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Electrode material and geometry effects on the electrical properties of particle traps in a parallel plate plasma etch reactor

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The University of Arizona, 1993
ELECTRODE MATERIAL AND GEOMETRY
EFFECTS ON THE ELECTRICAL PROPERTIES OF
PARTICLE TRAPS IN A PARALLEL PLATE
PLASMA ETCH REACTOR

by

Sean Michael Collins

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A newly designed Langmuir probe has been evaluated and was used to map the plasma potential near the powered electrode of a plasma etch chamber in 2 dimensions. Various electrode materials and geometries were used in order to investigate the relationship between electrode design and the presence of localized regions of elevated plasma potential. These regions of elevated plasma potential were known to be responsible for the presence of particle clouds suspended in the plasma during operation. A relationship was established between sharp edges on the powered electrode, insulating materials on the electrode and localized elevation in plasma potential. A thin layer of raised plasma potential has also been discovered at the plasma-sheath boundary. Suggestions for electrode design to reduce the presence of particles suspended in the plasma are made.
CHAPTER 1
INTRODUCTION

1.1 PARTICLES IN PLASMA ETCH TOOLS

Plasma etching has largely replaced wet etching for the fabrication of integrated circuits. The reason being that finer geometries may be achieved using plasma etching than with wet etching. This is because the plasma process may be designed to etch anisotropically where as wet etching is an inherently isotropic etch process. However, significant contamination issues in plasma processes have presented themselves. Fundamentally there are two sources of contamination in a plasma reactor. The two sources are gas phase generated particles and particles contributed from the chamber wall. Gas phase generated particles are reaction by-products which are deposited on the etch surface during plasma operation or the nucleation of particles during the pump down or vent phase of the tool operation cycle. Chamber wall sources contamination in the etch chamber are reaction by-products which have been deposited on the chamber and flake off, debris from the wear of moving parts in the chamber or gas lines, and contaminants left in the chamber from assembly and maintenance.
As integrated circuit feature size continues to decrease, the issue of particle contamination in during plasma processes becomes increasingly important. As the complexity of device structures increases, the number of etch steps in the fabrication process will continue to increase exacerbating the problem of particle contamination added by the plasma tools.

1.2 PURPOSE OF WORK

Particle contamination of wafers in plasma tools needs to be reduced, because of the negative impact it has on yield. One method[11] for reducing the gas phase nucleation contamination is to design a process which chooses reactant gases, plasma power, operating pressure, and other variable parameters to minimize the production of particles during the process. Unfortunately, the optimization of a process for contamination control is limited by the need to achieve practical wafer throughput. Another approach is to design carefully vacuum components that minimize particle contribution from surfaces in the chamber. This includes designing the vacuum chamber so that either reaction by-products do not adhere at all to the chamber or adhere completely to chamber surfaces. This will prevent the flaking of contamination from the chamber.
surfaces. The design valves, wafer handling and other components to prevent the production of particles by wear is also important to preventing contamination from surfaces.

A third and unique approach to the problematic presence of particles is to design the plasma chamber in such a way so that particles present in the chamber are kept away from the wafer. It has been shown in previous work[1,2,8-10] that particles present in a plasma form clouds of various shapes near the plasma sheath. It has also been shown that the particle clouds of various shapes exist in an region where the plasma potential is greater than the potential of the bulk plasma[2,8,9]. The purpose of this work is to establish the relationship between electrode design in a plasma reactor and the presence of localized regions of elevated plasma potential.

1.3 PREVIEW OF THESIS

This thesis will present an overview of the subject of particle clouds in a plasma and the results of new experimental work that establishes the relationship between the electrode configuration and the presence of particle clouds.

Chapter 2 presents a review of the experimental methods used to establish a link between the observation of particle
clouds with regions of raised plasma potential. Langmuir probe theory is presented in Chapter 3. The current theoretical treatment for an R.F. plasma is reviewed in Chapter 4 and is found not to account for localized elevated potentials in a plasma. Chapter 5 reviews previous work which predicts and experimentally confirms the charge of free particles in a plasma. A Langmuir probe, newly designed for this work, is presented in Chapter 6 along with the experimental methods used for measuring plasma potential. Chapter 7 presents the results of the experiments mapping plasma potential for various electrode geometries and materials. Conclusions are presented in Chapter 8.
CHAPTER 2
LANGMUIR PROBE MEASUREMENTS

2.1 DC LANGMUIR PROBE THEORY

To investigate the reason for the presence of the clouds of particles in the plasma etch tool a Langmuir probe was used to investigate the plasma during operation. A Langmuir probe collects current from inside the plasma as the probe is biased with a DC voltage across the range of electron and ion potentials. This range is generally -80 to +100 V. The current versus voltage characteristic of the probe is displayed on an oscilloscope or stored in a computer file. From the data many of the electrical parameters of the plasma may be obtained. These parameters include plasma potential, electron and ion energy distributions, and floating potential. For a DC plasma a typical curve is shown in Fig. 2.1. As the voltage of the probe is increased the current collected increases exponentially. This is because there is a Maxwellian distribution to the electron energy. As the voltage on the probe is increased, higher energy electrons are collected, thus increasing the total current that the probe collects. This increase in current will continue until the plasma potential is reached. This may be described by the
FIGURE 2.1, Langmuir Probe Curve for DC Plasma
following equation based on the treatment of Chen[6].

\[ I = An \left( \frac{kt}{2\pi m} \right)^{0.5} \exp \left( \frac{q(V_p - V_f)}{kT} \right) \]  

(1)

Where \( V_p \) is the probe bias voltage, \( V_f \) is the floating potential voltage, At this voltage the electron saturation current is reached and the curve levels off. As the probe bias voltage is increased further a space charge region is set up surrounding the probe tip and the current increased by the square root of the voltage.

The following equation [6] describes the probe current for a Langmuir probe in a DC plasma above the plasma potential.

\[ I = A \left[ 1 + \frac{V_p}{V_s} \right] \]  

(2)

Where \( V_p \) is the probe bias voltage, \( V_s \) is the saturation voltage and \( A \) is a constant related to the electron density, probe geometry and the collection area of the probe.

2.2 R.F. LANGMUIR PROBE MEASUREMENT THEORY

The analysis of Langmuir Probe operating in an R.F. plasma is similar to that of the DC langmuir probe. For a
Langmuir probe operating in a R.F. plasma, however the situation is complicated by the presence of a time varying field in the plasma. From the analysis of Paranjpe[4] it has been shown that, if the R.F. impedance from the sheath to the probe tip is not much smaller than the impedance of the probe tip to ground, an additional current component from the drop across the sheath will distort the Langmuir curve characteristic. If the Langmuir probe is collecting a time varying current, the observed floating potential will be lower than the true floating potential. The large R.F. current swings from negative to positive cause the probe to collect ions and electrons in varying amounts over the entire cycle. Since the electron energy distribution is increasing much faster above the floating potential than the ion distribution, the R.F. current in effect will produce an apparent floating potential lower than the true one. What is needed is a way to keep probe at the same R.F. voltage as the plasma. This would mean than there is no R.F. voltage difference across the sheath. If there is no R.F. voltage difference across the sheath the probe would collect the same electron and ion current over the entire R.F. cycle for each DC bias point.

Shown in Fig. 2.2 is a typical voltage versus current plot for a tuned Langmuir probe in an R. F. plasma. By
FIGURE 2.2, Langmuir Probe Curve for R.F. Plasma
tuned it is meant that the probe is constructed in such a way as to prevent an R.F. drop across the sheath between the plasma and the probe tip. In order for this to be true the probe must have a means for maintaining its tip at the same voltage and phase as the plasma either by use of a double probe or a blocking circuit within the probe. The floating potential for the plasma is the voltage at which the net current to the probe is zero. At this voltage equal numbers of electrons and ions are collected. Current at voltages less than the floating potential is due to the collection of positively charged ions. As ions are drawn to the probe tip a positive space charge region is set up surrounding the probe tip. This space charge region limits the flow of ions to the probe and an ion saturation current results.

As the probe bias voltage is increased fewer ions are collected and increasing numbers of electrons are collected. This results in a net increase in current. This transition regions exists because both ions and electrons exist in a non-uniform distribution with respect to thermal energy.

At a bias voltage equal to the plasma potential the rate of increase in the current decreases slightly. This is seen on the i-v characteristic of the probe as a "kink".
The bias voltage at which this "kink" occurs is approximately the plasma potential. As the bias voltage is increased above the plasma potential the current increases as the three-half power of the voltage. This is because a space charge region around the probe is set up by drawing electrons to the probe a rate which is faster than can be collected by the probe. The plasma surrounding the probe acts like a thermonic emitter and these electrons are collected by the probe tip according to the Child-Langmuir law.

In order to achieve a Langmuir probe characteristic a circuit must be included in probe to eliminate any R. F. voltage drop between the plasma and the probe tip. There are many ways that have been proposed and experimented with in order to eliminate a difference in R. F. voltage across the sheath from a plasma to a Langmuir probe[3]. One method involves the use of two probes in the plasma. One probe is used as the Langmuir probe and collects current. The other probe is essentially a voltage sensing probe whose output is sent through a voltage follower circuit to the Langmuir probe. Through careful matching of the two R.F. voltages the R.F. component of the current collected by the probe may be eliminated.
2.3 EXTERNALLY TUNED R.F. PLASMA MEASUREMENTS

Another approach to eliminating the R.F. current collected by the Langmuir probe is to use a tuned circuit to increase the impedance of the probe at the frequency of the plasma to the point where it is much greater than the R.F. impedance of the sheath. This, in effect, eliminates any voltage drop across the sheath.

This later method was used by Paranjpe[4] et al, to measure the plasma potential of a fixed point in a small parallel plate reactor. The R.F. impedance was tuned by means of a matching network placed external to the chamber. Tuning was achieved by adjusting a capacitor in the tuning network until the floating potential shown on a dc coupled oscilloscope is maximized. This method ensured that the contribution of the R.F. current to the average current measured by the probe is minimized. Paranjpe et al, discussed results from both Ar and SF₆ plasmas.

2.4 REMOTELY TUNED R.F. LANGMUIR PROBE MEASUREMENTS

In order to map plasma potentials inside the etch chamber it was necessary to have a Langmuir probe which was movable. The probe for Paranjpe's work was short in length and fixed in the chamber. For the work at the University of Arizona Geha[2] designed a movable probe. In order to map the plasma parameters in the center of the chamber the
length of the probe itself also needed to be longer than Paranje's. For this reason the design of probe itself needed to be changed. The primary change was the repositioning of the tunable network to the inside the chamber. This change was required because of the increased probe length. The tank circuit needed to be as close to the end of the probe as possible in order to increase effectively the R.F. impedance of the probe tip to the plasma. A long cable length between the probe tip and the tank circuit reduced its apparent impedance. Locating the tunable circuit inside the chamber mandated that the tuning be accomplished remotely. This was achieved by using a MOSFET in the circuit as a variable capacitor. Figure 2.3 is a circuit diagram of the probe used by Geha. Bias was applied between the source and drain of the MOSFET and the gate-to-body capacitance was used in parallel with a choke to make a tunable tank circuit.

Results from the work of Geha[9] showed that there was a direct relationship between the location of particle clouds in the plasma, as seen by in situ laser scattering, and areas of elevated plasma potential, as measured by the movable Langmuir probe. The plasma potential of the region where partial clouds formed was determined to be 6-to-8 V higher than the ambient plasma potential.
FIGURE 2.3, Langmuir Probe Circuit of Geha
CHAPTER 3
PLASMA THEORY AND PARTICLE CHARGING

3.1 PREDICTED PLASMA POTENTIAL FROM ANODE TO CATHODE

In an R.F. plasma the variation of the potential across the chamber from the powered electrode to the grounded chamber wall is shown in Fig. 3.1. From current theory of R.F. plasma as proposed by Misium et al[7] predict plasma potential between the center of a parallel plate plasma chamber and the sheath region to be

\[ V(r) = V_0 \cos \left( \frac{x}{x_0} \right) \]  

(3)

where the period of the cosine function is much larger than the chamber width and \( V_0 \) is the plasma potential at the center of the chamber and \( x \) is the distance from the center of the chamber toward the anode or cathode. From the plasma sheath interface the potential drops linearly from the value of the potential at the sheath edge to the self bias potential of the cathode and to ground from the sheath edge to the anode.

3.2 DOES NOT PREDICT PARTICLE TRAPS

What is unaccounted for in this is the presence of localized areas of increased plasma potential (i.e. particle traps) at the plasma sheath interface. Figure 3.1 shows the voltage variation across a plasma chamber with the
FIGURE 3.1, Potential between R.F. Powered Electrode and Anode
presence of a particle trap region at the plasma sheath interface. The trap is a region of raised potential in which particles collect. This raised potential is unaccounted for by the current theory, and an important contribution to the understanding of particle trapping in plasmas.

One important result from the work of Geha proved that the traps were formed before there were any particles present in the trap. This means that the traps were not caused by particles but rather by either the geometry or the materials of the electrode and wafer. It was observed, however, that the shape of the traps changed with time. This evolution seemed to occur as the traps filled with particles.

3.3 PARTICLES CHARGE NEGATIVELY IN THEORY

One part of the theory of particle clouds in the plasma that is complete, is their charging behavior in a plasma. Work by Nowlin and Carlile[5] has shown theoretically that particles are charged negatively on the order of $10^{-17}$ to $10^{-14}$ Coulombs. Thus, these negatively charged particles are attracted to the regions of elevated plasma potential. They found that the charge, $Q$, on a particle in a plasma is roughly dependant on the electron and ion energies as
follows,

\[ V(a) = -4.61T_i^{0.15}T_e^{0.85} \]  

(4)

Where \( a \) is the diameter of a particle in cm, \( T_i \) is the ion energy, and \( T_e \) is the electron energy. Figure 3.2 shows a plot of the charge computed for various sizes of particles as a function of the ratio of ion to electron energy. A 1 \( \mu \)m particle, for example, in a plasma with 0.0258 eV ions and 4 eV electrons will develop a charge of about \( 10^{-15} \) Coulombs.

3.4 MEASUREMENTS CONFIRM NEGATIVE CHARGE

Measurements by Geha[2] of the electron density inside the particle traps confirmed that the particles were charged negatively. Electron density in the traps was found to be less than the electron density found outside the traps. A typical electron concentration measured by Geha was \( 8 \times 10^{15}/m^3 \) where no particle traps were present. In traps the measured electron concentration decreased by a factor of about 2 while the ion concentration in the region remained relatively constant. These measurements were consistent with the theory that the particles in the traps are negatively charged. In order to maintain local quasi-neutrality inside the traps, electrons must be expelled to
FIGURE 3.2, Particle Charge vs. Log of Ion to Electron Energy Ratio for 10, 1 and 0.1 Micron Particles in a Plasma
compensate for the negative charge brought in a trap by a negatively charged particle.
CHAPTER 4
NEW LANGMUIR PROBE DESIGN

4.1 CIRCUIT DESCRIPTION

The Langmuir probe designed and used in the present research is similar to that used by Geha. However, several improvements have been made in order to increase the reliability. The new design has a higher current carrying capacity, the probe housing allows the probe to be installed into the plasma tool without disassembling the chamber and tuning of the probe is accomplished with a completely passive circuit.

The probe tip is made of a 0.25-mm-diameter tungsten wire 4 cm long is extended 2.0 mm from the end of a 2.0-mm-o.d. glass tube. (Fig. 4.1) This 2.0-mm-diam. portion of wire is the collection area for current in the plasma. The other end of the wire is connected to one end of a hollow core choke. The top of Fig. 4.2 shows schematic of the newly designed circuit. The variable inductor \((L_x)\) is used to tune the circuit so that floating potential of the Langmuir probe characteristic is maximized.

4.2 Equivalent Circuit

The electrical environment the Langmuir probe operates
FIGURE 4.1, New Langmuir Probe
in is diagramed at the bottom of Fig. 4.2. The parasitic capacitance elements in the circuit are plasma to ground \( (C_{pg}) \), housing to plasma \( (C_{hp}) \), housing to ground \( (C_{hg}) \), and probe tip to plasma \( (C_{pp}) \). The probe tip also has a resistance \( (R_{pp}) \) component to the plasma. The self capacitance of the variable inductor \( (C_L) \) is due to the capacitance between adjacent windings of the coil. Since \( C_{hp} \) is in parallel with the plasma to probe tip impedance through a \( 1\mu F \) capacitor from the probe tip to the housing, increasing the exposed area of the probe housing reduces the impedance across the sheath to the probe tip. Tuning \( C_L \) so that the floating potential is maximized maximizes the impedance of the circuit from the probe tip to ground thus minimizing the component of the current through the probe due to a voltage drop from the probe tip to plasma across the sheath.

4.3 OPEN CORE CHOKE DESIGN

The choke was made from 30 turns of magnet wire 0.15 inch in diameter wrapped around a paper tube 0.25-inch-o.d. The paper tube supported the choke windings. The interior of the tube was fitted with a threaded ferrite core. The threads on the core allowed it to move into the tube as it was rotated. This changed the tuned impedance of the choke so that the Langmuir probe could be tuned to have a maximum
FIGURE 4.2, New Langmuir Probe Circuit
impedance at the frequency of the R. F. generator which excited the plasma.

4.4 ROTARY FEEDTHROUGH ADJUSTMENT

The movement of the choke core was implemented using a double O-ring piston in a cylinder. The cylinder was machined into a Conflat flange which was welded to a stainless steel mount for the probe. The piston rotated in the cylinder and was connected to a 2.0-mm-diameter glass rod via a sliding coupling. One end of the glass rod was joined with epoxy to the sliding coupling. The other end was formed by heat to fit into a hexagonal opening in the ferrite core. The glass rod was necessary in order to transmit rotary motion from the feedthrough while at the same time preventing the choke from shorting out to ground. The sliding coupling allowed the glass rod to move laterally as the core moves into or out of the choke.

4.5 PROBE HOUSING

The probe is housed in a machined ceramic rod. A stainless steel rod welded to a Conflat flange supported the ceramic rod which housed the choke. A cover for the choke was fabricated from a thin sheet of stainless steel and prevented the choke from shorting to the plasma. This cover was, however, connected with a capacitor to the tungsten
wire of the probe at the point where it connected to the choke. This provided capacitive coupling of the Langmuir probe tip to the wall of the plasma chamber. Coupling to the wall improved the performance of the probe by reducing the R. F. drop from the plasma to the tungsten probe tip.

The advantage of this Langmuir probe design, over the probe design used in previous work at this university has been increased reliability. The gate capacitance of a MOSFET was used previously as a variable capacitor but it proved to be unreliable and not to provide adequate tuning.
CHAPTER 5
PLASMA POTENTIAL MEASUREMENTS

5.1 Automated Measurement Setup

The newly designed Langmuir probe was used in conjunction with a computer controlled parameter analyzer to obtain probe I-V characteristics used to determine plasma potentials. The parameter analyzer utilized was an Hewlett-Packard 4145A. The probe bias was controlled by the parameter analyzer and run in 0.5 V steps from -100 to +80 V. During each sweep of voltage the probe current was measured using the H-P 4145 and transferred via the IEEE 488 buss to a personal computer for storage and later analysis. The program used for the measurements is reprinted in Appendix A. The program was written especially for this project in BASIC. Routines for communicating via a IEEE 488 were included with the buss card which was purchased from National Instruments and were adapted for use in this program. The program uses the IEEE 488 Buss to set the test parameters of the HP 4145A remotely using the command set for the HP 4145A found in the operating manual for the HP 4145A. The program then prompts the user to start the measurement through the PC. After the measurement takes place the program transfers the current and voltage data to the hard drive of the PC for later analysis and prompts the
5.2 ELECTRODE MATERIAL EFFECTS

In order to compare the difference in plasma potential above an insulating material and a conducting material on the powered electrode four inch silicon wafers were prepared with a 2-inch-diameter dot of photoresist and a second wafer was prepared by sputter deposition of aluminum in the same 2 inch round pattern. Figure 5.2 is a plot of the results of langmuir probe measurements over the wafer with the photoresist pattern. A region of raised potential can be seen in the central portion of the plot near the center of the wafer. This corresponds to a particle trapping region located above the wafer 6.5 mm and 1 cm from the center of the chamber. Figure 5.3 is a plot of the plasma potentials above a wafer with the same 2 inch pattern except made from sputtered aluminum. This plot shows no region of raised potential which corresponds to the absence of any particle
FIGURE 5.1, Mapped Region of Plasma Chamber
FIGURE 5.2, Plasma Potential Measured over 2" diam.
Photoresist, 0.35 um thick on 4" Silicon Wafer @ 250 W, 15 mTorr

First Deriv. Method
FIGURE 5.3, Plasma Potential Measured over 2" diam.
Sputtered Al Film, 0.5 um thick on 4" Silicon Wafer @ 250 W, 15 mTorr
trap. A side by side comparison of plasma potential measurements over both the photoresist and the aluminum sample may be seen in Fig. 5.4. Over the photoresist there is a region of increased plasma potential. The measurement over the sputtered aluminum does not have this feature. This indicates that a trap for particles exists above the photoresist and that no trap is above the sputtered aluminum. It may be concluded that because the photoresist is an insulator the trap is formed.

5.3 ELECTRODE GEOMETRY EFFECTS

The effect of electrode geometry on the formation of particle traps was investigated by measuring plasma potentials over a 2-inch-diameter aluminum disc on a 4 inch silicon wafer and comparing it to the measurement made over the 2-inch diam. sputtered aluminum film on a 4 inch wafer. In Fig. 5.5 the results of plasma potential mapping over the aluminum disc are presented. The aluminum disc showed an area of raised plasma potential above the central portion of the disc and around the edge. This result indicated that particle traps were present in the shape of a ring and a disc. This verified the result of Geha[2]. A side by side comparison of the maps of plasma potential for both the aluminum disc and the sputtered aluminum is shown in Fig. 5.6. The presence of the ring above the edge of the disc is
FIGURE 5.4, Plasma Potential over Photoresist (bottom) and Sputtered Al Film (top)
Plasma Potential

First Derv. Method

FIGURE 5.5, Plasma Potential Measured over 2" diam., Sharp Edged Al disc, 0.125" thick, on 4" Silicon Wafer @ 250 W, 15 mTorr
FIGURE 5.6 Plasma Potential over Sharp Edged Disc (bottom) and Sputtered Al Film (top)
clear and no ring is found above the edge of the sputtered aluminum.

The third case compared the plasma potential measurements over a 2-inch-diameter aluminum disc having a rounded edged, with the measurement over the disc with a sharp edge. Figure 5.7 maps the plasma potentials above the aluminum disc with the rounded edge. The disc shaped particle trap over the sharp edged disc is missing for the measurement of plasma potentials over the rounded edge aluminum disc. A side-by-side plot of plasma potentials is shown in Fig. 5.8. Particle traps were present over the central region of both the sharp edged disc and the round edged disc however the trap over the round disc was hollow in the center. It was concluded from this comparison that the sharp edges of the powered electrode created the particle traps.

Plasma potentials for this experiment were determined by taking the first derivative of the probe current with respect to voltage. A computer program was written using the same method used by Geha[2] and is reprinted in Appendix B. In order to determine the repeatability of the measurements an experiment was performed which measured the plasma potential of a region above the plasma at a fixed
FIGURE 5.7, Plasma Potential Measured over 2" diam. Al Disc, 0.125" thick, Edge Radius 0.125" on 4" Silicon Wafer @ 250 W, 15 mTorr
FIGURE 5.8, Plasma Potential over Sharp Edged Disc (bottom) and Round Edged Disc (top)
height and at eight different positions radially from the center of the chamber. This set of measurements was performed five times and the results analyzed. A plot of the results is shown in Fig. 5.9. When the five measurements of plasma potential for each position are compared the standard deviation is found to be less than one percent. The standard deviation is shown on the plot by the bars above and below each data point.

As a result of a detailed measurement of probe current across the plasma sheath interface 0.1 mm steps it was found that the plasma potential increases as the probe passes through the plasma sheath transition region. An example of this result is shown in Fig. 5.10. The maximum of the first derivative of the current with respect to voltage gives the plasma potential for each location of the probe. The result of this measurement was plotted in Fig. 3.1 and shows the increase in plasma potential through the plasma to sheath transition region.
FIGURE 5.9, Average of Plasma Potential Measurements Repeated over a Silicon Wafer at Eight Positions with Standard Deviation Bars
FIGURE 5.10, First Derivative of Langmuir Probe Curves Measured through the Plasma Sheath Interface in steps of 0.1 mm
CHAPTER 6
CONCLUSION

The result of this work indicated that both electrode geometry and the presence of a dielectric material on the electrode affected the formation of particle traps. Particle traps were formed immediately above the sharp edges of the electrodes. The presence of a dielectric material on the powered electrode leads to a particle trap directly above the dielectric. These two results should have a significant effect on the design of the electrodes in plasma systems. Many plasma tools have wafer hold-down rings or clips on the electrodes, and this study indicates that the shape and material of the clips can effect the uniformity of the nearby plasma potential. Nonuniform potentials create particle traps above the clips. To prevent these traps from forming the clips should be eliminated or made from a conducting material that has round edges. In addition to the material and geometrical effects of the electrode on particle traps, it was also discovered that plasma potential increases through the plasma to sheath transition region.
APPENDIX A

'This program operates a HP 4145 via an IEEE488 bus to collect data from a langmuir probe
DECLARE SUB FuncKeys (Promt$, Numkeys!, S$, Z$)
'GOTO 20000

CLEAR , , 5000
10 V = 0
20 KEY OFF
30 'ON TIMER(1) GOSUB 290
40 TIMER ON
50 KEY 15, CHR$(4) + CHR$(70)
60 ON KEY(15) GOSUB 240
70 KEY(15) ON
80 CLS
90 SCREEN 0: WIDTH 80

100 COLOR 7, 8'1, 7, 8'or 6,7,8
110 CLS
120 GOSUB 290 'Clear screen print time & date
130 GOSUB 350 'Get last run number and add 1
140 GOSUB 430 'Get rundata for last run and correct for this run
150 GOSUB 1070 'use PATTERN$ to determine maxposit and motor movements!!!!
155 GOSUB 720 'Put Data for this run in runlog
  V = 1
  VIEW PRINT 19 TO 24
160 GOSUB 1140 'Establish communications with IEEE Bus
170 GOSUB 1420 'initialize HP4145
180 'osub 6950 '??????

190 GOSUB 1560 'start measurement
  GOSUB 10000 'All finished close files
END
200 'OR J=1 TO 30:PRINT STRING$(40,32):NEXT J
210 FOR I = 1 TO 100000000#
220 PRINT I;
230 NEXT
240 CLS
250 SCREEN 0: WIDTH 80
260 COLOR 7, 8
270 CLS
280 END

290 VIEW PRINT
OLDROW = CSRLIN
50
300 OLDCOL = POS(0)
310 LOCATE 2, 33: PRINT TIMES$
320 LOCATE 3, 31: PRINT DATES$
330 LOCATE OLDROW, OLDCOL
340 IF V = 1 THEN VIEW PRINT 19 TO 24
RETURN

350 OPEN "I", #1, "C:\PROBDATA\RUNNUM"
360 INPUT #1, RUNNUM$
370 CLOSE #1
380 RUNNUM$ = STR$(VAL(RUNNUM$) + 1)
390 OPEN "O", #1, "C:\PROBDATA\RUNNUM"
400 PRINT #1, RUNNUM$
410 CLOSE #1
415 RUNNUM% = INT(VAL(RUNNUM$))
420 RETURN
430 OPEN "C:\probdata\runlog1" FOR RANDOM AS #1
440 OPEN "R", #1, "C:\probdata\runlog2", 128
450 FIELD #1, 10 AS WHEN$, 8 AS TYME$, 2 AS pattern$, 3 AS
460 LOCATE 6, 10
470 GET #1, RUNNUM% - 1
480 RSET WHEN$ = DATE$
490 'TOP
500 RSET TYME$ = TIME$
510 LOCATE 1, 1
520 PRINT "EXPERIMENT PARAMETERS", CHR$(13)
530 LOCATE 3, 2: PRINT "Run Number", RUNNUM%
540 LOCATE 4, 2: PRINT "Measurement Pattern", pattern$
550 LOCATE 5, 2: PRINT "RF Power", POWER$; "Watts"
560 LOCATE 6, 2: PRINT "Gas Type", Gas$
570 LOCATE 7, 2: PRINT "Gas Flow", FLOW$; "scmm"
580 LOCATE 8, 2: PRINT "Pressure", PRESSURES$, "mTorr"
590 LOCATE 9, 2: PRINT "Plasma on for ", START$, "minutes"
600 LOCATE 10, 2: PRINT "Lower Wafer", LWAFER$
610 LOCATE 11, 2: PRINT "Upper Wafer", UWAFER$
620 LOCATE 14, 2: PRINT "Is this Correct?"
630 PRINT "lyes", "2no"; STRING$(60, 32)
640 KEY 1, "yes" + CHR$(13)
650 KEY 2, "no" + CHR$(13)
660 KEY ON
670 LOCATE 22.15: INPUT ; "
680 IF a$ = "yes" THEN RETURN
690 IF a$ = "no" GOTO ParamChange
700 GOTO 680
710 'info correct so write to file #1
730 PUT #1, RUNNUM%
740 CLOSE #1
750 RETURN

ParamChange:
    RESTORE Params
    CALL FuncKeys("Choose the Parameter to Change", 8, S$, Z$)

900 ON VAL(S$) GOTO 910, 930, 950, 970, 990, 1010, 1030, 1050
910 LOCATE 4, 2: PRINT "Measurement Pattern "
    DATA "A", "B", "C"
    CALL FuncKeys("Choose Measurement Pattern", 3, S$, pattern1$)
920 RSET pattern$ = pattern1$: PRINT pattern$, pattern1$: GOTO 520
930 LOCATE 5, 2: INPUT "RF Power ", POWER1$
940 RSET POWER$ = POWER1$: GOTO 520
950 LOCATE 6, 2: PRINT "Gas Type 
    RESTORE GasT
    GasT: DATA "Argon"
    CALL FuncKeys("Choose Gas Type", 1, S$, gas1$)
960 RSET Gas$ = gas1$: GOTO 520
970 LOCATE 7, 2: INPUT "Gas Flow ", FLOW1$
980 RSET FLOW$ = FLOW1$: GOTO 520
990 LOCATE 8, 2: INPUT "Pressure ", PRESSURE1$
1000 RSET PRESSURE$ = PRESSURE1$: GOTO 520
1010 LOCATE 9, 2: INPUT "Plasma on for ", START1$
1020 RSET START$ = START1$: GOTO 520
1030 LOCATE 10, 2: PRINT "Lower Wafer 
    RESTORE LWaf
    LWaf: DATA"Graphite", "Silicon", "Aluminum"
    CALL FuncKeys("Choose Lower Wafer Type", 3, S$, LWAFER1$)
1040 RSET LWAFER$ = LWAFER1$: GOTO 520
1050 LOCATE 11, 2: PRINT "Upper Wafer 
    RESTORE UWaf
    UWaf: DATA"Graphite", "Silicon", "Aluminum", "SiO2", "None"
    CALL FuncKeys("Choose Upper Wafer Type", 5, S$, UWAFER1$)
1060 RSET UWAFER$ = UWAFER1$: GOTO 520
1070 'FOR I = 1 TO 100000: PRINT "PATTERN$ is": PATTERN$,
PATTERN$ = NEXT I
1080 IF pattern$ = "A" THEN MaxPosit = 40: RETURN
1090 IF pattern$ = "B" THEN MaxPosit = 60: RETURN
1100 IF pattern$ = "C" THEN MaxPosit = 5: RETURN
1110 IF pattern$ = "?" THEN MaxPosit = 40: RETURN
1120 IF pattern$ = "?" THEN MaxPosit = 40: RETURN
1130 PRINT "Error in Pattern Type": STOP
1140 'Establish communications with Personal488
1150 DIM a$(46), C$(25), VBIAS(405), CURR$(405), CURR(405)
1160 'FIELD#3, 5213 AS B$ FOR OUTPUT AS #1
1170 PRINT "RESET"
1180 FOR y = 1 TO 13000: NEXT y
1190 PRINT "CLEAR"
1200 'Open file to read responses from Personal488
1210 PRINT "FILL ERROR"
1220 'Enable SEQUENCE error detection by Personal488
1230 PRINT "HELLO"
1240 PRINT "STATUS"
1250 INPUT #2, a$
1260 PRINT A$
1270 PRINT "TIME OUT 5"
1280 PRINT "STATUS"
1290 RETURN
1300 GOTO 1420
1310 GOTO 1230
1320 'This Subroutine initializes the measurement parameters
1330 RESTORE 1430
1340 DATA -100, 80, 0.5, -100, 100, -1.0E-4, 2.5E-3
1350 READ VSTART, VSTOP, VSTEP, XMIN, XMAX, YMIN, YMAX
1450 NDATA = INT(ABS(VSTOP - VSTART) / VSTEP) + 1
1460 PRINT "Initializing HP 4145"
1470 'PRINT VSTART, VSTOP, VSTEP, XMIN, XMAX, YMIN, YMAX, NDATA
1480 PRINT #1, "OUTPUT 17;IT1 CA1 DR1 BC"
1490 'INPUT ";IT1 CA1 DRO BC", D
1500 PRINT #1, "OUTPUT 17;DE CH1;CH2;CH3,'V1','I1',1,1;CH4"
1510 PRINT #1, "OUTPUT 17;VS1;VS2;VM1;VM2"
1520 PRINT #1, "OUTPUT 17;SS VR1,"; VSTART; ",", VSTOP; ",", VSTEP; ",.005;"
1530 PRINT #1, "OUTPUT 17;SM DM1 XN 'V1',1,"; XMIN; ",", XMAX; ",;YA 'I1',1,"; YMIN; ",", YMAX; ",;GLO"
   PRINT #1, "OUTPUT 17;MD;"
1540 BEEP: INPUT "Move Probe to Position 1 and Press Return when ready", D
   PRINT #1, "spoll 17"
   INPUT #2, sp
1550 RETURN
1560 Posit = 1
1570 Posit$ = STR$(Posit)
1580 PRINT "Measuring I/V Characteristic at Probe Position", Posit
   STOP
1590 PRINT #1, "output 17; MEl; "
1600 PRINT #1, "spoll 17"
1610 INPUT #2, sp
1620 ON PEN GOSUB 1680
1630 PEN ON
1640 PRINT #1, "ARM SRQ"

1645 FILENAME$ = "RN" + LTRIM$(RUNNUM$) + "P" + LTRIM$(Posit$) + ".IV"
   'PRINT "Filename is", FILENAME$
   FOR J = 1 TO 100000
   PRINT J
   NEXT J
   PRINT "measurement took too long ": END

I = 10
PRINT "Value of I at beginning of loop is "; I
DO WHILE sp <> 1
   PRINT #1, "spoll 17"
   INPUT #2, sp
   I = I + 1
LOOP
PRINT "Value of I at end of loop is "; I
GOTO 1680
STOP
1650 'do FOR T = 1 TO 100000
1652 PRINT T
1654 'NEXT T
1655 PRINT "MEASUREMENT TOOK TOO LONG": STOP
1660 PRINT #1, "SPOLL 17"
1670 INPUT #2, sp
1680 IF sp = 0 THEN PRINT "Non-SRQ Interrupt": STOP
1690 PRINT #1, "SPOLL 17"
1700 INPUT #2, STHP4145
1710 'IF (STHP4145 AND 64) = 0 THEN PRINT "Non-HP4145 SRQ!": STOP
1720 PRINT "Store Measurement to Disc, Measure Position ",
Posit$, "again":
1730 INPUT " or Quit altogether(S,M, or Q)", ANS$
1740 IF ANS$ = "M" THEN CLS 2: PRINT "Measuring Position",
Posit, "again": GOTO 1590
1750 IF ANS$ = "Q" THEN CLS 2: GOSUB 10000
1760 IF ANS$ = "S" THEN CLS 2: GOTO 1780
1770 PRINT "ANS$="; ANS$
GOTO 1720
1780 IF Posit = MaxPosit THEN GOTO 1810
1790 PRINT "Transfering Data,### Move to Probe to Position",
Posit + 1, "#####"
1800 GOTO 1820

1810 PRINT "Data for Last Measurement is Transfering"
1820 PRINT #1, "output 17; DO 'II'
PRINT #1, "enter 17"
'DIM Bs AS STRING * 5213
OPEN "\DEV\IEEE" FOR RANDOM AS #3 LEN = (NDATA * 13)
+ 3'5500'NDATA * 13
FIELD #3, (NDATA * 13) + 3 AS B$

GET #3

'PRINT B$: STOP: PRINT B$: PRINT LEN(B$): STOP

'PRINT "just got A$", P
'FOR N=1 TO 401
'PRINT "THIS IS LINE NUMBER ",P
'RINT B$
'INPUT D$
'VBIAS(N) = -100 + .5*(N-1)
'CURR$(N) = MID$(A$(N),2,11)
'CURR(N) = VAL(CURR$(N))
'PRINT N, VBIAS(N), CURR(N)
'NEXT N
'CLOSE #3

'PRINT #1, "OUTPUT 17;GL1 MK GL0"

2260 'PRINT "REFORMATTING DATA FOR PC FILE"
length = NDATA * 13
DIM JX AS STRING
JX = B$: PRINT LEN(JX); PRINT JX: STOP: PRINT LEN(JX)
'PRINT LEN(B$): STOP: PRINT B$
CLOSE #3
2290 OPEN "A:" + FILENAME$ FOR RANDOM LOCK WRITE AS #3 LEN = LEN(JX)
PRINT "FILE IS BEING WRITTEN TO, C:\probdata\": FILENAME$

2310 'FOR M = 1 TO 401
   FIELD #3, LEN(JX) AS B$
   LSET B$ = JX
   'PRINT B$: STOP: PRINT LEN(B$): STOP
2320 PUT #3 'VBIAS(M), CURR(M)
2330 'NEXT M
2340 CLOSE #3
2350 PRINT "FILE HAS BEEN WRITTEN TO, C:\PROBDATA\": FILENAME$
   IF Posit = MaxPosit THEN RETURN

2360 PRINT "Press Return When Ready to Measure Position", Posit + 1;

INPUT D
2370 'STOP
   Posit = Posit + 1
   GOTO 1570

2390 'this subroutine takes the data strings read from the
   'hp and returns voltage and current values in
   'IM C$(25), A$(45)
   'VBIAS and CURR
   'PRINT "C$","INIT1","INIT3","CHARS1","CHARS3"
FOR X = 0 TO 13 STEP 1
   'X
   'F X>13 THEN N=X-14
   INIT1 = 129 - (X * 9)
INIT3 = 1
CHARS1 = 0 + (X * 9)
CHARS3 = 119 - (X * 9)
'F INIT1<0 THEN INIT1=INIT1+128
'F CHARS1>128 THEN CHARS1=CHARS1-128
'F CHARS3<0 THEN CHARS3=CHARS3+128
'PRINT X+1,INIT1,INIT3,CHARS1,CHARS3
C$(X + 1) = MID$(a$(X * 2), INIT1, CHARS1) + a$(X * 2 + 1) + MID$(a$(X * 2 + 2), INIT3, CHARS3)
'PRINT "C$",(X+1),C$(X+1)
NEXT X
C$(15) = MID$(a$(28), 3, 126) + MID$(a$(29), 1, 121)
'RINT "C$",(15),C$(15)
FOR X = 0 TO 7
INIT1 = 122 - (X * 9)
INIT3 = 1
CHARS1 = 7 + (X * 9)
CHARS3 = 112 - (X * 9)
'PRINT X+1,INIT1,INIT3,CHARS1,CHARS3
C$(X + 16) = MID$(a$(X * 2 + 29), INIT1, CHARS1) + a$(X * 2 + 30) + MID$(a$(X * 2 + 31), INIT3, CHARS3)
'PRINT "C$",(X+16),C$(X+16)
NEXT X
K = 1
VSTART = -100
VSTEP = .5
FOR N = 1 TO 22
INIT = 2
FOR M = K TO K + 18
VBIAS(M) = VSTART + VSTEP * (M - 1)
CURR$(M) = MID$(C$(N), INIT, 11)
CURR(M) = VAL(CURR$(M))
'PRINT M, VBIAS(M), CURR$(M), CURR(M)
INIT = INIT + 13
IF M = 401 THEN RETURN
NEXT M
K = K + 19
NEXT N
RETURN

10000 PRINT #1, "CLEAR 17 "
PRINT #1, "RESET"
CLOSE
PRINT "Run", RUNNUM$, "ended at Position", Posit
END 'run this to create the first runnum file

20000 OPEN "O", #1, "C:\PROBDATA\RUNNUM"
PRINT #1, "1"
IOCTL #1, "BREAK"
PRINT #1, "RESET"
CLOSE #1
END

SUB FuncKeys (Promt$, Numkeys, S$, Z$)
  DIM Keys(10) AS STRING * 8
  LOCATE 15, 1: PRINT SPC(74);
  LOCATE 14, 2: PRINT SPC(74);
  FOR T = 1 TO Numkeys
    READ Keys(T)
    LOCATE 15, 1 + 9 * (T - 1): PRINT T; Keys(T): NEXT T
  FOR R = 1 TO Numkeys
    760 KEY R, STR$(R)
  NEXT R
  860 LOCATE 14, 2: PRINT Promt$;
  AGAIN: S$ = INKEY$
  890 IF VAL(S$) > Numkeys OR VAL(S$) < 1 THEN GOTO AGAIN
  Z$ = Keys(VA(VAL(S$))
END SUB
APPENDIX B

DECLARE SUB Deriv (X!(), Y!(), N!, DY!(), L!)
DIM VBIAS(401), CURR$(401), CURR(401), DCURR(401)
INPUT "input runnumber", RUNNUM$
INPUT "From postion number", FirstPos$
INPUT "to position number", LastPos$
INPUT "Input Smoothing value Try 10 or 5", L
L$ = STR$(L)
FOR PosNum = VAL(FirstPos$) TO VAL(LastPos$)
    Posit$ = STR$(PosNum)
    RESTORE VData:
    VData: DATA -100, 80, 0.5, -100, 100, -1.0E-4, 1.0E-3
    READ VSTART, VSTOP, VSTEP, XMIN, XMAX, YMIN, YMAX
    NDATA = INT(ABS(VSTOP - VSTART) / VSTEP) + 1
    PRINT "NDATA"; NDATA
    INPUT G$
    FILENAME$ = "RN" + LTRIM$(RUNNUM$) + "P" + LTRIM$(Posit$) + ". IV"
    PRINT "Filename is", FILENAME$
    OPEN "B:" + FILENAME$ FOR RANDOM AS #3 LEN = (NDATA * 13) + 3
        FIELD #3, (NDATA * 13) + 3 AS B$
        PRINT "FILE IS BEING Read from; C:\PROBDATA\"
        FILENAME$
        GET #3
        PRINT B$: STOP: PRINT B$: PRINT LEN(B$): STOP
    FOR N = 1 TO NDATA
        PRINT "THIS IS LINE NUMBER ", N
        VBIAS(N) = ((N - 1) * VSTEP) + VSTART
        CURR$(N) = MID$(B$, 2 + (N - 1) * 13, 11)
        CURR(N) = VAL(CURR$(N))
        PRINT N, VBIAS(N), CURR(N)
        DO
            'LOOP WHILE INKEY$ = ""
        NEXT N
        'STOP
    CLOSE #3
CALL Deriv(VBIAS(), CURR(), NDATA, DCURR(), L)
DRFILENAME$ = "RN" + LTRIM$(RUNNUM$) + "P" + LTRIM$(Posit$) + ". C" + LTRIM$(L$)
PRINT "Filename is for derivative is", DRFILENAME$

OPEN "A:" + DRFILENAME$ FOR OUTPUT AS #3

FOR N = 1 TO NDATA

PRINT #3, VBIAS(N), DCURR(N)
'PRINT N, VBIAS(N), DCURR(N)
'PRINT N, DerPlot.XData, DerPlot.YData
'DO
'LOOP WHILE INKEY$ = ""

NEXT N

CLOSE #3

NEXT PosNum

END

SUB Deriv (X(), Y(), N, DY(), L)
'DIM X(401), Y(401), DY(401)

AL = 2 * L + 1 'AL is the number of points
FOR K = L + 1 TO N - L
  SX = 0
  SY = 0
  SX2 = 0
  SXY = 0
  FOR JK = K - L TO K + L
    SX = SX + X(JK)
    SY = SY + Y(JK)
    SX2 = SX2 + X(JK) * X(JK)
    SXY = SXY + X(JK) * Y(JK)
  NEXT JK

  DY(K) = (SXY - SX * SY / AL) / (SX2 - SX * SX / AL)

NEXT K

FOR JN = 1 TO L

  DY(N + 1 - JN) = DY(N - L)
  DY(JN) = DY(L + 1)

NEXT JN

END SUB
REFERENCES


