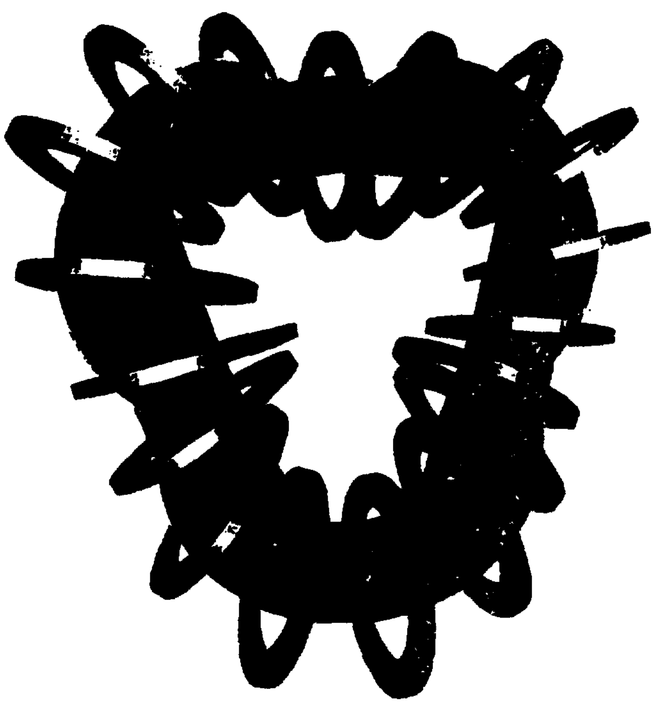
# AINSE
# Plasma Science and Technology Conference



&

# Elizabeth and Frederick White Workshop
on
# Fundamental Problems in the Physics of Magnetically Confined Plasmas

Canberra 12–15 July 1993



## Conference Handbook

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# AINSE
# Plasma Science and Technology Conference
&
# Elizabeth and Frederick White Workshop
on
# Fundamental Problems in the Physics of Magnetically Confined Plasmas

Australian Academy of Science
Canberra
12–15 July, 1993

## The Conference Committee

| | | |
|---|---|---|
| Prof R L Dewar | President | Australian National University |
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## Invited Speakers

| | |
|---|---|
| Prof Amitava Bhattacharjee | University of Iowa |
| Prof John Cary | University of Colorado, Boulder |
| Prof Liu Chen | University of California, Irvine |
| Dr Anthony Cooper | EPFL, Switzerland |
| Prof Peter Dyson | La Trobe University |
| Dr Barry Green | ITER Joint Central Team, Naka, Japan |
| Dr John Keller | IBM, East Fishkill, New York |
| Dr Hajime Kuwahara | Nissin Electric, Kyoto |
| Dr John Lowke | CSIRO Division of Applied Physics |
| Dr V Petrzilka | Czech Academy of Science, Prague |
| Dr S Ramakrishnan | CSIRO Division of Manufacturing Technology |
| Prof Alfred Wong | University of California, Los Angeles |

The Conference Committee gratefully acknowledges the support of the Elizabeth and Frederick White Research Conference Fund of the Australian Academy of Science and the support of the Australian Institute of Nuclear Science and Engineering. This is the 19th AINSE Plasma Physics conference. The Workshop component is integrated throughout the conference but is particularly reflected in the themes of the opening and closing sessions.

The Department of Theoretical Physics, RSPhysSE, ANU, Head Dr Brian Robson, is also gratefully acknowledged for financial support of Drs Cooper and Petrzilka. The Monday night reception is sponsored by the Research School of Physical Sciences and Engineering, Director Prof Erich Weigold.

## Contents



## Acknowledgements

The committee owes a great deal to Ms Helen Hawes for her organisational assistance in sundry matters, and to Ms Martina Landsmann for creating the database of participants and for conversion to LaTeX of those abstracts not electronically submitted. A debt of gratitude is owed also to Prof Anthony Roberts and Dr Stephen Cox for making available the LaTeX source of the handbook for the 1993 Applied Mathematics Conference, which acted as a template for this handbook.

# Summary

*Note:* Talks are at Becker House, the Academy dome. Posters on Monday are in the Oliphant/Cockcroft Link building tea room and in the Research School of Physical Sciences and Engineering plasma laboratories in the Cockcroft Building, preceding the reception. Posters on Tuesday are in the Academy dome followed by the Conference Dinner at Burgmann College.

Lunch will be served at Burgmann College from 12:30 till 1:15 to those displaying a conference badge. In view of the tight timing, participants are encouraged to car pool between Burgmann and the Academy.

## Sunday 11 July 1993

Registration at Burgmann College 4:00–5:30 pm.

| **Monday** | **12 July** | **Tuesday** | **13 July** |
|---|---|---|---|
| 9:00–10:30 | Registration | **Session III** | |
| 10:30–10:40 | Opening remarks | 9:00–10:20 | |
| **Session I** | | 10:20–10:40 | Morning tea |
| 10:40–12:30 | | 10:40–12:30 | |
| 12:30–2:00 | Lunch, Burgmann | 12:30–2:00 | Lunch, Burgmann |
| **Session II** | | **Session IV** | |
| 2:30–3:30 | | 2:00–3:20 | |
| 3:30–3:50 | Afternoon tea | 3:20–3:40 | Afternoon tea |
| 3:50–4:40 | | 3:40–5:20 | |
| **Posters P-I** | RSPhysSE | **Posters P-II** | Academy Dome |
| **& lab. tour** | Cockcroft & Link Bldgs | 5:20–6:50 | |
| 5:00–7:00 | | 7:00–7:30 | Bar, Burgmann Clge |
| **Reception** | | 7:00–10:30 | Dinner |
| 6:30–... | Link Building | Guest speaker | Professor |
| | | | John White, FAA,FRS |

| **Wednesday** | **14 July** | **Thursday** | **15 July** |
|---|---|---|---|
| **Session V** | | **Session VII** | |
| 9:00–10:30 | | 9:00–10:30 | |
| 10:30–10:50 | Morning tea | 10:30–10:50 | Morning tea |
| 10:50–12:20 | | 10:50–12:20 | |
| 12:30–2:00 | Lunch, Burgmann | 12:30–2:00 | Lunch, Burgmann |
| **Session VI** | | **Session VIII** | |
| 2:00–3:30 | | 2:00–3:00 | |
| 3:30–3:50 | Afternoon tea | 3:00–3:30 | Close of conference |
| 3:50–4:50 | | | |

## Timetable

*Note:* The page number of each abstract is indicated in parentheses at the end of the author list. Invited and review speakers are indicated in **bold type** and talk for 25 minutes with 5 minutes for questions. Contributed papers are 15 minutes with 5 minutes for questions. In multi-author papers the presenting author is indicated by underlining.

9:00–10:30 Registration

10:30–10:40 Opening remarks, R. L. Dewar, Conference President

### Session I MONDAY MORNING

I.1 Monday 10:40 am **John R. Cary**, I. Doxas, D. F. Escande, and A. D. Verga (T-8)
**SELF-CONSISTENT ENHANCEMENT OF VELOCITY DIFFUSION BEYOND THE QUASILINEAR VALUE**

I.2 Monday 11:10 am **A. Bhattacharjee** and Xiaogang Wang (T-3)
**CURRENT AND VORTEX SINGULARITIES**

I.3 Monday 11:40 am **Peter L. Dyson** (T-15)
**PLASMA INSTABILITIES IN THE EARTH'S IONOSPHERE**

I.4 Monday 12:10 pm Y.D. Hu and B.J. Fraser (T-19)
EMIC WAVE AMPLIFICATION AND SOURCE REGIONS IN THE MAGNETOSPHERE

12:30–2:00 LUNCH, Burgmann College

### Session II MONDAY AFTERNOON

II.1 Monday 2:00 pm **A. Y. Wong** (T-33)
**RESEARCH ON MITIGATION OF STRATOSPHERIC OZONE DEPLETION**

II.2 Monday 2:30 pm **S. Ramakrishnan** (T-28)
**PLASCON TECHNOLOGY FOR WASTE MANAGEMENT**

II.3 Monday 3:00 pm **B. J. Green** (T-17)
**THE INTERNATIONAL CONTROLLED THERMONUCLEAR FUSION RESEARCH PROGRAMME**

3:30–3:50 Afternoon tea

II.4 Monday 3:50 pm **S. M. Hamberger** for the Heliac Team (T-17)
**THE H-1 HELIAC: A VERSATILE RESEARCH FACILITY**

II.5 Monday 4:20 pm B.D. Blackwell, *et al* (T-5)
FIRST RESULTS FROM THE H-1 HELIAC

**Poster Session P-I** MONDAY EVENING
**P-I Monday 5:00 pm** Research School of Physical Sciences & Engineering
Cockcroft and Link Buildings

1. P.K.Loewenhardt and B.D. Blackwell (P-I-1)
HELICON WAVE PROPAGATION AND PLASMA PRODUCTION IN SHEILA
2. G. G. Borg, B. D. Blackwell and B. C. Zhang (P-I-1)
THE H-1 RADIO FREQUENCY POWER SYSTEM AND THE FIRST RESULTS ON PLASMA FORMATION
3. Andrew D Cheetham (P-I-2)
SOFT X-RAY TEMPERATURE DIAGNOSTIC FOR THE H-1 HELIAC
4. X.J.Dai, S.M.Hamberger, A. Perry, B.D. Blackwell, and J. Wach (P-I-3)
STUDY OF THE MECHANISM OF WOOL SURFACE MODIFICATION BY OXYGEN PLASMA
5. Sean A. Dettrick, Scott L. Painter, Gerard G. Borg, Robert L. Dewar, Henry J. Gardner (P-I-2)
DEVELOPMENT OF NEOCLASSICAL TRANSPORT SIMULATION FOR THE H-1 HELIAC
6. A.R.Ellingboe, R.W. Boswell, J.P.Booth, N.Sadeghi (P-I-3)
TIME AND SPATIALLY RESOLVED OPTICAL EMISSION IN A HELICON REACTOR
7. Stephen Hardy and Henry J. Gardner (P-I-4)
ARNOLD DIFFUSION OF ELECTRON ORBITS IN THE H-1 HELIAC
8. R. L. Dewar, S. R. Hudson and P. Price (P-I-4)
CAPTURE-THEOREM FOR FLUX-MINIMIZING MAGNETIC SURFACES
9. Mark Jarnyk, Kevin Orrman-Rossiter, Jim Williams & Rod Boswell (P-I-5)
ETCHING AND DEPOSITION IN THE HELICON REACTOR WITH $SiCl_4$
10. A. B. Khorev and R. L. Dewar (P-I-5)
FLUX-MINIMIZING CURVES THROUGH ISLANDS
11. M. Persson & C. R. Laing (P-I-6)
CALCULATIONS OF DIMENSIONS AND ATTRACTORS OF NON-LINEAR TEARING MODE DYNAMICS.
12. Hans Nordman, Mikael Persson & Henry Gardner (P-I-6)
CALCULATION OF DRIFT WAVES IN HELIAC GEOMETRY
13. B. A. Petrovichev (P-I-7)
PARTICLE DIFFUSION ALONG THE STOCHASTIC WEB IN THE FIELD OF A WAVE PACKET AND A MAGNETIC FIELD
14. V. Petržílka (P-I-8)
ON HELICON WAVE INDUCED RADIAL PLASMA TRANSPORT
15. M.G.Shats, D.L. Rudakov, B.D. Blackwell, L.E. Sharp, O.I. Fedyanin (P-I-9)
MAPPING OF MAGNETIC SURFACES IN H-1
16. L.E. Sharp, B.D. Blackwell, S.M. Hamberger, D.B. Shenton (P-I-9)
THE H-1 HELIAC: DESIGN & CONSTRUCTION
17. M.G. Shats, D.L. Rudakov, L.E. Sharp (P-I-10)
THOMSON SCATTERING DIAGNOSTIC FOR H-1
18. Helen Smith, R.K. Porteous, S. Defauconpret, & R.W. Boswell (P-I-10)
A MONTE-CARLO MODEL OF DIFFERENTIAL ARGON ION-NEUTRAL CROSS-SECTIONS
19. B.D. Blackwell, J. Howard, and R.B. Tumlos (P-I-11)
TOMOGRAPHIC WIRE-GRID IMAGING OF MAGNETIC SURFACES
20. George Warr and John Howard (P-I-12)
A MULTI-CHANNEL SIX-VIEW INTERFEROMETER FOR MEASURING PLASMA DENSITY PROFILES IN THE H-1 HELIAC
21. Beichao Zhang, Boyd Blackwell, Gerard Borg, Sydney Hamberger (P-I-13)
PLASMA FORMATION AND RF CURRENT DRIVE IN SHEILA

**Session III** TUESDAY MORNING

III.1 Tuesday 9:00 am **W. A. Cooper** (T-11)
**IDEAL MHD STABILITY OF 3D STELLARATOR CONFIGURATIONS**

III.2 Tuesday 9:30 am H. J. Gardner (T-16)
HELIAC EQUILIBRIUM

III.3 Tuesday 9:50 am R. L. Dewar and M. Persson (T-13)
TEARING MODES IN ROTATING PLASMAS WITH MULTIPLE RATIONAL SURFACES

10:20–10:40 Morning tea

III.4 Tuesday 10:40 am M. Persson, R. L. Dewar & E. K. Maschke (T-25)
EVOLUTION OF TEARING MODES WITH MULTIPLE RATIONAL SURFACES

III.5 Tuesday 11:00 am *Xiaogang Wang and* **A. Bhattacharjee** (T-4)
**FAST SAWTOOTH COLLAPSE IN TOKAMAKS**

III.6 Tuesday 11:30 am **Liu Chen** (T-10)
**THEORY OF MHD INSTABILITIES RESONANTLY EXCITED BY ENERGETIC** PARTICLES IN TOKAMAKS

III.7 Tuesday 12:00 pm P. Yushmanov, S. G. Shasharina, and **John R. Cary** (T-8)
**EFFECT OF UP-DOWN ASYMMETRY ON RIPPLE TRANSPORT IN** STELLARATORS AND TOKAMAKS

12:30–2:00 LUNCH, Burgmann College

**Session IV** TUESDAY AFTERNOON

IV.1 Tuesday 2:00 pm **J. J. Lowke**, *et al* (T-23)
**INVESTIGATION OF ELECTRODE MELTING BY ELECTRIC ARCS**

IV.2 Tuesday 2:30 pm N. Asagi, T. Hayashi, H. Kirimura, M. Kobayashi, **H. Kuwahara** (T-22)
**DEVELOPMENT OF PLASMA PROCESSING AT NISSIN ELECTRIC**

IV.3 Tuesday 3:00 pm G.A. Collins, R. Hutchings & J. Tendys (T-31)
PLASMA IMMERSION ION IMPLANTATION AT A RANGE OF TEMPERATURES

3:20–3:40 Afternoon tea

IV.4 Tuesday 3:40 pm J. Watkins (T-32)
RADIO FREQUENCY PLASMA IMMERSION ION IMPLANTATION (RF $PI^3$): STRUCTURE AND PROPERTY MODIFICATION OF STEEL SURFACES

IV.5 Tuesday 4:00 pm C. Charles, *et al* (T-9)
CHARACTERIZATION OF SILICON DIOXIDE FILMS DEPOSITED AT LOW PRESSURE AND TEMPERATURE IN A HELICON DIFFUSION REACTOR

IV.6 Tuesday 4:20 pm R. A. Bean, *et al* (T-2)
SURFACE ANALYSIS OF PLASMA TREATED WOOL

IV.7 Tuesday 4:40 pm Harold Persing & Andrew J. Perry (T-24)
ETCHING OF AMORPHOUS $Si_{1-x}Ge_x$ FILMS IN A HELICON REACTOR

IV.8 Tuesday 5:00 pm Y. Souilliart, *et al* (T-29)
PLASMA ETCHING OF InP IN A HELICON DIFFUSION REACTOR USING METHANE AND HYDROGEN MIXTURES

**Poster Session P-II** TUESDAY EVENING
**P-II Tuesday 5:20 pm** Becker House, Academy of Science

1. P. Abbott and B.W. James (P-II-1)
A MONTE CARLO MODEL OF BORON DIFFUSION IN AN ARGON PLASMA

2. I.R. Jones, C.K. Chakrabarty, I.M. El-Fayoumi, W. Mateer, B. Varcoe and S. Xu (P-II-1)
THE FLINDERS STEADY-STATE RF INDUCTIVE PLASMA SOURCE

3. P.A. Coop and W.N. Hugrass (T-10)
CALIBRATION PROCEDURE FOR SPACE-RESOLVED LINE EMISSION MEASUREMENTS.

4. N.F. Cramer and B.D. Higgins (P-II-2)
THE SIMULATION OF GLOW DISCHARGES

5. R.C. Cross, D.R. McKenzie, X. Li (P-II-3)
TOROIDAL PLASMA DEPOSITION SOURCE

6. N. Donaldson, I.R. Jones and S. Xu (P-II-4)
RESULTS FROM THE 50 LITRE ROTAMAK DEVICE AT FLINDERS

7. N. Donaldson, P. Euripides, K. White and S. Xu (P-II-4)
RF MEASUREMENTS AND ANALYSIS

8. S.W. Simpson and S.H. Law (P-II-5)
NEW APPROXIMATIONS TO THE TRANSPORT PROPERTIES OF LOW-TEMPERATURE PLASMAS IN ELECTRIC AND MAGNETIC FIELDS

9. B.S. Liley (P-II-5)
ANOMALOUS TRANSPORT IN CLOSED MAGNETIC SYSTEMS

10. Nikolai R. Lobanov (P-II-6)
THE HOLCROSS HIGH CURRENT ION SOURCE SYSTEM

11. M.S. Rice, B.W. James, I.S. Falconer, J. Khachan & J.R. Pigott (P-II-7)
A SPECTROSCOPIC STUDY OF A HYDROGEN/METHANE MICROWAVE PLASMA

12. Christopher J. Russell, Peter L. Dyson & John A. Bennett (P-II-7)
NUMERICAL IONOSPHERIC RAY TRACING AND BACKSCATTER IONOGRAM SYNTHESIS

13. Christopher J. Russell, Dan Censor & Peter L. Dyson (P-II-8)
REAL RAY TRAJECTORIES IN COMPLEX SPACE FOR COLLISIONAL PLASMAS

14. A.R. Schellhase and R.G. Storer (P-II-8)
EFFECT OF RESISTIVITY ON THE FULLY TOROIDAL MAGNETOHYDRODYNAMIC SPECTRUM

15. J Waller, X-H Shi, J Howard, B Blackwell (P-II-9)
TRANSPUTER SYSTEM FOR REAL-TIME PLASMA DIAGNOSTIC DATA ANALYSIS

16. C-Y Teo, R C Cross (P-II-9)
THE SPECTRUM OF DISCRETE ALFVEN WAVE EIGENMODES

17. C-Y Teo, B W James, J S Cannon, J Khachan & J Howard (P-II-10)
A SCANNING MICHELSON INTERFEROMETER FOR THE TORTUS TOKAMAK

18. S. Xu (P-II-10)
THE MEASUREMENT OF THE NON-LINEAR HALL FORCE IN A ROTAMAK DISCHARGE

19. Y. Yue, S.H. Law, and S.W. Simpson (P-II-11)
DYNAMICS OF ROTATING PLASMAS

20. P. Zhu, M. Rados, and S.W. Simpson (P-II-12)
CONSUMABLE ELECTRODE PHENOMENA IN A WELDING ARC PLASMA

## Session V WEDNESDAY MORNING

V.1 Wednesday 9:00 am **Ieuan R. Jones** (T-20)
**THE ROTAMAK — HOW IT WORKS!**

V.2 Wednesday 9:30 am R.G. Storer and J.A. Staines (T-30)
TRANSIENT EFFECTS IN TRAVELLING AND ROTATING FIELD CURRENT DRIVE

V.3 Wednesday 9:50 am K. White and A.L. McCarthy (T-33)
CURRENT DRIVE INFORMATION FROM MEASUREMENTS OF THE STEADY AND HIGH FREQUENCY MAGNETIC FIELDS IN THE TOROIDAL DEVICE $<\tilde{j} \times \tilde{b}>$ RYTHMAC

V.4 Wednesday 10:10 am **V. Petrzilka** (T-26)
**PONDEROMOTIVE EFFECTS OF HF HEATING IN FUSION DEVICES**

10:30–10:50 Morning tea

V.5 Wednesday 10:50 am G. G. Borg (T-6)
SLOW ALFVEN WAVE EXCITATION BY FAST WAVE RESONANT MODE CONVERSION AND DIRECT ANTENNA COUPLING IN THE SCRAPE-OFF LAYER OF A FUSION PLASMA

V.6 Wednesday 11:10 am R. C. Cross, D. G. Miljak and C-Y. Teo (T-12)
LOW FREQUENCY ALFVEN MODES IN TORTUS

V.7 Wednesday 11:30 am D. A. Schneider, *et al* (T-29)
EXPERIMENTAL STUDIES OF RF PRODUCED PLASMAS AND WAVE PROPAGATION IN BASIL

V.8 Wednesday 11:50 am Beichao Zhang, *et al* (T-34)
EXPERIMENTAL FAST WAVE STUDIES IN SHEILA

12:30–2:00 LUNCH, Burgmann College

## Session VI WEDNESDAY AFTERNOON

VI.1 Wednesday 2:00 pm **John H. Keller** (T-20)
**INDUCTIVE PLASMAS FOR ETCHING**

VI.2 Wednesday 2:30 pm **R.W. Boswell** (T-6)
**PHYSICS AND COMMERCIAL APPLICATIONS OF THE HELICON PLASMA** PROCESSING SYSTEM

VI.3 Wednesday 3:00 pm J. Khachan, J. R. Pigott, G. F. Brand, I. S. Falconer B. W. James (T-20)
A SIMPLE MICROWAVE PLASMA SOURCE FOR DIAMOND DEPOSITION

3:20–3:40 Afternoon tea

VI.4 Wednesday 3:40 pm I. J. Donnelly, *et al* (T-14)
GAS JET INTERACTION WITH A MICRO-WAVE PLASMA FOR SEMICONDUCTOR SURFACE PASSIVATION

VI.5 Wednesday 4:00 pm A. Durandet & J. Pelletier (T-15)
INDUSTRIAL APPLICATIONS OF PLASMA CVD: REACTOR SCALE UP CONCEPT, PERFORMANCES OF A LARGE PLANAR REACTOR

VI.6 Wednesday 4:20 pm B.D. Higgins, R.K. Porteous and R.W. Boswell (T-18)
TRANSPORT OF A NEUTRAL SPECIES THROUGH A HIGH DENSITY PLASMA

VI.7 Wednesday 4:40 pm Andrew Perry and Harold Persing (T-24)
PLASMA POTENTIALS IN THE HELICON PLASMA REACTOR

## Session VII THURSDAY MORNING

VII.1 Thursday 9:00 am **B. W. James** (T-19)
**LASER DIAGNOSTICS OF PLASMAS**

VII.2 Thursday 9:30 am John Howard (T-18)
A NOVEL PHASE SENSITIVE FAR-INFRARED POLARIMETER

VII.3 Thursday 9:50 am G. F. Brand (T-7)
MILLIMETRE-SUBMILLIMETRE WAVES IN THE PLASMA PHYSICS DEPARTMENT, UNIVERSITY OF SYDNEY

VII.4 Thursday 10:10 am M.J. Baldwin and W.N. Hugrass (T-1)
TIME RESOLVED PROBE MEASUREMENTS IN RF PLASMAS

10:30–10:50 Morning tea

VII.5 Thursday 10:50 am H. Kim, B. W. James & I. S. Falconer (T-21)
ATOMIC COPPER DENSITY MEASUREMENT IN A CYLINDRICAL MAGNETRON DISCHARGE

VII.6 Thursday 11:10 am R. K. Porteous (T-27)
MODELLING A HIGH DENSITY LOW PRESSURE MAGNETIZED ARGON DISCHARGE

VII.7 Thursday 11:30 am T.A. van der Straaten, N.F. Cramer, I.S. Falconer and B.W. James (T-30)
A SELF-CONSISTENT SIMULATION OF A MAGNETRON DISCHARGE

VII.8 Thursday 11:40 am Hoon Kim & Robert Porteous (T-21)
SIMULATION OF A LARGE LANGMUIR PROBE IN A MAGNETIZED FLOWING PLASMA

VII.9 Thursday 12:00 pm Zdzislaw Meglicki (T-23)
GRAVITATIONAL COLLAPSE ON A MAGNETIC DIPOLE

12:30–2:00 LUNCH, Burgmann College

## Session VIII THURSDAY AFTERNOON

VIII.1 Thursday 2:00 pm **E. G. Gamaly** (T-16)
**LASER-MATTER INTERACTION AT EXTREME INTENSITY**

VIII.2 Thursday 2:30 pm **Liu Chen** (T-9)
**KINETIC THEORY OF ULTRA-LOW-FREQUENCY GEOMAGNETIC PULSATIONS**

3:00–3:30 Close of conference

# ABSTRACTS OF TALKS

(alphabetically by presenting author)

# TIME RESOLVED PROBE MEASUREMENTS IN RF PLASMAS

M.J. Baldwin and W.N. Hugrass
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*Armidale, N.S.W, 2351*
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*Session:* VII.4 Thursday 10:10 am.

The Langmuir probe is one of the main diagnostic techniques used in studying low pressure gas discharges. Plasma parameters such as the electron number density, the electron temperature and the floating and plasma potentials are inferred from the voltage-current (V-I) characteristics of the probe.

In dc plasmas, the floating potential is constant and the probe V-I characteristics are obtained by varying the probe voltage around the floating potential and measuring the probe current. In radio frequency (rf) discharges the plasma parameters including the floating potential vary with time during the rf cycle. When a probe is biased with a constant voltage, the probe current varies with time. By repeating this procedure for a number of different constant bias voltages one can in principle obtain the V-I characteristics of the probe at all phases of the rf cycle. In practice however, this method can be used to obtain the V-I characteristics during the parts of the rf cycle when the floating potential is near its negative peak [1]. Obtaining the characteristics at other parts of the rf cycle requires one to bias the probe to constant voltages which are much larger than the negative peak of the floating potential. The probe may then draw currents large enough to change the discharge properties.

Alternatively, the probe can be biased by a constant current. The probe voltage in this case varies with time during the rf cycle. The V-I characteristics of the probe can thus be obtained at any phase of the rf cycle while the probe current is kept within acceptable limits. The main disadvantage of this procedure is that the varying probe voltage causes a capacitive current to flow from the probe leads to the surrounding grounded shield. For low rf frequencies (below 100 kHz), this difficulty can be overcome by modifying the design of the probe and using a special electronic feedback circuit to bias the probe and measure its characteristics. The design of the probe and the bias circuit as well as the calibration procedure will be presented in the *conference.*

[1] T. Mieno *et al.*, Joint Symposium on Electron and Ion Swarms and Low Energy Electron Scattering, Bond University Qld. (1991) pp 116–118.

# SURFACE ANALYSIS OF PLASMA TREATED WOOL*

R. A. Bean, X-J. Dai, B. V. Holcombe, T. J. Horr
and S. M. Hamberger
*Plasma Research Laboratory, RSPhysSE, ANU*
*& CSIRO Division of Wool Technology, Geelong, Victoria*
*& CSIRO Division of Wool Technology, Ryde, NSW*

*Session:* IV.6 Tuesday 4:20 pm.

The textile industry is currently moving into an era where the discharge of effluents is becoming a high profile issue on the public agenda, and both the cost of disposal and leglislative pressure are driving the search for alternative routes for chemical treatments. Dry finishing routes involving plasma surface treatments offer an attractive alternative. Plasma treatment can be used to modify fibre surface properties substantially without producing liquid waste or degrading other fibre properties.

Oxygen and air plasma treatments have long been known to significantly increase the wettability and frictional properties of wool. Detailed information about the actual physical and chemical changes which take place at the fibre surface producing these changes or the possible outcomes of using other gases for plasma treatment are not known.

Two possible mechanisms that could be occurring are physical removal of surface layers of the wool fibre and chemical modification of the surface. Field Emission Scanning Electron Microscopy and Atomic Force Microscopy indicate that morphological changes ($\sim$ 200 nm) occur at the wool surface during plasma treatment but show no significant signs of gross structural changes to the fibre. X-ray Photoelectron Spectroscopy and a modified Wilhelmy Plate technique for measuring surface energy show dramatic chemical changes occur at the surface of the wool fibre.

Results for plasma modification of wool in Oxygen and Argon under a range of conditions are presented allowing for a more definitive explanation of the mechanisms of plasma treatment.

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*Work supported by the Wool Research and Development Corporation

# CURRENT AND VORTEX SINGULARITIES

A. Bhattacharjee and Xiaogang Wang*
*Department of Applied Physics*
*Columbia University*
*New York, New York 10027*
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*Session:* I.2 Monday 11:10 am.

There are phenomena in which singular structures tend to grow spontaneously from smooth initial conditions. We discuss two examples : one is taken from plasma physics, the other from hydrodynamics. In plasma physics, we consider current sheet formation in solar coronal plasmas which have significant implications for coronal heating. In hydrodynamics, we consider the formation of vortex singularities which are an essential feature of turbulence.

A main theme of this talk is that singularities tend to develop near separatrices in both plasmas and fluids. However, the temporal evolution of the singularities in plasmas and fluids are profoundly different.

For coronal plasmas we show that true singularities take infinite time to form, and are hence not realizable. Resistivity intervenes in finite time, thwarting the formation of current singularities. For a coronal loop with an X-line, we give an initial-value calculation for the linear and nonlinear evolution of current sheets. The rate of coronal heating due to these quasi-singular current sheets is estimated, and shown to account for all quiet loops but not all active loops.

For a model of highly symmetric but three-dimensional Euler flows, we show that singularities in the vorticity occur at velocity nulls (stagnation points) that are flanked by vorticity nulls. These nulls are a source of separatrices. We show that vorticity diverges as $1/t$ at a velocity null. The effect of viscosity resolves these singularities and provides a mechanism for turbulence . We show that the spectrum in our model has similarities to real turbulence and given by the 1941 Kolmogorov law.

*This research is supported by the AFOSR and NSF

# FAST SAWTOOTH COLLAPSE IN TOKAMAKS

Xiaogang Wang and A. Bhattacharjee*
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*Columbia University*
*New York, New York 10027*
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*Session:* III.5 Tuesday 11:00 am.

An important and as yet theoretically unresolved feature of sawtooth oscillations is the so called "fast trigger", routinely observed in large and hot tokamaks like JET and TFTR. The "fast trigger" is essentially the sudden and spontaneous transition from the ramp phase to the collapse phase in a sawtooth cycle. Though several analytical and numerical models can account for the rapidity of the collapse phase, they cannot account for the sudden transition from the ramp to the collapse phase. In attempting to resolve this issue, we have developed a theory for the nonlinear evolution of the $m = 1$ instability based on a generalized Ohm's law that includes the Hall term [Phys. Rev. Lett. **70**, 1627 (1993)]. Though the Hall term cannot break field-lines, it nevertheless has a profound influence on the dynamics of the instability. An island equation is derived for the entire nonlinear evolution of the island. We show that the initial exponential growth of the island is followed by an almost explosive phase in which the island size grows as $1/(t_c - t)$. However, the island does not truly become singular because as the island width becomes of the order of the minor radius, the growth rate decays rapidly. The predictions of the model are compared with JET data and show reasonable agreement. The model also fits recent numerical results by Aydemir [Phys. Fluids **B 2**, 2135 (1990)] which provided the stimulus for this work.

*This research is supported by the AFOSR and DOE

# FIRST RESULTS FROM THE H-1 HELIAC

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*Session:* II.5 Monday 4:20 pm.

On the 2nd of December, 1992, the fir.. plasma was produced in the H-1 heliac in the Plasma Research Laboratory at the Australian National University. The plasma was produced in argon with $< 1$ kW of RF at 13.56 MHz, using a twisted loop (helicon wave-type) antenna at a magnetic field of 0.05 Tesla, within a few minutes of making the final connections to the toroidal field coil set. The parameters of H-1 [1] are $R = 1$ m, $< a > = 0.2$ m, $N = 3$ turns, 36 TF coils, $B_0 < 1$ Tesla and $\iota = 0.6 \rightarrow 2$.

Subsequently plasma densities up to $2 \times 10^{17}$ m$^{-3}$ were achieved in argon, with up to 20 kW of rf power at 7 MHz. Initially the optimum filling pressure was near $10^{-4}$ Torr, but as the base pressure improved (ultimately $\sim 4 \times 10^{-8}$ Torr), the best parameters were achieved at the lowest filling pressures $\sim 1 \times 10^{-5}$ Torr. A magnetron source (2 kW pulsed, 2.45 GHz) operated near electron cyclotron resonance ($B_0 \sim 0.07$ Tesla) produced slightly lower densities ($\sim 10^{17}$ m$^{-3}$) with less need for re-tuning but over a smaller range of $B_0$.

Particle confinement times estimated from an 8 mm double pass interferometer were much longer than energy confinement times ($\sim$ ms) estimated from the Langmuir probes. The electron density scaled approximately in proportion to $B_0$. The interpretation of this scaling will be discussed in relation to both changes in particle confinement, and to the dispersion relation of the helicon wave.

The electron density signal was relatively quiet in most cases, but an interesting instability in the drift wave frequency range was observed in argon at higher rf powers and magnetic fields.

Measurements of magnetic surfaces show encouraging agreement with computation, and are reported in detail elsewhere in this conference [2]. Measurements of antenna radiation resistance varied from $\sim 1\,\Omega$, consistent with launching helicon waves, to (under certain conditions) higher values indicative of plasma formation near the antenna, or electrostatic modes [3].

Results at higher powers and magnetic fields will be presented.

[1] S. M. Hamberger, B. D. Blackwell et al., Fusion Technology, 17 (1990) 123
[2] D. Rudakov et al., this conference
[3] G.G. Borg et al., this conference

# SLOW ALFVEN WAVE EXCITATION BY FAST WAVE RESONANT MODE CONVERSION AND DIRECT ANTENNA COUPLING IN THE SCRAPE-OFF LAYER OF A FUSION PLASMA

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*Session:* V.5 Wednesday 10:50 am.

It is well known that an antenna located in the scrape-off layer of a fusion plasma can couple to a cold plasma quasielectrostatic Alfven wave below the ion cyclotron frequency by resonant mode conversion of a fast magnetosonic wave. The mode conversion point is referred to as the Alfven resonance layer (ARL) and is located where $\omega/k = v_A$, where $\omega$ is the frequency, $k$ the parallel wave number and $v_A$ the Alfven speed. The slow wave propagates radially on the low density side of the ARL and is evanescent on the high density side.

Despite numerous experimental observations suggesting the existence of a slow Alfven wave excited directly by the antenna, the possibilty of direct excitaton has never been properly explained from a theoretical view point.

In this paper, we consider the problem of simultaneous coupling to the slow wave by fast wave resonant mode conversion and direct antenna coupling using analytical techniques. It is shown that direct coupling can indeed occur and we consider the relative strengths of the two excitation mechanisms. The spatial frequency components of the two waves differ significantly owing to the different natures of the two excitation mechanisms. For real antennas, the directly excited wave has a broad wavenumber spectrum and each component is reflected after reaching a cut-off located at the ARL determined by its $k$-value. The mode converted wave is expected to have a more monochromatic wavenumber spectrum characteristic of the fast wave from which it converts.

# PHYSICS AND COMMERCIAL APPLICATIONS OF THE HELICON PLASMA PROCESSING SYSTEM

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*Session:* VI.2 Wednesday 2:30 pm.

The Helicon reactor was amongst the first of the new generation of inductively-coupled plasma sources. It is now one of the accepted R&D tools in the microelectronics industry and will probably be used in production lines in the mid- to late-1990's. Scientifically, it is interesting as the coupling of the rf power to the plasma involves non-linear wave-particle interactions which are yet to be understood fully. Industrially, it has the advantages of high coupling efficiency at low confining magnetic fields, low plasma potential, high plasma density at low gas pressures, high reliability and the possibility of scaling up to allow large surface areas to be processed. This talk will review the basic physics of the Helicon reactor and describe recent results obtained at the ANU and overseas.

# MILLIMETRE-SUBMILLIMETRE WAVES IN THE PLASMA PHYSICS DEPARTMENT, UNIVERSITY OF SYDNEY

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*Session:* VII.3 Thursday 9:50 am.

This paper will survey the broad range of plasma diagnostic applications of msm waves that have been employed in the Plasma Physics Department at the University of Sydney.

Electron density has been measured at 35 GHz, 110 GHz, 433 $\mu$m and 337 $\mu$m with klystron and far-infrared laser sources using interferometry and the self-modulation of lasers. Refinements to interferometry give direct displays of density with time and allow the plasma profiles to be deduced. In the course of this work we have made significant contributions to the development of HCN and optically-pumped far-infrared lasers.

Electron temperature has been measured by Fourier Transform Spectroscopy. The heart of the instrument is a Michelson interferometer with a moving mirror. The rapid movement of the mirror that is required can be achieved by mounting it on a rotating stage or placing a pulsed plasma in one arm of the interferometer. Under suitable conditions, obtaining a spectrum of the radiation from the plasma at harmonics of the electron cyclotron frequency allows the electron temperature to be deduced. Instruments like this have been developed here and used by our students at Culham, England.

Scattering of millimetre-submillimetre radiation to study waves and fluctuations in plasmas has been carried out using a optically-pumped molecular vapour laser and a tunable gyrotron as the radiation source. DAW modes and KAWs that have been excited in RF heating experiments have been investigated.

# SELF-CONSISTENT ENHANCEMENT OF VELOCITY DIFFUSION BEYOND THE QUASILINEAR VALUE

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*Session:* I.1 Monday 10:40 am.

In both test-particle[1] and self-consistent simulations[2], the coefficient of velocity diffusion in turbulent electrostatic fields has been observed to exceed the value given by quasilinear theory. In test-particle simulations the enhancement is seen at intermediate overlap parameter. A maximum enhancement of approximately 2.5 is observed. Self-consistent simulations show a turbulent field that evolves into one with intermediate overlap parameter when the linear growth time of the mode is long compared with the effective discretization time, which is about an order of magnitude greater than the resonance broadening time.

[1] J. R. Cary, D. F. Escande, A. D. Verga, Phys. Rev. Lett. 65 (1990) 3132–3135.
[2] J. R. Cary, I. Doxas, D. F. Escande, A. D. Verga, Phys. Fluids B 4 (1992) 2062–2069.

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# EFFECT OF UP-DOWN ASYMMETRY ON RIPPLE TRANSPORT IN STELLARATORS AND TOKAMAKS

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*Session:* III.7 Tuesday 12:00 pm.

Up-down asymmetry of the ripple wells in stellarators and tokamaks causes the toroidally trapped trajectories to convect out of or into the plasma. As there are many more toroidally trapped trajectories than ripple trapped, this can create a much greater loss region in velocity space and increase plasma loss in the low-collisionality regime. In the high-collisionality regime standard estimates based on the time for collision out of the loss region and the fraction of particles participating in the loss mechanism indicate that up-down asymmetry could substantially increase transport over that of ripple-induced loss. However, a more careful examination shows that the constraints of Liouville's theorem cause the usual methods of estimation to be wrong, and the loss rate to be identical to that of standard ripple induced diffusion.

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# CHARACTERIZATION OF SILICON DIOXIDE FILMS DEPOSITED AT LOW PRESSURE AND TEMPERATURE IN A HELICON DIFFUSION REACTOR

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*Session:* IV.5 Tuesday 4:00 pm.

Silicon dioxide films have been deposited at low pressure (a few mTorr) and low substrate temperature ($< 200^\circ$C) by oxygen/silane helicon diffusion radiofrequency plasmas. High deposition rates (20–80nm/min) are achieved at 800W rf source power when varying the oxygen/silane flow rate ratio. The deposition kinetics have a great effect on the internal film structure: for films presenting a good stoichiometry ($x \geq 1.95$ with $SiO_x$), a decrease in the deposition rate is accompanied by a decrease of the refractive index, P-etch rate and XPS line width and by an increase of the Si-O stretching peak frequency towards the thermal oxide values. A sufficient oxygen/silane flowrate ratio leads to stoichiometric films which exhibit good optical properties. Small differences in the P-etch rate, XPS line width and infrared stretching peak frequency are still observed between our stoichiometric plasma deposited film and a thermally grown oxide film.

# KINETIC THEORY OF ULTRA-LOW-FREQUENCY GEOMAGNETIC PULSATIONS

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*Session:* VIII.2 Thursday 2:30 pm.

A general review will be given on the stability properties of ULF geomagnetic pulsations (Pc waves) in the Earth's magnetosphere. While the instabilities (drift Alfven-ballooning mode or DABM) may be excited in the fluid regime, the emphasis here is kinetic excitation via the drift-bounce resonances of the energetic ring-current ions. Theoretical predictions of the wave properties and associated ion flux modulations will also be compared with satellite observations.

*Work supported by DOE Contract No. DE–AC02–76–CHO3073 and NSF.

# THEORY OF MHD INSTABILITIES RESONANTLY EXCITED BY ENERGETIC PARTICLES IN TOKAMAKS

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*Session:* III.6 Tuesday 11:30 am.

A general review on MHD instabilities resonantly excited by energetic particles in tokamaks will be given. Topics will include $n = 1$ fishbone, high-$n$ kinetic ballooning modes (KBM), and toroidal Alfven eigenmodes (TAE). We will attempt to show that there exists a generic "fishbone" dispersion relation which demonstrates characteristically that the unstable modes consist of MHD gap modes and energetic-particle continuum modes. Properties of both types of modes will be briefly discussed.

*Work supported by DOE Contract No. DE–AC02–76–CHO3073 and NSF.

# CALIBRATION PROCEDURE FOR SPACE-RESOLVED LINE EMISSION MEASUREMENTS.

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*Session:* P-II Tuesday 5:20 pm.

The measurement of the spectral line emission is one of the main diagnostics used to study glow discharge plasmas. The line emissions from some discharges are relatively weak and it is necessary to use techniques such as photon counting or image intensification. The apparatus developed at UNE utilizes 2 micro-channel plate image intensifiers, a CCD video camera, and an image-grabbing card plugged in a personal computer. This apparatus is unique because it can be used to obtain 2-d space-resolved and time-resolved measurements. However, the image intensifiers, the associated lenses and ccd camera introduce spatial nonuniformity in the sensitivity of the system. Significant improvement in the spatial uniformity of the sensitivity of the apparatus can be achieved using the following calibration procedure [1]. A stable extended light source is moved with respect to the apparatus and its image is recorded at each position. The relative calibration of each pixel is then calculated such that the differences between the images are minimized. The calibration factors are calculated in [1] assuming that the image is moved by the equivalent of an integer number of pixels. This assumption greatly simplified the calculations but it imposed some limitation on the accuracy of the calibration factors. A new calibration procedure in which general displacements are allowed, will be presented in the conference, and the two calibration procedures will be compared.

[1] G Xu et al, submitted for publication in J Phys E.

# IDEAL MHD STABILITY OF 3D STELLARATOR CONFIGURATIONS

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*Session:* III.1 Tuesday 9:00 am.

The ideal MHD stability properties of 3D equilibria with imposed nested magnetic flux surfaces generated with the VMEC code [1] have been investigated with the TERPSICHORE suite of codes [2]. Applications to proposed (W7X, LHD) and existing (ATF) stellarator devices have been carried out. A sequence of configurations that range from a conventional $l = 2$ stellarator to the W7X device at a fixed $\beta = 4.5\%$ value demonstrates that the marginally stable point imposed by global modes agrees with the prediction of the Mercier criterion at a configuration that is 80% the W7X. The mode structure is dominated by the $m = 10, n = 9$ component and is basically internal. The LHD torsatron studies indicate that global modes become unstable at $\beta \simeq 5\%$. Two types of instabilities compete near the marginal point. One is a global kink double-ballooning structure driven by strong mode coupling interactions. The other is a more localised kink-interchange structure. The 3D Mercier criterion predicts a second region of stability for $2.2\% \leq \beta \leq 3.7\%$. No second stability is observed, however, for 3D ballooning modes, which become unstable at $\beta > 1.5\%$. The ballooning stability properties depend sensitively on which field line of each surface they are evaluated on, invalidating the stellarator expansion approach for this type of mode in the LHD. The investigation of the 3D ideal MHD global stability of the ATF torsatron demonstrates that the external modes are destabilised by the presence of the $\iota = 1$ surface just outside the plasma and that the coupling to toroidal satellites is an important factor in the stability analysis. The quadrupole field used to control the rotational transform at finite $\beta$ strongly destabilises the $n = 1$ and $n = 2$ modes because this field annihilates the vacuum magnetic well. We find no evidence to support the claim that MHD theory predicts that the ATF device accesses a second region of stability at reactor relevant values of $\beta$.

[1] S.P. Hirshman and O. Betancourt, J. Comput. Phys. **96** (1991) 99–109.
[2] W.A. Cooper, G.Y. Fu, R. Gruber, S. Merazzi, U. Schwenn and D.V. Anderson, Proc. Joint Varenna-Lausanne Int. Workshop on Theory of Fusion Plasmas (Editrice Compositori, Bologna, 1990) pp. 655–665.

# LOW FREQUENCY ALFVÉN MODES IN TORTUS

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*Session:* V.6 Wednesday 11:10 am.

Experimental results are presented on global modes of the shear Alfvén wave observed in the TORTUS tokamak. The modes are excited by two shielded antenna loops at the plasma edge, separated toroidally by 135°, and driven at 1.0 or 3.2 MHz. The antennas can be rotated to generate either a transverse or longitudinal magnetic field. Discrete Alfvén Wave (DAW) modes are observed when the dispersion relation $\omega = k_{\parallel}v_A = (n + m/q)v_A/R_0$ is satisfied over a significant fraction of the plasma cross section, where $n$ is the toroidal mode number and $m$ is the poloidal mode number. DAW modes are observed (with an array of magnetic probes) with both $b_\theta$ and $b_z$ antennas, but the antenna loading depends on the antenna orientation. The $b_\theta$ antennas also excite a magnetically guided shear wave beam which propagates only in the plasma edge and which can interfere constructively or destructively with DAW mode fields in the plasma edge.

A search is currently underway in TORTUS for $n = 0$ DAW and $n = 1$ Toroidal Alfvén Eigenmodes (TAE or "gap" modes) that are expected at frequencies $\omega = v_A/qR_0$ and $\omega = v_A/2qR_0$ respectively. TAE modes are of interest in relation to the confinement of $\alpha$ particles, and have been observed in neutral beam injection experiments, but have not yet been observed directly as a result of antenna excitation. DAW modes have been studied extensively in the TCA tokamak, but have not received as much theoretical attention as TAE modes in connection with $\alpha$ particle confinement.

Our present interest in $n = 0$ modes is stimulated by the fact that they have a similar frequency to TAE modes and are more global in extent than $n \neq 0$ modes, since the shear wave dispersion relation is satisfied over a wider cross section of the plasma when $n = 0$. The $n = 0$, $m = 1$ DAW mode has a parallel wavelength equal to the length of the closed magnetic field lines on integer q surfaces. The $n = 1$, $m = -1$ and $m = -2$ toroidally coupled TAE mode exists as a standing wave with $\lambda_{\parallel}$ equal to the length of a closed field line on the $q = 1.5$ surface. Similarly, the $n = 1$, $m = -2$ and $m = -3$ modes are coupled near the $q = 2.5$ surface. We have observed $n = 0$ and $n = 1$ DAW modes, but $n = 1$ TAE modes have not yet been observed.

# TEARING MODES IN ROTATING PLASMAS WITH MULTIPLE RATIONAL SURFACES

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*Session:* III.3 Tuesday 9:50 am.

The global asymptotic matching equations for multiple coupled resistive modes of arbitrary parity in a cylindrical plasma are derived. Three different variational principles are given for the outer region matching data. The toroidal generalization of one of these forms the basis of the new PEST3 code [1].

The dispersion relation is compared with initial value calculations of a double tearing mode when there are small relative rotation velocities between the rational surfaces. In treating differential rotation within the asymptotic matching formalism, flow is ignored in the outer region and is assumed to affect the inner response solely through a Doppler shift. It is shown that the relative rotation can have a strong stabilizing effect by making all but one rational surface effectively ideal.

[1] A. Pletzer, Ph D thesis, ANU 1992.

# GAS JET INTERACTION WITH A MICRO-WAVE PLASMA FOR SEMICONDUCTOR SURFACE PASSIVATION

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*Session:* VI.4 Wednesday 3:40 pm.

Solid-state detectors based on GaAs are of great interest for particle detection in the next generation of high energy particle collider experiments. In these experiments, detector components near the interaction vertex will be subjected to large fluences of neutrons and other radiation, with subsequent damage. The radiation hard properties of GaAs make it desirable for detector use.

One of the problems to be overcome with GaAs detectors is the leakage current arising from the dangling bond structure in the surface. It is possible to reduce this problem by the addition of $H$ and $H^+$ to the surface region. Typically this is done by the application of hydrogen plasmas.

Omeljanovsky *et al* [1] have recently developed a variation of plasma passivation by using a micro-wave plasma to partially dissociate and ionise a $H_2$ gas jet which is directed onto the GaAs. This technique minimises damage done to the surface arising from direct contact with the plasma.

This principle has been incorporated in a micro-wave plasma device which has been constructed at Ansto. Langmuir probe measurements of the plasma density and temperature are in progress, and initial results will be reported. Emphasis in this presentation will be on model calculations of the interaction between the plasma and the $H_2$ jet, and the predicted densities of $H$ and $H^+$ species created in this jet.

[1] E.M. Omeljanovsky, A.V. Pakhomov and A.Y. Polykov, J. Electronic Materials **18** (1989) 659-70.

# INDUSTRIAL APPLICATIONS OF PLASMA CVD : REACTOR SCALE UP CONCEPT, PERFORMANCES OF A LARGE PLANAR REACTOR

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*Session:* VI.5 Wednesday 4:00 pm.

Plasma CVD allows deposition of high quality materials. However, deposition rate and film uniformity remain the key requirement in many industrial fields. In fact, the limiting factor of many industrial applications lies in the difficulty of producing large (up to square meters) uniform plasmas. The Uniform Distributed Electron Cyclotron Resonance (UDECR), where linear microwave applicators can sustain constant amplitude standing waves along the multipolar magnetic structure, can be used to make large planar plasma sources. The capabilities of this technique are illustrated at 2.45 GHz excitation frequency with a $40 \times 50$ $cm^2$ planar plasma reactor. We present the evolution of the density and uniformity of an Ar plasma, as well as results on $SiO_2$ deposition from a silane-oxygen gas mixture. Scaling-up concepts for large-dimension industrial applications are debated.

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# PLASMA INSTABILITIES IN THE EARTH'S IONOSPHERE

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*Session:* I.3 Monday 11:40 am.

The Earth's ionosphere is a relatively cold plasma. Its large scale behaviour is determined by many factors including photoionization, particle heating, ion chemistry, collisions with neutrals, electric and magnetic fields and gravity. Plasma instabilities are a major cause of many small scale features known as ionospheric irregularities. The properties of these irregularities vary with latitude and height and a wide range of plasma instabilities are involved. For example, the two-stream instability produces irregularities in the E region (100–120 km altitude) at equatorial and high latitudes and, in the equatorial F region (200–400 km altitude), the Rayleigh-Taylor instability is an important mechanism. Plasma instabilities can also be generated in the ionosphere by RF heating and in-situ transmitters can stimulate various plasma resonance emissions. This review will concentrate on plasma processes involved in the production of F region irregularities commonly referred to spread F.

# LASER-MATTER INTERACTION AT EXTREME INTENSITY

E. G. Gamaly
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*Session:* VIII.1 Thursday 2:00 pm.

A review of the different physical phenomena occurring when a high power (up to $10^{15}$ W), ultra short (less than 1 ps) laser pulse interacts with gaseous or solid targets is presented. We emphasize the qualitatively new nonlinear (including relativistic) effects in the super intense laser field such as ATI and tunnel ionisation, harmonic generation, ponderomotive force induced absorption, ion acceleration and instabilities, effects of QED etc. The recent status of the theoretical and experimental studies is surveyed. We conclude with a discussion of possible applications (ultra short point X-ray source, table top X-ray laser etc.) and future perspectives for the field.

# HELIAC EQUILIBRIUM

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*Session:* III.2 Tuesday 9:30 am.

In spite of more than a decade of development of computational models of ideal magnetohydrodynamic equilibrium in three-dimensions, the problem remains open. Some of the earliest models used Eulerian grids to catch the change in magnetic islands and stochastic regions with plasma pressure. These tended to be impractical for the calculation of the complicated magnetic geometries of real fusion devices and were superseded by Lagrangian models which assumed that the magnetic flux surfaces were simply-nested about a single magnetic axis. These codes have been instrumental in the design of the next generation of stellarator experiments, however recent work has shown that some of their more extravagant predictions may be wrong. With the advent of modern supercomputers, the wheel seems to be turning back to the Eulerian point of view.

These notions will be illustrated with reference to the H-1 Heliac. Its magnetic topology, which is (arguably) the most complicated of any fusion machine in existence, provides a stringent test of the theoretical models.

# THE INTERNATIONAL CONTROLLED THERMONUCLEAR FUSION RESEARCH PROGRAMME

B. J. Green
*ITER Joint Central Team, Naka, Japan*

*Session:* II.3 Monday 3:00 pm.

The production of nearly 2 MW fusion power in the Joint European Torus (JET) in November 1991 demonstrated that fusion reactor fuel conditions can be reproducibly achieved in a laboratory experiment. This was a significant step in the demonstration of the feasibility of fusion energy production.

Nevertheless, the details of the energy transport mechanisms in the plasma are still being actively investigated (primarily in tokamak devices). Plasma performance in alternative magnetic configurations (e.g, stellarators and reversed field pinches), which may have advantages for a reactor, are also being studied.

However, the JET results and the high level of performance of other large tokamaks have given the international community sufficient confidence to embark on the next phase of the development of controlled fusion energy production, which is to explore its technical feasibility.

A large international project, the International Thermonuclear Experimental Reactor (ITER) has begun a 6 year period of Engineering Design Activity (EDA). Ultimately it is hoped to build the ITER device to demonstrate fusion reactor-relevant technology.

This paper will discuss the international fusion research programme and describe the ITER EDA.

# THE H-1 HELIAC: A VERSATILE RESEARCH FACILITY

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*Session:* II.4 Monday 3:50 pm.

The H-1 heliac produced its first plasma late last year. Its design is such that, when complete with all its planned plasma heating, diagnostics and control facilities, it will provide unrivalled opportunities to Australian and overseas plasma physics for leading-edge research into fundamentals of toroidal plasma confinement.

The talk will outline the general construction of the machine and its auxiliary supplies and principal diagnostics. Some of the wide range of magnetic configurations will be described and related to their significance to and opportunities for exploring physical phenomena, e.g. the effects of toroidal resonances on equilibrium and stability, ranging from the experimental study of non-linear particle dynamics to that of finite pressure Mercier stability limits.

# TRANSPORT OF A NEUTRAL SPECIES THROUGH A HIGH DENSITY PLASMA

B.D. Higgins, R.K. Porteous and R.W. Boswell
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*Session:* VI.6 Wednesday 4:20 pm.

Plasma discharges are often used in conjunction with vapour deposition systems to provide a flux of energetic ions to the growing film. Additionally, some proportion of the vapour may itself be ionized and become subject to the magnetic field and the electric field in the plasma. Efficient ionization can enhance the transport of the vapour to the substrate and, by increasing the energy of the depositing species in a controlled way, alter the character of the deposited film. The Hamlet hybrid PIC-fluid plasma simulator has been used to investigate the transport of neutral species through a high density plasma to a substrate, as a function of magnetic field, gas pressure and discharge power. Ion pumping, ion wind and heating/cooling due to collisions with the background gas have been taken into account.

# A NOVEL PHASE SENSITIVE FAR-INFRARED POLARIMETER

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*Session:* VII.2 Thursday 9:30 am.

A new type of phase sensitive multi-channel polarimeter for plasma current and density measurements is discussed. The Faraday rotated linearly polarized far-infrared laser probe beam is post-processed by a polarization-interferometer to produce two anti-phase signals whose relative phase shift is twice the Faraday rotation angle [1]. Many independent spatial channels can be obtained using a single pair of detectors by using frequency or time domain multiplexing diffraction gratings [2]. Possible applications for densitometry and current profile measurements in magnetically confined plasmas are discussed.

[1] J. Howard, Infrared Physics, **34** (1993) pp. 175–189
[2] J. Howard, G. B. Warr and P. Dodds, Rev. Sci. Instrum. **63** (1991) pp. 4965–4967

# EMIC WAVE AMPLIFICATION AND SOURCE REGIONS IN THE MAGNETOSPHERE

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*Session:* I.4 Monday 12:10 pm.

The amplification of electromagnetic ion cyclotron (EMIC) waves in the magnetosphere is studied by integrating local convective growth rates along the wave path. The integrated wave amplification is used to investigate the radial extent of wave source regions. The typical heavy ion concentrations (He+ 10-20that the radial structure of the integrated wave amplification is controlled by the ion composition in the magnetosphere, as well as by the total plasma density profile. It is found that the source region of the lowest frequency wave branch is restricted near the plasmapause and inside the plasmasphere, whereas the other wave branches can be amplified over the whole amgnetosphere. It is suggested that the structured Pc 1-2 waves observed mainly on the ground are due to the lowest frequency wave branch, and the unstructured Pc 1-2 waves observed both on the ground and in space are caused by the other wave branches.

# LASER DIAGNOSTICS OF PLASMAS

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*Session:* VII.1 Thursday 9:00 am.

There are many laser-based techniques for measuring plasma properties. In general the advantages of such techniques are that they are non-purturbing and allow good spatial resolution. Lasers, at wavelengths from submillimetre to the visible, have long been used as radiation sources for various interferometric techniques for measuring electron density. Thompson scattering of laser radiation is routinely used for measuring electron temperature in high temperature plasmas, but has recently also been used to measure electron temperatures of a few eV in excimer laser plasmas. With the dye laser it is possible to tune the laser radiation to a specific transition in an atom, molecule or ion in the plasma - a situation which is particularly useful for measurements in processing plasmas. Applications include absorption spectroscopy, optogalvanic spectroscopy and laser induced fluorescence. The latter can be used to identify the presence of species and some circumstances, usually with the aid of collisional radiative models, their densities. It has also been used to measure velocity distributions and flow velocities (via the Doppler shift) and electric fields from the enhancement or forbidden line fluorescence. This talk will discuss a wide range of laser-based diagnostic techniques. The emphasis will be on applications to low temperature, rather than magnetically confined plasmas.

# THE ROTAMAK — HOW IT WORKS!

Ieuan R. Jones
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*Session:* V.1 Wednesday 9:00 am.

Following a brief resume of the rotating magnetic field method of driving plasma current and its application in the Rotamak, recent results obtained in high-powered rotamak experiments conducted with spherical pyrex discharge vessels of 10- and 50-litre volume will be presented.

We have only recently arrived at an understanding of the working of a rotamak discharge. This understanding will be presented and discussed.

# INDUCTIVE PLASMAS FOR ETCHING

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*Session:* VI.1 Wednesday 2:00 pm.

RF induction is an efficient means of producing a high density plasma for plasma processing and more recently for a light source. A number of high density sources are now commercially available for etching.

This talk will cover some of the theory for plasma generation by rf induction. Curves of efficiency and effective collision rate vs density will be discussed. Experimental data on ion density, ion current and transverse energy will be presented.

Finally etch results for selective oxide etching will be presented.

# A SIMPLE MICROWAVE PLASMA SOURCE FOR DIAMOND DEPOSITION

J. Khachan, J. R. Pigott, G. F. Brand
I. S. Falconer B. W. James
*Department of Plasma Physics,*
*School of Physics,*
*University of Sydney, Australia 2006*

*Session:* VI.3 Wednesday 3:00 pm.

We describe a simple microwave-produced plasma source that has been constructed for plasma-assisted chemical vapor deposition of diamond thin films. Microwave power from a 700 watt domestic microwave oven magnetron is fed into a water-cooled cylindrical stainless steel vacuum vessel. A methane/hydrogen gas mixture introduced into the vessel is excited by the microwaves to produce a well-defined plasma ball which does not interact with the walls of the vessel. The position of the plasma ball in the vessel can be predicted by cold cavity calculations of the axial electric field profile. The vessel has several diagnostic ports which do not alter its resonant condition. Diamond is deposited on various substrates, placed beneath the plasma ball on a graphite-capped quartz pedestal. Some of these results are presented and discussed.

# ATOMIC COPPER DENSITY MEASUREMENT IN A CYLINDRICAL MAGNETRON DISCHARGE

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*Session:* VII.5 Thursday 10:50 am.

Absorption spectroscopy is a standard technique for measuring ground state densities. Absorption at the two Cu resonance lines (324.7 nm and 327.4 nm) of radiation from a Hg arc has been used to measure the Cu atomic density in a cylindrical magnetron discharge with Cu cathode. Absolute densities have been obtained as a function of radial position for a variety of discharge conditions. This paper will describe the measurement technique and discuss its interpretation.

# SIMULATION OF A LARGE LANGMUIR PROBE IN A MAGNETIZED FLOWING PLASMA

Hoon Kim*and Robert Porteous
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*Session:* VII.8 Thursday 11:40 am.

In ECR and helicon reactors for plasma processing, a high density plasma is generated in a source region which is connected to a diffusion region where the processing takes place. Large density and potential gradients can develop at the orifice of the source which drive ion currents into the diffusion region. The average ion velocity may become the order of the sound velocity [1]. Measurements of the ion saturation current to a Langmuir probe are used as a standard method of determining the plasma density in laboratory discharges. However, the analysis becomes difficult in a streaming plasma. We have used the HAMLET plasma simulator to simulate the ion flow to a large langmuir probe (d $\gg \lambda_D$ ) in an ECR plasma. The collection surface was aligned with the field upstream, normal to the field, and downstream. Ion trajectories through the electric and magnetic fields were calculated including ion-neutral collisions. We examined the ratio of ion current density to plasma density as a function of magnetic field and pressure.

[1] T. Nakano, N. Sadeghi, and R. A. Gottscho, Appl.Phy.Lett. 58 (1991) 458

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# DEVELOPMENT OF PLASMA PROCESSING AT NISSIN ELECTRIC

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*Session:* IV.2 Tuesday 2:30 pm.

A plasma CVD process has been used to deposit a Si thin film for a Thin Film Transistor (TFT) in the active matrix LCD panel. In the deposition process, dust particles are also formed in the plasma and this causes a serious problem in the production yields. Dust reduction by plasma parameter control and system consideration, such as a chamber structure, are one of the main objectives of this study.

Other efforts are being made to improve the quality of Si films. The mobility of a Si TFT panel is of the order of 1 $cm^2/Vs$. However it is desirable to improve the mobility. This is also being tried by controlling plasma parameters. An overview of the problems in the p-CVD process, and some results, will be presented at the meeting.

# INVESTIGATION OF ELECTRODE MELTING BY ELECTRIC ARCS

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*Session:* IV.1 Tuesday 2:00 pm.

We have recently developed an arc-electrode theory [1], which treats the electrode and arc regions together and predicts temperature contours by solving the conservation equations of energy, mass and momentum. A special treatment is used to represent the plasma sheath regions between the arc and the electrodes. The theory has been used to predict melting of electrodes of free burning electric arcs in argon, and these predictions are compared with new experimental measurements that we have made . Three particular cases have been examined: (a) melting of the extreme tip of a thoriated tungsten cathode; (b) the property that at high current the cathode can melt away from the tip so that the conical tip falls from the main cathode; (c) the melting of anodes of various thicknesses. For case (a) both theory and experiment indicate that at 200 A a cathode with a 60° conical tip melts and forms a hemispherical tip of radius 0.1 mm. For case (b) we find experimentally that a sharp tungsten cathode of conical angle 16° has a maximum temperature $\sim$ 3 mm from the tip at a current of 200 A, and the tip falls from the cathode for higher arc currents. Our theoretical results are in fair agreement with this experiment, and indicate that the result is due to the combined effects of the cooling at the cathode tip by thermionically emitted electrons and Ohmic heating within the solid cathode. For case (c) predictions are presented for the current required for the onset of melting of copper anodes of various thicknesses, and the results for a 5 mm thick anode are in fair agreement with experiment.

[1] P.Zhu, J.J.Lowke and R.Morrow, J.Phys.D:Appl. Phys. **17** (1992) 1189.

# GRAVITATIONAL COLLAPSE ON A MAGNETIC DIPOLE

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*Session:* VII.9 Thursday 12:00 pm.

The final stages of a supernova collapse are investigated using Smoothed Particle Magnetohydrodynamics. The special features of the numerical method adopted to the problem and its verification will be discussed. The investigation centres around the problem of generating dipolar jets from such a system. A variety of outflows will be illustrated and discussed.

# PLASMA POTENTIALS IN THE HELICON PLASMA REACTOR

Andrew Perry and Harold Persing
*Plasma Research Laboratory, RSPhysSE, ANU*

*Session:* VI.7 Wednesday 4:40 pm.

During plasma etching of $SiO_2$ the energy of the ions (in the range 15 – 200 eV) incident on the wafer being etched can be determined from the waveform of the rf bias applied to the substrate. These measurements suggest that, under certain conditions, the plasma potential rises well above its usual value of around 15 V. Using emissive and langmuir probes we have determined that the rf power applied to the wafer does not drive the plasma to higher potentials. These experiments show that the changes in the plasma potential occur because polymers, deposited on the reactor walls, insulate the plasma from earth.

# ETCHING OF AMORPHOUS $Si_{1-x}Ge_x$ FILMS IN A HELICON REACTOR

Harold Persing* and Andrew J. Perry
*Plasma Research Laboratory, RSPhysSE, ANU*

*Session:* IV.7 Tuesday 4:40 pm.

Previous etching of SiGe alloys has focused on the etching of crystalline films using conventional Reactive Ion Etching (RIE) [1,2]. In contrast, the Helicon reactor allows etching at low pressures with complete control of ion energies. Undoped $Si_{1-x}Ge_x$ films, with $0.05 \leq x \leq 0.8$, were evaporated onto Si(100) wafers. These films were etched in a Helicon reactor using $CF_4$, $CHF_3$, $SF_6$, and $CF_2Cl_2$ chemistries. The etch characteristics were measured as functions of etchant flow rate (neutral density), rf power (ion density), and substrate bias voltage (ion energies). The implications of these results for device fabrication will be discussed.

[1] A.A. Bright, S.S. Iyer, S.W. Robey and S.L. DeLage Appl. Phys. Lett. 53 (23), 5 December 1988, 2328
[2] G. S. Oehrlein, Y. Zhang, G.M.W. Kroesen, E. de Fresart and T.D. Bestwick, Appl. Phys. Lett. 58 (20), 20 May 1991, 2252

*The authors thank the Materials and Microelectronics Technology Centre, Royal Melbourne Institute of Technology for the SiGe films

# EVOLUTION OF TEARING MODES WITH MULTIPLE RATIONAL SURFACES

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*Session:* III.4 Tuesday 10:40 am.

The non-linear evolution of tearing modes with multiple rational surfaces is discussed. It is demonstrated that, in the presence of small differential rotation, the non-linear growth might be faster than exponential. This growth occurs as the rotation frequencies of the plasma at the different rational surfaces equilibrate.

# PONDEROMOTIVE EFFECTS OF HF HEATING IN FUSION DEVICES

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*Session:* V.4 Wednesday 10:10 am.

A survey of ponderomotive effects at plasma heating by high frequency (HF) waves in fusion devices is presented. Three groups of such effects are discussed:
(i) Changes in coupling due to ponderomotive force effects.
(ii) HF waves induced radial plasma transport.
(iii) Nonlinear scattering of HF waves.
Changes in coupling are due to plasma density variations near the coupling structure due to ponderomotive force of the wave. Plasma density in front of the coupling structure may decrease or increase due to ponderomotive forces in dependence on the sign of the HF potential of these forces. For example, at lower hybrid heating, the plasma is expelled along the magnetostatic field lines and the plasma density in front of the coupling structure (grill) decreases when the HF power grows. These effects have been found first on small experiments in low temperature plasmas and then also on tokamaks, e.g. on the Frascati FT tokamak and on the ASDEX tokamak in Garching.

HF induced radial plasma transport may arise due to the wave momentum and/or helicity injection. In the presence of a poloidal magnetostatic field not only the azimuthal (poloidal) but also the axial (toroidal) momentum injection leads to HF induced radial plasma transport. Effects of this type have been observed, e.g. on the linear RFC-XX device in Nagoya and on the small toroidal plasma experiment R-O in Sukhumi. It is noted that for some sets of parameters, such effects might be observed also on the BASIL and SHEILA devices in Canberra. These effects are more emphasized at lower frequencies; at lower hybrid and higher frequencies, they are too weak to be observed in the bulk plasma in high temperature plasma experiments. Transport of some fraction of plasma (a sort of impurities) might be influenced.

Finally, the wave may scatter on axial plasma modulations selfconsistently produced by ponderomotive forces. This may lead to generation of higher spatial harmonics (higher $N_{\parallel}$), which is an effect important for solving the so called spectral gap problem of the lower hybrid heating.

# MODELLING A HIGH DENSITY LOW PRESSURE MAGNETIZED ARGON DISCHARGE

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*Session:* VII.6 Thursday 11:10 am.

The HAMLET plasma simulator models plasma transport in self consistent electric fields and applied magnetic fields, for azimuthally symmetric systems. It can be used to investigate the interaction between neutrals and a high density argon plasma under typical plasma processing conditions. The model includes ionization and excitation, ion neutral charge exchange, ion pumping, and heating of neutrals by both electrons and ions. The neutrals thermalize collisionally and are accommodated at the walls. Ions and neutrals are modelled using particle-in-cell techniques which follow their trajectories in the electric and magnetic fields, and which take account of collisions. The plasma potential, and electron density and temperature are modelled through a finite element solution of Poisson's equation and the continuity equations for mass and energy. Magnetized plasmas can exhibit sharp cross-field gradients of plasma potential and electron temperature. The nature of "shadow regions", where the electron temperature is depressed, is examined using HAMLET and is shown to be very sensitive to the details of plasma surface interactions.

# PLASCON TECHNOLOGY FOR WASTE MANAGEMENT

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*Session:* II.2 Monday 2:30 pm.

The application of plasma technology for the destruction of hazardous, toxic chemicals is gaining popularity and considerable amount of research and development work is under pursuit in many parts of the world. The work pursued in Australia is discussed in this paper in the light of the applicability of the technology, the experience gained from pilot studies and a few technical issues relevant to its continued development.

In Australia, the application development of the plasma technology has been pursued by CSIRO and Siddons Ramset Limited of Australia. This technology is known as the PLASCON (PLASma CONversion) and has been applied to the treatment of chlorophenolic substances, which are the byproducts of the manufacture of 2,4-D herbicide. A pilot plant, rated at 150 kW electrical, to treat approximately 900 kgms of material per day has been constructed by Nufarm Limited (manufacturer of herbicide), Siddons Ramset Limited and CSIRO. Studies aimed at optimising its performance in terms of throughput and destruction efficiency have been conducted.

PLASCON has achieved a destruction performance of better than 1 part per million remaining (DRE 99.9999%). Modelling of the process together with chemical kinetic studies has allowed us to develop an understanding of how this has been achieved. For a highly concentrated waste mixture of organochlorines containing over 30% chlorine, Dioxin and Furan air emissions from PLASCON are in the range 0.006 and 0.009 $\mu g/m^3$ (TE). This is at least 10 times better than the tightest world standard.

Our experience shows the plasma technology takes its place amongst the wide range of available waste treatment technologies. Plasma technology is particularly suited to the treatment of highly concentrated wastes. The inherent very high temperature nature of plasma lends the technology to small scale plants for on site waste treatment.

# EXPERIMENTAL STUDIES OF RF PRODUCED PLASMAS AND WAVE PROPAGATION IN BASIL

D. A. Schneider, B. D. Blackwell, G. G. Borg, R. W. Boswell and B. C. Zhang
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*Session:* V.7 Wednesday 11:30 am.

The BASIL plasma source has recently been upgraded to 30 kW radio frequency power in the range 4 – 26 MHz. It is now possible to produce a wide range of plasma conditions in BASIL with fields in the range 0.01 to .2 T, a range of gases including Hydrogen and densities up to $10^{20}$ $m^{-3}$. Experiments have now begun on fundamental wave propagation studies in RF produced plasmas, non-linear wave excitation, RF induced transport and mechanisms of plasma formation.

In this paper we report results taken at 7 MHz with three different types of antenna: (1) a $|m| = 1$ double loop antenna, (2) a $|m| = 1$ helical antenna with helicity sign$(k/m) > 0$, where $k$ is the parallel wave number and $m$ the poloidal mode number and (3) an $m = 0$ poloidal loop antenna. We present detailed spatial profiles of the wavefields for a variety of different gases and make a preliminary attempt to explain the observations and link these to the properties of the plasma.

Large effects depending on the exciting antenna are observed. For example, it is shown that the dominant mode excited has $m = +1$ for both type (1) and (2) antennas. For the type (1) antenna the plasma is symmetrical along the axis around the antenna as would be expected. For the type (2) antenna plasma formation is strongly enhanced along the magnetic field in the direction of positive $k$.

# PLASMA ETCHING OF InP IN A HELICON DIFFUSION REACTOR USING METHANE AND HYDROGEN MIXTURES

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*Session:* IV.8 Tuesday 5:00 pm.

Plasma etching of InP in a Helicon diffusion reactor has been investigated using methane and hydrogen mixtures. Measurements of etch rate as a function of pressure, substrate rf bias and confining magnetic field will be presented together with measurements of ion current density. These measurements show that the etch rate is a strong function of the ion current density. Very high etch rates (500 nm $min^{-1}$) at low pressure (up to 4 mTorr) were obtained with methane and hydrogen mixtures (25 % of $CH_4$ in $H_2$) and confirms the advantage of the Helicon source for the production of high density plasma for plasma processing.

# TRANSIENT EFFECTS IN TRAVELLING AND ROTATING FIELD CURRENT DRIVE

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*Session:* V.2 Wednesday 9:30 am.

A general method has been developed to calculate the time-dependent currents driven by travelling waves applied to toroidal plasmas and rotating or oscillating magnetic fields applied to spherical plasmas due to the non-linear interaction between the driven radio-frequency currents and the magnetic fields. These results apply to the Rythmac and Rotamak devices at Flinders University. Time-dependent calculations are necessary to determine the time scale of the establishment of a steady configuration and its dependence on the plasma and applied field parameters. They also provide an alternative route to the determination of the steady configuration. In toroidal, large aspect ratio, geometry the method involves expansion of the field quantities in double Fourier harmonics, while in spherical geometry we need to use a vector spherical harmonic expansion which involves the use of generalised Clebsch-Gordon coefficients in order to handle the non-linear terms. The results showed the feasibility of establishing the current within a reasonable time scale and predicted the existence of second and higher temporal harmonics in the driven current, an observation that was later experimentally confirmed.

# A SELF-CONSISTENT SIMULATION OF A MAGNETRON DISCHARGE

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*Session:* VII.7 Thursday 11:30 am.

Magnetron discharges are widely employed in industry to manufacture thin films by sputter deposition. To gain insight into the physical mechanisms sustaining the discharge a self-consistent numerical simulation in argon is being developed using cylindrical geometry. The electrical behaviour of the discharge is modelled using a 1-D, 3-V Particle-In-Cell (PIC) code, while ion-atom and electron-atom collisions are modelled using Monte-Carlo techniques.

Results of this simulation will provide detailed understanding of the physical characteristics of the system, including potential distributions, particle trajectories, sheath widths and energy distributions. The performance of the discharge can be examined for a large range of input parameters such as gas pressure, applied voltage, magnetic field strength and system geometry. A set of optimum operating conditions can thus be determined which will aid in the design of future magnetron discharges.

This talk will present some preliminary results from this PIC simulation.

# PLASMA IMMERSION ION IMPLANTATION AT A RANGE OF TEMPERATURES

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*Session:* IV.3 Tuesday 3:00 pm.

Plasma Immersion Ion Implantation (**PI**$^3$) is a surface treatment technique for metallurgical tools and components that was originally developed as an alternative to ion beam implantation [1]. Nitrogen ions are accelerated from a rf plasma by high voltage pulses (up to 50 kV) applied directly to the component to be treated and give rise to significant heating of the workpiece. In the absence of additional cooling, radiation is the dominant energy loss mechanism and the treatment temperature is controlled by regulating the high voltage pulse frequency. In the **PI**$^3$ treatment of steels, this heating can be exploited to give a duplex implantation/diffusion treatment in a single process [2]. At low temperatures (up to 250 deg C), the microstructural and compositional changes in the surface region are similar to those obtained by conventional ion beam implantation of nitrogen. Under such conditions, significant improvements in the tribological behaviour of a range of steels have been obtained. At higher temperatures, a hardened diffusion zone forms under the implanted layer. Compositional studies indicate that nitrogen is introduced into the material not only by the high energy implantation but also by direct thermochemical absorption. The microstructure obtained is reminiscent of those obtained by plasma nitriding, with a nitride layer several microns thick and a diffusion zone extending deeper into the steel. The exact nature of the nitride layer, however, is dependent on treatment temperature, composition of the steel and plasma properties. Support for this work has been provided under the Generic Technology component of the Australian Industry Research and Development Act 1986.

[1] J.Tendys, I.J.Donnelly, M.J.Kenny and J.T.A.Pollock, Appl. Phys. Lett., **53** (1988) 2143.
[2] R.Hutchings, G.A.Collins and J.Tendys, Surf. Coat. Technol., **51** (1992) 489.

# RADIO FREQUENCY PLASMA IMMERSION ION IMPLANTATION (RF PI$^3$): STRUCTURE AND PROPERTY MODIFICATION OF STEEL SURFACES

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*Session:* IV.4 Tuesday 3:40 pm.

Nitrogen ion implantation by the RF PI$^3$ process has been shown[1] to significantly improve the surface properties of some steels whilst retaining the bulk properties of the substrate. For example, a rod of H13 tool steel, originally 750HV throughout, developed a surface hardness of 1500HV25g with a bulk hardness of 500HV, after a PI$^3$ treatment of a dose of 15 × $10^{17}$ at 350° C. Current techniques for observing the implanted layers have included the $^{14}N(d,\alpha)^{12}C$ nuclear reaction and glancing angle X-ray diffraction, while the surface properties have been found by microhardness measurements and pin on disc wear tests. The use of transmission electron microscopy (TEM) in determining the microstructural changes occurring through implantation has been hampered by the difficulty of preparing a thin area in shallow surface layers. Furthermore, there has been the need for a controlled wear test more representative of the harsh service conditions encountered in proposed applications of PI$^3$. Finally, there is no mathematical model available to assist in the prediction of the depth of hardening from a given treatment.

This paper presents the observation on PI$^3$ modified surface layers on steel from the techniques of micro-hardness measurement, TEM and wear testing. A description of the approach to a mathematical model of the PIII process will be given.

Rod specimens, 2mm in diameter, of a secondary hardening tool steel (type AISI A2) were implanted with a dose of 12 × $10^{17}$ N/cm$^2$ at a temperature of 350°C.

Micro-hardness depth profiles were obtained by scanning electron microscope examination of implanted cross sections indented with a 25g Vickers load. A peak hardness of 1500HV was recorded at a depth of 18mm below the surface with a diffusion depth of 60mm .

Microstructural observations were made by TEM on a transverse cross section of the implanted rod. Fine plate-like precipitates of vanadium nitride were present in the hardened layer. A novel sample preparation was developed and involved wedging the treated rod into a 3.05mm diameter tube with epoxy, before dimple grinding at the contact point, and ion milling.

Reciprocating wear tests were performed using two rods loaded together, crossed an angle of 35°. Implanted and untreated rods were tested against a standard rod of WC with parafin oil lubrication. This test was designed to simulate the wear environment at the cutting edges of sheep shearing tools. The results showed a clear improvement in the surface wear life by ion implantation.

A mathematical model of the PI$^3$ process is under development and is designed to assist in the prediction of the implantation conditions required to produce a surface layer with the optimum properties by taking account of thermal diffusion.

[1] R. Hutchings, M.J. Kenny, D.R. Miller and W.Y. Yeung, paper presented at the Surface Engineering Conf., SAIT, 12-14 Mar., 1992.

# CURRENT DRIVE INFORMATION FROM MEASUREMENTS OF THE STEADY AND HIGH FREQUENCY MAGNETIC FIELDS IN THE TOROIDAL DEVICE $< \tilde{\mathbf{j}} \times \tilde{\mathbf{b}} >$ RYTHMAC

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*Session:* V.3 Wednesday 9:50 am.

Detailed measurements of both the steady and radio-frequency magnetic field distribution within the toroidal rf current drive device RYTHMAC, $R_0 = 0.375$ m, $a = 0.075$ m have been performed and will be presented.

A total rf power of about 250 kW at $f = 500$ kHz, coupled through an $m = 1$ double helix antenna drives steady toroidal current ($\sim 600$ A) and steady poloidal current ($\sim 6000$ A) in a plasma formed from hydrogen at 4 mtorr. The steady current density distribution, determined from the steady magnetic field measurements, is found to be hollow as is the driving $< \tilde{\mathbf{j}} \times \tilde{\mathbf{b}} >$ force density, calculated from the rf magnetic field data. Furthermore, the experimental data on the rf fields reveals strong magnetic field harmonics at $2f$, $3f$, $4f$ etc. produced by the non-linear $< \tilde{\mathbf{j}} \times \tilde{\mathbf{b}} >$ effect. These results and their implications to the $< \tilde{\mathbf{j}} \times \tilde{\mathbf{b}} >$ technique of rf current drive will be discussed.

# RESEARCH ON MITIGATION OF STRATOSPHERIC OZONE DEPLETION

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*Session:* II.1 Monday 2:00 pm.

Chlorine atoms relased from CFCs by solar Ultraviolet (UV) radiation and from natural sources, are effective catalytic agents for the destruction of stratospheric ozone. Research into large-scale mitigation methods is based on charging the chlorine radical, converting it into negative ions of low reactivity. Generation of charges and subseqent removal of chlorine ions by atmospheric platforms and electromagnetic waves are described. This method is generally applicable to all halogens. This research is guided by the principle that the solution should be as non-intrusive environmentally as possible: i.e. no chemicals are to be injected. The large-scale mitigation requires the process to be energy efficient and to utilize energy sources( solar radiation and auroral current) already present in the atmosphere. Each remediation system is being tested using a combination of laboratory and field experiments together with computer modeling. The first laboratory demonstration of ozone depletion and subsequent recovery due to charge injection is presented. The extension to field experiments and the confirmation of this concept by computer modeling will be discussed.

# EXPERIMENTAL FAST WAVE STUDIES IN SHEILA

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*Session:* V.8 Wednesday 11:50 am.

Fast magnetosonic waves were excited by an electrostatically shielded half-turn loop antenna in SHEILA. Some fundamental properties, including the radial structure, of the excited waves at $f = 18$ MHz were studied and compared with theory. Measurements of radiation resistance showed that about half the total RF power on the antenna could be coupled to plasma waves. The excited waves were mainly composed of two azimuthal eigenmodes, $m = 0$ and $m = +1$, consistent with the calculated antenna power spectrum. The ratio of the magnitude of the two modes was about 100 : 60 (100 for $m = +1$, 60 for $m = 0$) and the $m = +1$ mode propagated slightly slower than the $m = 0$ mode. We also found that for a wide range of magnetic fields, $n_e/B_0$ was constant, and under these conditions the measured parallel phase velocities of the waves were also constant. The propagation of the excited waves agrees very well with the theory of the helicon wave in a cylindrical plasma [1].

[1] F. F. Chen, Plasma Physics and Controlled Fusion, **33** (1991) 339.

# ABSTRACTS OF POSTERS IN SESSION P-I

(alphabetically by presenting author)

# HELICON WAVE PROPAGATION AND PLASMA PRODUCTION IN SHEILA

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*Session:* P-I Monday 5:00 pm.

Helicon waves are launched in SHEILA ($B_0 = 0.02 - 0.2$ Tesla, $n_e \sim 10^{19}$ $m^{-3}$, $f = 3 - 28$ MHz) from a pair of current loops placed on opposite sides of the plasma, and twisted to follow the magnetic field lines and magnetic surfaces. Wave propagation characteristics are presented, including parallel and perpendicular wave numbers, and radial and azimuthal mode analysis. The dominant modes are $m = 0$ and 1, and their ratio depends on magnetic field and gas.

Plasma is efficiently generated by this antenna over a wide range of magnetic fields and gases. Detailed results for helium and argon will be presented, supplemented by data for neon, hydrogen and deuterium.

Evidence for wave-particle interaction in both argon and helium is presented in the form of observations of the electron distribution function. Langmuir probe data will be presented in detail, with some directional information from paddle probes. Hot probe measurements are interpreted to obtain the r.f. plasma potential oscillation amplitude and mean value. A high energy bump-on-tail feature is shown to coincide with the wave phase velocity, with energies corresponding to a large ionization cross-section.

Although frequency spectra show little evidence of parametric decay, a component offset from the r.f. carrier by the drift oscillation frequency is observed.

# THE H-1 RADIO FREQUENCY POWER SYSTEM AND THE FIRST RESULTS ON PLASMA FORMATION

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*Session:* P-I Monday 5:00 pm.

Over 200 kW of radio frequency power is available for plasma formation and heating in H-1. 200 kW in the range 4–26 MHz will be provided by eight type CLH30-J commercial broadcast transmitters and 20 kW at 64 MHz by one type TVB10/A television transmitter.

In this paper we describe the design and performance of the different components of the radio frequency transmission system. The eight broadcast transmitters will be combined into two antennas by six high power combiners. We describe the design and performance of a prototype power combiner, the DC break which isolates H-1 from the RF earth and the forward and reflected power line diagnostic.

Plasma formation was achieved with a $|m| = 1$ double loop antenna and for the first phase of operation, 30kW of power was available at 7 and 14 MHz. We describe the characteristics of the first RF produced plasmas in H-1 for a range of RF powers, magnetic fields and filling gases.

# SOFT X-RAY TEMPERATURE DIAGNOSTIC FOR THE H-1 HELIAC

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*Session:* P-I Monday 5:00 pm.

An x-ray measurement system has been designed to monitor the soft x-ray emission from the H-1 plasma. This system will comprise two silicon surface barrier detectors used in avalanche mode. The two detectors will be mounted close to the plasma in a re-entrant tube viewing the plasma from above, along the long axis of the bean shaped cross-section. They will be mounted behind Beryllium windows of thicknesses 12.5 and 25 microns such that the filter ratio method can be used to determine the central electron temperature.

The predicted electron temperature and density combination of the H-1 plasma will generate low levels of x-ray flux at very low energies. Consequently the x-ray detection system will be operating at the upper limit of sensitivity. Because of the requirement of high sensitivity, detailed simulations of the H-1 x-ray emission have been carried out, including the heliac plasma geometry with bean shaped temperature and density profiles and the detector system geometry. Folding in the window, filter and detector transfer functions allows the calculation of the resulting detector current. These simulations have been used to adjust the window/filter/detector geometry for optimum flux and resolution. The detection system includes carefully designed and matched, high sensitivity, low noise transimpedance pre amplifiers such that low flux measurements can be made.

Details of the simulations and design will be presented.

# DEVELOPMENT OF NEOCLASSICAL TRANSPORT SIMULATION FOR THE H-1 HELIAC

Sean A. Dettrick, Scott L. Painter, Gerard G. Borg, Robert L. Dewar, Henry J. Gardner
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*Session:* P-I Monday 5:00 pm.

A parallelised Monte Carlo code simulating neoclassical transport using the guiding centre motion of ions in the H-1 Heliac [1] has been ported to the Connection Machine CM-5 supercomputer. The code currently uses a set of Ito stochastic differential equations in Boozer coordinates to simulate the effects of test particle ions scattering off background ions in a fixed electric field. A self consistent electric field, an ion-electron scattering term for energy transfer and a cold ion source to replace lost particles are being introduced to the code.

[1] S.L. Painter, submitted to Comput. Phys. Commun. (1993)

# STUDY OF THE MECHANISM OF WOOL SURFACE MODIFICATION BY OXYGEN PLASMA*

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*Session:* P-I Monday 5:00 pm.

The study is undertaken in the plasma device, JUMBUCK, which consists of an r.f. discharge plasma source (15cm diameter x20cm long glass cylinder) supplied with $0_2$ at $10^{-4}$mb to $10^{-1}$mb, mounted above a reaction chamber. A fine wire mesh can be inserted between the source and the chamber to restrict the flow of charged particles into the chamber without affecting the neutrals. The proposed reaction model involves a three-step process:
(1) ionization and excitation: $e + 0_2 \longrightarrow 0_2{}^+ + e$ ; $e + 0_2 \longrightarrow 0_2{}^* + e$;
(2) dissociation: $e + 0_2{}^+ \longrightarrow 0 + 0$ ; $e + 0_2{}^* \longrightarrow 0 + 0 + e$;
(3) $0$ + Wool $\longrightarrow$ ?.

Plasma parameters and relative reactive particle densities have been measured in the chamber using a langmuir probe and vacuum ultra-violet spectroscopy, both with and without the separated mesh. The weak radiation from the plasma in the chamber is used for both emission and absorption measurements to derive reactive particle densities. The outcome of the experiments support the view that the surface modification results mainly from interaction with reactive neutral species. The neutral particle density in the chamber is directly related to the source parameters. It is found that the plasma condition and optimization of the processing reaction rate are determined mainly by the source operating pressure.

*Work supported by the Wool Research and Development Corporation

# TIME AND SPATIALLY RESOLVED OPTICAL EMISSION IN A HELICON REACTOR

A.R.Ellingboe, R.W. Boswell, J.P.Booth†, N.Sadeghi†
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*Session:* P-I Monday 5:00 pm.

Short lifetime argon ion line ($\lambda = 443$ nm, $\tau = 20$ ns) emission strengths have been measured as a function of axial and angular positions (integrated over the radius) and phase within an RF cycle in a helicon reactor. The modulation is found to travel in the axial dimension at the same speed as the waves launched by the antenna. Implications for landau damping and power deposition will be discussed.

# ARNOLD DIFFUSION OF ELECTRON ORBITS IN THE H-1 HELIAC

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*Session:* P-I Monday 5:00 pm.

An experiment has been proposed [1] to examine the diffusion of the drift island centres of electron orbits in the H-1 Heliac due to Arnold diffusion. The Arnold Diffusion is driven by interaction between magnetic field line stochasticity and a time dependent electric field. A calculation of the diffusion rate using magnetic coordinates is discussed, as well as the effects of introducing a collision operator to the formalism.

[1] A. J. Lichtenberg, Phys. Fluids B 4 (1992) 3132–3137.

# CAPTURE-THEOREM FOR FLUX-MINIMIZING MAGNETIC SURFACES

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*Session:* P-I Monday 5:00 pm.

Three dimensional MHD and transport studies in nonaxisymmetric devices, such as the H-1 heliac, routinely make use of curvilinear coordinate systems based on the assumption that magnetic field lines lie in invariant (KAM) surfaces. This is only approximately true since the magnetic field is equivalent to a time-dependent Hamiltonian system, which is not generically integrable. In order to quantify the quality of the approximation, the surface integral over a trial surface of the square of the normal component of the magnetic field is studied as an objective functional whose minimum defines an optimal approximating magnetic surface. It is shown, both by using a curvilinear coordinate system and by coordinate-free differential geometric methods, that a surface extremizing the quadratic flux is such that if a field line is at some point tangent to the surface, then it is tangent to the surface everywhere along its length. This "capture theorem" is the analogue of the theorem [1] that intersections of flux-minimizing curves for area-preserving maps are orbits.

[1] R. L. Dewar and J. D. Meiss, Physica D 57 (1992) 476–506.

# ETCHING AND DEPOSITION IN THE HELICON REACTOR WITH $SiCl_4$

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*Session:* P-I Monday 5:00 pm.

Experiments in the helicon reactor have demonstrated that etching in a $SiCl_4$ plasma competes with a deposition process. Adjusting any of the operating parameters — gas flow, source power, bias voltage or target temperature — can determine whether etching or deposition occurs. This process has been characterized for a wide range of operating conditions. Plasma parameters, SEM, RBS, and AES measurements of the deposited films and the etched surfaces will be presented together with etch rates of GaAs.

*MJ thanks the Australian Telecommunication and Electronics Research Board for financial support

# FLUX-MINIMIZING CURVES THROUGH ISLANDS

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*Session:* P-I Monday 5:00 pm.

An area-preserving map acts provides a model problem for studying the properties of the Poincaré surface of section map, or "puncture plot", generated by following magnetic field lines around a toroidal plasma confinement device. In particular it allows the careful study of the problem of defining approximate magnetic surfaces by minimizing a quadratic flux functional [1]. The Euler-Lagrange equation for an appropriate discrete version of the quadratic flux [2] is solved not only by KAM curves, but also has smooth solutions passing through the stable and unstable periodic orbits of island chains. The lowest order resonances, 0/1 and 1/2, of the Standard Map have analytic solutions that can be shown to exist for arbitrarily high nonlinearity. Progress on the existence or otherwise of a critical nonlinearity in the case of higher order resonances will be reported.

[1] R. L. Dewar, S. R. Hudson and P. Price, this conference.
[2] R. L. Dewar and J. D. Meiss, Physica D 57 (1992) 476–506.

# CALCULATIONS OF DIMENSIONS AND ATTRACTORS OF NON-LINEAR TEARING MODE DYNAMICS.

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*Session:* P-I Monday 5:00 pm.

Simulations of resistive magnetohydrodynamics in a rotating plasma are analyzed by calculating correlation dimensions and local intrinsic dimensions. A rotating plasma with a nonlinear oscillatory state is found to be associated with a low-dimensional attractor. The solutions are also checked for sensitivity to initial conditions, characterized by the sign of the largest Lyapunov exponent.

# CALCULATION OF DRIFT WAVES IN HELIAC GEOMETRY

Hans Nordman,
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*Session:* P-I Monday 5:00 pm.

Preliminary results from linear eigenvalue calculations of electron drift waves in 3-dimensional helical axis stellarator equilibria are presented. The calculations, which are relevant to the H1 Heliac, are based on the standard ballooning mode formalism in Boozer coordinates. A shooting method is used to solve the eigenvalue problem along the field lines. Our emphasis is on the effect of the 3-dimensional geometry so that a simple dissipative electron model is used for the drift wave modes themselves. In particular we will discuss the localization of the drift wave in the helical ripple and make comparisons with earlier work.

# PARTICLE DIFFUSION ALONG THE STOCHASTIC WEB IN THE FIELD OF A WAVE PACKET AND A MAGNETIC FIELD

B. A. Petrovichev

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*Department of Theoretical Physics, RSPhysSE, ANU*

*Session:* P-I Monday 5:00 pm.

A brief review of the results for the motion of a particle in an homogeneous magnetic field and the field of a wave packet is presented. The conditions for the existence of stochastic webs in this dynamical system and some peculiarities of the diffusional transport of particles along such webs are discussed. It is shown that the main conditions for the existence of the stochastic webs are: 1) the unperturbed dynamic system is linear or degenerate and 2) there exists an exact resonance relation between the cyclotron frequency and the frequencies of the wave packet. Examples of the stochastic webs are presented as well as their symmetry, width and structural changes when the wave packet have one, finite or infinite number of harmonics.

A global stochastic web has been observed when a wave packet has only one harmonic. The existence of a global stochastic web leads to an universal particle diffusion similar to the Arnold diffusion. In this case however the diffusion quickly ceases because the width of the web decreases exponentially fast as the perturbation diminishes as well as the distance from the origin of the phase portrait increases. In the case of a uniform and infinitely broad wave packet the global stochastic web also exists. The thickness of the web is approximately constant over the whole phase plane and unbounded stochastic heating of the particles is possible. Nevertheless the diffusion does not occur very rapidly since the thickness of the web is exponentially small according with perturbation parameter. The stochastic web also was found in the case of finite number of harmonics. In this case the rate of the stochastic heating of a particle is effectively finite and grows only if number of harmonics grows. If the wave packet propagates obliquely to the magnetic field, one more degree of freedom, corresponding to the longitudinal motion, appears in the system and this leads to a sharp enhancement of the diffusion.

# ON HELICON WAVE INDUCED RADIAL PLASMA TRANSPORT

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*Session:* P-I Monday 5:00 pm.

The purpose of this contribution is to estimate the helicon wave induced radial transport of plasma. We use two fluids magnetohydrodynamic equations and consider here a cylindrical model of plasma which allows to obtain analytical expressions for ponderomotive forces and to elucidate the role of the poloidal magnetostatic field and of the wave polarization on the radial plasma transport.

It has been found that for helicon waves with electric fields of the order of 1 kV/m, the wave induced transport velocity may be of the order of tens of meters per second, which is comparable to the estimated diffusion velocity in some experiments with plasma generated by helicon waves. However, this wave induced transport may change its sign in dependence on whether the $m = 1$ or the $m = -1$ helicon is excited.

For magnetostatic field oriented along the positive direction of the coordinate $z$, the $m = 1$ helicon induces plasma transport velocity oriented to the plasma interior. In other words, the plasma confinement is ammended in this case. On the contrary, the $m = -1$ helicon induces plasma transport which supports the outward plasma diffusion and thus worsens the confinement. For the $m = 1$ and $m = -1$ helicons, the wave induced transport velocity does not change sign, goes to zero near the plasma centre and near the boundary and is maximum for radius slightly smaller than one half.

For the $m = 0$ helicons, the wave induced transport is smaller, as the term corresponding to the azimuthal wave momentum dissipation does not contribute to the azimuthal ponderomotive force. Further, for a given value of the radial electric field the azimuthal electric field is smaller for the $m = 0$ helicon than for the $m = 1$ and $m = -1$ helicons. The wave induced plasma transport velocity for the $m = 0$ helicons is directed outwards near the plasma centre and inwards near the boundary, which might support creation of hollow discharges.

We conclude that helicon waves induced radial transport may play an important role in the total plasma transport.

# MAPPING OF MAGNETIC SURFACES IN H-1

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*Session:* P-I Monday 5:00 pm.

Magnetic surfaces were studied experimentally in H-1 flexible heliac to confirm in situ the position and the shape of the magnetic surfaces and to search for errors in field-coil geometry. Magnetic lines are traced by an electron beam launched toroidally from an electron gun that is movable along the major radius of H-1. Eleven phosphor-coated rods mounted on a rotatable bean-shaped frame are used for detection of the electron beam. The design combines the advantages of the commonly used detection methods, namely, fluorescent mesh and single fluorescent movable rod. Accuracy of the measured location of the images is independent of the accuracy of the mechanical motion of the detector. The images appearing on the detector are recorded by a Reticon CCD camera for further computer processing and geometrical transformation. Both the electron gun and the detector system are driven by the stepping motors controlled by a computer.

Magnetic surfaces shape and rotational transform were studied for various magnetic configurations of H-1, including dependencies on the vertical and helical magnetic fields. The effect of the magnetized objects surrounding H-1 on the magnetic structure was investigated by mapping at very low magnetic fields. Experimental results on the magnetic mapping show good correspondence with numerical simulations for both closed configurations and a bifurcation-like case.

# THE H-1 HELIAC: DESIGN & CONSTRUCTION

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*Session:* P-I Monday 5:00 pm.

The H-1 Heliac is intended as a general research facility for basic studies of the behaviour of plasma confinement in a current free toroidal system. Operation with both pulsed ($< 1$ T) and continuous fields ($< 0.25$ T) allows the experimentalist to access a wide range of magnetic configurations and plasma conditions. Placing the magnetic field coil assembly inside the vacuum tank provides good diagnostic access. This design took account of the local construction and electrical power facilities as well as minimizing overall cost. Within these overall constraints, the dimensions of H-1 were set by the desire to maximize the minor cross section to keep the central plasma region from being contaminated by impurity recycling from the walls ($a > 150$ mm), and at the same time maintain a sufficiently large aspect ratio ($R = 1.0$ m) to reduce magnetic field ripple, and toroidal curvature for studies in plasma transport and stability of finite beta plasmas. The coil-in-tank assembly posed major consequences to the design and construction. First, all components had to be high vacuum compatible. Second the support structure and the coil assembly had to be fabricated to provide a position tolerance of the coils of $\pm 1$ mm and a deflection under operating load of $\pm 1$ mm. The major deflection is due to gravity and is 2 mm. Second, all coils have to be water cooled, using a complex water manifold inside the vacuum tank. H-1 has been operated in continuous mode with a magnetic field of 0.2 T and a base pressure of $3 \times 10^{-8}$ Torr.

[1] Fusion Technology, **17** (1990) 123

# THOMSON SCATTERING DIAGNOSTIC FOR H-1

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*Session:* P-I Monday 5:00 pm.

Measurements of the electron temperature and its spatial distribution in a magnetically confined plasma are vital for the study of the transport phenomena, plasma heating efficiency, plasma stability, confinement, etc. A Thomson scattering system has been designed to measure the radial profiles of electron temperature and density in H-1 plasma in the range of plasma densities $n_e > 4 \times 10^{18}\,\mathrm{m}^{-3}$ and $T_e = 100 \div 600\,\mathrm{eV}$.

The light of the 4J ruby laser ($\lambda_0 = 694.3\,\mathrm{nm}$), with a 30 ns pulse length is launched vertically through the plasma at the "standard" diagnostic cross-section of H-1. The input system consisting of three steering prisms and an input lens focuses laser radiation into the scattering volume. The last of these prisms is mounted on the flexible bellow in the upper port and serves as the vacuum window, allowing scanning of the laser beam along the major radius. The beam angle is controlled by two stepping motors. Stray light is minimised by input baffles mounted on the input prism subassembly, a viewing dump mounted on the helical conductor and a BG7 glass light filter acting as a beam dump. The receiver system is designed to maximize the amount of collected light with reasonable spatial resolution (typically the resolution is better than 8% of the plasma radius). A 0.5m diffraction grating spectrometer accepts the collected light from two f/4.5 lenses. Different diffraction gratings (600, 1200, 2400 lines/mm) can be used for different temperature ranges. The CCD detector array (512 pixels) and image intensifier allows flexibility in the number of the wavelength channels to obtain the necessary sensitivity.

The whole system is computer-controlled. This allows calibration of the scattering volume position (using calibration target) and spatial scanning of the beam. Further development of the system includes modification of the collection optics and the viewing window to scan the scattering volume vertically as a next step towards multichannel system.

# A MONTE-CARLO MODEL OF DIFFERENTIAL ARGON ION-NEUTRAL CROSS-SECTIONS

Helen Smith, R.K. Porteous, S. Defauconpret, and R.W. Boswell
*Plasma Research Laboratory, RSPhysSE, ANU*

*Session:* P-I Monday 5:00 pm.

Experimental measurements of perpendicular argon ion energies in low pressure plasmas have been found to be of the order of 10 times the neutral gas temperature. This is unexpectedly large, since the cross-section for ion-neutral collisions is expected to be highly anisotropic - leading to scattering angles close to 0° or 180° - and hence resulting in negligible perpendicular heating. To investigate this effect the collisions were modelled by classically integrating the $Ar - Ar^+$ interaction potentials to give the scattering angle as a function of energy and impact parameter. The resulting cross-sections are compared to experimental results, and are used in a one dimensional Monte Carlo code to simulate argon ions travelling through a background of neutral argon gas.

# TOMOGRAPHIC WIRE-GRID IMAGING OF MAGNETIC SURFACES

B.D. Blackwell, J. Howard, and R.B. Tumlos
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*Session:* P-I Monday 5:00 pm.

Initial studies of plasma confinement for a stellarator, like a heliac, involve understanding the structure and characteristics of the vacuum magnetic surfaces. After the construction of a stellarator device, the magnetic field, as designed, may be distorted by mechanical defects like coil misalignment or stray fields from sources like unshielded cables. In anticipation of this occurence, it is important to study the actual vacuum magnetic surfaces and compare them with the computer simulations to determine the presence or absence of such field errors.

The basic component of the technique of mapping the surfaces involves the use of an electron gun or a bare emissive-filament. Previous optical techniques used phosphor-coated mesh or rod detectors and CCD camera to store the light pulses from the detector.

In the method that we have developed, a grid of fine wire is used to make chordal scans of the electron beam and the current signals are then inverted using techniques similar to tomography. This will give a puncture plot of the magnetic surface not unlike the image from the optical technique.

The new technique was first applied in the small prototype heliac, SHEILA [1], using a grid which consists of 11x0.3-mm molybdenum wires and average spacing of 3.5-mm. Using low-energy electron beam, a few surfaces were mapped despite the challenging conditions that the size of SHEILA presented. The investigation that was done has proven that this approach is feasible and capable of results with the resolution and accuracy better than existing methods and avoids problems related to optics for imaging. The application of our surface mapping method in H1[2] is now on-going and design considerations will be presented based on simulations that we have done for the conditions existing in the bigger heliac.

[1] B.D. Blackwell, J. Howard, and R.B. Tumlos, Rev. Sci. Instrum. **63** (1992) 4725
[2] S.M. Hamberger, B.D. Blackwell, L.E. Sharp, and D.B. Shenton, Fusion Tech. **17** (1990) 123

# A MULTI-CHANNEL SIX-VIEW INTERFEROMETER FOR MEASURING PLASMA DENSITY PROFILES IN THE H-1 HELIAC.

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*Session:* P-I Monday 5:00 pm.

The H-1 heliac confines a helical plasma ($R = 1$m, $< a > \approx 0.2$m) defined by a set of nested magnetic flux surfaces with indented bean-shaped cross-section. In general the cross-section has no symmetry. Therefore many line integrals in many views are required to obtain a good tomographic reconstruction of the plasma density profile in the cross-section. Fourier analysis of the profile shows that almost all of the density distribution information is encoded in the first six angular harmonics so that at least six views are required to obtain a good reconstruction of the profile. We will discuss the status of a proposed novel multi-channel far-infrared laser-based interferometer that satisfies this requirement.

The interferometer uses a rotating cylindrical diffraction grating [1] to create a set of plasma-probing beams from a single incident beam and recombine those beams back onto a single return beam. As a result only one detector is required for each set of beams. A single-view 10-channel scanning interferometer based on such a grating has recently been installed on the University of Sydney TORTUS tokamak. The six-view interferometer extends on this system by splitting each beam incident on the plasma into two spatially separated orthogonally polarised plasma-probing beams. Thus six views are obtained from three sets of beams and sensed by six detectors. We will present tomographic images of synthetic phase objects illustrating the spatial resolution of a prototype dual-polarisation multi-channel two-view interferometer that uses this orthogonal polarisation technique.

[1] J. Howard. *Novel Scanning Interferometer for Two-Dimensional Plasma Density Measurements.* Rev. Sci. Instrum. **61** (1990) 1086–94.

# PLASMA FORMATION AND RF CURRENT DRIVE IN SHEILA

Beichao Zhang, Boyd Blackwell, Gerard Borg, Sydney Hamberger
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*Session:* P-I Monday 5:00 pm.

A half-turn fast wave loop antenna and an $|M| = 1$ double loop antenna are compared in SHEILA for plasma formation, RF current drive and antenna-wave coupling. When both antennas are excited simultaneously, the resulting plasma density is observed to depend (sinusoidally) on the phase difference between the two antennas, indicative of interference between the wave fields. Measurements of antenna cross-coupling show that a part of this coupling is dependent on the frequency difference of the two sources, and may be occurring as a result of the density variation. RF driven DC current is measured by a 900-turn bean-shaped, compensated Rogowski coil encircling the plasma. A value of $I = 3 - 5$A is obtained without antenna optimization. Numerous experiments with antennas driven separately or individually suggest that the current is real, although its excitation mechanism is not yet clear. Relative antenna-wave coupling efficiencies are measured under large-signal conditions by exciting each antenna by two different RF sources at slightly different frequencies. In this way, the individual wave fields can be detected separately. These experiments will provide a technique for studying the non-linear dynamical effects of two high power sources on the plasma, while still being able to measure the individual wave fields.

# ABSTRACTS OF POSTERS IN SESSION P-II

(alphabetically by presenting author)

# A MONTE CARLO MODEL OF BORON DIFFUSION IN AN ARGON PLASMA

P. Abbott and B.W. James
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*Session:* P-II Tuesday 5:20 pm.

A Monte Carlo model of the diffusion of neutral boron in an argon plasma is being developed in order to understand the incorporation of boron evaporated near the edge of the plasma by an electron beam. The model at present includes elastic scattering of boron by argon atoms and ionization of boron by electron collision. This work complements experimental studies of deposition of thin films of boron compounds using rf plasmas such as the ANU's helicon wave plasma source [1].

[1] A. J. Perry, D. Vender, and R. W. Boswell, J. Vac. Sci. Tech. B 9 (2) Mar/Apr 91

# THE FLINDERS STEADY-STATE RF INDUCTIVE PLASMA SOURCE

I.R. Jones, C.K. Chakrabarty, I.M. El-Fayoumi, W. Mateer,
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*Session:* P-II Tuesday 5:20 pm.

A steady-state RF inductive plasma source has been constructed. The power supply consists of an industrial RF induction heater capable of delivering 14 kW of power at a frequency of 0.55 MHz. The working gas is argon. The conditions required to produce a steady-state, stable plasma discharge will be discussed.

# THE SIMULATION OF GLOW DISCHARGES

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*Session:* P-II Tuesday 5:20 pm.

A computer simulation code has been developed to model DC glow discharges. The simulation uses a combination of Particle-in-cell (PIC) techniques to model the space-charge effects and Monte Carlo techniques to allow for collisional processes such as elastic scattering and ionization. The ultimate aim of the model is to investigate the effect on glow discharges of the use of unusual materials as electrodes which might be used in plasma processing experiments, in particular a high temperature superconductor material. Experiments with a YBaCuO cathode [1] have shown a negative resistance, which is thought to be due to the secondary emission coefficient of the superconductor being an increasing function of the energy in a certain energy range. We present here preliminary results of testing the code using a cathode of simpler properties, in particular a constant secondary emission coefficient. The simulation is one-dimensional and reproduces the expected sharp drop in potential in the cathode sheath region. We find good agreement with the potential, ionization and excitation profiles previously found using fluid models of the glow discharge.

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# TOROIDAL PLASMA DEPOSITION SOURCE

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*Session:* P-II Tuesday 5:20 pm.

Toroidal plasma sources have been developed over many years for fusion research, but have not been developed specifically as plasma deposition sources. The toroidal PLADEPUS device, under construction at Sydney University, is essentially a small iron core tokamak operated continuously (at 5kHz) with a low magnetic field (500 gauss) and at low plasma current (500A), rather than in a pulsed, high current, mode. The main plasma parameters are $T_e \sim 2$eV and $n_e \sim 10^{19}\text{m}^{-3}$. The stainless steel vacuum vessel is rectangular in cross section, with a major radius of 22cm and a minor radius of 8cm.

We see the following advantages of such a source for plasma deposition (and etching and ion implantation) purposes:

- Because of the good magnetic confinement, and absence of end losses, a relatively high density plasma can be generated in a torus at relatively low input power.
- The plasma is highly ionized, and the filling gas pressure is very low (about $1 \times 10^{-4}$ torr), so ion motion can be directed towards a target without significant scattering by neutrals.
- The voltage required to ionize and sustain the plasma is low, about 10 volts, so there are no unwanted high energy ions. The ion energy can therefore be controlled independently, with little spread in energy, by applying a bias voltage to the substrate.
- Most deposition systems operate with an ion current of about 10mA – 100mA/cm$^2$. In tokamak devices, an electrode at the plasma edge, biased to about $-30$V, draws an ion saturation current of about 3A/cm$^2$. Tests have shown that an ion current of at least 200A can be drawn by a substrate without significant modification of the plasma.
- An important geometrical advantage of a toroidal plasma for plasma processing is that many substrates can be processed simultaneously.
- Toroidal plasmas are electrodeless. The plasma can be generated inductively, or by RF heating or by microwave heating, and the advantages of each method can be compared directly in the same device.

# RESULTS FROM THE 50 LITRE ROTAMAK DEVICE AT FLINDERS

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*Session:* P-II Tuesday 5:20 pm.

The paper will present results and a preliminary analysis of experiments performed in the high-power 50 litre Rotamak. Scaling studies reveal evidence of two distinct regions of operation, determined by the gas filling pressure, resulting in the transition of a compact torus configuration to a non-reversed one. Of special interest is a possible explanation for the "discharge failure" phenomenon developed in light of comparison with data taken from a previous 10 litre Rotamak device. Experiments being presently undertaken are aimed at improving the understanding of the discharge.

# RF MEASUREMENTS AND ANALYSIS

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*Session:* P-II Tuesday 5:20 pm.

A knowledge of the plasma impedance and power is important to our understanding of the $< \mathbf{j} \times \mathbf{b} >$ current-drive mechanism in a magnetically confined plasma. To obtain accurate measurements of these quantities, along with the driven current, all diagnostics are systematically calibrated. The signals from these diagnostics are collected by high- and low-speed instruments, and then analysed by a specific software package developed by the Flinders Plasma Group. The data acquisition system and the calibration procedures are discussed at length.

# NEW APPROXIMATIONS TO THE TRANSPORT PROPERTIES OF LOW-TEMPERATURE PLASMAS IN ELECTRIC AND MAGNETIC FIELDS

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*Session:* P-II Tuesday 5:20 pm.

Accurate values of the transport properties of partially ionised gases in electric and magnetic fields are of particular relevance to industrial processes utilising magnetised plasmas as well as in the field of magnetohydrodynamic (MHD) power generation.

In closed-cycle MHD power generation, and in various industrial applications, the plasma is formed from an inert gas such as argon. Due to the pronounced Ramsauer minimum in the electron-neutral momentum-transfer cross-section for inert gases, it is difficult to calculate precise values of transport properties. In particular, the electrical conductivity and Hall parameter cannot be calculated accurately using standard techniques based on polynomial expansions of the electron velocity distribution function.

In this work, results of two formulations are presented: one based on using "Lorentzian" functions to approximate the distribution function, and the other employing a model BGK electron-electron collision operator. The formulae based on the model collision operator are simple to evaluate and should be useful for practical purposes despite limited accuracy.

Accurate calculations using a large set of basis functions have produced the following results: at electron temperatures corresponding to the energy of the Ramsauer minimum, it is found that the electrical conductivity and Hall parameter are significantly reduced by quite low magnetic fields. At high magnetic fields, the electrical conductivity and Hall parameter approach their "Maxwellian" values at all temperatures.

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# ANOMALOUS TRANSPORT IN CLOSED MAGNETIC SYSTEMS

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*Session:* P-II Tuesday 5:20 pm.

It is generally believed that anomalous transport in high temperature magneticallly confined plasmas is a consequence of fully developed turbulence of one form or another. It is argued that this is not necessarily so and that a physically realisable quasi-linear state may exist instead. It is shown that (if applicable) Onsager symmetry leads to the conclusion that a steady state system corresponds to one in which the (magnetic) surface components of the current density and electron heat flux density vectors must be parallel. In the presence of radial pressure and electron temperature gradients and/or an applied electric field this requires the excitation of waves in order to produce necessary anomalous terms for this to be so. The waves are ion drift-type waves, while the radial anomalous fluxes, which are of prime interest, are simply a byproduct of this basic behaviour. An expression for the energy containment time which is quite independent of wave amplitude and number is obtained. There is good agreement with recent large-scale Tokamak experiments.

# THE HOLCROSS HIGH CURRENT ION SOURCE SYSTEM

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*Session:* P-II Tuesday 5:20 pm.

The model HOLCROSS ion source is designed for the production of high current and brightness ion beams for application in ion implantation and plasma technology. The cross-type hollow cathode device in which the cross size of the cathode is greater than the longitudinal size is described [1]. This system allows the creation of a quiet, cold and stable plasma of all cross sections. Compared with traditional hollow cathode systems this one is characterised by improved technical and operational performance. In the case of a duoplasmatron ion source the cross hollow cathode is optimised for gaseous charges such as noble gases, nitrogen, oxygen etc [2,3]. With a one aperture extraction system in which the square of the anode hole equals 0.25 $mm^2$ this source will produce for than 15 mA $H_1^+$ at 8 keV and 200 mA discharge current. Due to the modular construction of the HOLCROSS system, it is fairly easy to introduce modifications. One special version uses an internal negatively biased sputtering target to produce ions from elemental metal samples. Another configuration is equipped with an additional cross type hollow cathode system placed between the auxiliary plasma generator and the extractor [4]. A negative voltage is applied to the cathode so that dependent low pressure gas discharge (DGD) is observed. High homogeneity and emission density of the plasma (50 mA/$cm^2$) in the extraction region and multi-aperture extraction are advantages of this version. The voltage of the DGD has the value 300-1200 V depending on the auxiliary discharge current so the plasma chemical reactions in the extraction region may be controlled [5]. A description of the source is given, together with some recent results.

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# A SPECTROSCOPIC STUDY OF A HYDROGEN/METHANE MICROWAVE PLASMA

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*Session:* P-II Tuesday 5:20 pm.

Thin films of polycrystalline diamond can be produced by Microwave Plasma Assissted Chemical Vapour Deposition (MPACVD). Emission spectroscopy is being used to investigate the dependence of both the chemical composition of the plasma, and plasma properties on the methane concentrations of the feed gas in a MPACVD system, in order to further our understanding of the processes which give rise to these films. Analysis of the methane fragments will enable the products which interact to form the diamond to be identified; measurement of the shape and relative intensities of vib-rotational bands will enable the rotational and vibrational temperature of the molecules to be measured; measurements of the relative intensities of the Balmer emission lines, together with the modelling of the plasma, will enable an estimate to be made of the electron temperature.

# NUMERICAL IONOSPHERIC RAY TRACING AND BACKSCATTER IONOGRAM SYNTHESIS

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*Session:* P-II Tuesday 5:20 pm.

Numerical ray tracing programs for ionospheric applications have been developed based on Haselgrove's equations plus additional equations enabling quantities such as ray divergence to be calculated. A number of ionospheric models have been used for ray tracing simulations to gain insight into the propagation characteristics of the equatorial ionosphere. The Frequency Management System of the Jindalee over-the-horizon radar facility at Alice Springs includes a backscatter sounder and we are able to reproduce gross features appearing on the backscatter ionograms. For this work the ionosphere is considered to be a cold plasma with no collisions and no magnetic field.

# REAL RAY TRAJECTORIES IN COMPLEX SPACE FOR COLLISIONAL PLASMAS

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Numerical investigations of real electromagnetic rays have been carried out in collisional, unmagnetised, cold plasmas. A complex form of the dispersion equation is used. While the use of Hamilton's equations would result in complex ray paths (in an absorbing media), with the use of a correction term it is possible to restrict the ray to real space-time and group velocities. Examples dealing with plane stratified ionospheres are presented.

# EFFECT OF RESISTIVITY ON THE FULLY TOROIDAL MAGNETOHYDRODYNAMIC SPECTRUM

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*Session:* P-II Tuesday 5:20 pm.

The magnetohydrodynamic (MHD) spectrum of a fully toroidal resistive plasma is analysed numerically using the linearised MHD equations with constant density and finite resistivity. The stable and unstable eigenmodes are found by reducing the equations with a coordinate system based on flux surfaces of the toroidal equilibrium, and by Fourier analysis in the poloidal and toroidal directions. Both the stable and unstable spectra are calculated for the fully toroidal model, with particular emphasis on the global Alfvén modes introduced due to the inherent poloidal coupling. The effect on the eigenvalue spectra due to varying the resistivity of the plasma under consideration is discussed.

# TRANSPUTER SYSTEM FOR REAL-TIME PLASMA DIAGNOSTIC DATA ANALYSIS

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*Session:* P-II Tuesday 5:20 pm.

With recent advances in detector array technology and development of multi-channel experiments [1], it has become desirable to pre-process or condense the vast data flow prior to archiving. The use of transputers and parallel processing architecture has realized some of these goals, while also allowing the possibility of real-time feedback control of the plasma conditions [2].

We are assessing the use of a transputer network for real-time tomographic analysis of plasma interferometer measurements of the electron density profile on the H-1 heliac. We report first results using a two-view 30-channel interferometer to image a moveable test phase object. The tomographic inversion and image display in real-time (20 frames per second) was obtained using a four transputer network. The data rates and computational complexity are similar to those anticipated in future experiments on H-1.

[1] J. Howard, G. B. Warr and P. Dodds, Rev. Sci. Instrum. **63** (1991) pp. 4965-4967
[2] E. van der Groot, A. W. Edwards and J. Holm, Fusion Technology, **2** (1990) pp. 1244-1248.

# THE SPECTRUM OF DISCRETE ALFVÉN WAVE EIGENMODES

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The spectrum of Discrete Alfvén Wave (DAW) Eigenmodes is examined in a cylindrical current-carrying inhomogeneous cold plasma. These global eigenmodes of the torsional Alfvén wave appear just below the lower edge of the Alfvén continuum and have dispersion relations which depend on the mass and current density profiles of the plasma. Consequently, the dispersion of these eigenmodes has been used in attempts to measure the $q$−profiles of the TCA [1] and TEXTOR [2] tokamaks.

The results presented here are related to experiments presently being carried out on the TORTUS tokamak at the University of Sydney [3], in which low order eigenmodes are excited by means of filamental loop antennas placed close to the edge of the plasma. These low order eigenmodes and their related Toroidal Alfvén Eigenmodes (TAE modes) are of particular interest in relation to the confinement of $\alpha$−particles.

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[2] P Descamps et al, Phys Lett A **143** (1990) p 311
[3] R C Cross et al, this conference (1993)

# A SCANNING MICHELSON INTERFEROMETER FOR THE TORTUS TOKAMAK

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A scanning Michelson interferometer has been designed for the measurement of radial electron density profiles on the TORTUS tokamak at the University of Sydney. This profile is to be reconstructed from ten channels of line-integrated electron density information. A far-infrared laser beam ($\lambda = 433\mu m$) from an optically pumped formic acid vapour laser is focussed onto a multi-sectored blazed grating wheel [1]. The grating wheel diffracts the incident beam into a sequential fan of ten beams. A parabolic reflector converts this fan of beams into ten distinct beams along chords through a cross-section of the tokamak plasma. A plane mirror returns beams along their original paths. These probe beams are then combined with a reference beam to produce interference fringes. Phase comparison between these fringes and a reference signal yields the line integral of the electron density along the chord probed by the probing beam. The present design is based on an existing prototype [2] which has proved the viability of such an interferometer.

[1] J Howard, Rev. Sci. Instrum. **61** (1990) pp 1086–1094
[2] J S Cannon, Honours Year Thesis, Department of Plasma Physics, School of Physics, University of Sydney (1991)

# THE MEASUREMENT OF THE NON-LINEAR HALL FORCE IN A ROTAMAK DISCHARGE

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*Session:* P-II Tuesday 5:20 pm.

The oscillating magnetic fields of a spherical Rotamak discharge were experimentally investigated. Detailed measurements have enabled us to derive the associated screening currents and the non-linear Hall force produced by the interaction of the currents with the fields. The results show that the rotating magnetic field partially penetrates the plasma and that the screening currents close in both the poloidal cross-section and in the meridional plane. The Hall force has three components: the toroidal component exhibits a triplet structure, the radial component contributes significantly to the confinement of the plasma, and the poloidal component generates a bi-directional toroidal field. By expansion in vector spherical harmonics we found that only $l \leq 2$ harmonics are important, which supports the assumption made in many theoretical analyses.[1]

[1] D. Brotherton-Ratcliffe and R.G. Storer, Plasma Phys. Contr. Fusion **30** (1988) 967.

# DYNAMICS OF ROTATING PLASMAS

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*Session:* P-II Tuesday 5:20 pm.

This work presents a model of the Hartmann boundary layers appropriate to a high- density plasma which is in local thermodynamic equilibrium. The purpose of the model is to predict the performance of plasma centrifuges operating at high pressures.

Following Swedish work in the 1950's and 60's by H. Alfvén and others, it has been generally assumed that the azimuthal velocity of rotating plasmas would be affected by the critical velocity interaction. In fact, the great majority of experimental data on rotating plasmas can be explained without recourse to the artefact of the critical velocity interaction, using conventional Hartmann boundary layer modelling techniques. The critical velocity interaction concept itself has never been adequately explained, and the concept has not assisted in the industrial development of plasma centrifuges because it does not provide a basis for detailed engineering designs.

The high-density model presented makes approximations appropriate to magnetohydrodynamic plasmas and employs a mixing-length treatment of turbulence in the boundary layer which includes a laminar sub-layer adjacent to the wall. The model can be used to predict the performance of plasma centrifuges operating with various gas mixtures. It is found that under a range of conditions the model does predict rotation at the Alfven velocity, and this result can be explained using a straightforward enthalpy balance relation in the boundary layer.

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# CONSUMABLE ELECTRODE PHENOMENA IN A WELDING ARC PLASMA

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A better understanding of the behaviour of the consumable anode in a welding arc plasma is important for further improvement of quality control in gas-metal-arc welding (GMAW). The problems relating to a moving anode are generally complicated because (a) the melting rate of the anode is strongly coupled with the arc plasma, which is not stable, for example, the length of the arc plasma varies during the formation and detaching of an electrode droplet, and (b) the formation of the electrode droplet itself is influenced by the anode-plasma interface, and also the location of the liquid-solid interface inside the anode.

This paper presents primary results of experimental observations and theoretical analyses of the behaviour of a consumable welding anode, including a numerical treatment of droplet formation and the motion of the plasma-anode interface with a consumable anode. The droplet formation is analysed with a quasi-one-dimensional model of a pendant drop which accounts for the electromagnet pinch effect and surface tension. The moving anode is investigated by coupling the results from a two-dimensional arc model [1] with a one-dimensional thermal model of the anode wire, which includes a source term from the arc plasma. The position of the moving anode-arc interface and the arc current for given arc voltage have been calculated as a function of time for various anode feeding rates. Comparisons between experimental observation and theoretical predictions will be presented and discussed.

Results are given for arc currents in the range of 200 to 300A for an arc burning between iron electrodes in a shielding gas consisting of argon plus small amounts of molecular gases.

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*Hamilton, New Zealand*
Prof B.S. Liley

## Sessions

### Listed alphabetically by last name, with times of presentations for presenting authors.

| | | | |
|---|---|---|---|
| Mr | Phillip | Abbott | *Session:* P-II Tuesday 5:20 pm. |
| Mr | Matthew J. | Baldwin | *Session:* VII.4 Thursday 10:10 am. |
| Mr | R. Andrew | Bean | *Session:* IV.6 Tuesday 4:20 pm. |
| Prof | Amitava | Bhattacharjee | *Session:* I.2 Monday 11:10 am.<br>*Session:* III.5 Tuesday 11:00 am. |
| Dr | Boyd | Blackwell | *Session:* II.5 Monday 4:20 pm.<br>*Session:* P-I Monday 5:00 pm. |
| Dr | Gerard | Borg | *Session:* V.5 Wednesday 10:50 am.<br>*Session:* P-I Monday 5:00 pm. |
| Dr | Rod | Boswell | *Session:* VI.2 Wednesday 2:30 pm. |
| Dr | Ferg | Brand | *Session:* VII.3 Thursday 9:50 am. |
| Prof | Max | Brennan, AO | |
| Prof | John | Cary | *Session:* I.1 Monday 10:40 am.<br>*Session:* III.7 Tuesday 12:00 pm. |
| Mr | Chandan Kumar | Chakrabarty | *Session:* P-II Tuesday 5:20 pm. |
| Dr | Christine | Charles | *Session:* IV.5 Tuesday 4:00 pm. |
| Dr | Andrew | Cheetham | *Session:* P-I Monday 5:00 pm. |
| Prof | Liu | Chen | *Session:* VIII.2 Thursday 2:30 pm.<br>*Session:* III.6 Tuesday 11:30 am. |
| Mr | Paul | Coop | *Session:* P-II Tuesday 5:20 pm. |
| Dr | Anthony | Cooper | *Session:* III.1 Tuesday 9:00 am. |
| Dr | Neil | Cramer | *Session:* P-II Tuesday 5:20 pm. |
| A/Prof | Rodney | Cross | *Session:* P-II Tuesday 5:20 pm.<br>*Session:* V.6 Wednesday 11:10 am. |
| Ms | Xiu-Juan | Dai | *Session:* P-I Monday 5:00 pm. |
| Mr | Sean | Dettrick | *Session:* P-I Monday 5:00 pm. |
| Prof | Robert | Dewar | *Session:* III.3 Tuesday 9:50 am. |
| Mr | Nigel | Donaldson | *Session:* P-II Tuesday 5:20 pm. |
| Dr | Ian | Donnelly | *Session:* VI.4 Wednesday 3:40 pm. |
| Dr | Antoine | Durandet | *Session:* VI.5 Wednesday 4:00 pm. |

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|---|---|---|---|
| Prof | Peter | Dyson | *Session:* I.3 Monday 11:40 am. |
| Mr | Ibrahim Mahmoud | El-Fayoumi | |
| Mr | Albert | Ellingboe | *Session:* P-I Monday 5:00 pm. |
| Mr | Peter | Euripides | *Session:* P-II Tuesday 5:20 pm. |
| Dr | Ian | Falconer | |
| Dr | Eugene | Gamaly | *Session:* VIII.1 Thursday 2:00 pm. |
| Dr | Roger | Gammon | |
| Dr | Henry | Gardner | *Session:* III.2 Tuesday 9:30 am. |
| Dr | Barry | Green | *Session:* II.3 Monday 3:00 pm. |
| Prof | Sydney | Hamberger | *Session:* II.4 Monday 3:50 pm. |
| Mr | Stephen | Hardy | *Session:* P-I Monday 5:00 pm. |
| Mr | Ben | Higgins | *Session:* VI.6 Wednesday 4:20 pm. |
| Dr | John | Howard | *Session:* VII.2 Thursday 9:30 am. |
| Dr | Yiding | Hu | *Session:* I.4 Monday 12:10 pm. |
| Mr | Stuart | Hudson | *Session:* P-I Monday 5:00 pm. |
| Dr | Waheed | Hugrass | |
| Dr | Brian | James | *Session:* VII.1 Thursday 9:00 am. |
| Mr | Mark | Jarnyk | *Session:* P-I Monday 5:00 pm. |
| Prof. | Ieuan | Jones | *Session:* V.1 Wednesday 9:00 am. |
| Dr | John | Keller | *Session:* VI.1 Wednesday 2:00 pm. |
| Dr | Joe | Khachan | *Session:* VI.3 Wednesday 3:00 pm. |
| Mr | Alexei | Khorev | *Session:* P-I Monday 5:00 pm. |
| Miss | Hee Jae | Kim | *Session:* VII.5 Thursday 10:50 am. |
| Dr | Hoon | Kim | *Session:* VII.8 Thursday 11:40 am. |
| Mr | Peter | King | |
| Dr | Hajime | Kuwahara | *Session:* IV.2 Tuesday 2:30 pm. |
| Dr | Susan Hilary | Law | *Session:* P-II Tuesday 5:20 pm. |
| Prof | Bruce | Liley | *Session:* P-II Tuesday 5:20 pm. |
| Dr | Nikolai | Lobanov | *Session:* P-II Tuesday 5:20 pm. |
| Dr | John | Lowke | *Session:* IV.1 Tuesday 2:00 pm. |
| Prof | Barry | Luther-Davies | |
| Dr | Gustav | Meglicki | *Session:* VII.9 Thursday 12:00 pm. |
| Dr | Andrew | Perry | *Session:* VI.7 Wednesday 4:40 pm. |
| Dr | Harold | Persing | *Session:* IV.7 Tuesday 4:40 pm. |
| Dr | Mikael | Persson | *Session:* III.4 Tuesday 10:40 am. |
| | | | *Session:* P-I Monday 5:00 pm. |
| | | | *Session:* P-I Monday 5:00 pm. |
| Dr | Boris | Petrovichev | *Session:* P-I Monday 5:00 pm. |
| Dr | Vaclav | Petrzilka | *Session:* P-I Monday 5:00 pm. |
| | | | *Session:* V.4 Wednesday 10:10 am. |
| Mr | John | Pigott | |
| Dr | Robert | Porteous | *Session:* VII.6 Thursday 11:10 am. |
| Dr | Rama | Ramakrishnan | *Session:* II.2 Monday 2:30 pm. |
| Mr | Matthew | Rice | *Session:* P-II Tuesday 5:20 pm. |
| Mr | Dmitri | Rudakov | *Session:* P-I Monday 5:00 pm. |
| Mr | Chris | Russell | *Session:* P-II Tuesday 5:20 pm. |
| | | | *Session:* P-II Tuesday 5:20 pm. |
| Mr | Anthony | Schellhase | *Session:* P-II Tuesday 5:20 pm. |
| Mr | Darryn | Schneider | *Session:* V.7 Wednesday 11:30 am. |
| Dr | Leslie | Sharp | *Session:* P-I Monday 5:00 pm. |
| Dr | Mikhail | Shats | *Session:* P-I Monday 5:00 pm. |
| Dr | Xuehua | Shi | *Session:* P-II Tuesday 5:20 pm. |
| Ms | Helen | Smith | *Session:* P-I Monday 5:00 pm. |
| Mr | Yann | Souilliart | *Session:* IV.8 Tuesday 5:00 pm. |
| Mr | Bill | Stanton | |
| A/Prof | Robin | Storer | *Session:* V.2 Wednesday 9:30 am. |
| Mr | Andrew | Studer | |

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|---|---|---|---|
| Dr | John | Tendys | *Session:* IV.3 Tuesday 3:00 pm. |
| Mr | Chih-Yas | Teo | *Session:* P-II Tuesday 5:20 pm. |
| | | | *Session:* P-II Tuesday 5:20 pm. |
| Mr | Roy | Tumlos | *Session:* P-I Monday 5:00 pm. |
| Ms | Trudy | van der Straaten | *Session:* VII.7 Thursday 11:30 am. |
| Mr | George | Warr | *Session:* P-I Monday 5:00 pm. |
| Mr | John | Watkins | *Session:* IV.4 Tuesday 3:40 pm. |
| Mr | Kruger | White | *Session:* V.3 Wednesday 9:50 am. |
| Prof | Alfred | Wong | *Session:* II.1 Monday 2:00 pm. |
| Mr | Michael | Wouters | |
| Mr | Lee | Xiaobing | |
| Dr | Shuyan | Xu | *Session:* P-II Tuesday 5:20 pm. |
| Mrs | Yi | Yue | *Session:* P-II Tuesday 5:20 pm. |
| Mr | Beichao | Zhang | *Session:* P-I Monday 5:00 pm. |
| | | | *Session:* V.8 Wednesday 11:50 am. |
| Dr | Peiyuan | Zhu | *Session:* P-II Tuesday 5:20 pm. |

# AINSE-White Conference Announcements

## 1 Lunches

Lunch will be served at Burgmann College from 12:45 till 1:30 Monday–Wednesday, 12:30 till 1:45 Thursday. Please wear your conference badge.

## 2 Conference Dinner

Guest tickets are available at $25 per head until 12 noon, Monday, for the Conference Dinner, which is at 7:30 pm on Tuesday evening at Burgmann College. There will be a cash bar from 7:00 to 7:30. Conference badges will act as the Dinner ticket for participants.

## 3 Parking

If you wish to park in the Academy parking lot, please obtain an AINSE-White "parking permit" at the registration desk and display it on your car's dashboard. Permits will be given preferentially to non-ANU participants. ANU participants should park in a University lot (there is a close one in a paddock at the corner of Liversidge and McCoy Circuit-Garran Rd near the University Housing Office) or in the 2 hour free parking on McCoy Circuit.

## 4 Session Chairmen

(Before/after tea where appropriate)

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|---|---|
| Monday | |
| Session I | S. M. Hamberger, *ANU* |
| Session II | R. L. Dewar, *ANU* |
| Tuesday | |
| Session III | R. G. Storer, *Flinders*/ B. S. Liley, *Waikato* |
| Session IV | R. W. Boswell, *ANU*/ W. N. Hugrass, *New England* |
| Wednesday | |
| Session V | R. C. Cross, *Sydney*/ I. R. Jones, *Flinders* |
| Session VI | J. Tendys, *ANSTO*/ A. D. Cheetham, *Canberra* |
| Thursday | |
| Session VII | L. E. Sharp, *ANU*/ N. F. Cramer, *Sydney* |
| Session VIII | M. H. Brennan, *ARC* |

## 5 E-Mail Addresses Update

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| X.-H. Shi | shix@topaz.ucq.edu.au |
| R. G. Storer | phrgs@cc.flinders.edu.au (correction) |
| Y. Yue | yi@ee.su.oz.au |

# 6 Program Changes

• Poster P-II.13 by C.J. Russell *et al.* has been withdrawn.
• Poster P-II.16 by C-Y. Teo and R. C. Cross, THE SPECTRUM OF DISCRETE ALFVÉN WAVE EIGENMODES, will be given as a **talk** V.9 at 12:10 pm on Wednesday.
• There is an additional poster, unfortunately omitted from the handbook,
P-II.21 X. B. Li and R. C. Cross
EFFECTS OF PLASMA BIASING ON PLASMA EDGE PARAMETERS.

## EFFECTS OF PLASMA BIASING ON PLASMA EDGE PARAMETERS

X.B. Li and R.C. Cross
*Department of Plasma Physics, School of Physics,*
*University of Sydney, N.S.W. 2006, Australia*

Electrode bias experiments have been performed on TORTUS, a small research Tokamak. A small biased electrode made of graphite is located 3 mm radially outside the main poloidal limiter which is electrically connected to the vacuum vessel. The inside area of the biasing electrode which comes into contact with plasma is 10 mm x 91 mm. The biasing voltage was varied from −350 V to +350 V and was applied for a period of 5 ms near the end of the discharge, while the electron density was decaying, in order to distinguish between a density rise due to gas puffing and a density rise due to applied bias voltage.

The results show that plasma edge parameters can be strongly affected by the boundary electric field caused by a biased electrode. Under a positive bias, the line-averaged electron density increases and the hydrogen and the impurity intensities increase strongly. Under a negative bias, the density increases, the intensity of hydrogen increases, intensities of carbon emissions increase (because the biasing electrode and main limiter are made of graphite), the oxygen emission is unchanged, and chromium emissions decrease. In this case the density rise seems to be due to the working gas and the slight impurity accumulation. Negative bias therefore can control the impurity level.

The floating potential increases strongly, to a maximum near $r = 9$ cm, with positive biasing and slightly decreases by negative biasing. The amplitude of the magnetic fluctuations and the frequency (the main frequency is 40 kHz on TORTUS) increase with positive bias. For negative biasing the amplitude decreases and the frequency decreases slightly. Improved particle confinement is possibly associated with a decrease in the level of magnetic fluctuation.