GASEOUS ELECTRONICS CONFERENCE

RF REFERENCE CELL NEWSLETTER

May 1993

GENERAL COMMENTS

Jim Olthoff

The GEC RF Reference Cell newsletter has been dormant for over a year due to the usual problems of busy schedules and competing obligations. During that time, Jim Roberts has taken a temporary position in the NIST Program Office, and has asked me to take over the job of editor. I apologize for the length of time it took me to get this together, but hopefully you will find the information in this newsletter to be worth the wait.

The number of users of GEC RF Reference Cells has grown significantly since the last issue of the newsletter. To my knowledge, there are now 13 GEC cells in existence at 10 research institutions. Ten of these cells are in full operation with 3 still in the development stages. Additionally, I believe that there are some GEC cells in operation that I do not know about.

The proliferation of GEC cells, the lack of recent newsletters, and the rapid progress being made by many of the research programs have made it increasingly difficult to keep up with the state of GEC-cell-related research. This issue of the newsletter is therefore dedicated to reacquainting everyone with the work being done with GEC RF Reference Cells.

Beginning on page 2 are brief summaries of the research programs using GEC reference cells. The summaries include the address of a primary contact, details of the cell configuration and modifications, brief statements concerning present and future research plans, and lists of other users. The information was obtained from a survey sent earlier this year to known GEC cell operators. The order of the summaries is based upon approximate dates of operation. Some institutions are listed more than once because multiple cells exist at those sites.

After the GEC cell summaries is a list of known publications related to experimental research on GEC RF Reference Cells. This will hopefully be a permanent part of future newsletters. The publication list is organized by approximate date of publication, and includes entries for papers in press, under review, and in preparation. Talks presented at the GEC are not included due to the large number of them, and due to the limited information contained in the GEC abstracts.

1993 GASEOUS ELECTRONICS CONFERENCE

Montreal, Quebec, Canada

The 1993 Gaseous Electronics Conference will be held in Montreal, Quebec, Canada on October 19-22. An oral session is being organized for the presentation of work related to the GEC RF Reference Cell. Paul Miller, of Sandia National Labs, has agreed to present the invited talk, entitled "*Nonlinear Electric Phenomena in the GEC RF Reference Cell and in Industrial Reactors.*" Contributed talks for this session are invited from anyone performing research related to the GEC cell program. If you would like your abstract to be considered for this session, please indicate this in your cover letter. Abstracts are due by July 9, 1993.

MORE INFORMATION

If you would like to be put on the mailing list to receive the GEC RF Reference Cell Newsletter, please contact:

James K. Olthoff
National Institute of Standards and Technology
Building 220, Room B344
Gaithersburg, MD 20899
(301)975-2431
(301)975-4091 (FAX)
olthoff@eeel.nist.gov (e-mail)

If you are working on a GEC RF Reference Cell and are not listed in the Research Summaries, please contact me so that your name can be added to the "official" list of GEC cell users. Thoughts about the content of this newsletter are also invited.

INDEX

Sandia National Laboratories

Paul Miller

Address:
Sandia National Laboratories
Department 1128
P.O. Box 5800
Albuquerque, NM 87185
(505)844-8879
(505)844-3211 (FAX)

Cell Configuration:
Insulators: Teflon
Electrodes: Aluminum
Powered Electrode: Either or both
Filter box and shunt are used.
Plasma values are calculated.

Gases Used: Ar, Cl_2, HBr, CF_4

Diagnostics:
- Current and voltage waveforms measured at each electrode.
- Current measured to walls and ground shields.
- Wafer etch analysis.

Significant Modifications:
- A wafer handler, manipulator, and loadlock have been installed to facilitate wafer handling.
- A transformer system has been designed and installed to allow balanced excitation of both electrodes.

Experiments:
- Model validation of wafer etching processes.
- Use of circuit tuning for increased control of the plasma.
- Investigation of subharmonics generated by the interaction of the plasma and rf circuitry.

Other Users:
- H. Pak
- J. T. Verdeyen

University of New Mexico

Harold Anderson

Address:
Department of Chemical and Nuclear Engineering
University of New Mexico
Albuquerque, NM 87131
(505)277-5661
(505)277-6433 (FAX)

Cell Configuration:
Insulators: Teflon
Electrodes: Aluminum
Powered Electrode: Bottom
Filter box and shunt are used.
Plasma values are calculated.

Gases Used: Ar, CF_4, and CHF_3

Diagnostics:
- Current and voltage waveforms measured at the powered electrode.
- Parallel optical emission spectroscopy.
- Diode laser spectroscopy.

Significant Modifications:
- None

Experiments:
- Spatially- and temporally-resolved optical emission spectroscopy.
- Chemometric calibration and plasma monitoring.
- Diode-laser spectroscopy for the detection of CF_2, CF_3, and COF_2.
- Characterization of a micro-engineered ion energy analyzer (planned).
- Dynamic laser light scattering (planned).

Other Users:
- M. P. Splichal

Sandia National Laboratories

Ken Greenberg

Address:
Sandia National Laboratories
Department 1128
Albuquerque, NM 87123
(505)844-1243
(505)844-3211 (FAX)

Cell Configuration:
Insulators: Alumina (original)
Electrodes: Aluminum
Powered Electrode: Both
Filter box and shunt are available.
Plasma values are calculated

Gases Used:
Ar and He (Cell 1)
Ar, He, NF_3, SF_6, CHF_3 (Cell 2)

Diagnostics:
- Current and voltage waveforms measured at powered electrodes.
- Microwave interferometer.
- Optical diagnostics for the monitoring of absorption and emission in the plasma.

Significant Modifications:
- The electrodes may be driven by a balanced drive rather than grounding one of the electrodes.

Experiments:
- Spatially resolved measurements of electron and metastable densities in rare gas discharges (primarily helium) for comparison with theory.
- Use of laser spectroscopic techniques (Laser-induced fluorescence, Raman, absorption) for the monitoring of species densities.
- Spatially- and temporally-resolved electric field measurements.

Other Users:
- G. A. Hebner
- M. E. Riley

National Institute of Standards and Technology

James Olthoff

Address:
NIST
Building 220, Room B344
Gaithersburg, MD 20899
(301)975-2431
(301)975-4091 (FAX)

Cell Configuration:
Insulators: Alumina (original)
Electrodes: Aluminum
Powered Electrode: Bottom
Filter box and shunt are used.
Plasma values are calculated.

Gases Used: Ar, He, H_2, O_2, and N_2

Diagnostics:
- Voltage and current waveforms measured at the powered electrode.
- Mass spectrometer with ion energy analyzer.
- Optical emission apparatus for spatial scans of the plasma.
- Langmuir probe.

Significant Modifications:
- Showerhead electrode mounted in bottom position.
- Top electrode assembly modified to allow sampling of ions through the grounded electrode.

Experiments:
- Measurements of energy distributions of ions sampled from plasmas in rare gases and gas mixtures.
- Absolute spatially- and temporally-resolved measurements of optical emission from rare gas plasmas.
- Development of current and voltage measurements as a real-time diagnostic.

Other Users:
- J. R. Roberts
- M. A. Sobolewski
- J. R. Whetstone
- R. J. Van Brunt
- S. Djurovic
- S. B. Radovanov
- J. A. Rees

Wright-Patterson Air Force Base

Peter Bletzinger

Address:
WL/POOC-3 Building 450
Wright-Patterson AFB, OH 45433-7919
(513)255-2923
(513)476-4095 (FAX)

Cell Configuration:
Insulators: Alumina (original)
Electrodes: Aluminum
Powered Electrode: Bottom
No filter box or shunt are used.
Plasma values are calculated.

Gases Used: Ar, He, N_2, and H_2

Diagnostics:
- Voltage and current waveforms measured at the powered electrode.
- Scanning laser-induced fluorescence (LIF) system for two-photon excitation and measurement.
- Scanning of time-averaged emission profile.
- Microwave interferometer to measure line integrated electron density.

Significant Modifications:
- None.

Experiments:
- Two photon LIF measurements of H atom concentrations using 205 nm laser radiation. Laser beam is scanned vertically to measure concentration profiles.
- Time-averaged emission profiles are measured with separate scanning photomultiplier/filter.
- Measurements of current and voltage transients with pulsed rf amplifier (no matching network) for switch-on and switch-off.
- Measurements of electron density in Ar, He, and N_2 plasmas using a microwave interferometer.

Other users:
- A. Garscadden

University of Michigan

Mary Brake

Address:
Dept. of Nuclear Engineering
University of Michigan
Ann Arbor, MI 48109-2104
(313)764-1976
(313)763-4540 (FAX)

Cell Configuration:
Insulators: Teflon
Electrodes: Aluminum
Powered Electrode: Bottom
Filter box and shunt are used.
Plasma values are calculated.

Gases Used: Ar, O_2, CF_4, and He

Diagnostics:
- Current and voltage waveforms measured at the powered electrode.
- Optical emission apparatus for time and spatially-resolved (vertical and horizontal) scans of the plasma.
- Laser-induced fluorescence.

Significant Modifications:
- A cryo pump is used to achieve the base vacuum and a turbo pump is used to maintain the gas flow while running a discharge.

Experiments:
- Optical emission spectroscopy using a diode array detector to make spatially-resolved measurements. Photon-counting electronics are being installed to allow time-resolved measurements.
- Etch rates and species production for silicon in CF_4 and O_2 have been measured and compared to those in a commercial reactor.
- Preliminary LIF experiments in Ar and He have been performed.
- Experiments using an electrostatic probe have been initiated, including electron energy distribution function calculations.

Other Users:
- J. Pender
- M. Buie

University of Texas at Dallas

Lawrence Overzet

Address:
University of Texas at Dallas
P.O. Box 830688, EC33
Richardson, TX 75083-0688
(214)690-2154
(214)690-2710 (FAX)

Cell Configuration:
Insulators: Alumina
Electrodes: 306 Stainless Steel
Powered Electrode: Top
Filter box and shunt are used.
Plasma values are calculated.

Gases Used: Ar, N_2, and CF_4

Diagnostics:
- Voltage and current waveforms measured at the powered electrode.
- Retarding potential analyzer for the measurement of kinetic energy of ions striking the grounded electrode.
- Microwave interferometer.
- Langmuir probe.
- Optical emission apparatus (future).

Significant Modifications:
- The showerhead electrode is powered and the grounded electrode has been modified to allow sampling of ions.

Experiments:
- Comparison of Langmuir probe and microwave interferometry results.
- Measurement of ion kinetic-energy distributions from various gases.
- Current and voltage are measured at the powered electrode in real time.

Other Users:
- M. B. Hopkins
- M. Turner

Michigan Technology University

Jacek Borysow

Address:
Department of Physics
Michigan Technology University
1400 Townsend Drive
Houghton, MI 49931
(906)487-2092
(906)487-2933

Cell Configuration:
Insulators: Teflon
Electrodes: Aluminum
Powered Electrode: Bottom
Filter box is used, but not a shunt.
Plasma values are calculated.

Gases Used: Ar, CF_4, and O_2

Diagnostics:
- Voltage and current waveforms measured at the powered electrode.
- Infrared absorption spectrometer based on the tunable diode laser.
- $CF_4(O_2)$ plasma etch rate interferometric system.

Significant Modifications:
- None.

Experiments:
- Spatially-resolved (vertical and horizontal) absorption by argon metastable states as a function of pressure and rf power. Absolute densities are determined.
- Saturation doppler-free absorption measurements of argon metastable states.

Other Users:
- E. Augustyniak
- S. Filimonov

National Institute of Standards and Technology

Mark Sobolewski

Address:
NIST
Building 221, Room B312
Gaithersburg, MD 20899
(301)975-2980
(301)869-5924 (FAX)

Cell Configuration:
Insulators: Alumina (new)
Electrodes: Aluminum
Powered Electrode: Bottom
Filter box and shunt are used.
Plasma values are calculated.

Gases Used: Ar, He, and SF_6 (future)

Diagnostics:
- Voltage and current waveforms measured at the powered and grounded electrodes.
- Mass spectrometer with ion energy analyzer (future).
- Planar laser-induced fluorescence imaging (future).
- Optical instrumentation for surface characterization (future).
- Langmuir probe (future).

Significant Modifications:
- None

Experiments:
- Measurement of time- and spatially-resolved gas-phase species concentrations in SF_6-O_2 plasmas.
- *In-situ* surface characterization of Si wafers during SF_6-plasma etching.
- Correlation of current and voltage measurements to ion densities and kinetic energies.

Other Users:
- J. R. Whetstone
- B. K. McMillin
- J. E. Maslar

IBM-East Fishkill

Michael Passow

Address:
IBM-East Fishkill
Z/53C, Route 52
Hopewell Junction, NY 12533
(914)894-4626
(914)892-6035 (FAX)

Cell Configuration:
Insulators: Alumina (new)
Electrodes: Aluminum
Powered Electrode: Bottom
RF electronics to be determined.

Gases to be Used: NF_3, Cl_2, HBr, Freon

Diagnostics:
- To be determined.

Significant Modifications:
- Anticipate installing mass spectrometer in grounded electrode.

Experiments:
- To be determined.

Other Users:

University of Illinois

Joseph Verdeyen

Address:
Gaseous Electronics Laboratory
University of Illinois
607 E. Healey
Champaign, IL 61820
(217)333-2480
(217)244-5422 (FAX)

Cell Configuration:
Insulators: Alumina (original)
Electrodes: Aluminum

All else to be determined.

The Queen's University of Belfast

Bill Graham

Address:
The Queen's University of Belfast
Belfast. BT7 1NN
Northern Ireland
44 232 245133 ext. 3564
44 232 438918 (FAX)

Cell Configuration:
Insulators: Alumina (new)
Electrodes: Aluminum
Powered Electrode: Bottom
RF electronics to be determined.

Gases to be Used: Ar, He, and H_2

Anticipated Diagnostics:
- Voltage and current waveforms measured at the powered electrode.
- Mass and kinetic energy analysis through the grounded electrode.
- Time-resolved optical emission.
- Compensated Langmuir probe.

Significant Modifications:
- None

Anticipated Experiments:
- Correlation of Langmuir probe, ion energy, and optical emission measurements.
- Studies of electronegative gases.
- Lower frequency operation.

Other Users:
- Nick Braithwaite (Open University, UK)

GEC RF REFERENCE CELL LIST OF PUBLICATIONS

1. **"Electrical characterization of rf plasma discharges"**
   P. A. Miller and M. Kamon, SETEC Report 90-0009, 1990.

2. **"The GEC RF Reference Cell: Diagnostic techniques and initial results"**
   K. E. Greenberg, P. J. Hargis, and P. A. Miller, SETEC Report 90-013, 1990.

3. **"Measurements on the NIST GEC Reference Cell"**
   J. R. Roberts, J. K. Olthoff, R. J. Van Brunt, and J. R. Whetstone, in *Advanced Techniques for Integrated Circuit Processing*, (Society of Photo-Optical Instrumentation Engineers, SPIE, 1990), Vol. 1392, p. 428.

4. **"Status of the GEC Reference Cell / Laser diagnostics of plasma etching discharges"**
   P. J. Hargis, Jr., K. E. Greenberg, and P. A. Miller, Intl. Seminar of Reactive Plasmas, Nagoya, Japan (17-19 June 1991).

5. **"Mass spectrometric and Optical Emission Diagnostics for rf plasma reactors"**
   J. K. Olthoff, J. R. Roberts, R. J. Van Brunt, J. R. Whetstone, M. A. Sobolewski, and S. Djurovic, in *Process Module Metrology, Control, and Clustering*, (Society of Photo-Optical Instrumentation Engineers, SPIE,1991), Vol. 1595, p. 168.

6. **"Electrical characterization of rf plasmas"**
   P. A. Miller, in *Process Module Metrology, Control, and Clustering*, (Society of Photo-Optical Instrumentation Engineers, SPIE, 1991), Vol. 1595, p. 179.

7. **"Application of chemometrics to optical emission spectroscopy for plasma monitoring"**
   M. P. Splichal and H. M. Anderson, in *Process Module Metrology, Control, and Clustering*, (Society of Photo-Optical Instrumentation Engineers, SPIE, 1991), Vol. 1595, p. 189.

8. **"Electrical isolation of radio-frequency plasma discharges"**
   P. A. Miller, H. A. Anderson, and M. P. Splichal, *J. Appl. Phys.* 71, 1171 (1992).

9. **"Period-doubling bifurcation in a plasma reactor"**
   P. A. Miller and K. E. Greenberg, *Appl. Phys. Lett.* 60, 2859 (1992).

10. **"Diagnostic measurements in rf plasmas for materials processing"**
    J. R. Roberts, J. K. Olthoff, M. A. Sobolewski, R. J. Van Brunt, J. R. Whetstone, and S. Djurovic, in *Atomic Processes in Plasmas, AIP Conference Proceedings 257*, (American Institute of Physics, New York, 1992), p. 157.

11. **"Ion kinetic-energy distributions and electrical measurements in argon-oxygen rf glow discharges"**
    J. K. Olthoff, R. J. Van Brunt, and M. A. Sobolewski, in *Proc. Tenth Intl. Conf. on Gas Discharges and Their Applications*, (University College of Swansea, Swansea, Wales, U. K., 1992), p. 440.

12. **"Ion kinetic-energy distributions in rf glow discharges"**
    J. K. Olthoff, R. J. Van Brunt, and S. B. Radovanov, *J. Appl. Phys.* 72, 4566 (1992).

13. **"Electrical Characterization of radio-frequency discharges in the Gaseous Electronics Conference Reference Cell"**
    M. A. Sobolewski, *J. Vac. Sci. Technol.* A 10, 3550 (1992).

14. **"Measurements and analysis of the equivalent circuit of the GEC RF Reference Cell"**
    J. T. Verdeyen, Sandia Report SAND92-7284, 1992.

15. **"Electrical measurements for monitoring and control of rf plasma processing"**
    M. A. Sobolewski and J. R. Whetstone, in *Advanced Techniques for Integrated Circuit Processing II*, (Society of Photo-Optical Instrumentation Engineers, SPIE, 1992), Vol. 1803, p. 309.

16. **"Absolute spatially- and temporally-resolved optical emission measurements of rf glow discharges in argon"**
S. Djurovic, J. R. Roberts, M. A. Sobolewski, and J. K. Olthoff, *J. Res. Natl. Inst. Stand. and Technol.* 98, 159 (1993).

17. **"Electron and metastable densities in parallel-plate radio-frequency discharges"**
K. E. Greenberg and G. A. Hebner, *J. Appl. Phys.*, in press (June 15, 1993).

18. **"The GEC RF Reference Cell: A parallel-plate radio frequency system to study plasma-processing discharges"**
P. J. Hargis, Jr., K. E. Greenberg, P. A. Miller, J. B. Gerardo, J. R. Torczynski, M. E. Riley, G. A. Hebner, J. R. Roberts, J. K. Olthoff, J. R. Whetstone, R. J. Van Brunt, M. A. Sobolewski, H. M. Anderson, M. P. Splichal, J. L. Mock, P. Bletzinger, A. Garscadden, R. A. Gottscho, G. Selwyn, M. Dalvie, J. E. Heidenreich, J. W. Butterbaugh, M. L. Brake, M. L. Passow, J. Pender, A. Lujan, M. E. Elta, D. B. Graves, H. H. Sawin, M. J. Kushner, J. T. Verdeyen, R. Horwath, and T. R. Turner, *Rev. Sci. Instrum.*, submitted.

19. **"Theoretical and experimental study of low-temperature, capacitively-coupled, rf-driven helium plasmas"**
M. E. Riley, K. E. Greenberg, G. A. Hebner, and P. J. Drallos, *Phys. Rev. E*, submitted.

20. **"Hydrogen Balmer Alpha line shapes for hydrogen-argon mixtures in a low pressure rf discharge"**
S. Djurovic and J. R. Roberts, *J. Appl. Phys.*, submitted.

21. **"Kinetic-energy distributions of ions sampled from argon plasmas in a parallel-plate rf reference cell"**
J. K. Olthoff, R. J. Van Brunt, S. B. Radovanov, J. A. Rees, and R. Surowiec, *J. Appl. Phys.*, submitted.

22. **"Use of an ion energy analyzer-mass spectrometer to measure ion kinetic-energy distributions from rf discharges in argon-helium gas mixtures"**
J. K. Olthoff, R. J. Van Brunt, S. B. Radovanov, and J. A. Rees, *IEE Proc. A*, submitted.

23. **"Spatially resolved optical emission measurements of the UM GEC Reference Cell"**
J. Pender, M. Buie, J. Holloway, and M. Brake, in preparation.

24. **"A comparison of etch performance of the GEC Reference Cell with a commercial parallel-plate etcher"**
J. Pender, M. Buie, and M. Brake, in preparation.

25. **"A comparison of electron density measurements made using a Langmuir probe and microwave interferometer in the Gaseous Electronics Conference reference reactor"**
L. J. Overzet and M. B. Hopkins, *Rev. Sci. Instrum.*, in preparation.

26. **"Spatial dependencies of the electron concentration in the Gaseous Electronics Conference reference reactor"**
M. B. Hopkins, L. J. Overzet, and M. Turner, *Appl. Phys. Lett.*, in preparation.

If you have published or are working on a paper that you would like included in this list, please send a preprint or reprint to J. K. Olthoff at the address given on the first page of this newsletter.

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
GAITHERSBURG, MD 20899

May 1993

RF REFERENCE CELL NEWSLETTER

GASEOUS ELECTRONICS CONFERENCE