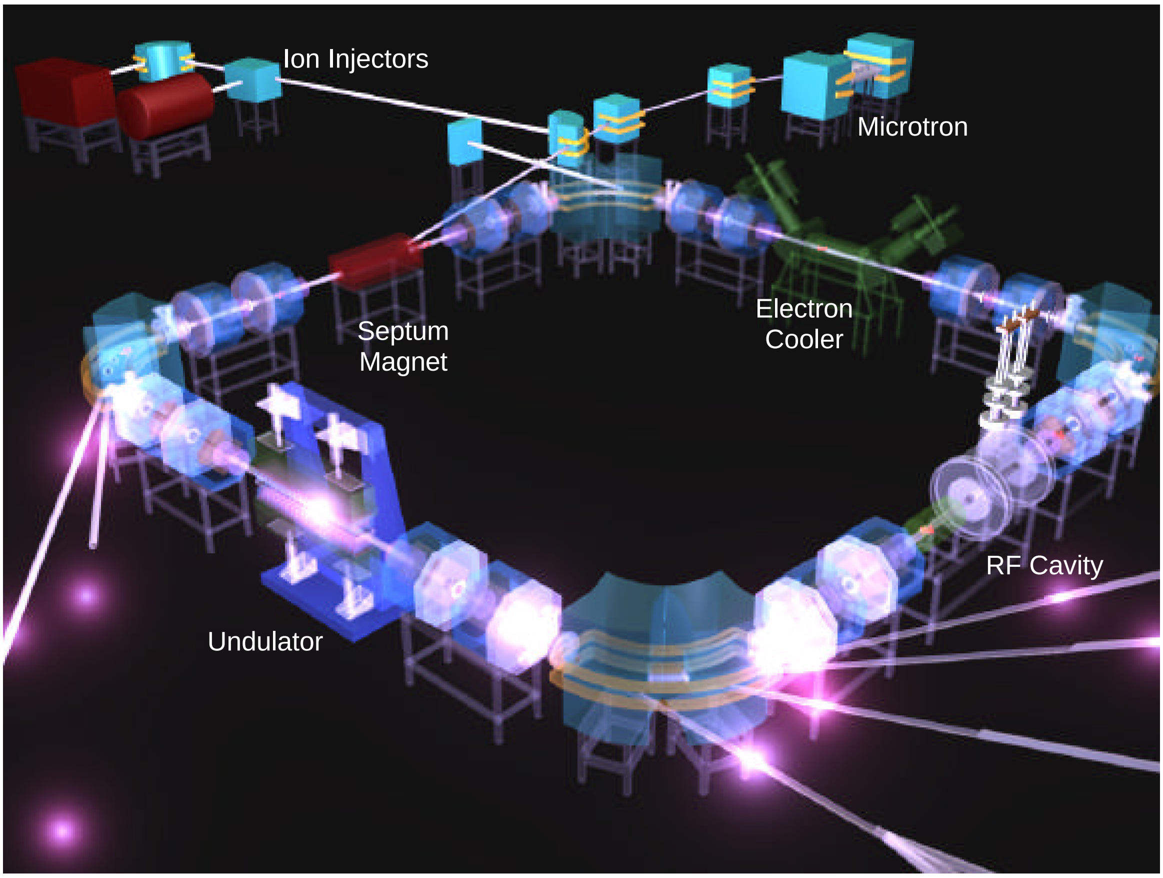
Institute for
Storage Ring Facilities
University of Aarhus

Newsletter No. 9, March 2005

The figure to the right is from an animation of ASTRID which was made in 2004.
At the top of the figure you can see the electron microtron to the right and the ion injectors to the left.
The ring is depicted in electron storage mode, showing synchrotron radiation being generated in the dipole magnets in the corners and in the undulator in the lower left straight section of the ring.
The lower right straight section shows the RF-cavity, the upper right the electron cooler while the upper left section houses the septum magnet.
The entire animation may be viewed or downloaded by following the link on our home page, www.isa.au.dk.



Present status of ISA

by Søren Pape Møller *fyssp@phys.au.dk*

It is now time for another newsletter from ISA, partly because a long time has passed since the last issue, but also because of major improvements to the financial situation of ISA. The research outcome of the facilities is as high as ever and reflects the interests in the use of the facilities for a very wide range of projects.

Our first contract with the EC, providing access free of charge to the ISA facilities to users from the EU, ended in March 2004. During the 28 month contract, a total of 385 days of beam were provided to 77 users from 34 different projects. Fortunately the contract has been followed up by a new contract under Framework Programme 6. ISA is a partner in the new Integrated Infrastructure Initiative *Integrating Activity on Synchrotron and Free Electron Laser Science* (IA-SFS), *www.elettra.trieste.it/i3*, a program for research co-operation involving 16 laboratories and institutions throughout Europe. One of the strategic objectives is to support transnational users of national facilities in the domain of synchrotron and FEL science, and ISA will provide more than 575 days of beamtime in the 5-year period, to over 100 users from more than 30 projects.

Another very positive financial breakthrough has been the funding of an *Instrument Centre for UV and soft X-rays at ASTRID* initially for 3 years. Instrument Centres are one of the funding instruments provided by the Danish Natural Science Research Council. This grant provides operating costs for both equipment and personnel for the facility. Together with the EU contract, the use of the facilities is secured for several years to come for the benefit of the users, but also for the Danish research scene.

In addition to the usual operation of the ASTRID facilities, some of us have also been busy with external projects, in particular the Free Electron Laser project at DESY, Hamburg and accelerator projects in collaboration with Danfysik A/S. The former project is described below in some detail, and for the latter project, ISA has been heavily involved in the design of the 3-GeV booster for the Australian Synchrotron Project. ISA will continue to be consulted on this project, in particular during the commissioning of the accelerator.

Finally, I wish you all continued successful use of ASTRID, and in doing so also invite you to contact us for future proposals for the use of the facilities, not only for those possible today, but also those requiring new developments. After all, the facility is no more successful than the outcome of the experiments being made.

Spin-split surface states on Bi: Possible application in *Spintronics*

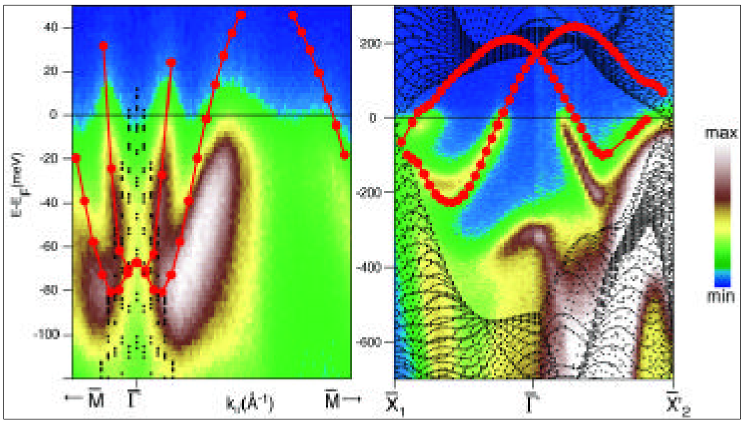
by Philip Hofmann, *philip@phys.au.dk*

Computers and micro-electronics are an integral and rapidly evolving part of today's world. Nevertheless, the development of micro-electronic devices will at some stage reach a variety of physical limits and one will have to look for alternative approaches.

The revolutionary concept of "spintronics" is based on the following idea: All current electronic devices are based on the electron's charge, i.e. information is transmitted by charge currents. The aim of spintronics is to design a new class of devices which is based on the spin degree of freedom in addition to, or instead of, the charge. Such devices would be capable of a much higher speed at very low power (because of the reduced Ohmic losses) and could also be applied in quantum computing.

Key ingredients of spintronics are sources and filters of spin-polarized currents and to this date, the most promising approach to build these is based on the spin-orbit splitting in semiconductor heterostructures, the so-called Rashba effect. The disadvantage of this approach is the small size of the spin-orbit splitting; it is only a few meV.

Recently, we have shown that the electronic surface states on the semimetal bismuth (Bi) constitute a nearly two-dimensional metal with a spin-orbit splitting of up to several hundred meV, much stronger than in the semiconductor heterostructures.



The figure shows the dispersion of the electronic states on two Bi surfaces (colour images) together with a calculation (red markers). The agreement between experiment and theory is excellent, but only if the spin-orbit splitting is taken into account in the calculation. The splitting is zero at some high symmetry points (where the red band cross each other) but very large elsewhere. Therefore, Bi surface states or, more likely, interface states could have promising applications in spintronics.

Ultrathin dielectric films on Si: Growth and properties

by Per Morgen, Ali Bahari, Christian Janfelt, Kjeld Pedersen, Z.S.Li and Mohan G. Rao. For more information, contact *per@fysik.sdu.dk*

The ability to grow ultrathin uniform films of metallic, semiconducting and dielectric materials on various substrates represents a vital field of nanostructure research and applications. Such films, when only a few atomic layers thick, show quantum mechanical behavior in the direction perpendicular to the surface.

In the past, layered heterostructure systems composed of semiconducting materials and dielectrics were found to respond strongly to a perpendicular magnetic field, as embodied in the Quantum Hall Effect.

In a series of experiments with depositions of ultrathin metal films on Si surfaces, we have demonstrated quantum confinements of electrons in these films in a direction perpendicular to the surface. These effects demonstrated our ability to grow epitaxial films on top of a *suitably modified* Si surface.

In parallel studies we are growing dielectric (SiO_2, Al_2O_3, and Si_3N_4) and semiconducting (AlN_3) films on Si surfaces. These studies have discovered new methods for *atomically controlled* growth processes.

Future work will include a few high-k dielectric materials, (TiO_2, Zr_2O_3, and mixed systems (Ti, Al)-oxides etc.), due to their potential applications as gate dielectric materials to replace SiO_2 for sub-nanometer thick dielectric layers on Si. Thus, below 2 nm thickness, quantum mechanical electron tunneling is detrimental for SiO_2.

New results

In an attempt to judge if the so-called Deal-Grove mechanism for the thermal oxidation of Si is valid at lower temperatures and pressures, or how the mechanism should be described under these conditions, a series of experiments were conducted, with a spectacular outcome. At a range of temperatures (300^0C-700^0C) the oxidation of a Si surface with exposure of oxygen gas at $5x10^{-7}$ Torr leads to a universal behaviour of the reactions. This is shown in Fig. 1.

The curves depict the O 1s signal recorded with XPS (x-ray photoelectron spectroscopy). They show very similar growth and saturation, except for the results obtained at 800^0C. In this case the oxide decomposes after the initial growth phase. The reaction at 500^0C forms the thickest layer. When followed in more detail, and converted into thickness, its appearance, as seen in Fig. 2, shows a saturating thickness of about 7-8 Å.

To explain this behaviour, which has not been reported earlier, we are proposing a new model, following a Boltzmann sigmoidal functional behaviour, indicating direct volume absorption of molecular oxygen. The final structure is one where oxygen atoms gradually occupy sites in a certain stable three dimensional configuration of maximum energy including minimized strain and maximum surface and interface energies.

Similar experiments have been completed with N-atoms instead of oxygen molecules to form Si_3N_4 and AlN_3 films on Si .

For these investigations of nano-properties and atomic growth processes, the availability of synchrotron radiation with high quality and stability, as met at ASTRID, has been very important. This work is supported by SNF, and NanoS.

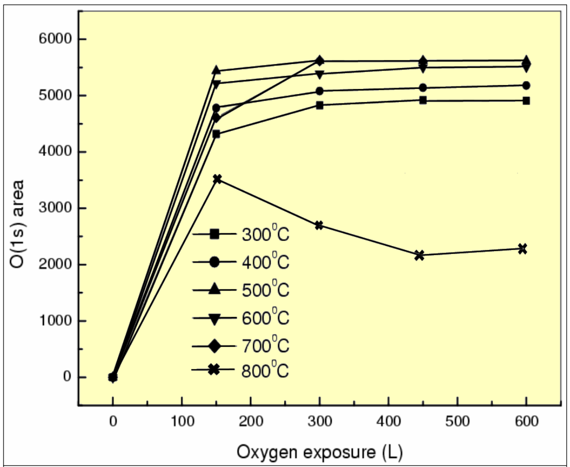


Figure 1. Isothermal oxide growth (O1s signal vs time) $P_{O2}=10^{-7}$ Torr.

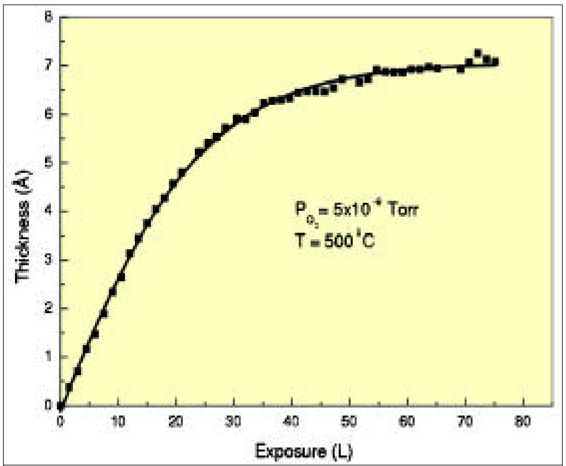


Figure 2. Isothermal oxide growth (thickness vs. time).

The seeding option for the free electron laser in Hamburg

by Søren V. Hoffmann, *vronning@phys.au.dk*

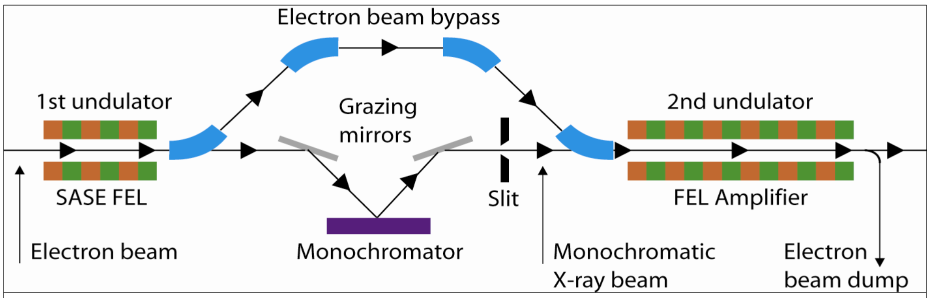


Figure 1: Schematic outline of the seeded FEL.

A new light source, a so called Free Electron Laser (FEL), for the generation of laser radiation in the vacuum-ultraviolet and soft X-ray regime is currently under construction at the DESY site in Hamburg, Germany. The facility will deliver ultra bright radiation down to a wavelength of about 6 nm, and is part of the second phase of the Tesla Test Facility (TTF2).

The radiation is generated via the Self Amplified Spontaneous Emission (SASE) process in very long undulators (nearly 30 m) using the, up to 1 GeV energy, bunched electron beam delivered from the superconducting TTF2 linacs. Please visit the DESY website (www.desy.de) for more details on SASE and the TTF. The radiation will be very bright with peak brilliance up to 10 orders of magnitude higher than what is obtained on 3rd generation light sources. In addition the temporal length of the radiation is determined by the electron bunch length, and is in the sub picosecond range.

The transverse coherence of the radiations is ensured by the SASE principle, but the temporal structure is very spiky and non coherent. This problem can be solved by seeding the process with monochromatic radiation.

This will be done in the so-called seeding option by generating radiation in a first set of undulators, separating the electrons from the photons into a bypass, and then monochromatising the photon radiation. The electrons and the photons are then merged again, and enter a second set of undulators where the SASE process is brought to saturation.

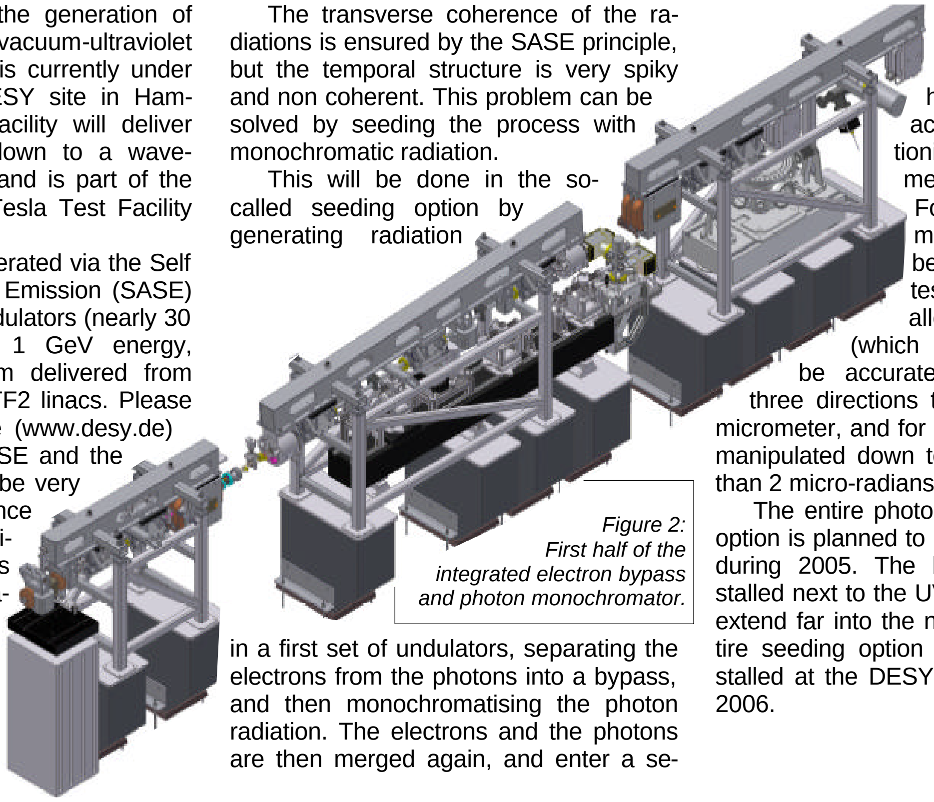


Figure 2: First half of the integrated electron bypass and photon monochromator.

ISA has undertaken the task of constructing an integrated monochromator and electron bypass, the seeding option, to be placed between the two sets of undulators. The mechanical construction is made by Henrik K. Bechtold and Henrik J. Jensen, and the mechanical workshop at the Department of Physics and Astronomy is producing most of the components. The seeding option is very long (22 m in total), and bringing the small photon beam and electron bunch back together at the end, sets very high demands to the accuracy of the positioning of the optical elements.

For this purpose a new mirror manipulator has been developed and tested. The manipulator allows for the mirror (which is under vacuum) to be accurately positioned in all three directions to within less than a micrometer, and for all three angles to be manipulated down to an accuracy better than 2 micro-radians.

The entire photon part of the seeding option is planned to be tested on ASTRID during 2005. The beamline will be installed next to the UV1 beamline, and will extend far into the new ring hall. The entire seeding option is planned to be installed at the DESY site near the end of 2006.

Sunshine from the Ring: Studies in Atmospheric Chemistry

by N J Mason, P Limao-Vieira, A Guiliani, A Dawes, R Mukerji, M J Hubin Franskin. For more information, contact *n.j.mason@open.ac.uk*

The Earth's atmosphere is literally 'solar driven', all the physical and chemical processes prevalent in the atmosphere being initially driven by the incoming solar radiation. Thus any study of the atmosphere requires a detailed study of the interactions of solar radiation with the constituents of the terrestrial atmosphere. Synchrotron radiation provides a natural mimic for solar radiation, providing a continuous light source over a wavelength range compatible with sun light.

Experiments related to atmospheric chemistry started on the ASTRID storage ring in 2000 with the commissioning of the UV1 beam line. Initial experiments concentrated upon the derivation of absolute photo-absorption cross sections of atmospheric molecules from which the photolysis lifetime, i.e. the time taken for the molecule to photo-dissociate may be determined. Determining the lifetime of any atmospheric species to sunlight is vital in assessing the likely role of the molecule in the atmosphere. Short lived species are easily broken down by visible sunlight and will be localised to the lower altitudes while long lived species can rise through the atmosphere into the stratosphere where the intense solar ultraviolet may dissociate them.

Many of gases used in industry (e.g. CFCs, halons) although stable in visible light, are dissociated by solar UV light in the stratosphere releasing halogens that subsequently form free radicals (e.g. ClO_x) which can destroy ozone allowing genetically dangerous solar UV to penetrate to the ground. The chemical reactivity of such compounds is defined by their *Ozone Depletion Potential* (ODP) which in turn is related to the lifetime and thus the structure of the photo-absorption spectrum.

Similarly in determining whether a gas is capable of adding absorption of terrestrial infrared radiation and thus causing 'global warming' it is necessary to know the lifetime of the species. Short lived molecules with weak infrared absorption will have a low '*Global Warming Potential'* (GWP), while long lived species with strong infrared absorption will be strong 'greenhouse gases' with a large GWP (e.g. N_2O, SF_6, fluorocarbons). New international treaties are forcing industry to find substitutes for 'greenhouse gases' and thus it is essential to develop a *spectral atlas* of molecules released (or likely to be released) into the Earth's atmosphere.

UV1 on ASTRID has proven an invaluable tool for measuring the photo-absorption spectra of atmospheric gases. The figure on page 4 shows that of dimethylsulphide $(CH_3)_2S$. This is produced in marine environments and upon release into the atmosphere, is changed into different sulphur species all of which can contribute to the acidity of rain. Moreover sulphur gases are known to be precursors of sulphate aerosol particles and cloud condensation nuclei over remote parts of the oceans and so can affect the Earth's radiation balance by direct scattering of solar radiation. Our results show that the

Continued on page 4

The Performance of ASTRID

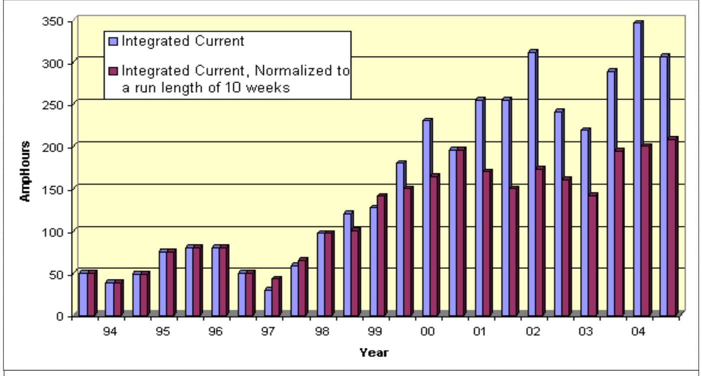
by Jørgen S. Nielsen, *jsn@phys.au.dk*

ASTRID has now been in operation for 15 years. Over the years a number of improvements in the operation and performance of the machine have been made. The two largest upgrades have been the installation of the undulator in 1997 and the implementation of a new PC-based control system in 1997-1998.

The new control system has had many operational impacts. The most important is that it has allowed a much higher degree of automation. As an example, it is now possible to run several different ion species during a single day, whereas earlier, it was normal to run one ion species per week.

Electron operation has benefited highly from automation as well. The many steps involved in accumulating and accelerating the electrons are now made automatically, which allows more advanced control. For instance many parameters now have different settings for injection/accumulation and storage.

The figure shows the integrated current per electron run. As is evident from the figure, there has been a significant increase in the integrated current per run over the years. This has several reasons: In the last 5 years or so the number of weeks per electron run has increased at the expense of the length of the ion runs. If the run length is normalized to 10 weeks (purple bars) it is seen that especially in the last years of the nineties there was a strong increase in the normalised integrated current. The most important reason is improved beam lifetime. This is mainly a result of the implementation and careful trimming of a phase modulation of the RF-frequency, resulting in a bunch lengthening and consequently reduced Touschek scattering, but it is also due to a gradually improving vacuum.



Integrated current per run during the past 11 years.

Another reason for the growth in integrated current during the late nineties is the fact that beams were stored and used, overnight. This increased utilization was partly due to the increase in the number of beam lines in the late nineties, but especially due to computerization of the data taking systems of several of the beam lines, allowing more automatic data taking.

Since the beginning of 2004 a system has been in place which keeps track of the status of each beamline and automatically dumps the beam if none of the beamlines are active.

Over the years effort has been put into either improving the reliability of troublesome power supplies or changing them if necessary. Apart from a transformer in the dipole magnet supply, which failed in February 2003, resulting in 4 weeks of downtime, our operation has not suffered from major faults, and generally the availability of the beam is very high (>95%).

In conclusion, one can say that even though ASTRID is becoming an old machine, the performance has never been better.

Sunshine from the Ring...

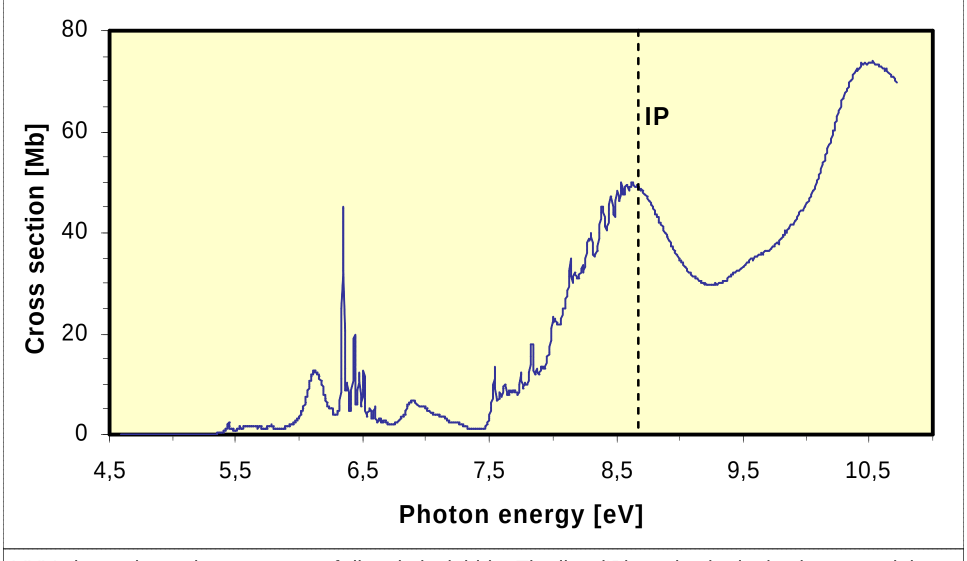
Continued from page 3

lifetime of $(CH_3)_2S$ varies from around one year near the ground to just over one hour at 50 km with an average of the order of a few weeks such that $(CH_3)_2S$ may play a key role atmospheric chemistry.

Gas phase studies alone are, however, not sufficient to understand the many of atmospheric phenomena including the ozone hole. Indeed most of chemistry responsible for ozone depletion is 'heterogeneous chemistry' and takes place of the surface of ice particles within clouds formed in the stratosphere. Therefore in 2004 we commenced a new series of studies on UV1 to investigate photo-chemistry on ice surfaces.

At wavelengths > 200 nm many of the species absorbed on the ice may be ionised producing low energy electrons that trigger new types of chemistry. Recently Lu and Sanche (2001) proposed a new photon driven process that is one or two orders of magnitude more effective than gas phase chemistry and a process that may explain the observed correlation between cosmic ray ionisation rates and ozone loss. Incident cosmic rays liberate an electron in the icy grains found in clouds formed in the stratosphere. These electrons may then dissociate CFCs etc absorbed on the ice to produce chlorine species which then participates in the catalytic destruction of ozone. However these experiments remain controversial so we are developing experiments to study electron induced chemistry on analogues of atmospheric ices at ASTRID.

In conclusion synchrotron radiation is an important source for future investigations of atmospheric physics and chemistry. A new generation of experiments using synchrotron radiation as an analytical tool to investigate reaction dynamics pertinent to atmospheric chemistry is being developed. Furthermore when the synchrotron facility is coupled to laser sources it will be possible to investigate the radical driven chemistry that dominates much of the atmospheric science. Using the synchrotron ring to produce 'sunshine' promises to continue to be an exciting topic of research !



VUV photo-absorption spectrum of dimethylsulphide. The line (IP) marks the ionization potential.

Institute for
Storage Ring Facilities
University of Aarhus
Ny Munkegade
DK-8000 Aarhus C
Denmark

Director: Søren Pape Møller, Dr. Scient

Telephone: (+45) 8942 3603
Telefax: (+45) 8612 0740
E-Mail: isa@phys.au.dk
WWW: www.isa.au.dk

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