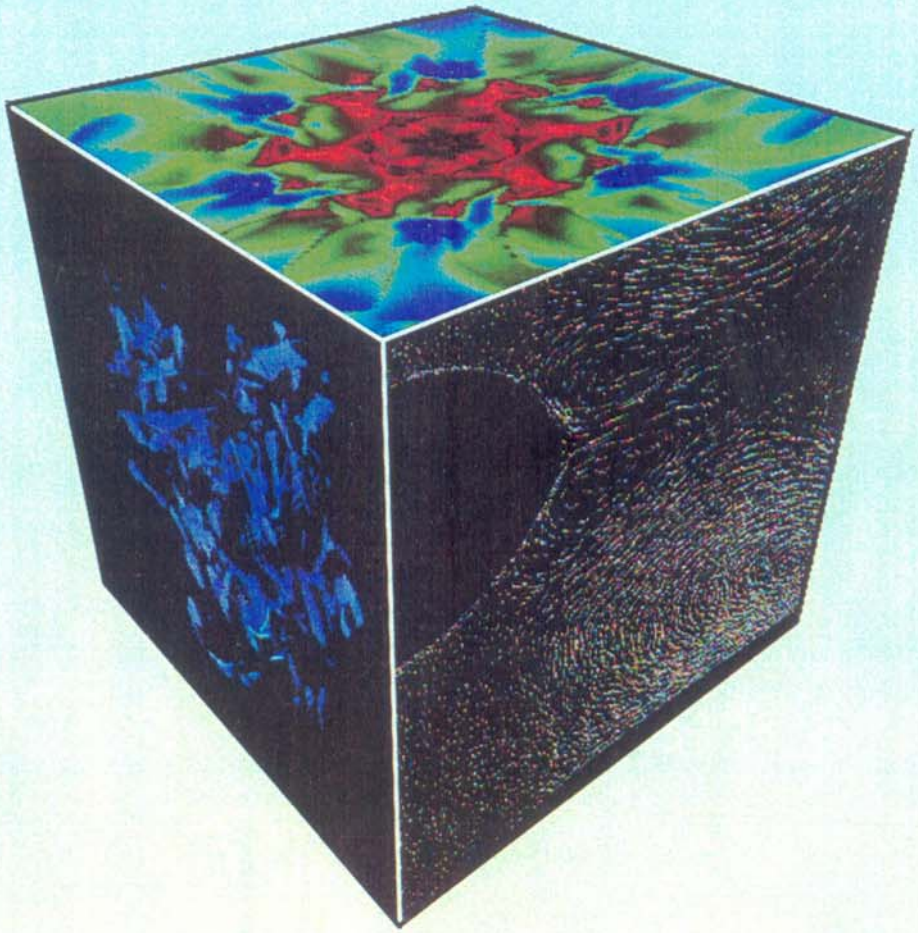
IPP

CENTRE FOR INTERDISCIPLINARY PLASMA SCIENCE

MPE



Report 2000/2001

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I. EXECUTIVE SUMMARY

The role of CIPS

The "Centre for Interdisciplinary Plasma Science" (CIPS) carries out fundamental and applied research in new and developing fields with high innovation potential. The research generally has its roots in plasma physics and bridges the gap to other disciplines (e.g. colloid physics, astrophysics, plasma technology including fusion, particle growth and surfaces, information dynamics etc.), both in fundamental science and applications including know-how transfer to industry, where appropriate.

Synergies

The two participating institutes (IPP and MPE) contribute their own unique special expertise and resources to this joint venture - thus enabling research at a level not possible individually by a single institute. It is desirable, of course, that the research conducted at CIPS will result in some positive feedback into the mainstream areas of IPP (fusion) and MPE (astrophysics) - but primarily the success of the centre has to be evaluated on its own merits - by the quality of the scientific projects and the results obtained - the same criteria as for any other scientific institution. This point is important, because it has been noted from the outset that the potential of CIPS in unusually high, that the interdisciplinarity complements existing plasma research in many ways, that it bridges a gap between fundamental research and applications (in particular in plasma technology and diagnostic analysis techniques) - and that therefore CIPS should develop freely towards "best science" in its chosen research. The quality of the science and the resulting international standing will then determine the future development of this centre.

Research topics

The interdisciplinary research topics are:

- ***Theoretical Plasma Science***
  (in particular plasma-astrophysics, complex and dusty plasmas as well as fundamental processes)

- ***Experimental Plasma Science***
  (in particular the combination of colloid research and plasma research; low temperature plasma physics, plasma technology and materials science; plasma-surface interactions)

- ***Analysis Techniques and Applications***
  (in particular model-free information dynamics techniques based on kinetic transport equations, model-based analysis techniques based on the Bayesian approach - with applications in fusion research and astrophysics)

Cooperations and outreach

In addition to these research corner stones, considerable know-how transfer - into other research disciplines as well as industrial applications - takes place and is actively supported (in particular medical diagnostics, nano-science, plasma technology, biotechnology, engineering, asset management). Currently CIPS has active transfer cooperations with 6 companies and several Universities. There are 6 patents, the most recent ones are held jointly by scientists from MPE and IPP.

CIPS has elected a number of "associate" members to strengthen its ties to Universities and to extend the scope of interdisciplinary plasma science and applications to other exciting research topics beyond those currently pursued actively at CIPS. This broadens the intellectual base and is hoped to lead to further added value in the future. A one day workshop with the associates was held in March 2002.

CIPS has contributed to a student laboratory for practical plasma physics and student experiments have been offered for the first time in February 2002 in an agreement reached between IPP and the University of Ulm. This offer will be extended to the Ludwig-Maximi-lians-Universität later this year. CIPS contributions to the student laboratory comprise experiments on complex plasmas and on plasma enhanced chemical vapour deposition.

Summary of accomplishments

In the first two years of its existence, CIPS has accomplished a number of things, which we briefly summarise here:

Science output

- 20 colloquia and 52 seminars were held, with the aim to introduce the research carried out in the different groups to their counterparts and to broaden and complement the science programme.

- 81 papers have been written, of those 76 were refereed publications.

- 99 invited talks at international conferences were presented, and about 100 contributed talks were given.

- PKE-Nefedov, the first natural science experiment in the International Space Station (ISS) has started its operation (complex plasma research). 8 papers have so far been submitted based on the first results.

New Laboratories (complex plasmas)

- A laboratory for investigating strongly coupled, strongly magnetised complex plasmas was installed. This facility is unique and should provide new insights into basic physical processes in a regime not accessible experimentally so far.

- A laboratory for investigating paramagnetic complex plasmas was installed. This allows research of many-particle systems with dipole interactions, and opens the way for the investigation of thermodynamically closed systems for the first time – at the kinetic level and with very little damping. This facility is also unique.

- A "thermophoretic laboratory" was installed, which enables a (limited) gravity compensation via the thermophoretic force. With this facility, which is also unique at present, we plan to investigate complex plasmas under controlled low-stress situations. It is envisaged that this facility will be particularly useful e.g. for research into finite system thermodynamics.

- An adaptive electrode laboratory is being developed. By employing individually controlled pixelled electrodes (a small prototype is operational) we plan to produce large complex plasma systems (with 1000's of lattice planes) and induce controlled perturbations, structures, flow patterns and dynamics. This unique facility will be used to investigate 2 D flow phenomena, in particular the kinetic transition from laminar flow to turbulence in different systems. It is planned that this laboratory will become operational in 2003/2004. The technology could be useful for plasma deposition or etching. This is currently under investigation together with an industrial partner.

New experiments

- A laboratory experiment to investigate the possibility of diamond formation in a reactive Hydrogen/Methane plasma is being developed. This follows on from work carried out originally at Tohuko University (Japan) and is developed jointly with Profs. Sato and Watanabe. The plasma chamber will also employ the thermophoretic effect, in order to suspend large crystals of perhaps 30 μm in the main plasma. If successful, preliminary agreement has been reached with our Russian partners to conduct further experiments under microgravity conditions on the ISS, where it should be possible, in principle, to produce cm-sized particles.

- The molecular beam apparatus with two radical sources for the study of elementary processes in thin film deposition has been enlarged to incorporate an ion source. First studies have revealed large synergistic effects between Ar^+ ions and CH_3 radicals in the growth of amorphous hydrogenated carbon layers.

- A new apparatus allowing for pulsed plasma operation in thin film deposition has been set up. Film growth will ultimately be studied time resolved. Initial measurements were time integrated and show a dependence of film growth on duty cycle.

- Mass spectrometry of ions and neutrals emitted from a low temperature process plasma will be performed in an apparatus presently under construction. Bayesian analysis will provide the fractions of radicals in neutral spectra, while ion molecule reaction constants shall be derived from the ion spectra.

Data management and Software

- In the new CIPS laboratories some unique complex plasma facilities have been installed, as mentioned above. From the scientific point of view it is desirable to be able to follow the particle trajectories with high temporal and spatial resolution in all experiments. This enables us for example to examine fundamental processes like the melting of plasma crystals, shear flows, turbulence or wave propagation at the kinetic level. Up to now the experimental data were recorded and stored on S-VHS video tapes. For improved observation of the particles and for a real time analysis of complex plasmas we developed a system, consisting of 2 commercial CCD cameras (Pulnix TM-1040, 30 frames per second, 1 megapixel, 10 bits) and a computer system which enables us to store the single frames on an array of hard disks. The data rate reaches up to 37.5 MByte/sec per camera. For the recording of the experiments over a time period of 30 min uncompressed data of about 135GB are digitized. In addition two compression procedures were adapted to reduce the quantity of data.

- For plasma simulation studies new computer codes were written, with the purpose to study magnetic reconnection, collisionless shocks, plasma turbulence and the physics of strongly coupled complex plasmas.

Future Experiments

The future prospects for interdisciplinary plasma research in CIPS are very good:

The **new complex plasma laboratories** will start operating this year and will provide unique research opportunities for many years to come. These laboratories and the research facilities they provide have required and combine expertise and resources from both partner institutes (in the form of hardware, workshops, software, laboratory space, science and engineering manpower). None of the new laboratories could have been set up by a single partner on their own – at least not in such a short time. Our plans for the future are to obtain the "return" from these investments by maximising the science output.

The new experiments currently under construction and in planning in our **low temperature plasma laboratory** will continue to provide up-to-date insights into surface physics and particle growth mechanisms required in plasma processing, manufacture and fusion applications. The demand for innovative research in these areas remains high and with our recent investments CIPS remains well-positioned to continue making fundamental contributions.

In space, the **"microgravity plasma programme"** is consolidated. Following the highly successful PKE-Nefedov project, agreement has been reached with Russia for two further space projects on the ISS. These are:

1. PK3-Plus – a radiofrequency plasma chamber (like PKE-Nefedov) – with improved diagnostics and manipulation capability, projected start is in 2004.
2. PK4, a new design DC plasma chamber especially suited for investigating basic properties of plasma fluids at the kinetic level, such as the transition from laminar to turbulent flow. Projected start is 2005/2006. PK4 may be made available to other researchers too, which is highly desirable from a scientific point of view.

In addition, **"IMPF"** – the proposed "International Microgravity Plasma Facility" is scheduled to receive the go-ahead by the European Space Agency (ESA) for Phase B in autumn this year. This project – according to current planning – will become operative in 2007. It is designed to be used as a fully functional laboratory for a period of about 10 years. Scientific project leadership is located at CIPS, the scientific guidance is provided by an International Advisory Board of experts.

Organisation of this report

This report covers the first two years of CIPS-activities. It therefore necessarily highlights three important components of this formative phase:

1. The continuation of previous research by the groups from MPE and IPP that have been brought together,
2. the build-up of new activities (in particular in the experimental fields),
3. the first joint projects.

In order to facilitate comparison with the annual reports from MPE and IPP and to take account of the "historical" development (in particular point (1) above), we have decided to organise this report along the classical lines of the two institutes, with two exceptions – in "theoretical plasma science" the intellectual overlap is already so advanced, that it did not make sense to artificially divide the topics any more (although we have made an effort that the "roots" are still visible, of course) and in "analysis techniques and applications" we have decided to combine "know-how transfer" into one sub-chapter, since this represents a substantial effort across the groups. Generally, coordinated (or joint MPE/IPP) approaches are pointed out where appropriate, but it needs to be borne in mind that the mutual support and help occurs (unmentioned) between the groups sometimes on a daily basis (e.g. in plasma diagnostics, build-up of new laboratories and experiments, sharing experience in plasma simulation software, technological aspects etc.) and sometimes more sporadically as and when required.