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PLASMA THEORY AND SIMULATION GROUP

Professor C.K. Birdsall

January 1 to December 31, 1990

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ELECTRONICS RESEARCH LABORATORY
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University of California, Berkeley, CA 94720
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<td>Annual Progress Report</td>
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<td>Professor Charles K. Birdsall</td>
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<td>University of California</td>
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<td>Arlington, VA 22217</td>
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<th>18. SUPPLEMENTARY NOTES</th>
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<tr>
<td>Our group uses theory and simulation as tools in order to increase the understanding of plasma instabilities, heating, transport, plasma-wall interactions, and large potentials in plasma. We also work on the improvement of simulation both theoretically and practically.</td>
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<th>19. KEY WORDS (Continue on reverse side if necessary and identify by block number)</th>
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<td>Research in plasma theory and simulation, plasma-wall interactions, large potentials in plasmas, bounded plasmas</td>
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<tr>
<th>20. ABSTRACT (Continue on reverse side if necessary and identify by block number)</th>
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<tr>
<td>This is a brief progress report, covering our research in general plasma theory and simulation, plasma-wall physics theory and simulation, and code development. Reports written in this period are included with this mailing. A publications list plus abstracts for two major meetings are included.</td>
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</tbody>
</table>
Our research group uses both theory and simulation as tools in order to increase the understanding of instabilities, heating, transport, plasma-wall interactions, and large potentials in plasmas. We also work on the improvement of simulation, both theoretically and practically.

Our staff is:

Professor C.K. Birdsall 191M Cory Hall 643-6631

Principal Investigator

Dr. Scott Parker (May-August) 199MD Cory Hall 642-1297
Dr. Xueqiao Xu (August on) 187M Cory Hall 642-3477
Dr. A. Tarditi (from Genoa, Italy, NATO Fellow, October on)

Post-doctorates

Mr. Scott Parker (Ph.D. completed April) 199MD Cory Hall 642-1297
Mr. Richard Procassini (Ph.D. completed April) 199MD Cory Hall 642-1297
Mr. Vahid Vahedi 199MD Cory Hall 642-1297
Mr. John Verboncoeur 199MD Cory Hall 642-1297
Mr. Henry Heikkinen 199MD Cory Hall 642-1297
Mr. Frank Tsung 199MD Cory Hall 642-1297
Mr. Ed Chao 199MD Cory Hall 642-1297

Research Assistants (students)

M. Virginia Alves (from Brazil, until July)
Prof. Jan Trulsen (from Tromso, Norway, April-July)
Prof. S. Kuhn (from Innsbruck, Austria, August)
Dr. M.J. Gerver (from SatConTech, MA, two weeks, August)

Visitors

Our advisers are:

Dr. Ilan Roth 304 SSL 642-1327

Physicist, Space Science Lab, UCB

Dr. Bruce Cohen L630 LLNL 422-9823
Dr. Alex Friedman L630 LLNL 422-0827
Dr. A. Bruce Langdon L472 LLNL 422-5444

Physicists, Lawrence Livermore Natl. Lab
Our research for 1990 has been widely reported, as given by the listing following, of 16 Journal Articles, 3 ERL Reports, 4 Talks, and 12 Poster Papers.

Abstracts are attached for some of the talks.

Sent along with this Report are reprints of Journal Articles and the ERL Reports.

Our prior mode was to publish Quarterly Progress Reports; these then became Semi-Annual Reports, which ended in 1988. In 1989, we began publishing Annual Progress Reports. While QPR's were excellent exercises in reporting, they required an immense effort; in today's research climate, such effort is not available.

We trust that our reporting is still useful.

C.K. Birdsall
Principal Investigator
Publications for 1990

Journal Articles


S.E. Parker, and C.K. Birdsall, "Numerical Error in Electron Orbits with Large $\omega_c \Delta t$," accepted by *J. Comp. Physics*.


ERL Reports


Conference Proceedings, Poster Papers

*Sherwood Fusion Theory Conference*, Williamsburg, VA, April 23-25, 1990:


Live demonstration in Plasma Visualization evening session 7-11pm April 24 of our bounded plasma PC codes, applications. (by Birdsall, Vahedi)

*Microwave Power Tube Conference*, Monterey, CA, May 7-9, 1990:

I.J. Morey, and C.K. Birdsall, "Traveling-Wave Tube Simulation; the IBC Code."


M.V. Alves, M.A. Lieberman, V. Vahedi, C.K. Birdsall, "Sheath Voltage Ratio For Asymmetric RF Discharges."

J.P. Verboncoeur, V. Vahedi, M.A. Lieberman, C.K. Birdsall, "Work Done And Energy Balance in RF Discharges."


V. Vahedi, M.A. Lieberman, M.A. Alves, J.P. Verboncoeur, and C.K. Birdsall, "A One Dimensional Collisional Model For Plasma Immersion Ion Implantation."

43rd Annual Gaseous Electronics Conference, Urbana-Champaign, IL, October 16-19, 1990.
C.K. Birdsall, "Particle-In-Cell Combined with Monte Carlo Collisions In Living Color." (Invited talk)
J.P. Verboncoeur, V. Vahedi, and C.K. Birdsall, "Power Deposition in Parallel Plate Discharges."

APS/Division of Plasma Physics, Cincinnati, OH, November 12-16, 1990.
S.E. Parker, and C.K. Birdsall, "Particle Transport due to Kelvin-Helmholtz Vortices and Small Scale Turbulence."


Course


Invited Talks


C.K. Birdsall, "Interactive Plasma Computer Experiments; Plasma Device Simulations on PC's and Workstations," June 1, 1990 Naval Post Graduate School, Monterey, CA.

C.K. Birdsall, "Particle-In-Cell Combined with Monte Carlo Collisions In Living Color; October 16-19, 1990, at the 43rd Annual Gaseous Electronics Conference, Urbana-Champaign, Illinois."
Particle Simulations Of Transport In A Diverted Tokamak Scrape-Off Layer: The High-Recycling Regime

Richard J. Procassini and Charles K. Birdsall

Electronics Research Laboratory
University of California
Berkeley, CA 94720

Bruce I. Cohen

Magnetic Fusion Energy Division
Lawrence Livermore National Laboratory
Livermore, CA 94550

The transport of particles and energy through a tokamak scrape-off layer (SOL) is studied via the particle simulation code DIPS1 (Direct Implicit Plasma Surface Interactions). This code combines direct-implicit particle-in-cell (PIC) techniques with Monte Carlo models for Coulomb collisions, and charged/neutral atomic physics interactions. The fully-kinetic guiding-center PIC code provides a self-consistent solution of the electrostatic potential profile in one spatial dimension (along the open field lines in the SOL) and two velocity components ($v_x, v_y$).

The Monte Carlo, binary-particle Coulomb collision model conserves both the momentum and kinetic energy of the interacting particles. The full range of Coulomb collisional processes (e-e, e-i and i-i) are included. Recycled neutral particles are treated in an ad hoc manner: the density is assumed to decay exponentially with increasing distance from the divertor plate (the e-folding length is taken to be the average mean-free path to ionization) and the temperature of the neutrals is prescribed by the user. The neutral particles interact with the background plasma via charge-exchange events with ions and impact ionization events arising from electron/neutral collisions.

This model is used to determine the effect of charged/neutral interactions on the transport properties of a tokamak SOL plasma. The prescribed neutral particle density will span a wide range of recycling fractions. Values of the presheath and collector sheath potential drops, plasma temperature, flow velocity and parallel heat fluxes as a function of charged/neutral collisionality will be presented.

We will also discuss the possibility of extending this model to include the effects of sputtered impurity particles, which could be evolved as a second ionic species. This would allow one to determine the effect of sputtered impurities on the potential profile (and ultimately, the transport of particles and energy) in the plasma-sheath region.

* Work performed for the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract W-7405-ENG-48.
Particle Simulations of Transport in a High-Recycling Divertor Scrape-Off Layer

Richard J. Procsassini and Charles K. Birdsall
Electronics Research Laboratory
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Berkeley, CA 94720 U.S.A.

Bruce L. Cohen
Magnetic Fusion Energy Division
Lawrence Livermore National Laboratory
Livermore, CA 94550 U.S.A.

The transport of particles and energy through a tokamak scrape-off layer (SOL) is studied via the particle simulation code DIPSI (Direct Implicit Plasma Surface Interactions). This code combines direct-implicit particle-in-cell (PIC) techniques with Monte Carlo models for Coulomb collisions and charged/neutral atomic physics interactions. The full-kinetic guiding-center PIC code provides a self-consistent solution of the electrostatic potential profile in one spatial dimension (along the open field lines in the SOL) and two velocity components \((v_x, v_y)\).

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This model is used to determine the effect of charged/neutral interactions on the transport properties of a tokamak SOL plasma. The prescribed neutral particle density span a wide range of recycling fractions. Values of the presheath and collector sheath potential drops, plasma temperature, flow velocity and parallel heat fluxes as a function of charged/neutral collisionality will be presented.

Extensions of this model which include the effects of sputtered impurity particles will also be discussed. The sputtered particles may be evolved as a second ionic species. This will allow one to determine the effect of sputtered impurities on the potential profile (and ultimately, the transport of particles and energy) in the plasma-sheath region.

Work performed for the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract W-7405-ENG-48.

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SHEATH VOLTAGE RATIO FOR ASYMMETRIC RF DISCHARGES

M. V. Alves, M. A. Lieberman, V. Vahedi and C. K. Birdsall
University of California
Berkeley, CA 94720

Spherical and cylindrical many-particle models are being used to simulate RF discharges in which the RF powered and the grounded electrodes have different areas. This asymmetry determines the magnitude of the self-bias voltage \(V_s\) (the ion bombarding energy) at the powered electrode, which is a critical process parameter. Recent analytical models for the sheath voltage ratio including the effect of the floating potential have been developed that agree with some experimental results. One dimensional (radial) spherical shell models have also been developed, incorporating various assumptions for the sheath and the glow discharges, leading to a scaling which is in agreement with some measurements. We have simulated the spherical model with a non uniform ionization and the results agree with the theory. The cylindrical simulation shows that the floating potential plays an important role. The simulation results will be given graphically as the sheath voltage ratio versus area ratio, and will be compared with the theory. The simulation codes are PDC1 (cylindrical) and PDS1 (spherical) which utilize particle-in-cell techniques plus Monte-Carlo simulation of electron-neutral (elastic, excitation and ionization) and ion-neutral (scattering and charge-exchange) collisions.

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1. This work is supported in part by ONR contract N00014-90-J-1198.
2. M. V. Alves, visiting from INPE-Brazil, supported partially by CAPES-Ministry of Education, Brazil.
7. Codes available from Industrial Liaison Program, EECS Dept., UC Berkeley.
WORK DONE AND ENERGY BALANCE
IN RF DISCHARGES\textsuperscript{1}

J. P. Verboncoeur and V. Vahedi
M. A. Lieberman, and C. K. Birdsall
University of California
Berkeley, CA 94720

The fields applied to a parallel plate RF discharge do work on the plasma particles (deposit energy) non-uniformly in space and time at a rate given by \( J \cdot E \). Similarly, energy is lost by the plasma particles when they strike the electrodes or collide with neutrals or radiate. We are currently characterizing the work done and the losses as a function of time and space in a manner similar to that of Vender and Boswell\textsuperscript{2} self-consistently. We compare these results to discharge models and other simulations. The simulation code is PDPI which utilizes particle-in-cell techniques plus Monte-Carlo simulation of electron-neutral (elastic, excitation and ionization) and ion-neutral (scattering and charge-exchange) collisions\textsuperscript{3,4}. The code can simulate different environments with various gases and various pressures commonly used in RF discharges needed in plasma processing.

\textsuperscript{1} This work is supported in part by ONR contract N00014-90-J-1198
\textsuperscript{4} Codes available from Industrial Liaison Program, EECS Dept., UC Berkeley.

A COLLISIONAL MODEL FOR PLASMA
IMMERSION ION IMPLANTATION\textsuperscript{1}

V. Vahedi, M. A. Lieberman,
M. V. Alves\textsuperscript{2}, J. P. Verboncoeur,
and C. K. Birdsall
University of California
Berkeley, CA 94720

In plasma immersion ion implantation, a target is immersed in a plasma and a series of negative short pulses are applied to it to implant the ions. A new analytical model is being developed for the high pressure regimes in which the motion of the ions is highly collisional. The model provides values for ion flux, average ion velocity at the target, and sheath edge motion as a function of time. The model suggests that the transient ion flux at the target scales with:

\[ J_I = \sqrt{2} \varepsilon u_0 n_e (1 + \omega_e) \frac{a}{t} \]

where \( \omega_e \) and \( u_0 \) are characteristic frequency and velocity of the ions in the sheath, \( n_e \) is the density, and \( t \) is the time. These values are being compared with those obtained from simulation and show good agreement. A review will also be given (for comparison) of the earlier work done at low pressures, where the motion of ions in the sheath is collisionless\textsuperscript{3}, also showing good agreement between analysis and simulation\textsuperscript{4}. The simulation code is PDPI which utilizes particle-in-cell techniques plus Monte-Carlo simulation of electron-neutral (elastic, excitation and ionization) and ion-neutral (scattering and charge-exchange) collisions\textsuperscript{5}.

\textsuperscript{1} This work is supported in part by ONR contract N00014-90-J-1198
\textsuperscript{2} M. V. Alves, visiting from INPE-Brazil, supported partially by CAPES-Ministry of Education, Brazil.
\textsuperscript{5} Codes available from Industrial Liaison Program, EECS Dept., UC Berkeley.
Particle Transport due to Kelvin-Helmholtz Vortices and Small Scale Turbulence: S. E. Parker and C. K. Birdsall, University of California, Berkeley—In simulations of the cross-field plasma sheath, which has \( B \) parallel to an absorbing wall and \( v_\parallel = k_\parallel = 0 \), we have found that the \( E \times B \) drift velocity shear produces the Kelvin-Helmholtz instability which saturates to large scale drifting vortices (\( \frac{2\pi}{\lambda_\theta} \approx -2 \), diameter \( \approx 5-15\rho_i \)), with subsequent Bohm-like diffusion. In addition to the circular vortex flow, there is a smaller amplitude, small scale turbulent spectrum (\( \frac{k}{k_i} \ll 1 \), \( k\rho_i \sim 1 \) and \( \omega \sim \omega_{ci} \)). We have now modeled the vortex as a Gaussian potential well and the small scale turbulence as perturbing plane waves traveling parallel to the wall. With no waves present, \( E \times B \) drifting test electrons stay on the equipotential lines. The addition of one wave leads to stochastic motion and loss of particles. Use of many waves of a given spectrum will also be presented, as well as ties between rate of transport and wave(s) amplitude. Our objective is to understand how the K-H vortices provide a mechanism for enhanced transport.

*This work supported by DoE contract No. DE-FG03-86ER53220 and ONR contract N00014-85-K-0809.

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