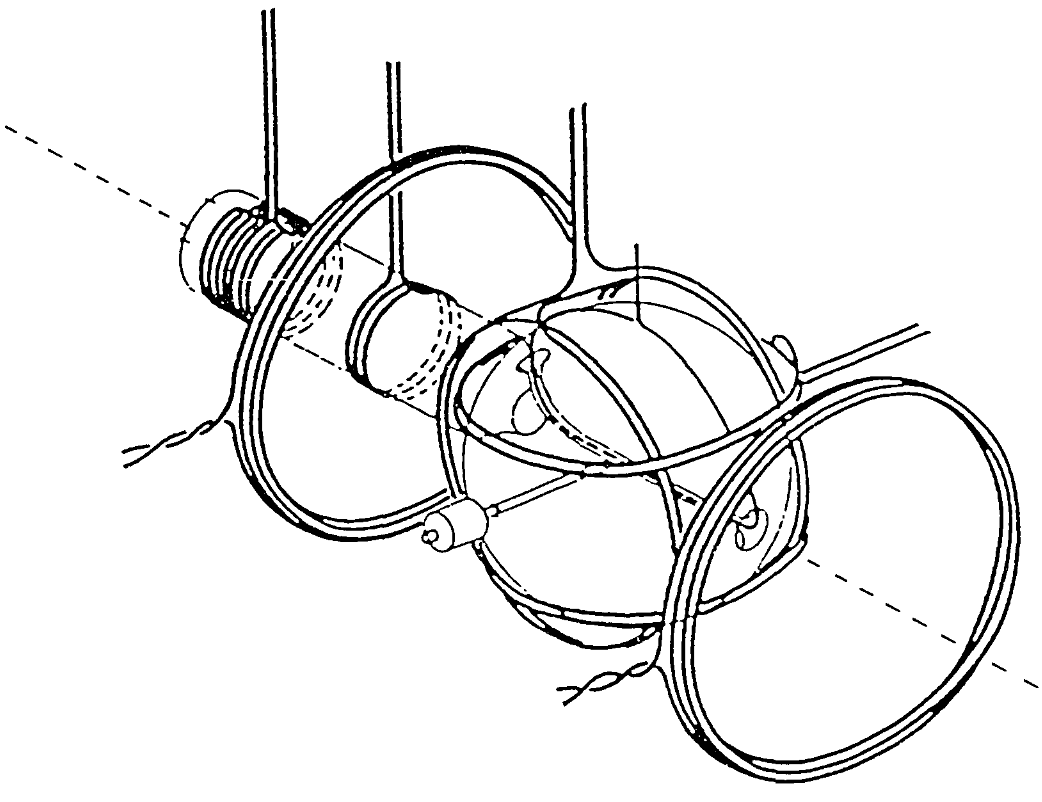
AUSTRALIAN INSTITUTE OF NUCLEAR SCIENCE
& ENGINEERING Inc.

20TH AINSE PLASMA SCIENCE AND TECHNOLOGY CONFERENCE

FLINDERS UNIVERSITY OF SOUTH AUSTRALIA

13-14 February 1995



CONFERENCE HANDBOOK

(Program, Abstracts and List of Participants)

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AUSTRALIAN INSTITUTE OF NUCLEAR SCIENCE
AND ENGINEERING

20TH AINSE PLASMA SCIENCE & TECHNOLOGY CONFERENCE

Flinders University of South Australia

13-14 February 1995

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A/Professor R Storer	Flinders University of S.A.

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Professor R L Dewar	The Australian National University
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PROGRAM

SUNDAY 12 FEBRUARY 1995

Technical Tour to southern wineries and Victor Harbour

0930	Coach departs from University Hall, Sturt Drive, Flinders University
	Visit to two wineries
1230	Lunch at Middleton Winery
1400	Travel to Victor Harbour
	Travel on horse tram or by foot to Granite Island at Victor Harbour
1600	Depart from Victor Harbour
1700	Coach returns to University Hall

MONDAY 13 FEBRUARY 1995

Tele Theatre, School of Information Science & Technology, Flinders University

	Paper No.	
0800		Registration
0900		Opening remarks
0910	1	**"Fusion 1994"** S M Hamberger, The Australian National University
0930	2	**"A Helicon Wave Plasma Source for the Deposition of Diamond-Structure Materials"** I S Falconer, B W James, J Khachan, H-J Kim, W D McFall, D R McKenzie, J R Pigott and H B Smith, The University of Sydney
0950	3	**"Experimental Investigations of the Current Termination Phenomenon in Rotamak Discharges"** P Euripides and I R Jones, The Flinders University of South Australia
1010	4	**"The Modular Helias-Like Heliac Reactor"** P R Garabedian and H J Gardner, The Australian National University

	Paper No.	
1030		**MORNING TEA**
1100	5	**"Effects of Antenna Phasing on Plasma Formation by Helicon Waves in Basil"** D A Schneider, G G Borg and R W Boswell, The Australian National University
1120	6	**"The Toroidal Plasma Deposition Source, PLADEPUS"** A Degeling and R C Cross, The University of Sydney
1140	7	**"Pulsed Oxygen and Oxygen/Silane Helicon Diffusion Plasmas"** C Charles, R W Boswell and H Kuwahara, The Australian National University
1200		**POSTER REVIEWS**
1200	8	**"High Resolution Electron Beam Wire Tomography on the H-1 Heliac"** B D Blackwell, R B Tumlos and J Howard, The Australian National University
1202	9	**"Diamagnetism and Internal Currents in H1"** B D Blackwell, G G Borg, H J Gardner, M G Shats and L E Sharp, The Australian National University
1204	10	**"Radio Frequency Wave Propagation in H-1"** G G Borg, B D Blackwell and B C Zhang, The Australian National University
1206	11	**"Possibilities for Collaborative Experiments on H-1"** The Australian Fusion Research Group, The Australian National University
1208	12	**"A Novel Homodyne Polarimeter for Measurement of Plasma Density and Magnetic Field"** J Howard, G G Borg and H-1 team, The Australian National University
1210	13	**"Density Profiles and Fluctuations During Configuration Scans in H-1 Plasma"** M Shats, B Blackwell, G Borg, J Howard, L Sharp and D Rudakov, The Australian National University

	Paper No.	
1212	14	**"Gyro-Kinetic Calculations in 3-Dimensional Geometry"** J L V Lewandowski, M Persson, R E Waltz and D Singleton, The Australian National University
1214	15	**"Drift Waves in the H-1 Heliac"** H Nordman, J L V Lewandowski, H Gardner and M Persson, The Australian National University
1216	16	**"Arnol'd Diffusion in a 4-D Map"** V Robins, The Australian National University
1218	17	**"Scaling Properties of Inhomogeneous Cyclotron Maser Instabilities"** H B Smith, P A Robinson, N F Cramer and R M Winglee, The University of Sydney
1220	18	**"The Simulation of Plasma Based Ion Implantation"** H B Smith, N F Cramer and P A Robinson, The University of Sydney
1222	19	**"DSP Enhanced Interface for Pre-Processing Real-Time Diagnostic Signals"** J Waller, X Shi and N Altoveros, Central Queensland University, Rockhampton, and J Howard, B Blackwell and G Warr, The Australian National University
1224	LUNCH	
1330	20	**"A New Study of RF Plasma Nitriding"** S C Haydon, M P Fewell, M J Baldwin and S Kumar, University of New England, and G A Collins, R Hutchings, K T Short and J Tendys, ANSTO
1400	21	**"Experimental Investigation of the Magnetic Structure on the H-1 Heliac"** M G Shats, D L Rudakov, B D Blackwell, L E Sharp, R Tumlos, S M Hamberger and O I Fedyanin, The Australian National University
1420	22	**"Low-Frequency Waves in a Magnetized Dusty Plasma"** N F Cramer and S V Vladimirov, The University of Sydney

Time	Paper No.	
1440	23	**"Automated Instrumentation for Plasma Monitoring and Control"** A Cheetham, J Rayner, T Lund, L Davidson and J McGuire, University of Canberra
1500	AFTERNOON TEA	
1530	24	**"The Effect of Magnetic Field Structure on Instabilities in 3-Dimensional Plasmas"** J L V Lewandowski, M Persson and H Gardner, The Australian National University
1550	25	**"Generalized Magnetic Coordinates"** S R Hudson and R L Dewar, The Australian National University
1610		**POSTER REVIEWS**
1610	26	**"Transport in a Helicon Magnetiplasma"** R W Boswell and B D Higgins, The Australian National University
1612	27	**"Antenna Coupling to Helicon Waves in Cylindrical Geometry"** L V Kamenskij and G G Borg, The Australian National University
1614	28	**"Antenna-Wave Coupling Studies and Plasma Formation in SHEILA Using Two Different Antennas"** B C Zhang, G G Borg, B D Blackwell and S M Hamberger, The Australian National University
1616	29	**"Fast Two and Three Dimensional Plasma Ion Current Density Measurement System"** Y Souilliart, A Perry and R Boswell, The Australian National University
1618	30	**"Quasilinear Transport of Trapped and Passing Ions in Tokamaks with a Radial Electric Field"** R V Shurygin, The Australian National University

MONDAY 13 FEBRUARY Cont'd

	Paper No.	
1620	31	**"Spectral Line Broadening in Cathode Spot Emissions in a Pulsed Vacuum Arc"** A J Studer, I S Falconer and B W James, The University of Sydney
1622	32	**"Scattering of a Guassian Beam by Density Fluctuations in a Plasma"** G F Brand, The University of Sydney
1624	33	**"Beam Formation for Plasma Scattering with Tunable Gyrotrons"** G P Timms, G F Brand, I Ogawa and T Idehara, The University of Sydney
1626	34	**"Caesium System for Seeded Plasmas"** S H Law, S W Simpson and Y Yue, The University of Sydney
1628	35	**"RF Matching for Helicon Plasma Sources"** J Rayner, A Cheetham and G French, University of Canberra
1630	36	**"Simulation of the Cathode Fall Region of a Cylindrical Magnetron Discharge"** T A van der Straaten, N F Cramer, I S Falconer and B W James, The University of Sydney
1632	37	**"Deposition of Reactively Sputtered Titanium Nitride Thin Films Using a Low Frequency Flat-coil, Inductively Coupled Plasma Source"** C K Chakrabarty and I R Jones, The Flinders University of South Australia
1634	38	**"The Measurement of Atomic and Ionic Densities in Processing Plasmas"** K-J Kim, B W James and I S Falconer, The University of Sydney
1636		DISCUSSION SESSION
1710		CLOSING NOTICES

MONDAY 13 FEBRUARY Cont'd

1715		**POSTER SESSION/PRE-DINNER DRINKS, Foyer, Tele Theatre**
1900		**CONFERENCE DINNER, Flinders University Club**

TUESDAY 14 FEBRUARY

	Paper No.	
0830	39	**"Current Status of H1 Heliac"** L F Sharp, B D Blackwell, G Borg, R Dewar, H Gardner, S M Hamberger, J Howard, M G Shats, G Warr and B Zhang, The Australian National University
0900	40	**"Non-Axisymmetric Plasma Transport Simulation with a Self Consistent Radial Electric Field"** S A Dettrick, R L Dewar and H J Gardner, The Australian National University
0920	41	**"First Results from the Plasma Density Interferometer for the ANU Helical Axis Stellarator H1"** G Warr, J Howard and H-1 team, The Australian National University
0940	42	**"Experimental Studies of the Neoclassical Current in the SHEILA Heliac Plasma"** B C Zhang, B D Blackwell, G G Borg and S M Hamberger, The Australian National University
1000	43	**"An Experimental Study of Breakdown in a Pulsed Helicon Plasma"** R W Boswell and D Vender, The Australian National University
1020		MORNING TEA
1050	44	**"Global Alfven Modes in TORTUS"** D Miljak, R Cross and A Teo, The University of Sydney
1110	45	**"The Alfvén Branch of the Stable Resistive Magnetohydrodynamic Spectrum"** R G Storer and A R Schellhase, The Flinders University of South Australia

TUESDAY 14 FEBRUARY Cont'd

1130	46	**"Magnetospheric Internal Compressional Pc 3 Waves Associated with a Magnetic Storm: Observations and Theory"** Y D Hu and B J Fraser, The University of Newcastle
1150	47	**"WKB-Ballooning vs Global Expansion Methods for Short-Wavelength MHD Waves in Stellarators"** R L Dewar, D B Singleton, H J Gardner, J Lewandowski and W A Cooper, The Australian National University
1210	48	**"Modelling of a Microwave Plasma Jet"** S A Gower and F J Paoloni, The University of Wollongong
1230		**LUNCH**
1330	49	**"The Application of Plasma Devices to the Fabrication of Semiconductor, Photonic and Optical Components"** I S Falconer, The University of Sydney
1400	50	**"Gyrotrons for Electron Cyclotron Resonance Heating in ITER"** G F Brand, The University of Sydney
1420	51	**"Langmuir Probe Measurements in a Microwave Discharge"** M J Wouters, The University of Sydney
1440	52	**"Start Up Conditions for RF Current Drive in Toroidal Plasma Vessels"** L McCarthy, The Flinders University of South Australia
1500	53	**"Reaction Mechanisms on Wool Surface Modification by Plasma"** X J Dai, S M Hamberger, A Perry and R A Bean, The Australian National University
1520	54	**"Electrical and Electromagnetic Characteristics of a Low Frequency, Flat-coil, Inductively Coupled Plasma Source"** I M El-Fayoumi and I R Jones, The Flinders University of South Australia
1600		**CLOSING REMARKS AND PRESENTATION OF AWARDS**
1610		**DEPART FOR AIRPORT**

ABSTRACTS

"Fusion 1994"

S. M. Hamberger

Plasma Research Laboratory
R.S.Phys.S.E., ANU
Canberra ACT 0200

Some of the 'highlights' of the recent IAEA Conference on Plasma Physics and Controlled Fusion will be presented.

A Helicon Wave Plasma Source for the Deposition of Diamond-Structure Materials

I.S. Falconer, B.W. James, J. Khachan, H.-J. Kim, W.D. McFall,
D.R. McKenzie, J.R. Pigott and H.B. Smith

Plasma Physics Department
University of Sydney. NSW. 2006. Australia
email: james@physics.su.oz.au

A helicon wave plasma source has been modified by the incorporation of an electron beam evaporator to make an ion plating system for the deposition of thin films of diamond structure materials. A radiofrequency biased, heated substrate holder enables the energy of the ions incidence of the growing film, which is critical to the formation of diamond-structure materials, to be controlled. Films of cubic boron nitride have been successfully deposited by evaporating boron into an Ar/N_2 plasma in this device. Transport studies of the flux of B atoms from the evaporator have been made using both measurements of the deposition rate of B at the substrate plane and absorption and emission spectroscopy. Preliminary results from Langmuir probe measurements of plasma parameters will also be reported.

Experimental Investigations of the Current Termination Phenomenon in Rotamak Discharges

P. Euripides and I.R. Jones

Department of Physics

Flinders University of South Australia

GPO Box 2100, Adelaide, 5001, Australia

Current is driven in a rotamak device by the application of a rotating magnetic field B_ω. Increasing the driven current results in an increase in the reflected plasma resistance which, in turn, causes a drop in B_ω. Once B_ω falls below a critical value, B_ω^{crit}, the current terminates. B_ω^{crit} depends on the vessel geometry and the RF circuit used to deliver the power. To drive a larger current before current termination is reached, it is desirable to undertake rotamak experiments with as large a value of B_ω as possible. A larger B_ω was achieved by building a smaller 2 litre discharge vessel with an associated smaller coil structure. The results of experiments undertaken in this vessel are presented.

THE MODULAR HELIAS-LIKE HELIAC REACTOR

P.R. Garabedian* and H.J. Gardner

* *New York University, USA, and*

Plasma Research Laboratory, RSPhysSE, ANU

The Modular Helias-like Heliac (MHH) is an optimised stellarator which has been chosen for the US Stellarator Power Plant Study. It has a smaller aspect ratio, and a more Heliac-like magnetic axis than the WVII-X machine which is planned for construction in Germany. Calculations of the bootstrap current have resulted in a redesign of the MHH from a 4-period machine to one having 3 field periods, similar to the H-1 Heliac. The new design appears to be even more suited to reactor conditions as it allows for more space between the coils and the plasma. The indications are that the MHD equilibrium and stability limit is probably 5% $<\beta>$ and that it has a confinement time of about 2 seconds.

Effects of Antenna Phasing on Plasma Formation by Helicon Waves in Basil

D.A. Schneider, G.G. Borg and R.W. Boswell
Plasma Research Laboratory, RSPhySE, ANU

Experiments with a helical antenna, capable of coupling to modes of positive helicity ($k/m > 0$) demonstrate that plasma forms only along the positive direction of the magnetic field where m=+1 propagates. To date, under no conditions has m=-1 excitation ever been observed and attempts to generate plasma by either the helical antenna or a phased azimuthal antenna array with m=-1 have failed. Attempts to produce plasma with m=0 helicon waves have also failed.

We describe recent experiments to excite the m=-1 and m=0 modes with the addition of a small amount of m=+1 to form the plasma. These experiments should allow us to determine whether these modes can propagate in a preformed plasma and whether plasma formation by these modes alone is impossible.

The Toroidal Plasma Deposition Source, PLADEPUS

A. Degeling and R.C. Cross
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School of Physics. A28. University of Sydney. NSW. 2006
email: cross@physics.su.oz.au

PLADEPUS is a new plasma deposition source designed to take advantage of the good plasma confinement in a toroidal device. The plasma is confined by a toroidal magnetic field, up to 400 gauss, and is generated by a single turn loop antenna, inside the stainless steel vacuum chamber, connected to a 1kW, 13.6MHz generator. Argon plasmas have been generated with an edge electron density up to 1 x 10^{19} per m^3 and an electron temperature of about 3eV. A surprising feature is that the highest densities are obtained at relatively low magnetic fields, about 100 gauss, while stronger magnetic fields support only a tenuous, low density plasma. Results will be presented on measurements of plasma parameters and rf magnetic fields observed in PLADEPUS.

PULSED OXYGEN AND OXYGEN / SILANE HELICON DIFFUSION PLASMAS*

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Plasma Research Laboratory
RSPhysSE, ANU, ACT 0200, Australia
H. Kuwahara
Nissin Electric Co., LTD., Kyoto 615, Japan

Continuous and pulsed oxygen plasmas have been created and partially modelled in a helicon diffusion reactor used for the deposition of silicon dioxide films. An energy selective mass spectrometer and a Langmuir probe attached to the wall of the silica covered aluminum diffusion chamber below the source have been used to characterize the plasma (Ion Energy Distribution Function (IEDF), plasma potential, floating potential, plasma density). The ion flux can be significantly modified by pulsing the discharge. In the continuous case, the IEDF of the O_2^+ ions escaping from the plasma to the sidewalls of the chamber consists of a single peak at an energy corresponding to the plasma potential in the chamber (≈ 32 Volt). In the pulsed case, the IEDF exhibits two additional peaks at high (≈ 60 Volt) and low (≈ 15 Volt) energy as a result of different states of the plasma during the pulse period: three regimes corresponding to the plasma breakdown, steady-state and decay have been observed and characterized. Similar results were obtained for high oxygen/silane ratios and deposition of silicon dioxide films using pulsed oxygen/silane plasmas has been achieved and modelled.

*Work partially funded by and carried out on behalf of the Harry Tribugoff AM Research Syndicate.

High resolution electron beam wire tomography on the H-1 heliac

B.D. Blackwell, R.B. Tumlos and J. Howard

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Abstract

The experimental verification of vacuum magnetic surfaces of a plasma confinement system is crucial, especially for the fully three dimensional geometries in advanced stellarator configurations, such as H-1. The complicated structure needs to be mapped, and the effect of small error fields and errors in construction must be quantified, and possibly compensated. The wire tomography technique, demonstrated in SHEILA [1], has been applied to H-1 and produced results of very high absolute accuracy and resolution.

The rotating wire grid apparatus is an array of 64 fine molybdenum wires mounted on a carrier capable of high precision rotary motion, driven by a microstepping motor. Filtered current-to-voltage preamplifiers allow detection of nanoamperes, and are connected to a data system by optically isolated digital links, and one multiplexed isolation amplifier. An electron gun produces a 20 eV beam of 0.1-1 μA, minimizing the effects of space charge and electron drifts.

The resolution of the system, measured from cross-sectional scans of the electron beam by individual wires, is better than 1 mm, and approaches the beam collimator size (0.3 mm). Using this method, oscillation of the beam position caused by tiny ripple in the magnetic field coil currents can be observed under some conditions.

Various magnetic surfaces have been mapped, near and far from resonances and islands, and the individual punctures recovered show good agreement with computation. Up to 40 transits can be individually identified, limited mainly by the background pressure 2×10^{-7} and grid transparency (96%). Application of the "Arithmetic Reconstruction Technique" for tomographic inversion shows a promising potential for obtaining images of the surfaces, so that fine details of the spot image such as shear smearing, or coma, can be observed. Enhancements to the system will be described, including a improvements of grid transparency, and a real time controller and processor.

[1] Tomographic Wire-Grid Imaging of Magnetic Surfaces Blackwell, B.D., Howard, J. and Tumlos, R.B, Rev. Sci. Instr. v63 (1992) 47 25-4727.

Diamagnetism and Internal Currents in H1

B.D. Blackwell, G.G. Borg, H.J. Gardner, M.G. Shats, and L.E. Sharp

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Abstract

The pressure balance equation of MHD $\nabla p = \mathbf{j} \times \mathbf{B}$ shows that as B is decreased, provided that a reasonable pressure is maintained, the equilibrium currents in the plasma should increase. In H-1, at low magnetic fields (0.05-0.1T) moderate plasma pressures, with $<\beta>$ up to 0.14% equilibrium currents are large enough in magnitude to permit their local measurement using high sensitivity, glass-sheathed Rogowski coils inserted into the plasma. The measured radial distribution and direction of the current density show an asymmetric component that is qualitatively consistent with 3D numerical computation of the equilibrium current distribution. Its magnitude scales approximately as p/B. Details of construction and interpretation will be discussed.

A 10 turn diamagnetic loop encased in a stainless steel tube produces a signal proportional to total plasma perpendicular energy, and is found to be the single most useful plasma diagnostic. Signal processing is crucial to this diagnostic, although the absence of the usual complications of pulsed toroidal magnetic field and Ohmic current make the problem relatively simple. At present, for both Rogowski and diamagnetic diagnostics, all processing (integration, baseline subtraction) is performed digitally with satisfactory results, but a mixture of analog and digital processing is being tested.

The results obtained will be compared with line integral electron density measurements from 3 interferometers, and with Langmuir probe data. Surprisingly, the kHz oscillation observed in H-1 appears on the diamagnetic signal also. The implications of this will be discussed.

RADIO FREQUENCY WAVE PROPAGATION IN H-1

G.G. Borg, B.D.Blackwell and B.C. Zhang

Plasma Research Laboratory, RSPhysSE, ANU

In H-1, argon plasmas are formed using radio frequency waves at 7 MHz and radiated power <50 kW. Depending on the magnetic field, the magnetic field configuration and the filling pressure, quite different plasma conditions can be obtained with respect to the density, the density profile and the level of fluctuations. Detailed measurements of the radial profile of the wavefields indicates a significant variation in the character of the excited waves. In this paper we compare these results with a simple antenna-wave coupling theory that has worked well for describing antenna-wave coupling in SHEILA and we attempt to relate this information to the type of plasma produced.

Possibilities for Collaborative Experiments on H-1

The Australian Fusion Research Group

Abstract

The H-1 heliac is a state-of-the-art advanced stellarator confinement system, with unique research opportunities over the next few years until other comparable machines are fully operational. At this point, the emphasis can change to worldwide collaboration, comparison and competition, with notable helical axis machines in Europe and the United States.

The high-speed Australian Academic Research Network, and improvements in internal travel make Australia-wide collaboration a more viable alternative. H-1 is presently being upgraded to provide more diagnostic ports to allow simultaneous access for more experiments, and further enhancements to the facility have been proposed.

The potential for Australia-wide collaboration will be discussed.

A NOVEL HOMODYNE POLARIMETER FOR MEASUREMENT OF PLASMA DENSITY AND MAGNETIC FIELD

J Howard, G.G. Borg and H-1 team

Plasma Research Laboratory, RSPhysSE, ANU

A novel homodyne polarimeter is described allowing independent measurements of plasma induced Faraday rotation and birefringence. A prototype system was installed recently on H-1 to obtain line-integrated measurements of plasma density weighted by the magnetic field. Measurements of the static density were obtained and compared with a conventional interferometer. Measurements were also made of density and magnetic field fluctuations from plasma waves excited at 7 MHz by the radio frequency (RF) generator used to produce plasma. The polarimeter detected output had excellent signal-to-noise quality and was relatively unaffected by refraction of the 2 mm probing beam. These signals were processed by a RF quadrature analyser and compared with data from a magnetic probe.

Density Profiles and Fluctuations During Configuration Scans in H-1 Plasma

M. Shats, B. Blackwell, G.Borg, J. Howard, L. Sharp and D. Rudakov

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The effect of the magnetic field configuration on the density profiles in a current-free (except for the small, presumably pressure-gradient-driven currents) RF-sustained argon plasma in H-1 heliac has been studied experimentally. The electron density of $n_e \leq 4\times10^{12}$ cm^{-3} and electron temperature of $T_e \leq 15$ eV (estimated from the measurements with a microwave interferometer, diamagnetic loop and Langmuir probes) result in a high electron-ion collision rate ($(1\text{-}6)\times10^{7}$ s^{-1}) and a short electron mean-free-path (1 to 6 cm), thus, validating an extensive use of the Langmuir probes for the profile measurements.

In a standard magnetic configuration at the present moderate power levels, the highest central density is achieved at rather low magnetic field (0.07 T). This regime is characterised by the peaked density profiles having a maximum coinciding with the radial position of the vacuum magnetic axis. The high-level density fluctuations ($\delta n/n = 0.2\text{-}0.6$) observed in this regime correlate with the local density gradient ($\delta n/n \propto dn/dr$). An increase in the magnetic field leads to a flattening of the n_e-profile and reduces the fluctuation level. The fluctuations in this regime exhibit strong radial asymmetry with fluctuations inside the magnetic axis ($R < R_0$) being significantly lower than outside ($R > R_0$). Further increase in magnetic field results in hollow density profiles and suppression of the fluctuations everywhere in the plasma.

High correlation (> 0.5) between the density δn and the poloidal magnetic field δB_ϕ fluctuations has been observed.

In the magnetic configurations where the symmetry-breaking $\iota = 1$ resonance occurs the density profiles qualitatively agree with the experimentally measured vacuum magnetic structure.

Gyro-kinetic calculations in 3-Dimensional geometry.

J.L.V.Lewandowski, M.Persson, R.E. Waltz+ and D.Singleton++.

Department of Theoretical Physics

and Plasma Research Laboratory

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Abstract

Low frequency drift waves are studied in general 3-dimensional geometries by solving an initial value problem along the magnetic field lines using the ballooning mode formalism. The first preliminary results of the calculations will be presented. The code used for the calculations is a generalization to general 3-Dimensional geometry of that developed by Kotschenreuther[1].

+General Atomics, San Diego, USA.

++Australian National University Supercomputer Facility.

[1] Kotschenreuther, G.Rewoldt, W.Tang, PPPL – 2986, 1994.

Drift waves in the H-1 heliac

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J. L. V. Lewandowski, H. Gardner, and M. Persson

Department of Theoretical Physics

and Plasma Research Laboratory

The Australian National University

Abstract

Linear eigenvalue calculations of electron drift waves in 3-dimensional helical axis stellarator are presented. The calculations particularly focus at the H-1 heliac and are based on the standard ballooning mode formalism in Boozer coordinates. The effect on localization and stability of curvature and local magnetic shear will be discussed.

Arnol'd Diffusion in a 4-D Map

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Arnol'd diffusion has been identified by Lichtenberg as a new mechanism for the diffusion of particles in toroidal magnetic fields. This can occur when the dimensionality of the phase space (including time) is greater than or equal to five, so that the KAM surfaces no longer partition the phase space. To be certain that effects measured in numerical simulations are Arnol'd diffusion around KAM tori rather than global diffusion through destroyed tori, a detailed understanding of the phase space structure is needed. Presented here is an analysis of a 4-D symplectic mapping, as a model of the Poincaré section of a 2 1/2 degree of freedom Hamiltonian system. In particular, generalisations to higher dimensions, of techniques such as Greene's residue criterion for determining the existence of KAM tori are addressed.

Scaling Properties of Inhomogeneous Cyclotron Maser Instabilities*

H. B. Smith, P. A. Robinson, and N. F. Cramer
School of Physics, University of Sydney
and
R. M. Winglee
Geophysics Program, University of Washington, USA

Abstract

Electron cyclotron maser (ECM) instabilities driven by anisotropic electron distributions have been invoked to explain observations of millisecond microwave spike bursts from the Sun, auroral kilometric radiation, and Jovian decametric emission, among other phenomena. In the solar case, one longstanding challenge has been to reconcile the observed timescale of the bursts with theoretical estimates of microsecond growth times on one hand and build-up times of seconds for the unstable distribution on the other. A recent theory argued that the mean relaxation rate of the unstable distribution evolves until it balances the build-up rate at a point of statistical equilibrium in which the growth rate is spatially inhomogeneous and time-varying.[1] This theory successfully predicts the observed timescales of solar microwave spike bursts, but its additional predictions of scaling properties of the instability have not yet been tested in detail.

In this work we use particle-in-cell simulations to investigate the spatially inhomogeneous ECM instability, especially its statistical and scaling properties as the rate of build-up of the unstable particle distribution is varied. We find that ECM radiation is generated nonuniformly and emitted in bursts, thereby confirming earlier work.[2] The peak flux of the bursts has an exponential probability distribution, which can potentially be compared with observed statistics. The scalings of mean power output, burst rate, and other quantities are investigated numerically and it is shown that they scale as powers of the build-up rate.

[1] P. A. Robinson, Sol. Phys., 134, 299 (1991).

[2] R. M. Winglee, G. A. Dulk, and P. L. Pritchett, Astrophys. J., 328, 809 (1988).

* Work supported by the ARC, NASA, and the US National Science Foundation.

The Simulation of Plasma Based Ion Implantation*

H. B. Smith, N. F. Cramer and P. A. Robinson
School of Physics, University of Sydney, NSW 2006.

Abstract

Plasma Based Ion Implantation (PBII) is a relatively new and increasingly important technology for plasma processing of materials. Initially used for work-hardening of steel tools through implantation of nitrogen, it is now being utilised in the production of microelectronic devices and in the thin film deposition of metal and carbon. The process involves applying a large negative voltage to the target, which is immersed in a plasma. A sheath rapidly forms around the target which accelerates ions from the plasma so that they bombard the surface with large energies. A 1-D Particle-in-cell model with a Monte-Carlo treatment of collisions with neutral atoms is used to simulate the behaviour of the plasma during the application of a negative high voltage pulse, in both symmetric and asymmetric geometries. The simulation is used to follow the evolution of the electric fields in the sheath and relate this to results for the ion current and energy distribution at the target. The expansion of the sheath in the simulation is compared to analytic results using a time-dependent fluid model of the electron and ion behaviour. The effect of ion collisions with neutrals in the sheath on the ion energy and angular distributions at the surface is also examined. The ion characteristics at the surface in thin film deposition experiments being carried out at Sydney, utilizing ions produced by a vacuum arc with a macroparticle filter, are predicted.

* Work supported by the ARC.

DSP ENHANCED INTERFACE FOR PRE-PROCESSING REAL-TIME DIAGNOSTIC SIGNALS*

(Poster Presentation)

J. Waller, X. Shi, and N. Altoveros
Department of Applied Physics
Central Queensland University, Rockhampton

J. Howard, B. Blackwell, and G. Warr
Plasma Research Laboratory
Research School of Physical Sciences and Engineering
Australian National University, Canberra

Abstract

The large amount of diagnostic data generated in fusion experiments often necessitates some pre-processing of the data flow. We are assembling a transputer array for real time tomographic analysis of plasma interferometer measurements on the H-1 heliac at the Australian National University. The poster describes in detail the digital hardware interface for acquisition and pre-processing the interferometer data stream prior to inversion by the transputer network.

The design includes the use of a DSP (digital signal processing) enhanced interface for pre-processing the interferometer quadrature signals. The incorporation of an Analog Devices ADSP-2101 microprocessor, with 60ns clock cycle, into a conventional analog to digital converter interface can provide useful signal pre-processing, such as noise filtering. Using this in conjunction with a pipeline processing configuration can also improve the data throughput for real time systems.

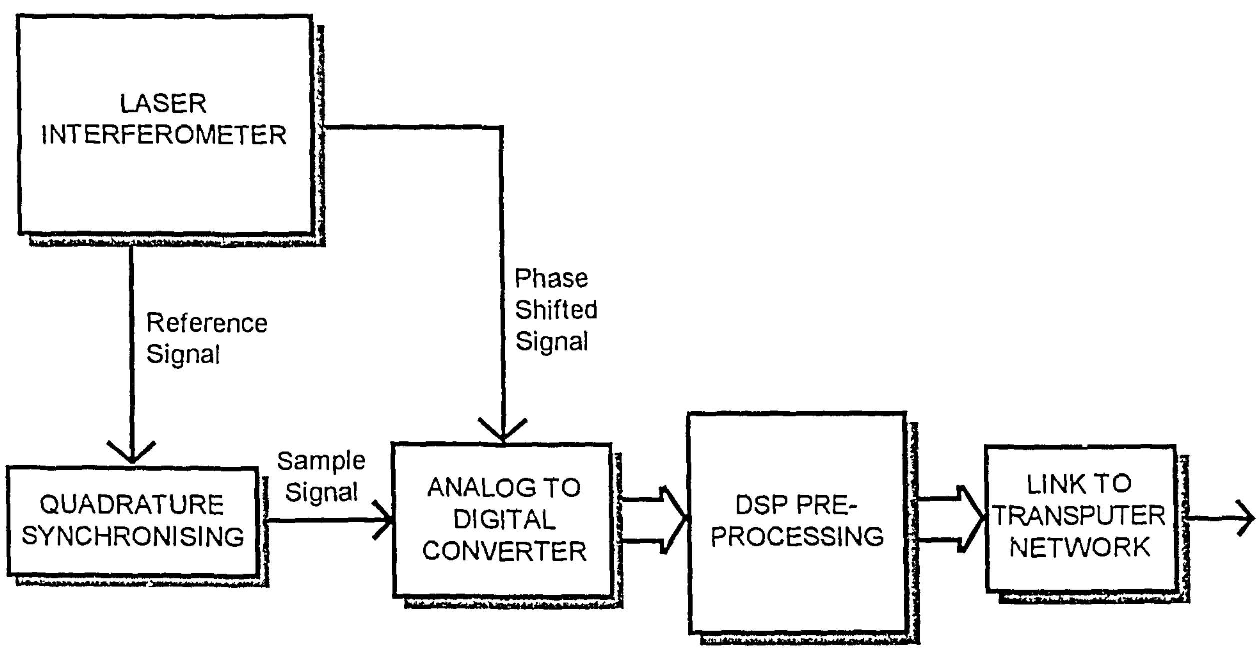

Figure 1. Block diagram of DSP Enhanced Interface

The block diagram in Figure 1 shows the three main sections of the interface with the DSP section providing a simple band pass filter. Inherent in the interferometer signals is noise which must be filtered out by a band pass filter centred around a predetermined multiple of the quadrature frequency. This is also the frequency at which the phase shifted laser beam is sampled. The interferometer scanning mechanism produces a range of these sampling frequencies during one measurement cycle, and consequently necessitates the use of a different bandpass filter for each frequency. The bandpass filter produced by the DSP implementation has the inherent characteristic of always being centred around the sampling frequency. This results in the filter always following the desired frequency throughout a measurement cycle. Figure 2 demonstrates the effectiveness of the interface to reduce the noise content of the raw data and the calculated phase information. The current system is capable of sampling at 330kHz.

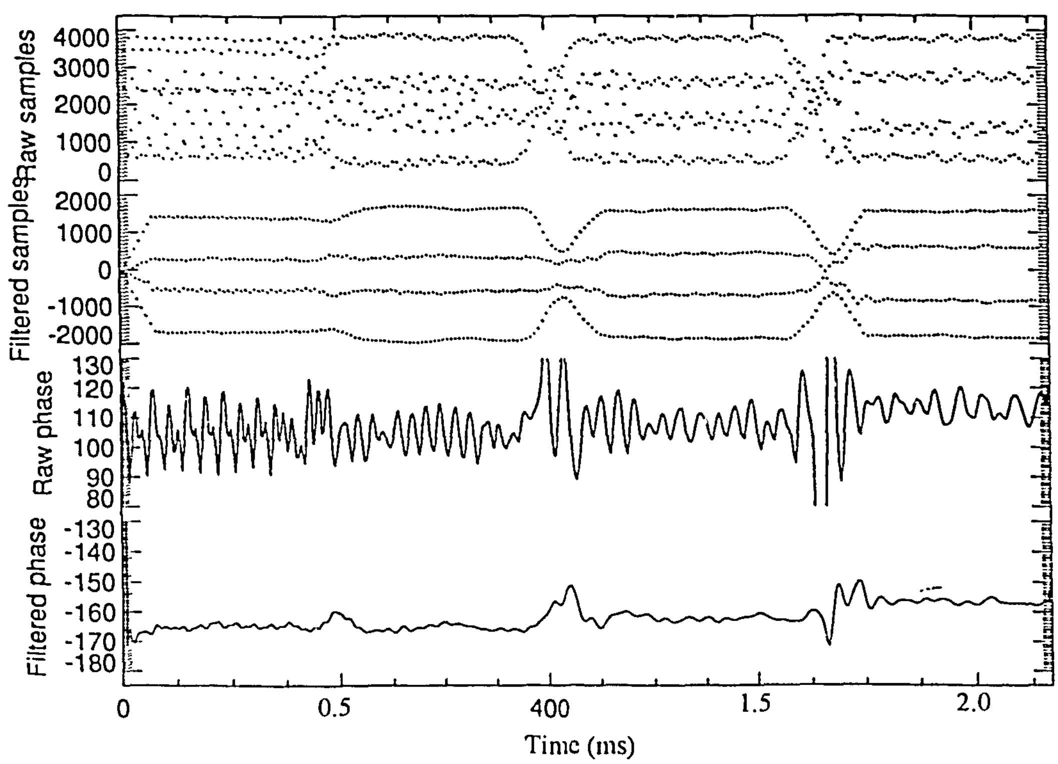

Figure 2. From top: the raw data sampled, the pre-filtered data, the phase extracted from the raw data, the phase extracted from the filtered data.

* This project is financially supported by Central Queensland University and The Institute of Advanced Studies, Australian National University.

A new study of rf plasma nitriding

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and

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Last year, ANSTO Advanced Materials and UNE Physics began a new collaborative project for the study of rf plasma nitriding of steel. Nitriding is an ancient and very widely used technique for hardening metal surfaces and increasing the load-bearing capacity of metal components. The most common nitriding processes in industry are chemical, but plasmas are becoming increasingly used. Plasma nitriding is widespread in Europe, and in our region is available in New Zealand and Singapore.

Commercial nitriding of steel is usually performed in an abnormal glow discharge in a nitrogen-hydrogen mixture. The component being nitrided is heated to temperatures in the range 400-600°C to promote diffusion of nitrogen into the metal. The role of the hydrogen in the gas mixture is unclear, and the detailed processes involved in nitriding are uncertain.

Some years ago, nitriding by an inductively-coupled rf plasma was demonstrated [1]. Small amounts of hydrogen are found to be beneficial to the process [2]. Recent experiments at ANSTO have shown that rf plasmas similar to those used in plasma-immersion ion implantation can nitride metals such as stainless steel [3], which are difficult to nitride by traditional methods.

It has long been known that neutral species play a central role in nitriding. Initially, the species were taken to be metastable atoms [4], but more recent work has shown that dc nitriding plasmas contain much higher concentrations of highly vibrationally excited nitrogen molecules than of metastable nitrogen atoms [5,6]. At UNE, we have made extensive studies of the influences of metastable particles in nitrogen discharges [7-10]. In particular, we have identified a slowly diffusing metastable species which is prolific near breakdown in pure nitrogen. Evidence suggests that this slowly diffusing species might be highly vibrationally excited [8-10].

The rationale for the present collaboration is to combine the expertise at ANSTO in rf plasmas and in metallurgy with the experience at UNE in the study of metastable species in discharges. Our aim is to explore the advantages of rf plasmas for nitriding and to attempt to identify and optimise the processes active in a nitriding plasma.

The first stage in the new project at UNE has been the construction of a new discharge chamber. During this time, we have been restricted to an extension of our prebreakdown dc studies, using the existing ionisation chamber and ultra pure gas handling facilities. Specifically, we have attempted to establish what role, if any, is played by the addition of hydrogen [11] to a nitriding plasma. Figure 1 shows our results

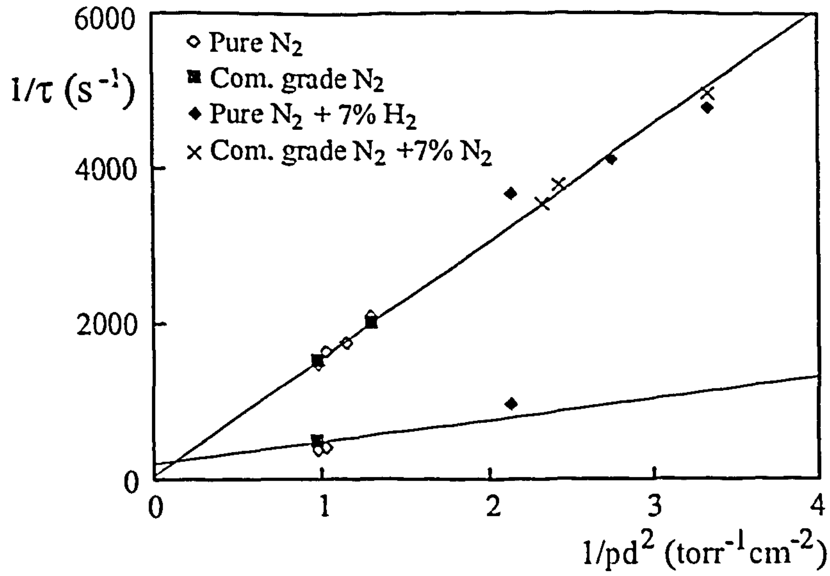

Fig. 1. Reciprocal diffusion time against $1/pd^2$, where p is the gas pressure reduced to 0°C and d is the electrode separation. The top line has a slope characteristic of diffusion of the N_2 A $^3\Sigma_u^+$ state.

at the time of preparing this abstract. This shows the variation of reciprocal metastable diffusion time against $1/pd^2$ for the two diffusion mechanisms present in nitrogen discharges: that due to the N_2 A $^3\Sigma_u^+$ state and that due to the as yet unidentified slowly diffusing state. Both processes have been well established in observations using pure N_2 over a wide range of *E/N* up to 1980 Td. The interpretation of our observations with 7% H_2 added to the gas sample remains unclear. A third discharge mechanism becomes evident at *E/N* of 1980 Td under prebreakdown conditions at electrode separations near to the breakdown distance. Further investigations are under way to clarify the relative contributions of the various mechanisms.

Our present investigations have been undertaken at room temperature, whereas commercial surface nitriding is carried out at elevated temperatures. Our new chamber will have facilities for heating an electrode, but we can only speculate about the possible influences of elevated temperatures at this stage. These may include rotational excitation. We also note recent work [12] on the existence and properties of the lowest lying quintet state of N_2: the A' $^5\Sigma_g^+$ state. It is expected that this state will be populated during recombination of N atoms, and so we can expect that it will be formed in a nitrogen discharge.

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EXPERIMENTAL INVESTIGATION OF THE MAGNETIC STRUCTURE ON THE H-1 HELIAC

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Abstract

The results of the experimental study of the magnetic structure in the H-1 heliac are presented. Electron beam magnetic mapping has confirmed the existence of closed nested flux surfaces in good agreement with a computer model. Measurements over a wide range of a helical winding currents demonstrated a variety of attainable magnetic configurations within the range of rotational transform of $0.6 \leq \iota_0 \leq 1.8$. We have observed small errors in the coil alignment of the magnetic structure in H-1. A magnetic island study and a correction in the model to fit the experimental observations revealed the error sources in the magnetic field .

Low-frequency Waves in a Magnetized Dusty Plasma

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School of Physics, University of Sydney, NSW 2006.

Abstract

The physics of dusty plasmas has recently been studied intensively because of its importance for a number of applications in space and laboratory plasmas. Dust particles in a plasma can be highly charged, and are of a size much less than the Debye length. Collective effects in the plasma are affected by the presence of the dust grains, due to the flow of charge onto and off the grain, and the dispersion properties of waves in the plasma can be altered. Here we consider waves propagating in a dusty magnetized plasma at frequencies below and of the order of the ion-cyclotron frequency, and with a non-zero electron temperature. The general dispersion relation for waves propagating at an arbitrary angle with respect to the external magnetic field is derived and discussed. It is shown how the character of the waves is radically altered when a proportion of the negative charge resides on the dust grains: with very small charge on the dust grains, the waves have the usual shear and compressional Alfven wave properties, while for a large charge on the grains the waves are better described as circularly polarized whistler or helicon waves extending to low frequencies.

We investigate in particular the modification of the Alfven resonance absorption mechanism due to dust grains, and show that wave energy propagating at oblique angles to the magnetic field in an increasing density gradient can be very efficiently absorbed at the Alfven resonance in a dusty plasma. This process can be important for the processes of heating of interstellar clouds of plasma containing dust.

Automated Instrumentation for Plasma Monitoring and Control

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The Plasma Instrumentation Laboratory at the University of Canberra was established to carry out research into automatic control and instrumentation of helicon source plasmas for use in plasma processing plants. In this paper we describe the development of decentralised stand alone instrumentation for diagnosis and control of steady state plasmas, in particular the so called Helicon Plasma Source. Several plasma diagnostics and control units are being developed each with an integrated, dedicated microprocessor controller using the General Purpose Interface Bus (GPIB) for communication with the central computer (an IBM PC). The units are being tested on the laboratory's helicon source plasma rig.

The GPIB is an industrial standard interface protocol that allows fast data transfer and control in noisy environments The bus comprises eight data lines and five control lines with a strict hand shaking protocol. Data transfer rates of up to 1 MHz can be realised. A central computer can control up to 15 instruments on one bus. The computer issues instrument specific commands and the addressed unit will respond, take action and return data when requested. A multipurpose instrument card with GPIB interface has been developed around the M68HC11 microprocessor. The card includes an 8 channel 100 kHz 8 bit ADC, two DACs (8 and 12 bit) and 12 channels of digital I/O. The card is programmed for instrument specific operation via an RS232 connection and once operational can be disconnected leaving only the GPIB for communications.

Several diagnostics have been developed that use this controller:

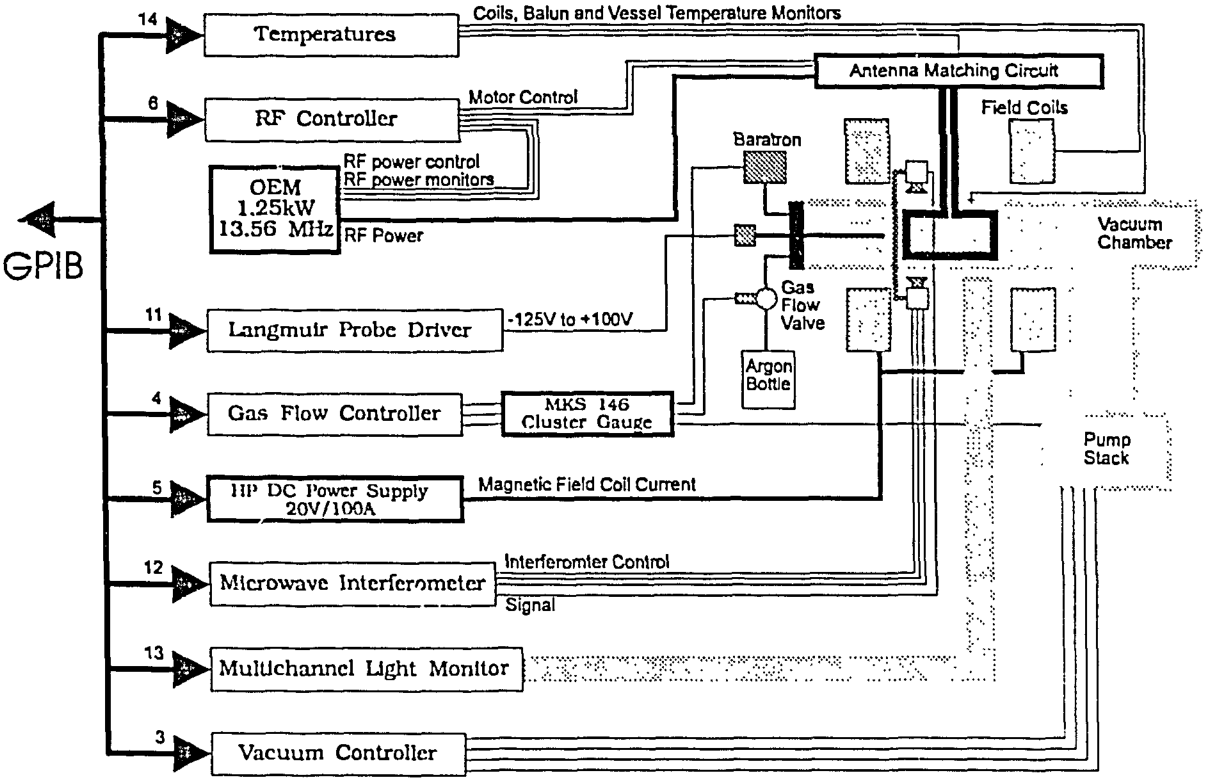
- A fully automated Langmuir Probe Driver sweeps the probe potential from -125 V to +100 V in up to 100 steps with a sweep period of less than 100ms. The probe current and potential are measured at each point and the data stored in onboard RAM to be down loaded to the central computer on request. The technique of matched filters (integrate and dump) has been implemented in the measurement circuit to maximise the Signal to Noise Ratio and provide external analogue to digital conversion while averaging the noisy data over the step interval. This technique avoids the necessity of taking many reading and averaging in order to reduce noise. Gain switching within the unit is automatic and optimised for maximum noise immunity leading to a resolution of better than 10 μA.

- A compact 10 GHz microwave Mach-Zehnder interferometer has been developed using stripline technology. The unit operates by establishing a null condition on the recombined signal with no plasma present by phase shifting and attenuating the signal in the reference arm of the interferometer, using voltage controlled varactor diodes. When the plasma is established a null search algorithm is performed by the microcontroller to continuously track the null condition by phase shifting the reference arm. The electron density is calculated from the phase difference, derived from the voltage on the varacter diodes, and returned to the central computer on request.

- A control interface for an OEM 1.25 kW, 13.56 MHz power supply is being developed as part of a project to implement automatic control of input power to the plasma together with an automatic controller for an RF matching network. In this case coupling is provided by a high power balun which matches the 50Ω power output to the antenna. A variable capacitor is used to tune out the inductive reactance of the antenna [This circuit is described in detail in another paper in this conference]. The unit connects to the RF power supply via the analogue control interface through which the RF power level can be set, monitored and switched on and off. Both the forward and reverse power from the unit can be measured. A control algorithm is required to simultaneously adjust the power supply and RF matching circuit to optimise RF power input to the plasma while negotiating mode jumps within the plasma that occur as the input power increases.

- Other instruments under investigation include: emissive probes, electron energy analysers, RF compensated Langmuir probes and spectroscopic measurements as well as machine control units and safety monitors.

An overview of the system and its operation as well as details of measurements made with these instruments will be presented and discussed.



The figure shows an overview of the decentralised control and measurement system as set up on the laboratory's rig. Units shown shaded are still under development. The system is controlled by an IBM 486 PC running LabTech Control as well as several control programs developed in the laboratory.

This work has been supported by an ARC Small Grant and several UC Research Grants.

The effect of magnetic field structure on instabilities in 3-Dimensional plasmas.

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Abstract

Local magnetic field quantities such as the local magnetic shear and the geodesic and normal curvatures play a major role for stability in 3-dimensional plasmas. A comparison between tokamaks and stellarators will be presented using advanced visulization techniques to clarify the similarities and differences. Both full equilibria and those obtained from analytical expansion will be discussed.

GENERALIZED MAGNETIC COORDINATES

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For toroidal plasma confinement devices one often assumes the existence of nested flux surfaces and constructs a coordinate system in which the magnetic field lines are straight. As plasma motion is strongly tied to the magnetic field lines such a coordinate system simplifies the equations governing plasma dynamics. However, generally, flux surfaces do not exist everywhere due to island formation and chaotic regions, so we consider constructing a set of nested quadratic flux minimizing surfaces, which reduce to flux surfaces where they exist. Using the framework of nested, flux minimizing surfaces. a suitable parametrization is imposed so the general expression for the magnetic field is as simple as possible.

Transport in a Helicon Magnetoplasma

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Abstract

Transport studies of ions in a new kind of Helicon processing reactor, reveal the importance of magnetic field geometries in the source for efficient processing. The expansion of a plasma into the diffusion region is controlled by the structure of the magnetic fields. The rate of expansion gives the potential drop from the source to diffusion region and thus controls the maximum energy ions can posess before impinging upon a processing substrate. The formation of plasma double layers in argon is suspected in certain configurations, opening the way for greater control of ion energy distributions at low pressures. A general transport model is presented, together with experimental results.

ANTENNA COUPLING TO HELICON WAVES IN CYLINDRICAL GEOMETRY

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Plasma formation in the helicon wave range of frequencies is known to be very efficient yet much controversy exists over the possibility of exciting modes with different azimuthal mode numbers. For example, in a typical helicon reactor, antennas capable of exciting asymmetric modes in the range $\omega_{ci} < \omega << \omega_{ce}$ tend to couple predominantly to the m=+1 first radial mode. Despite this, workers have suggested the possibility of controlling the density profile either by localised energy deposition or RF induced transport by exciting either m=+1 or m=-1 waves. Part of the controversy is due to the fact that theoretical investigations have never included the antenna in the analysis. In this paper we investigate the antenna wave coupling problem in cylindrical geometry and consider the cases of conducting and non-conducting boundaries. We consider under what conditions helicon waves of different azimuthal mode numbers can be excited and discuss the implications for plasma formation.

Antenna-wave Coupling Studies and Plasma Formation in SHEILA Using Two different Antennas

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November 1, 1994

Abstract

We present a comparison between antenna-wave coupling theory and experiment for low power helicon waves excited by a shielded half-turn loop antenna in the range 4 - 28 MHz. We report good agreement with the measured relative excitation efficiencies of different poloidal mode numbers, radial wavefield profiles and antenna radiation resistance.

Two different antennas, an unshielded half-turn loop antenna and a double-saddle coil were used for plasma formation by helicon waves in a toroidal heliac plasma. The wavefields and antenna radiation resistances of the two antennas were measured seperately and compared to each other and with theory. It was found that the double loop antenna has a higher radiation resistance and much higher plasma generation efficiency. Even though the unshielded half-turn loop antenna could only produce a very low density plasma at $P_{RF} \geq 10$ kW, it produced comparable wavefields to those of the double-saddle coil in a high density plasma produced by the double-saddle coil at 3 kW. This may suggest that the measured travelling wave fields played little role in the plasma formation while the high density produced by the double-loop antenna may be due to the effect of its strong near fields.

The frequency beating technique used in the experiment may suggest a new method to estimate the particle confinement time in a small plasma device.

Fast two and three dimensional plasma ion current density measurement system.

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Abstract

With the growing industrial importance of plasmas it is necessary to develop efficient diagnostics. The Space Plasma and Plasma Processing Laboratory has developed a diagnostic to map the distribution of the plasma ion current density on a surface or on a volume by multiplexing an array of Langmuir probes (up to 512). The main features of this system are full automatization of the acquisition by an on-board microprocessor, 12 bit resolution for the analogue signal at a sample rate of 10 kHz. This sample rate combined with the multiplexing time gives a total acquisition time of 0.1 second and 0.5 second. Data is displayed as a 3D surface or contour map on a PC.

The quick response time gives immediate feedback to parameter changes. Applications for this system include the optimisation of the magnetic field configuration and mapping the distribution of the power deposition for different antenna parameters

Quasilinear transport of trapped and passing ions in tokamaks with a radial electric field

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The influence of a strong radial electric field on ion drift orbits has been investigated. Analysis has shown that a new velocity distribution of passing and trapped ions is formed in the phase space. If the squeezing factor s is greater than 1 (where $s = 1 - v'/\Omega_p$, $v = cE(r)/B_p$, $\Omega_p = eB_p/mc$) the number of trapped ions increases, otherwise the number of passing ions decreases.

Using these results, the method of Hamiltonian variables was applied to calculate quasilinear (QL) ion transport driven by electrostatic drift turbulence. Our theory predicts decreasing QL-fluxes in the region $E' < 0$ ($s > 1$). This result concides with experimental data from DIII-D which show improved confinement in this regime.

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Spectral Line Broadening in Cathode Spot Emissions in a Pulsed Vacuum Arc

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The pulsed vacuum arc produces a plasma with a 500 ms lifetime, distinguished by the presence of small, mobile cathode spots over the surface. Time resolved measurements have been made of the visible spectral lines emitted by ionised species within the spot. Examination of the spectral profiles shows that the profile changes markedly- and asymmetrically- over the arc lifetime. Doppler broadening and Stark pressure broadening are the two main contributors to the spectral profiles. Determination of the relative contribution of these components determines a range of possible values of ion energies and electron densities within the cathode spot plasma. The spectral line measurements integrate along a line of sight normal to the cathode surface; in order to determine where in the spot plasma the measured energies and densities hold, an understanding of the optical depth of the spot plasma is desirable.

Scattering of a gaussian beam by density fluctuations in a plasma

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A tunable gyrotron has been used as the radiation source in a far-forward scattering experiment to investigate the density fluctuations associated with the appearance of discrete Alfvén wave (DAW) resonances and kinetic Alfvén waves (KAWs) in the TORTUS tokamak plasma. A new arrangement of a quasioptical antenna and a gaussian telescope focused the gyrotron output into the plasma. The experiments enabled DAW resonances and KAWs to be identified and their characteristics were in broad agreement with the predictions (Fekete *et al* 1994). The predictions of the scattered amplitude and phase took into account the diffraction and refraction of a gaussian beam in the plasma.

In the analysis adopted here, we consider a gaussian beam passing through the plasma and see how it is diffracted and refracted by the density perturbations. The calculation is carried out using the complex eikonal method (Choudary and Felsen 1973, 1974, Mazzucato 1989). More specifically, the detailed prescription which Nowak and Orefice (1993) describe as their First Method of quasioptical ray tracing has been adapted to calculate the detected signal.

First, the trajectory of the central ray is calculated using a Runge-Kutta integration. This central ray guides the other rays. Then, the geometrical construction of surfaces of constant phase gives the trajectories of rays on either side of the central ray.

We have applied this method as follows. Suppose the beam is going from left to right through the plasma.

(i) If there is no plasma, the beam has a waist 300 mm from the second gaussian telescope lens, a point halfway across the plasma vessel, as in Figure 1(a). Start the calculation at this beam waist and return to a point just outside the plasma (Figure 1(b)).

(ii) With the plasma present, calculate the path of the beam from left to right (Figure 1(c)).

(iii) In order to avoid calculating the path of the beam through the collecting lens and beyond to the detector waveguide located 300 mm away at its focal point, we use the fact that the fields at the mouth of the waveguide will be the same as those at the image plane. The image plane is 300 mm away from the lens on the plasma side. Once again the no plasma assumption is made and the beam traced back to the image plane (Figure 1(d)). (Note that in these illustrations the beam waist has been reduced by a factor of 0.5 and the density increased by 4 to emphasize the diffractive and refractive effects.)

The electric fields at points along a ray are easily calculated. Any arbitrary electric field distribution across the image plane can be treated as that of a linear combination of gaussian beams. It has the form

$$E = \Sigma\, a_n H_n(\sqrt{2}x/w) \exp(-x^2/w^2)$$

where x is measured (vertically in Figure 1) from the focal point of the lens, w is the beam waist which is 10.8 mm (this is the image of the beam waist which is located at the mouth of the detector waveguide) and the H_n are Hermite polynomials (Kogelnik and Li 1966).

We make the assumption that only the lowest order term couples into the TE_{11} mode in the detector waveguide. The coefficient a_0 is easily found by applying the orthogonality condition in a way similar to fourier analysis. The output signal from the detector is proportional to the $|a_0|$ squared.

This method of calculation encounters difficulties if there are any abrupt changes in refractive index. For this reason, we replaced a sharp drop in the plasma profile at the edge by a gentler sinusoidal variation starting at $r = 0.9\, a$ and extending to $r = 1.1\, a$.

The calculation is repeated for 16 instants of time corresponding to successive plasma rotations of 22.5°. A fourier transform of the result gives the component that varies at the frequency of the Alfvén waves, this will be referred to as the scattered signal.

The present treatment considers a two-dimensional gaussian beam, an obvious extension is to the three-dimensional case.

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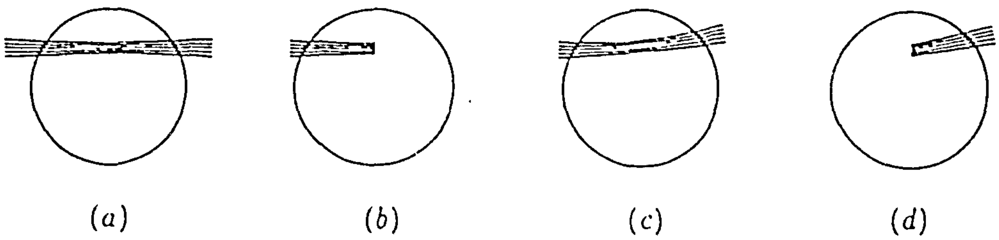

Figure 1 Ray diagrams to illustrate the calculation of the gaussian beam crossing the plasma.

Beam Formation for Plasma Scattering with Tunable Gyrotrons

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The formation of a Gaussian beam from the output of a tunable millimetre-wave gyrotron for plasma diagnostics can be achieved using quasioptical antennas, Gaussian telescopes and quasioptical transmission lines. The different approaches used in scattering experiments on the TORTUS tokamak at the University of Sydney and on the Compact Helical Device (CHD) at the National Institute for Fusion Science) Nagoya, Japan will be described.

CAESIUM SYSTEM FOR SEEDED PLASMAS

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In closed-cycle MHD disk generators, the presence of the ionisation instability in the partially ionized plasma must be avoided since it causes a deterioration in performance. This can be avoided by using the fully ionised seed concept: by maintaining the plasma in an operating regime where the seed material (eg. caesium) is fully ionised while the background gas (argon or helium) is neutral.

To establish these conditions in a laboratory environment requires strict control of the seed atom density. We have designed a system to maintain caesium pressure within a discharge vessel to within 5%. The system uses a mass of copper to provide thermal inertia and is heated using a PID-controlled electrical coil. The design principles and operating performance of the system are discussed.

RF Matching for Helicon Plasma Sources

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A Helicon Plasma Source employs a loop antenna with one turn mounted on each side of the plasma chamber to launch helicon waves which heat the plasma. Magnetic coupling is employed between the plasma and the antenna which therefore appears as an inductive load in series with a reflected plasma resistance. Since the effective plasma resistance is only ~2 ohm in series with an antenna reactance of ~40 ohm a matching network is required to couple the antenna to the radio frequency power source (Power: 1250 W, frequency 13.56 MHz, Output impedance: 50 ohm).

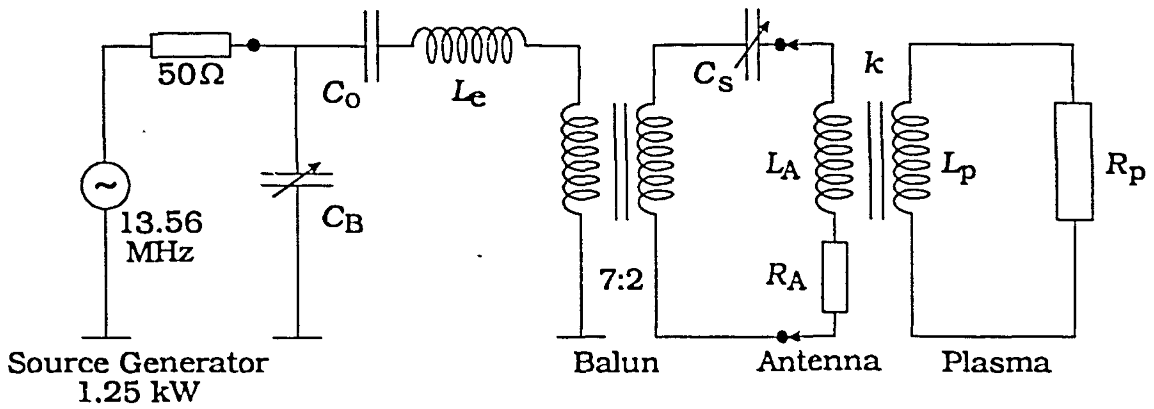
Traditional matching networks for Helicon Sources employ a Π-section matching network in which two capacitors need to be tuned. Because of the large mismatch between the output impedance of the source and the load impedance, a high-Q matching network is required with consequent sensitive tuning of the capacitors.

In this paper we describe the design and use of a high power RF transformer or balun with a turns ratio of 7:2 which provides a crude match between the source and the antenna. Initially a capacitor C_s is employed to tune out the inductive reactance of the antenna (see figure). The impedance seen across the primary winding of the balun is therefore essentially resistive with a typical value ~25 ohm. Final matching is obtained using a capacitor placed in parallel with the input to the balun. Because the impedances to be matched are now much closer to each other, a low-Q matching network results with very little variation required in the value of the shunt capacitor. This means that in an automated system, only the capacitor in series with the antenna would require continuous attention while the shunt capacitor would require occasional coarse adjustment. A further advantage is that the electrical isolation provided by the balun allows a balanced feed to the antenna from the single-end output of the RF Source.

We discuss the design and characterization of an RF transformer capable of handling in excess of 1 kW of RF power at a frequency of 13.56 MHz. The design led to a transformer with a coupling coefficient of 0.85 and a residual leakage inductance L_e of 3.7 μH. An *in situ* technique has been developed which allows precise determination of L_e with the plasma present. Knowing the value of L_e a fixed series capacitor C_0 has been introduced which optimizes the net reactance of the primary of the transformer for subsequent fine tuning of the matching network using the shunt capacitor C_B as shown in the diagram.

The network shown in the diagram has been modelled using PSPICE software and compared with the conventional Π matching arrangement. From this model study the broadband nature of the matching network is demonstrated for a wide range of plasma loads thus confirming its usefulness in an automated tuning system where it is desirable to minimize the amount of intervention necessary to maintain matching.

Results are presented for the effective antenna inductance L_A and plasma load resistance R_A as functions of the input parameters to the plasma (filling pressure, magnetic field and net RF power).



These results have been analysed using a transformer model to represent the coupling between the antenna and the plasma. In this model an effective transformer coupling coefficient k can be defined representing how well the RF power is coupled into the plasma. From the measurements of L_A and R_A values for k and the quality factor Q_A of the antenna can be deduced.

The results show that at low values of the imposed magnetic field (~25G) the coupling coefficient k~0.4 and Q_A~12. These results indicate that the coupling between the antenna and plasma is not particularly effective and are consistent with the suggestion of Perry *et al* (1991) that under these low field conditions the coupling is largely through the electric fields.

At higher magnetic fields (~400G) where a true helicon mode is established it is expected that coupling should be primarily via the RF magnetic fields. Under these conditions it is found that k~0.7 and that Q_A drops to ~7 thus indicating more effective coupling and enhanced dissipation of RF power in the plasma. The drop in the Q of the antenna in the higher mode is qualitatively similar to that observed by Perry *et al* (1991).

It is concluded that the use of an RF transformer facilitates the coupling of an RF generator to a helicon plasma source, and that a transformer model is a useful way in which to describe the coupling between the antenna and the plasma.

A J Perry, D Vender and R W Boswell, J Vac Sc Technol B, 9, 310 (1991).

This work has been supported by an ARC Small Grant and several UC Research Grants.

Simulation of the Cathode Fall Region of a Cylindrical Magnetron Discharge

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A DC magnetron sputtering discharge between concentric cylindrical electrodes has been simulated using a one-dimensional, electrostatic particle-in-cell code, with electron and ion collisions with the filling gas being modelled using Monte-Carlo techniques. The model incorporates non-periodic boundary conditions and an external circuit, and the electric field is calculated self-consistently from the charge density profile until a steady-state has evolved. This model has been used to examine discharges for a range of magnetic field strengths, discharge currents and gas pressures for both helium and argon. The spatial structure of the discharge is shown to be dependent upon the relative values of the electron and ion cross-field mobilities. The results of preliminary Langmuir probe measurements of the radial potential distribution in a laboratory magnetron are presented and compared with the predictions of the model to determine if the code realistically models a magnetron discharge.

Deposition of Reactively Sputtered Titanium Nitride Thin Films Using a Low Frequency Flat-coil, Inductively Coupled Plasma Source

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The aim of this project is to investigate the growth and properties of TiN thin films deposited on a variety of substrates by the reactive sputtering of pure titanium in a N_2/Ar plasma mixture.

The N_2/Ar plasma mixture is produced in a low frequency, flat-coil, inductively coupled plasma source. In the first stage of the project, the electrical and electromagnetic properties of these plasmas have been measured for different N_2/Ar ratios. Stable working points have been identified and the variation in the distribution of the electromagnetic field with mixing ratios has been determined.

Langmuir probe and spectroscopic measurements of the plasma mixtures will be presented at the conference.

The Measurement of Atomic and Ionic Densities in Processing Plasmas

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The reliable measurement of plasma parameters in processing plasmas is a necessary step in attempting to understand the physical processes in such plasmas and their relation to processing outcomes such as the characteristics of deposited thin films. This paper will discuss the measurement of atomic and ionic densities using absorption spectroscopy and hook interferometry. The relative advantages of each technique will be described. As an example of the use of these techniques, results from a study of transport of sputtered material in a magnetron discharge will be presented.

CURRENT STATUS OF H1 HELIAC

L.E.Sharp,B.D.Blackwell,G.Borg,.R.Dewar,H.Gardner,S.M.Hamberger,J.Howard,
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Abstract

Preliminary plasmas have been produced in H-1 over a wide range of magnetic configurations in steady magnetic fields 0.04<B<0.22 T using pulsed rf typically 7MHz. Peak densities up to $5\times10^{18}m^{-3}$ measured by a λ_0= 8mm Mach Zender interferometer, a λ_0= 2mm quadrature interferometer and Langmuir probes, were obtained with temperatures of ~10eV (deduced from both diamagnetic loop and Langmuir probes) in argon with 40kW of rf power. Measured <β> values up to 0.14% been obtained at low magnetic fields (~0.08 T) enabling internal ~~current~~ current distributions to be directly measured using small Rogowski loop coil 'probes' inserted into the plasma. These observed currents have been compared to a 3D numerical computation of the equilibrium current distribution.

The rotating diffraction grating interferometer, λ_0= 433μm (which will ultimately provide a detailed 2D tomographic map of the electron density) has been tested on the plasma with 12 channels sampling the horizontal direction (one of 6 views). A novel λ_0= 2mm 'spherical quadrature' polarimeter has measured low frequency (~ kHz) density and magnetic fluctuations in the plasma driven by the 7 MHz rf fields. These fluctuations have also been observed with both langmuir and magnetic coil probes. Low frequency fluctuations (~ 3 kHz) are also seen in the same frequency range as observed with the SHEILA drift type oscillations.

The vacuum magnetic surfaces measured previously with electron beam and fluorescent probe [1] have been compared with those obtained from the tomographic inversion of the electron beam currents measured with a (poloidally rotating) 64 fine wire grid.

The operation of the facility has been enhanced (i) by improving the machine base pressure to 1.5×10^{-7} Torr using a 4000 l/s liquid nitrogen cooled cryo-panel (this will be replaced with a 75,000l/s closed loop cryo pump) and (ii) 18 large (12" & 6") vacuum ports have been added to the cylindrical shell of the vacuum chamber, to provide additional diagnostic access.

1. M.Shats,D.Rudakov,B.Blackwell,L.Sharp,R.Tulmos,S.Hamberger,D.Fedyanin. Experimental Investigation of the Magnetic Structure on the H-1 Heliac. Rev.Sci.Instr. 66(1) 1995

NON-AXISYMMETRIC PLASMA TRANSPORT SIMULATION WITH A SELF CONSISTENT RADIAL ELECTRIC FIELD

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A parallelised Monte Carlo application of a predictor corrector method for stochastic differential equations, implemented on the Connection Machine CM-5, has been extended in order to obtain a more self-consistent simulation of neoclassical plasma transport in the H-1 Heliac. The code follows guiding centre orbits, and includes the effects of pitch angle and energy scattering, and a self consistent radial electric field.

The radial electric field profiles determined by the code are dependent on the initial plasma density profile. In some cases a sheath-like potential variation at the plasma boundary is formed. Peak electric potentials with magnitudes of the order of the ion temperature are produced, and the resultant increase in plasma rotation strongly enhances confinement in H-1.

Transport coefficients, with and without the electric field, have been calculated for the banana, plateau, and Pfirsch-Schlüter collisionality regimes.

First results from the plasma density interferometer for the ANU helical axis stellarator H1.

George Warr, John Howard and H-1 team.

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A single-view far-infrared ($\lambda = 433$ µm) 12-beam grating-scanned interferometer has recently been installed and tested on the H1 heliac. A number of novel features of the instrument, including the scanning wheel[1], optical design and digital sampling demodulation scheme[2] will be described and the first plasma results presented.

The 12 equispaced ~2 cm wide (FWHM) parallel beams span the central 20 cm of the plasma in a vertical plane. For peak plasma densities ($\sim 2 \times 10^{12}$ cm^{-3}) typical phase shifts of 50° (Michelson interferometer configuration) were measured with a phase resolution of ~1° against background vibration noise of ≈5°. Deep (≥ 50% on extreme channels) phase oscillations at 3 kHz were clearly resolved. The dwell time at each scan position could be optimised for study of these oscillating density fluctuations or for maximising the number of complete scans per plasma pulse (1 scan every 10 ms).

This work is the necessary first step in the development of the final 6-view 72-beam tomographic plasma density interferometer. Progress towards the completion of this system, including techniques for suppression of residual vibration noise, will also be discussed.

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Experimental Studies of the Neoclassical Current in the SHEILA Heliac Plasma

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November 1, 1994

Abstract

Toroidal currents are always of interest in thermonuclear devices, such as tokamaks and stellarators. Usually, a stellarator avoids any DC plasma current since it will introduce an extra magnetic field and may deteriorate the original magnetic field configuration, which is formed by external currents and finely designed.

The neoclassical current consists of the Pfirsch-Schlüter current and the bootstrap current. The Pfirsch-Schlüter current is required by charge neutrality while the bootstrap current is formed by trapped particles and is enhanced due to the friction betweem the trapped and passing particles. Both the currents are proportional to gradient of plasma pressure and are very important for an understanding of plasma equilibrium and transport in a toroidal theromonuclear plasma, in particlular, they are of great interest to the H-1 plasma, a large heliac plasma.

Net toroidal current in SHEILA has been observed. It is suggested that the measured current in the low density regime consists of the Pfirsch-Schlüter current and the bootstrap current. The measured net toroidal component corresponds to the uni-directional bootstrap current, but the measured asymmetric radial profile of the current may indicate a mixture of the current with the bi-directional Pfirsch-Schlüter current.

An Experimental Study of Breakdown in a Pulsed Helicon Plasma

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Abstract

Fast time resolved measurements of ion and electron energy distributions in the first 200 µsec of a discharge in a 20 cm diameter glass Helicon source show that 10 µsec after the rf is turned on, an intense burst of electrons is produced with average energy of 200 eV and lasting about 1 µsec .This initial pulse of high energy electrons can be explained by resonant secondary electron multiplication (the multipactor effect) of electrons which are accelerated in the rf fields produced by the Helicon antenna. These electrons ionize the background gas very rapidly and a plasma with high electron temperature and hence high plasma potential can be created in about 1 µsec. Subsequently, further ionization occurs and after 20 µsec, the plasma potential has fallen to about 200 V and the electron temperature to about 20 eV. The electron temperature continues falling and reaches a steady state value of 8 eV in about 30 µsec. The density and plasma potential reach steady state after about 70 µsec.

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Global Alfven Modes in TORTUS

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The shear Alfven wave can propagate either as a narrow, magnetically guided beam, or as cavity or global mode, depending on the perpendicular *k* spectrum and on the plasma parameters. In the TORTUS tokamak, global modes have been observed at frequencies below the ion cyclotron frequency, in pure hydrogen plasmas and also in gas mixtures.

A large range of modes is observed when the driving frequency is swept from 1 to 9 MHz during a single discharge. The toroidal and poloidal mode numbers are measured with an array of magnetic probes. All modes observed to date can be classified as DAW (Discrete Alfven Wave modes). A thorough search has failed to find any evidence for the TAE (Toroidal Alfven Eigenmodes) modes predicted in a torus, although such modes have been observed in other devices during neutral beam injection experiments. TAE modes are potentially dangerous since they are expected to lead to scattering or poor confinement of alpha particles in fusion devices.

THE ALFVÉN BRANCH OF THE STABLE RESISTIVE MAGNETOHYDRODYNAMIC SPECTRUM

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The effect of resistivity on the stable part of the spectrum of a tokamak-like plasma, described by magnetohydrodynamics, is to break up the ideal continua associated with the shear Alfvén and the slow magnetosonic wave branches into discrete modes [1-9]. The discrete eigenfrequencies, when plotted on the complex frequency plane, form a series of specific lines with a characteristic structure which depends on the equilibrium. Remarkably, the specific lines are almost independent of the resistivity, provided it is small enough, although the spectral density does depend on the resistivity. The wave structure has a particular character which is related to the position of the eigenvalue on the complex frequency plane and its proximity to the endpoints of the Alfvén ideal continuum. For example, the wave forms are large near the surface of the plasma if the mode is near the surface-related end-point of the Alfvén continuum. In this paper the toroidal effects on Alfvén branch of the stable spectrum are investigated. The spectra are obtained from a numerical analysis of the linear, compressible magnetohydrodynamic equations incorporating the effects of finite resistivity. It is found that poloidal coupling causes the characteristic lines, which mark the position of the cylindrical spectrum, to change significantly, particularly in the regions of the complex frequency plane where these lines cross over. This same code can be used to show the effect of resistivity on a typical toroidal Alfvén MHD eigenmode which arises because of the poloidal mode coupling in a toroidal plasma.

We have developed a toroidal spectral code, SPECTOR (Schellhase [10]), which numerically calculates the complete magnetohydrodynamic(MHD) eigenvalue spectrum of fully toroidal, resistive plasmas, from the linearised, compressible MHD equations assuming constant density and finite resistivity. Both the stable and unstable eigenmodes are found by Fourier analysing the linearised MHD equations in the poloidal and toroidal directions, utilising a coordinate system based on the flux surfaces of the toroidal equilibrium. This uses a different numerical procedure to another toroidal spectral code, CASTOR [11], which solves the resistive-MHD eigenvalue problem by means of the Galerkin procedure in combination with a finite-element discretisation in the radial direction and a Fourier expansion in the poloidal coordinate.

We use the linearized MHD equations for a compressible plasma and break the velocity into into a part depending on incompressible flows, via a vector potential **u**, and compressible flows, via a scalar potential w, so that $\mathbf{v} = \nabla \times \mathbf{u} + \nabla w$, and introduce a magnetic vector potential **a**. With a time dependence of the modes assumed to be proportional to $exp(-i\omega t)$ and using a coordinate system based on the equilibrium flux surfaces, Fourier analysis in both the poloidal and toroidal directions and finite difference techniques, the problem is reduced to a general eigenvalue system.

To demonstrate the toroidal dependence on the Alfvén branch of the spectrum for a simple case, we consider first a series of Solov'ev equilibria defined by $\kappa = \frac{na}{R} = \frac{1}{3}$, $nq_0 = 1.6$ for values of the aspect ratio ranging from the cylindrical limit to the toroidal case ($\frac{R}{a} = 150, .., 6$). It is useful to chose a sequence of equilibria with changing aspect ratio but with defined values of κ and nq_0 because the spectra for a simple constant current model [12] (which is the large aspect ratio limit of the Solov'ev equilibrium) depend only on these parameters. This will enable us to focus then on the changes due to toroidicity. We can compare the spectrum obtained for the almost cylindrical case ($\frac{R}{a} = 150$) and for the case with significant poloidal coupling ($\frac{R}{a} = 6$). In the cylindrical case the safety factor $q(\psi)$ is constant and so the ideal Alfvén spectrum corresponds to a series of points at $|\omega_A| = \frac{a}{Rq(\psi)}(l - nq(\psi))$, where l is the poloidal mode number.Let us focus on the area of the complex frequency plane where the modes are dominated by the $l = 1$ and $l = 2$ poloidal modes. For the cylindrical case, resistivity causes the eigenvalues to form a series of curves in the lower half plane corresponding to damped oscillating modes. Toroidicity and poloidal mode coupling (here with $l = 0, ..., 3$) cause the curves to move apart, change curvature and bifurcate into a distorted Y shape. This bifurcation has its origin primarily in the introduction of shear in the safety factor due to toroidicity.

We can use the Solov'ev equilibrium to investigate also the effect of ellipticity of the equilibrium by using a large aspect ratio equilibrium and systematically increasing the ellipticity. In this case the primary coupling is between poloidal modes whose mode number differs by 2. However the effect of increasing ellipticity is also to cause the lines of eigenvalues to move apart.

A systematic study of a sequence of equilibria with significantly non-constant current is more difficult to undertake as the number of parameters defining the equilibrium are larger. However we have looked at a sequence with a current chosen so that the safety factor for the large aspect ratio case ($\frac{R}{a} = 120$) is almost quadratic and ranges over $1.04 \leq q(\psi) \leq 2.40$. In this case, even at large aspect ratio, the resistive spectra form a set of bifurcated curves in which the lines corresponding to a poloidal mode 1 overlap with those corresponding to poloidal mode 2. As the aspect ratio is decreased to 4 it is found that the curves break up in an irregular fashion where they cross over.

The code can be used to investigate the resistive damping of toroidicity-induced Alfvén eigenmodes (TAE modes) [13]. Poloidal coupling can cause the ideal Alfvén continuum to break up and the formation of TAE modes in the gaps created. We have used SPECTOR to investigate the damping of these modes due to resitivity. Is was found that, in general, the damping is small and, over significant ranges of resistivity, is almost independent of the resistivity.

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Magnetospheric Internal Compressional Pc 3 Waves Associated with a Magnetic Storm: Observations and Theory

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ABSTRACT

Ultra-low-frequency MHD waves (20-100mHz) in the earth's inner magnetosphere are reviewed with focus on internal wave generation and cavity resonance responses. A CRRES observed compressional Pc 3 wave event with a constant frequency (~35 mHz) in the background magnetic field varing from 150 to 280 nT, occurring on 7th Aug., 1991, is studied. The CRRES observed Pc 3 waves basically show a non-localized characteristics. However, an 180° phase shift in transverse magnetic field components over a small fraction of the time interval within the event may imply an occurence of local field line resonance stimulated by these compressional wave. Over the rest of the event time interval, the phase relation of the transverse components remains unchanged. This event is associated with a sudden depression of the magnetosphere seen as a weak magnetic storm on the ground. The azimuthal wave number is large (O(10)) in this event, and the oscillations are mainly in radial and field-aligned directions. Particle data (10eV < energy < 33keV) indicate that the Pc 3 waves were associated with an enhancement of > 1keV ion flux. Ground stations at both low and high latitudes did not record similar Pc 3 waves. Observation may suggest an instability occurring in the inner magnetosphere or a cavity response of the magnetosphere to the depression. The cavity resonance of the compressional fast mode with a large azimuthal harmonic number is examined. The observed wave features agree well with the cavity model. Also, the drift-mirror and drift-compressional instabilities fed by > 1keV ring current ions are examined, and compared with the observation. The calculation indicates that to determine whether these ring current instabilities are responsible to the observed compressional internal Pc 3 waves, high energetic (at least > 100 keV) ion data are required.

1. Submitted to the 20th AINSE Conference

2. Oral presentation

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WKB-Ballooning vs. Global Expansion Methods for Short-Wavelength MHD Waves in Stellarators

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Many waves of interest in plasmas have phases that vary slowly (with a scale length greater than or equal to the machine size) parallel to the magnetic field, but rapidly (on a scale much shorter than the machine size) in directions transverse to the field. Physical understanding of these waves is greatly helped by taking them to be locally plane waves, with $k_{||} = 0$. There is a technical difficulty with implementing this constraint in toroidal geometry, which is solved by the "ballooning representation". The ballooning representation has become a standard method for treating pressure-driven MHD modes, drift waves and Alfvén waves. By using ray tracing methods, the local analysis can be extended to the construction of approximate global modes, even for non-axisymmetric devices [1]. However the limit of zero global magnetic shear is singular, and the question arises as to whether the method is really appropriate for low-shear devices such as stellarators. We have investigated this by solving the ballooning dispersion relation at many points in numerical plasma equilibria (both heliac and torsatron) using a version of the VVBAL code, parallelised for the Thinking Machines Corporation CM-5 at ANU and in addition performing a ray tracing calculation as prescribed in [1]. Results are compared with those from the Lausanne global code Terpsichore.

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Modelling of a Microwave Plasma Jet

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An argon plasma jet is being studied as a heat source suitable for material welding and joining applications. The jet is formed from a weakly ionised atmospheric pressure microwave plasma created in an alumina ceramic chamber positioned across a rectangular waveguide. The 2.45 GHz waveguide applicator shown in Figure 1, contains a stub section to allow coupling of microwave power to the plasma column. The microwave system consists of a 5 kW CW magnetron, isolator and directional couplers. The load impedance is measured by a slotted waveguide meter inserted before the applicator. By examining the standing wave ratio and location of voltage maxima, the normalised load impedance at any power level can be determined.

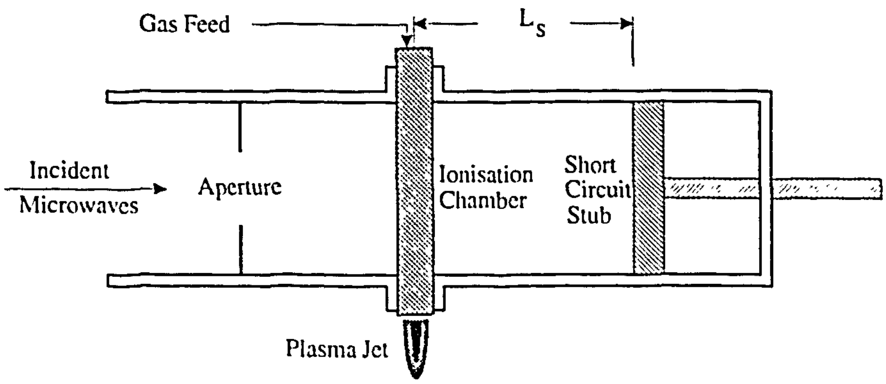

Figure 1. Schematic Diagram of Microwave jet applicator

Results indicate that extremely efficient coupling of microwave power to the plasma can occur with power levels exceeding 3 kW. The degree of coupling is critically dependant upon the tuning stub position as seen in Figure 2. Tests also reveal that, to a lesser extent, input power and plasma gas flow rate have an effect on the coupling.

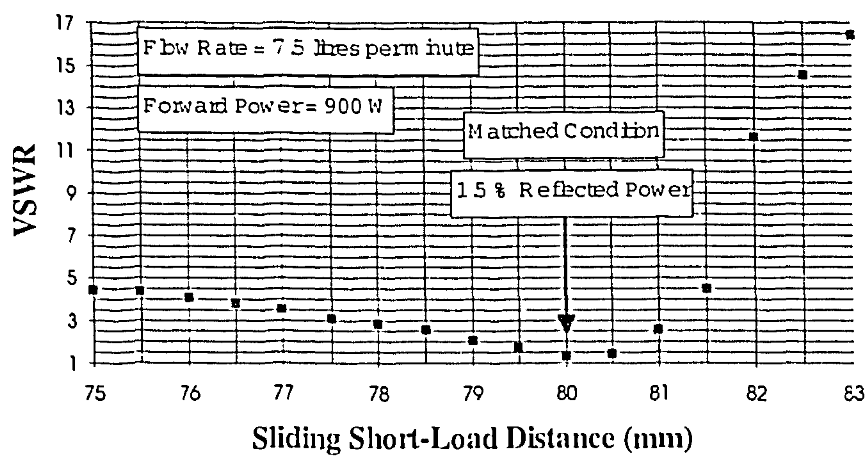

Figure 2. The effect of load-sliding short distance on VSWR

Measurements of the electrical impedance of the plasma column enable a simple electrical circuit model of the source to be developed as given in Figure 3.

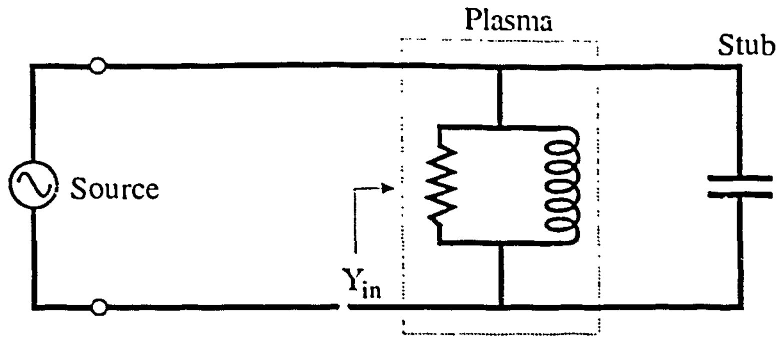

Figure 3. Electrical circuit model on the microwave induced plasma jet (MIPJ).

Y_{in} is the load admittance as calculated from measurements on the slotted line. Using the model, the effect of the stub can be subtracted and the resultant plasma admittance, Y_{plasma} is shown in the second column of Table 1. Note that the plasma admittance contains an inductive component that is essentially unchanged with the stub position and can be interpreted as the inductive component of the plasma column.

Load-Sliding Short Distance, L_s (mm)	VSWR (Measured)	Y_{in} (Normalised)	Y_{Plasma} (Normalised)
75.0	4.40	0.779-1.43j	0.779-3.59j
76.0	4.07	0.724-1.27j	0.724-3.62j
77.0	3.50	0.678-1.06j	0.678-3.66j
78.0	2.83	0.667-0.840j	0.667-3.76j
79.0	2.07	0.679-0.534j	0.679-3.83j
80.0	1.28	0.781-0.012j	0.781-3.80j
80.5	1.46	0.942+0.354j	0.942-3.73j
81.0	2.53	1.11+0.999j	1.11-3.42j
81.5	4.51	2.32+2.21j	2.32-2.62j

Table 1. Plasma admittance as a function of load-sliding short distance.

By modelling the plasma column as a perfectly conducting wire of diameter 6 mm (equal to the internal diameter of the ceramic tube) stretched across the waveguide, we calculate a normalised susceptance of 3.8 which closely matches the measured result. The purpose of the stub is to cancel the plasma inductance. L_s, being longer than a quarter wavelength means the stub reactance is capacitive, as indicated in Figure 3. When the stub length is 80 mm, the total load admittance is real and of value Y_{in} = 0.78 indicating that the plasma column has a microwave resistance of approximately 1200 Ω. At this point the VSWR is 1.28 and more than 98 percent of the forward power is absorbed in the plasma.

The electron density and temperature of the plasma jet are still under investigation but researchers[1] have reported values of 7E13 cm^{-3} and 6700 K respectively for a 2.45 GHz, 1.8 kW plasma jet.

This project is supported by the Cooperative Research Centre for Materials Welding and Joining at the University of Wollongong.

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The application of plasma devices to the fabrication of semiconductor, photonic and optical components

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Plasma devices are commonly used for the etching and deposition of thin films of a range of materials in the fabrication of semiconductor and photonic devices, and the deposition of thin films on optical components. The pursuit of the semiconductor industry of tools for manufacturing smaller devices packed closer together on a substrate, and the recent explosive growth of commercial interest in photonic devices, has lead to increased interest in "second generation" plasma etching and deposition devices. In the semiconductor industry, which is aiming to make devices where the gate width is ~ 0.25 μm by the turn of the century, this necessitates the development of an etching system with a precision of ~ 0.025 μm! It is necessary in such devices that the ion energy and ion flux to a substrate be independently controlled.

In this talk the following systems, which are already coming into use for etching and deposition and which are the subject of considerable research effort, will be discussed:

- The ECR (Electron Cyclotron Resonance) discharge
- The Helicon discharge
- The ICP (Inductively Coupled Plasma) discharge
- The Helical Resonator Discharge

In addition the filtered cathodic arc, which is being increasingly used for the reactive and non-reactive "evaporative" deposition of a range of exotic materials, will be described.

Gyrotrons for electron cyclotron resonance heating in ITER

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1. ECRH on ITER

The development of gyrotrons has been driven by the requirement of the fusion community to heat plasmas to high temperatures by electron cyclotron resonance heating (ECRH) and to maintain a steady toroidal current in the tokamak so it can operate continuously (current drive).

In one early proposal for ITER (International Thermonuclear Experimental Reactor), the millimetre wave power requirements were 20 MW at 120 GHz which would be supplied by a bank of 28 gyrotron oscillators. Each gyrotron would be capable of delivering 1 MW CW. Because gyrotrons are only about 35% efficient, each tube would require its own 3 MW power supply (80-100 kV, 40 A). The millimetre wave frequency in the current design has now been increased to 170 GHz.

2. First generation gyrotrons

The first generation of gyrotron could be represented by the standard, off the shelf, Varian 60 GHz, 200 kW CW gyrotron (Felch *et al* 1984) shown in Figure 1.

The electron gun provides a beam of electrons in the shape of an annular cylinder. The accelerating voltage is 80 kV and the beam current is 7.5 A so the input power is 600 kW. In the resonant cavity where the interaction takes place the individual electrons gyrate in very small orbits because of the magnetic field provided by the superconducting magnet. The interaction whereby some electron energy is converted into electromagnetic radiation relies on a bunching in phase which follows from small relativistic mass differences the electrons acquire.

The millimetre waves escape from the cavity, travel up the tube and out of the output window.
The spent electrons strike the collector some distance below the window (remember, the beam power was 600 kW, the output power is 200 kW so the power that must be dissipated by the collector is 400 kW).

The gyrotron output is converted into a gaussian beam externally by rippled-wall and serpentine mode converters.

All window materials will absorb millimetre-wave energy to some extent. This energy must be removed to avoid destruction of the window. For pulsed operation, an edge-cooled ceramic disc may be adequate, For CW operation a double disc arrangement with a low-loss dielectric fluid flowing between them is preferred. Sapphire is another commonly used window material. It can be cryogenically cooled to take advantage of the properties that the absorption at 20 K is one hundredth that at room temperature and the thermal conductivity is a maximum at 30 K

3. Second generation gyrotrons

Many problems of this gyrotron design are dealt with better by what I shall call the second generation of high-power gyrotrons. An example is shown in Figure 2 (Denisov *et al* 1992). This kind of design will operate at 170 GHz and with an 80 kV, 45 A beam deliver 1 MW CW.

The first thing to note is that the mode converter is now inside the gyrotron tube and the output window is at the side of the tube. The mode converter is a quasioptical antenna. The electron beam travels to the collector separately from the microwave beam. So two problems are solved at once. The output beam profile is gaussian and the collector can be a much larger structure better able to handle the energy that remains in the electron beam.

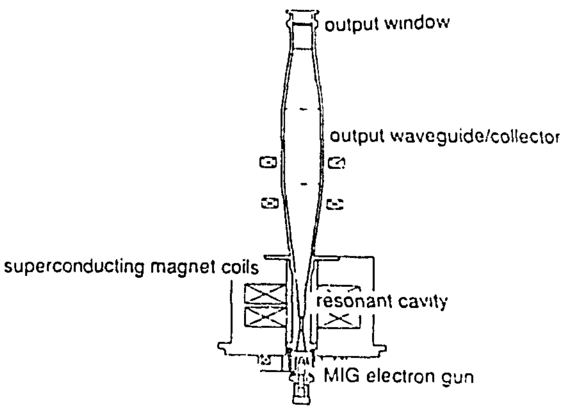
Improvements to the quality of the beam can be achieved by dimpling the wall of the launcher (the so-called Denisov converter). Furthermore, output window problems may be reduced by shaping the mirrors so the beam profile is tailored so as to distribute the power more uniformly over the window. In other designs the launcher is modified to send two beams to separate mirrors after which the beams emerge from different windows.

More efficient operation (with a corresponding reduction in the power handling demands on the collector) can be achieved by slowing down the electrons by a retarding field before they strike the collector. This is known as collector potential depression. Efficiencies may be improved from 35% to 50%.

References

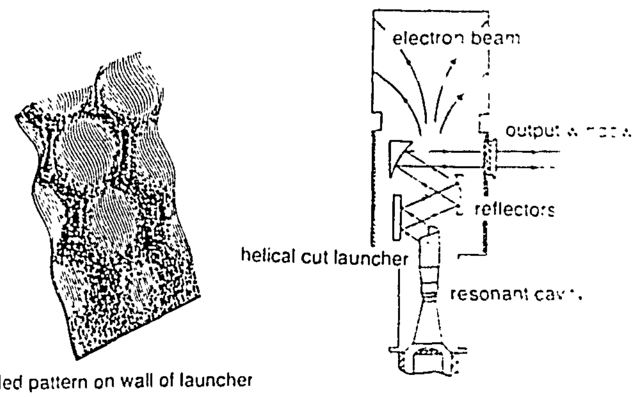
G.G. Denisov *et al* " 110 GHz gyrotron with a built-in high efficiency converter" *Int. J. Electron.* **72** 1079 (1992).

K. Felch *et al* "A 60 GHz, 200 kW CW gyrotron with a pure output mode" *Int. J. Electron.* **57** 815 (1984).



60 GHz, 200 kW CW Varian gyrotron

Figure 1



Denisov converter

Figure 2

Langmuir Probe Measurements in a Microwave Discharge

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The plasma conditions in the moderate pressure (20 to 100 torr) microwave discharges used for the chemical vapour deposition of diamond are not well known. In particular, Langmuir probe measurements of the average electron energy appear to be too high. Typical results reported in the literature range from 8 to 15 eV. Estimates based on simple ionization balance indicate a much lower average energy of around 2 eV for this pressure range [1].

Such measurements have usually been made without taking precautions against distortion of the probe I-V curve by the microwave electric field. The effects of high frequency fields are well known in connection with probe measurements in RF discharges - a shift in the floating potential and distortion of the I-V curve, generally resulting in higher apparent average electron energies.

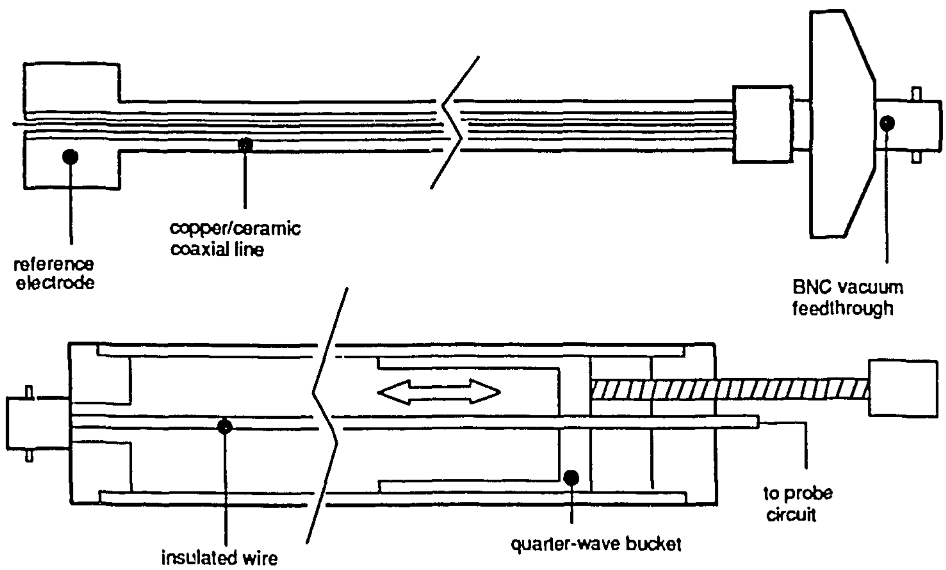

Figure 1: Coaxial Langmuir probe and variable short for adjustment of the probe circuit impedance.

The probe system that we are developing minimises the distortion by allowing the probe impedance (at 2.45 GHz) to be adjusted so that it is very large compared with the sheath impedance. Most of the microwave voltage then appears across the probe rather than across the sheath. Ivanov [2] discusses this in more detail.

The Langmuir probe is shown in figure 1. The reference electrode, attached to the probe and in contact with the discharge, is grounded. The tungsten probe tip is attached to a coaxial line constructed from copper pipe. A short coaxial cable connects the probe to the variable short. The variable short needs to be at least half a wavelength long to get the full range of impedance. A continuation of the inner conductor through a small hole in the rear of the quarter wave bucket allows a connection to the probe driver and measurement electronics.

The probe is inserted in a tube type reactor. Here, a discharge is developed in a quartz tube passing through through the centre of the broad face of a length of WR340 waveguide. The reference electrode is coplanar with one face of the waveguide.

Typical I-V curves are shown in figure 2 for two positions of the variable short, corresponding to the extremes in apparent floating potential. The optimal probe position corresponds to the most positive floating potential. The apparent average electron energy deduced from these curves is three times bigger for position (b) than for position (a). These measurements were taken at a reduced pressure of about 1 torr.

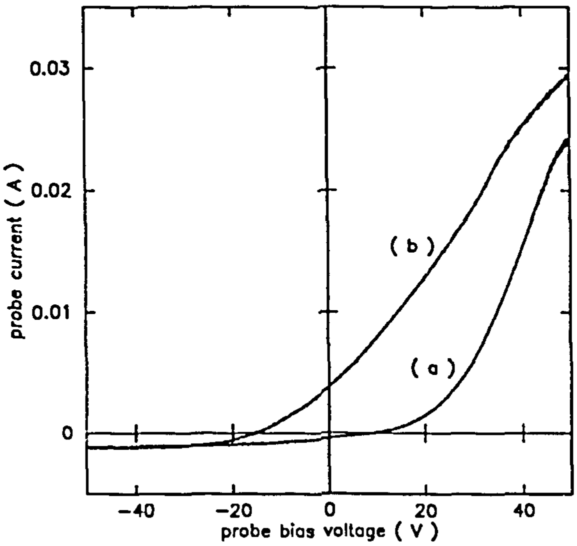

Figure 2: I-V characteristics for different positions of the short: (a) is optimally tuned, (b) is worst case.

It is clear that there are still problems. The average energy in figure 2 as estimated from the difference in floating potential and space potential is about 10 eV (and one would expect about 4 eV). This is not much of an improvement over previously reported measurements. One indication of problems is the EEDF obtained from the I-V measurements. This typically shows a double humped structure with a large peak at around 20 eV. This may indicate residual distortion by the microwave field. Alternatively, the intense electric fields (the peak power is around 4 kW) may be causing a secondary discharge in the vicinity of the probe. At pressures of greater than 20 torr, a distinct glow can be observed around the probe tip. We shall be able to test whether the intense fields are causing problems with a better controlled power supply in the near future.

References

[1] Wouters M J *The EEDF in a Diamond Forming Microwave Discharge and the Validity of Assuming a Maxwellian EEDF* (submitted for publication)

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Start Up Conditions for R.F. Current Drive in Toroidal Plasma Vessels

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The problems associated with doing both plasma production and radio frequency current drive, of toroidal and poloidal currents in a toroidal plasma vessel using radio frequency power coupled through helical antennas surrounding the vessel will be presented.

This will be followed by a progress report on the production of a suitable target plasma for RF current drive, by inductive coupling. This target plasma which is similar to the start up stages of a tokamak will be prepared through the Townsend avalanche phase and the Coulomb phase, and then the high power RF will be applied, enabling a direct comparison of RF current drive with inductive current drive.

Reaction Mechanisms on Wool Surface Modification by Plasma†

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Abstract

The reactions occurring on wool surface in an rf plasma have been studied. The active neutral species were measured using vuv spectroscopy while the electron energy distribution function (EEDF) and plasma density were obtained from Langmuir probe measurements. A kinetic model of the rf oxygen plasma was developed to predict the concentration of oxygen atoms (N[O]) and metastable singlet molecules ($N[O_2^*]$). The rate coefficients for electron impact processes were calculated from the measured EEDF. The N[O] and $N[O_2^*]$ calculated from the model agree well with the experimental measurements.

A comparison is made between the changes to the wool surface and the measured concentrations of the neutral and charged particle species for a wide range of plasma conditions. Results show that the measured increase in wool surface energy is well correlated with the integrated flux of atomic oxygen to the fibre, regardless of its origin. Charged particles appear to have little effect beyond sputtering, while the role of metastable excited oxygen molecules seems not to be statistically significant. Similar but weaker effects sometimes seen with discharges in argon appear to be due to the presence of oxygen as an impurity.

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Electrical and Electromagnetic Characteristics of a Low Frequency, Flat-coil, Inductively Coupled Plasma Source

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Various gases and mixtures of gases (Ar, H_2, N_2, CH_4) at filling pressures lying in the range 100 mTorr - 15 Torr have been converted into steady-state plasmas in a low frequency, flat-coil, inductively coupled plasma source. The global electrical properties of these discharges have been measured and working points have been identified which allow stable discharges to be produced.

The electromagnetic field of the spiral-coil plasma source has been investigated, both theoretically (fluid model) and experimentally. A comparison of the experimental data with theoretical predictions has allowed estimates to be made of both the effective electron collision frequency and electron number density for argon plasmas.

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THE FLINDERS UNIVERSITY OF SOUTH AUSTRALIA	
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Mr I M El-Fayoumi	54
Mr P Euripides	3
Professor I R Jones	3, 37, 54
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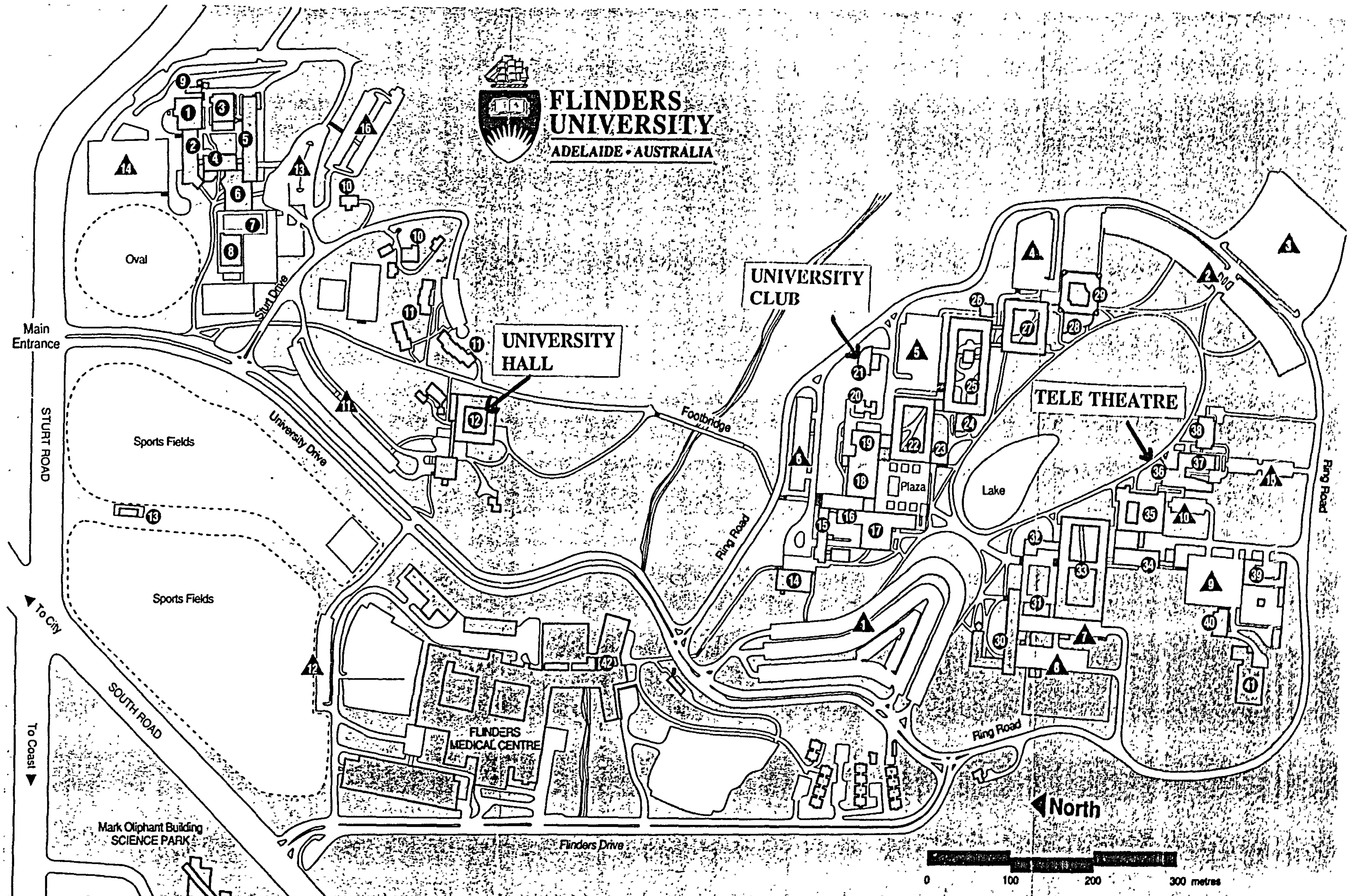
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