction. V-groove structures for example, useful for the passive alignment of opto-electronic devices, are easily fabricated using anisotropic etchants like KOH or tetra methyl ammonium hydroxide. Modern exacting demands in this rapidly growing industry require methods to produce structures with well-defined anisortopic ratio and an excellent surface finish.

Objectives of the FUPUSET project:

- To achieve a fundamental physico-chemical understanding of the kinetics and the mechanism of chemical and electrochemical dissolution of silicon in aqueous KOH by investigating the elementary steps of the dissolution reaction
- To understand the mechanism of the formation of micro pyramids often observed during the etching of micro-machined components and to eliminate these defects reproducibly.
- To investigate surface redox reactions, especially with a view to identify etching intermediates and to find an oxidising agent, which leads to a good surface finish.
- To investigate the influence of chemical and electrochemical factors on both the surface finish and the anisotropic ratios.

The strategy to achieve the above objectives was to investigate the correlation of surface morphology and etch rates with surface termination and band structure for different crystal orientations using *in-situ* techniques like SPM, AC impedance, IR and photocurrent spectroscopy. Another major strategic aspect was to establish a link between results obtained under UHV conditions (EELS, XPS, NEXAFS) with experiments in the condensed phase.

Main deliverables:

Anisotropic Ratios:

Advances have been made concerning the improvement of anisotropic ratios:

It has been shown that the Si(100)/Si(111) junction in micro-machined components acts as a local electrochemical cell in which the anisotropic ratio is determined by the relative surface area of the different crystallographic orientations, that is to say (111) planes are protected by neighbouring (100) planes. These findings are a key to improve existing design rules in order to achieve the desired anisotropic ratios up to values above 200:1 between the Si(100) and the Si(111) surface.

For the case of p-silicon it is proposed that the anisotropic ratio between Si(100) and Si(111) can be improved by the appropriate choice of the electrochemical potential during etching. This proposal results from etch rate measurements of Si(100) and Si(111) in dependence of the electrochemical potential.

Reliable and improved anisotropic ratios have been obtained under production conditions with the use of solution agitation, lower concentration etch solutions and the use of suitable tank materials.

Surface redox reactions:
The aim of this part of the work was to study the chemistry of redox couples at Si (100) surfaces in order to gain insight into the etching mechanism. Three oxidizing agents were used: CrO_4^{2-}, MnO_4^- and OCl^-. Despite the fact that MnO_4^- and OCl^- are strong oxidizing agents, they are not reduced cathodically at p-type Si, i.e. they do not inject holes into the valence band. Instead, all three oxidizing agents undergo reduction via a chemical reaction at the etching semiconductor both at open circuit and at more negative potentials. This result suggests that an intermediate of the etching reaction is responsible for reducing the oxyanions. Since the acceptor levels of the CrO_4^{2-} system are well above the valence band edge of Si the surface state intermediate must have an energy level rather high in the band-gap. In addition, the potential dependence of the chemical etch rate of Si was studied for a range of KOH concentrations and temperatures.

Flatness:
The three oxidizing agents, CrO_4^{2-}, MnO_4^- and OCl^- prevent pyramid formation during anisotropic chemical etching of Si. MnO_4^- cannot be used at higher concentration since it suppresses etching. CrO_4^{2-} and OCl^- do not influence the etch rate. Improved flatness and pyramid free surfaces have been achieved with the use of additives and increased solution strength under industrial conditions.

Transistor technique:
The observation of a large anodic current from n-type Si in KOH solution can only be explained by electron injection. Using a p/n junction electrode we showed that electron injection also occurs at p-type Si. The injecting species is very likely an intermediate of the chemical etching reaction. This part of the work was carried out in collaboration with the DIMES Institute of the Technical University of Delft.

Silicon dissolution kinetics:
The results from the tasks on photoluminescece, surface redox-reactions, flatness and transistor techniques allowed us to develop a model to describe redox reactions and chemical etching. The model, which involves a strong coupling of chemical and electrochemical steps via a surface-state intermediate of chemical etching, accounts for some unusual features of the system such as (a) a mechanisms for anodic oxidation and passivation based on electron injection and (b) the strong influence of a weak oxidizing agent on the surface morphology of chemically etched silicon.

New information about the activation energies for the chemical and electrochemical dissolution process was gained from studies of the temperature dependence of the electrochemical dissolution current and of the chemical etch rate. The results have shown that the chemical and the electrochemical dissolution of Si(100) in KOH and TMAH have very similar activation energies of about 0.5 - 0.6 eV and hence a similar etching intermediate for both types of reaction is likely. The temperature dependence of the electrochemical dissolution current of Si(100) in KOD/D_2O solutions has shown, that the rate determining step of the electrochemical etching mechanism involves the breakage of an Si-H bond. For the chemical dissolution, the rate-determining step also involves the breakage of on Si-H bond as earlier experiments have shown.

Metal ion impurities:

The influence of metal ion impurities, such as $Cu^{2+,}$ Fe^{3+}, Sn^{2+} and $Hg_2{}^{2+}$, on the surface finish has been investigated for several concentrations in the ppm and ppb region. Mercury and Copper have the most pronounced effect on the surface roughness and deteriorate the surface finish markedly already at a concentrations in the ppb range. Consistently KOH produced in an amalgam process increased the roughness of micro-machined components and should not be used for industrial applications.

Time domain capacitance measurements

A very fast experimental set-up for time domain capacitance measurements has been developed in Liverpool University. This set-up is being used for further measurement at the solution/semiconductor interface.

Defect formation on Si(100) during anisotropic etching:

Video microscopy studies have clearly demonstrated, that the formation of defects (micro-pyramids) is closely related to the adhesion of hydrogen bubbles, which are formed on the surface during etching. Micro-pyramids are observed only, when hydrogen bubbles are adhering to the surface and hence defects are formed at the boundary between liquid, solid and gas. On the other hand a very good surface finish can be achieved when the bubble adhesion is reduced.

Wafer pre-treatment:

Wafer pre-treatment with HF or buffered HF deteriorates the surface finish when the wafers are etched directly after the HF dip since the hydrophobic nature of the hydrogen terminated surface increases the adhesion of hydrogen bubbles and defects may be formed during the initial etching due to the presence of slow etching SiH_2 species. Prolonged rinsing after the HF dip improves this situation. Ideally, a plasma-oxidation should be performed after the HF dip to ensure a hydrophilic surface termination at the initial stages of etching.

The influence of the etchant concentration potential and temperature on the surface finish:

At low concentrations of KOH or TMAH (< 3 Mol per liter) at the OCP, excessive defect formation was observed during the etching process which can be rationalised by the observation that the adhesion of hydrogen-bubbles is increasing with decreasing concentration of the etchant. "Ideal" conditions for V-Groove etching are 6 M KOH at 80 °C. However, for some structures, the use of lower KOH concentrations seems to be advantageous to achieve a better etching selectivity between specific surface planes. Generally the surface finish improved when etching was performed at potentials anodic of the OCP, whereas the anisotropic ratio deteriorated due to an increased etchrate of the Si(111) surface plane at anodic potentials.

Potential dependence of the surface termination:

In-situ-FTIR, AC impedance and contact angle measurements have been used to determine the potential dependence of the surface termination of Si(100) under etching conditions. It has been demonstrated that hydrogen is removed successively from the Si-surface with increasing electrode potential and a concomitant change of the surface potential at the Si/KOH interface was observed with time domain AC impedance measurements. These results are of importance to explain the potential dependent surface finish as a result of the surface termination.

Photoluminescence (PL):

(i) *in-situ* PL measurements: PL measurements show that intermediates formed during chemical etching can quench radiative recombination in Si. This effect is reduced in the potential range between current onset and the peak current, as a result of the change in surface chemistry.

(ii) PL experiments under UHV conditions: The photoluminescence (PL) technique is the preferred method for the *in situ* and *time resolved* study of the evolution of electronic defects at silicon surfaces. In order to enable PL measurements at silicon surfaces under UHV conditions, a novel laser based system has been developed. The optical system comprises a nitrogen laser, monochromator, focussing units and detectors for time-resolved and time-integrated PL measurements. Due to UHV requirements, the detection units are placed outside the vacuum system. In order to increase the optical stability, all pumping units are mechanically decoupled from the vacuum system.

New additives and potential control

The oxidizing agents CrO_4^{2-}, MnO_4^- and OCl^- have a very favourable effect on surface roughness during open-circuit etching. This effect is similar to that of an applied positive potential.

Sample transfer facility

Electron spectroscopic analytical techniques, such as XPS and HREELS are excellent techniques to determine the chemical and physical properties of surfaces. However, the surface sensitivity of these techniques requires that the surface contamination of the samples, particularly with organic materials, is kept as low as possible. Therefore, a sample transfer system compromising a glove box, fast entry lock chamber and sample carriers has been developed, which enables the transfer of etched samples from the solution into UHV without contact to ambient air. Special attention has been focussed on the design of glass vessels and handling procedures, in order to possible up-take of contaminants during the etching process. The new transfer system has been successfully employed to investigate organic adsorption on Si surfaces.

Bath Control:

(i) Monitoring of production tanks have shown that increased solution usage has a detrimental effect on the anisotropy of the etch solution. Also tank construction and solution agitation as part of the etching process have an effect on the control of the etching parameters.

(ii) The quality of different types of KOH used for micromachining applications has been investigated. Surface roughness and anisotropic ratios were monitored systematically on the industrial scale for several years, using different types of KOH from different manufacturers. The best results were achieved with KOH from Riedel de Haen. The quality of the water used was shown to have a pronounced influence on the etching process too and hence even minute contamination with organic materials should be avoided.

(iii) Different types of etch tank materials (pyrex; stainless steel; teflon) and solution agitation (ultrasound; rotation; gas bubbling) have been investigated in industrial trials by Druck. It was found that solution agitation, especially ultrasound, has a benefital influence on the surface finish and under certain circumstances on the anisotropic ratios.

4. Exploitation Plans and follow-up actions

a.) Siemens AG

The main outcomes of project FUPUSET transferred into the fabrication of V-groove-arrays resulting in an improvement of V-groove precision, are design rules, a novel process step (which is will be protected by a patent) and other results such as KOH and water quality will be used in the future; the application of these results require major changes of fabrication procedures and require qualification with the customers and these procedures are under way.

b.) Druck Ltd

- The project's investigations have indicated some of the compromises between surface quality and anisotropic etch ratios. Industrial quantity wafer batches have been etched in new etch solutions to quantify the exact effects on real designs.

- Experimental etch tanks have been used with and without the application of ultrasonic agitation. These tests indicate that a higher wafer throughput than our existing etch tanks is possible.

Druck is continuing to investigate anisotropic etching and will be selecting techniques appropriate to the companies exact structures and techniques and will be exploiting the techniques to generally reduce scrap and help to increase our wafer throughput.

In particular we will be employing:

- Increased throughput in etch tanks, moving to larger batch sizes.
- Reduced pyramid formation, and improved yields
- Generally improved surface finish

c.) University of Utrecht

i. Bath additives for improved surface finish

One of the important aims of the project was to develop etchants for Si(100) giving a very smooth surface finish while maintaining a strong anisotropy. Of the wide range of oxidizing agents studied as additives, hypochlorite (OCl^-) is the most attractive for practical etching. Like the other systems it suppresses pyramid formation. It is stable and can be used at high concentration, thus avoiding problems of depletion. Its decomposition products (OH^- and Cl^-) are both environmentally acceptable and do not interfere with the etching of (100) Si. Oxidizing agents may disimprove the anisotropic etching ratio. When this ratio is important, Si can be etched in KOH solution and given a brief post-etch treatment in KOH/OCl^- solution to smoothen the surface. Our results have shown that removal of pyramids by the oxidizing agent is very fast.

ii. Galvanic cells for micro-electro-mechanical systems (MEMS)

An important spin-off was the development in collaboration with DIMES of a technology involving the use of galvanic cells for microelectromechanical systems (MEMS). There are two fields of interest.

(a) The control of surface morphology. When a noble metal is in electrical contact with a semiconductor (e.g. on the wafer) in a solution containing a suitable oxidizing agent, a galvanic cell is formed. The system establishes a mixed potential at which the rate of silicon oxidation is equal to the rate of reduction of the oxidising agent at the metal electrode; a galvanic current flows between the two "electrodes". The mixed potential determines the nature of the oxidation process. By choosing the solution and a suitable oxidising agent we can control the surface morphology without an external source. For example, microporous or macroporous layers can be formed in HF solution or pyramid formation can be suppressed in alkaline solution.

(b) An etch-stop mechanism with a p/n junction. In this case the thin n-type epilayer of the junction is metallized (with Au, for example). Unlike case (a) no galvanic current can flow since the p/n junction is reverse-biased. The p-type substrate dissolves in the alkaline etchant. The galvanic cell is "switched on" as the etched surface reaches the p/n junction. The n-type Si layer is passivated and etching stops. In this way thin n-type beams and membranes can be produced. The success of these galvanic cells depends on the electrochemistry of the system, in particular on the choice of the oxidizing agent and its reduction kinetics at the metal. This open-circuit method has considerable advantages compared to the conventional electrochemical etch stop. In the latter the Si wafer with its fragile structures has to be clamped into an electrode holder (with the risk of stress and damage) and connected to a counter electrode via an external voltage source. Such an approach is not readily compatible with batch fabrication. The galvanic approach avoids these difficulties.

The Utrecht group has contacts with Philips Research in Eindhoven. The aim is to develop the galvanic cell approach for producing macroporous silicon for integrated capacitor and other applications. The present photoelectrochemical technology is very cumbersome, requiring external contacts and illumination of the wafers to obtain macropores. The possibilities of the galvanic approach are currently being investigated. It is hoped to get support from the Dutch funding agency for technical research (STW) for this collaboration.

d. University of St. Anderews

Photoluminescence system:

The novel PL analytical system, which has been successfully employed for the *in situ* study of surface defects on silicon surfaces inside ultra high vacuum chambers, has been developed at St. Andrews University, U.K. in collaboration with Technische Universität München, Gemany. Further joined investigations on the oxidation of crystalline and meso-porous silicon have been already scheduled for 2001.

In order to model the chemisorption of organic molecules on silicon surfaces, a collaboration between St. Andrews University, U.K. and University College London, U.K. has been established. In January and February 2001, the adsorption of maleic anhydride on Si(100)-2x1 is being calculated with *ab-initio* methods. It is planned to extend the simulation to other organic compounds on Si(100)-2x1.

d.) University of Liverpool

After patent protection of a novel process step for improved surface finish of micro machined components, it is planned to optimise the procedure in collaboration with Siemens and to run further trials under industrial conditions. After this trial period, new partners from industry can be contacted to market the patent on a wider scale.

The expertise in micro-machining that the University of Liverpool gained from the FUPUSET project is also important to start follow-up projects. Collaboration with the University of Southampton, the Siemens AG, the Hahn-Meitner-Institut in Berlin and other partners has been initiated and it is planned to transfer the knowledge from the FUPUSET project to the fabrication of micromachined components for bio-technological applications.

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