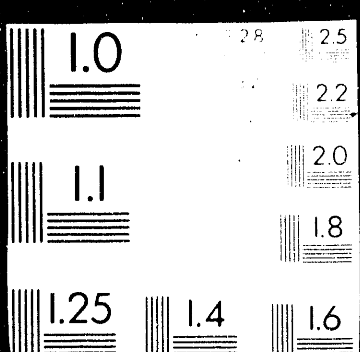
1 OF 1



1. R.M. Roth, K.G. Spears, G.D. Stein, and G. Wong, Appl. Phys. Lett., **46**, 253(1985).

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Particle Behavior in an ECR Plasma Etch Tool

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Abstract: Sources of particles in a close-coupled electron cyclotron resonance (ECR) polysilicon plasma etch source include flaking of films deposited on chamber surfaces, and shedding of material from electrostatic wafer chucks. A large, episodic increase in the number of particles added to a wafer in a clean system is observed more frequently for a plasma-on than for a gas-only source condition. For polymer forming process conditions, particles were added to wafers by a polymer film which was observed to fracture and flake away from chamber surfaces. The presence of a plasma, especially when rf bias is applied to the wafer, caused more particles to be ejected from the walls and added to wafers than the gas-only condition; however, no significant influence was observed with different microwave powers. A study of the effect of electrode temperatures on particles added showed that thermophoretic forces are not significant for this ECR configuration. Particles originating from the electrostatic chuck were observed to be deposited on wafers in much larger numbers in the presence of the plasma as compared to gas-only conditions.

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1. Introduction

The sources and behavior of particles in processing plasmas are of critical interest in the field of semiconductor wafer fabrication. Although particle generation in a plasma system was first reported in 1985 [1], the presence of particulate contamination and their deposition on wafer surfaces has been observed for over a decade by users of plasma processes in the semiconductor industry. Only in the last few years have modeling studies and systematic and real time experimental studies been performed on plasma systems as a means of understanding and, hopefully, controlling particle generation [2-9]. The motivation, well known and appreciated in the high density integrated circuit manufacturing industry, is to reduce yield loss due to wafer level particulate contamination.

With the advent of high density, low pressure plasma sources, such as electron cyclotron resonance (ECR), radio frequency induction (RFI), and helicon systems as promising candidates for critical layer etching, there is great interest in the particle generation modes and transport characteristics for these tools. For example, recent modeling work by Graves, *et al.*, has demonstrated that for an ECR source, particle trapping is less likely than for parallel plate electrode plasma sources [10]. A recent report by Selwyn [11] reporting laser light scattering results from an ECR tool is cited as evidence confirming this prediction.

In this paper we report post-processing wafer-level particle count results (using a laser-based surface particle detector) from a close-coupled ECR etch tool. The influence of the plasma and its characteristics on particles from two principal sources is investigated: 1) particles generated by the cracking and delamination of a polymer film deposited on chamber walls during the ECR etching of polysilicon, and 2) particles from the electrostatic wafer chuck transported onto the wafer by a burst of He from the backside of the wafer.

2. Experiment

The configuration of the etch tool is shown in Figure 1. The 2.45 GHz microwave power (0 - 1400 W) is introduced from rectangular and circular waveguides into the quartz bell jar. The magnetic fields are produced by two coils concentric with the process chamber with current ranges of 15 to 35 amps (upper coil) and 3 to 25 amps (lower coil). The resonance zone (nominally 875 G) was measured experimentally to occur at 85 mm above the wafer at coil current settings of 30 amps (upper) and 4 amps (lower) for the process conditions in this work. The chamber is evacuated by a 2000 l/sec turbomolecular pump through a large exhaust port below and to the side of the wafer chuck. The base pressure of the chamber is 1×10^{-6} torr. Process gases are introduced through a gas distribution ring around the base of the bell jar. The system can be configured for 150 mm or 200 mm wafers, which are introduced into the chamber through a separately pumped load lock and clamped onto the chuck electrostatically with -500 V clamping voltage. The electrostatic chuck is assisted by a mechanical clamp ring with 16 contact points around the wafer. For particle studies under gas-only (no plasma) conditions, no electrostatic clamping occurs. rf power (2 MHz) from 0 to 140 W is applied to the chuck for substrate bias control. Wafer temperature control is achieved by circulating coolant (from -50 to +80°C) on the backside of the chuck and applying helium to the backside of the wafer. Electrode temperature, taken to be the coolant temperature exiting the electrode, was maintained at 20 °C for all studies except where noted.

Wafer-level particle count data were obtained using a 488 nm, Ar ion laser surface particle detector (Tencor Surfscan 6200). A 3 mm edge exclusion was employed to eliminate observation of surface damage caused by the 16 mechanical clamp fingers, which were 2.5 mm long and 2 mm wide. All experiments were performed in a state-of-the-art, Class 1 clean room using proper clean room practice. Particle test wafers were 150 or 200 mm diameter bare silicon substrates of prime grade (virgin) for studies during etch processing in a clean chamber; monitor grade wafers were used for studies of a heavily particle contaminated chamber. Only wafers with 15 or fewer starting particles greater than 0.3 µm in size were used in the testing, and most had fewer than ten. All particle measurement data were obtained using the following procedure: 1) test wafers were flat/notch oriented and then pre-measured just prior to loading into the etch tool, 2) wafers were post-measured just after exiting the plasma system. No manual wafer handling was performed between the pre- and post-measurements. Wafers are transferred from a load cassette to an unload cassette as a consequence of the etch tool wafer process sequence. Control wafers were run at regular intervals and consistently showed less than two particles added to wafers as a result of manual cassette handling during transfer between the measurement tool and the etch tool (separated by about 5 meters). Consequently, all data reported as particles added are simply the difference between the pre- and post-etch tool measurements.

3. Particle addition to wafers in a clean ECR system

As part of a study of doped polysilicon gate etch processes using HBr and Cl_2, a process stability experiment was performed on an optimized etch process. In the stability experiment, several hundred wafers were etched and etch process metrics (e.g. etch rates, selectivities, etc.) were obtained at regular intervals. One of the metrics was particles added to wafers for the conditions of gas-only (no plasma) and plasma-on (500

W), using 100 sccm O_2 at 5 mT. Figure 2 shows a plot of particles of size 0.16 to 1.6 μm added to wafers at various points throughout the process stability experiment. The experiment was performed in a nominally clean system, i.e. all internal chamber parts were cleaned and a clean bell jar was installed prior to the optimization study. An *in situ* plasma cleaning of the reaction chamber (referred to as "aging") was performed at the beginning of each day and at the end of the experiment. The cumulative number of wafers etched after each aging are indicated for each particle test. All particle tests consisted of one wafer each for the conditions of plasma-on and plasma off (gas-only). Figure 2 illustrates five interesting points: 1) there is a slight upward trend in the data, indicating the system is becoming dirtier, 2) the *in situ* plasma clean had no consistent effect on the particle counts, 3) except for three points, the plasma-on particle test resulted in lower particle counts than the gas-only test, 4) two of the plasma-on tests (numbers 9 and 15) show significant positive deviation from the rest of the plasma-on data - it will be shown that these excursions are common for plasma-on testing and are evidence of plasma induced particle ejection from chamber surfaces, 5) one of the plasma-on tests with a large positive deviation (number 15) occurred in a cold system (the test was the first plasma in the system for that day) - this "cold system" effect is repeatable.

To quantify whether there is a statistical difference between the plasma-on and the gas-only data in Figure 2, a Wilcoxon test was performed to test the means and an F-test was performed to test the variances. The Wilcoxon test assumes no particular type of distribution. The results are that both the mean and the variance of the plasma-on data are statistically different from the gas only data, the plasma-on mean being smaller but the variance larger due to the outliers (excursions). This is graphically illustrated in Figure 3 by comparing the box plot for each data set.

4. Particle addition to wafers during a polymer forming etch process

A small amount of oxygen added to a doped polysilicon etch process using HBr greatly improves the ECR polysilicon etch selectivity to oxide [12]. If the amount of oxygen is greater than about one percent of the total flow, however, a polymer deposition mode is created during the etch reaction [12]. The polymer is deposited as a film on the chamber surfaces, including the quartz bell jar. The film is observed to preferentially deposit in a ring half-way up the bell jar and at the top of the bell jar where there are microwave "cold spots," areas which are aligned with and close to physical nodes in the waveguide. Table I shows results of plasma-on and gas-only particle tests performed on the clean system just prior to running this etch process and after every 10 resist patterned, polysilicon wafers were etched. Two wafers were run for each of the gas-only and the plasma-on particle tests and both tests were performed using the etch process parameters of 120 sccm HBr, 2 sccm O_2, 5 mT, and (for the plasma-on test) 750 W microwave power and an ECR point of 85 mm. Except for the cold system tests where both gas-only wafers were run first, the tests were performed in the following order: gas-only, plasma-on, gas-only, plasma-on. It should be noted that the gas-only and plasma-on particle tests do not etch the silicon substrate due to the high selectivity of HBr to native oxide - a breakthrough step, using Cl_2 for example, is required to initiate etching.

Several points are noted from these data: 1) the nominal, clean system background particle count is exceeded when between 10 and 20 wafers are etched - however, the source of particles (the film) is evident after only a few wafers are etched, 2) the cold system effect is again realized, for both plasma-on and gas-only measurements (both gas-only measurements were performed before the plasma-on tests), 3) except for the second plasma-on test after 20 wafers (151 adders), and not including the cold system results, the number of particle adders monotonically increases, 4) the second plasma-on test after 20 wafers (151 adders) is a positive excursion and is probably a plasma-induced, episodic event, 5) except for the clean system and the positive excursion just noted, the first plasma-on test places a larger number of particles on the wafer than the second test - this is also true of the gas-only tests when the system becomes very dirty.

5. Plasma effects on particle addition to wafers in a dirty ECR system

After the study described in Section 4, 25 more wafers were etched using the polymer depositing etch process. The bell jar was then removed and the system was throroughly cleaned and converted to process 150 mm wafers. The dirty bell jar was reserved and the system was tested for particles with a clean bell jar in place. Plasma-on and gas-only tests using Ar proved the system was clean, with average particle adders of less than 15 particles (0.32 - 28 μm). The dirty bell jar was then placed on the system and used as a known source of particles to study plasma effects on particle behavior. All polymer coated regions on the bell jar were cracked and delaminating to varying degrees. The following studies were performed with 100 sccm Ar at 5 mT pressure.

5.1 Effect of microwave power on particle addition to wafers

The effect of microwave power on particles added to wafers was evaluated by sequentially processing a cassette of wafers for each of three conditions in order as follows: 1) gas-only, 2) plasma-on at 1100 W incident microwave power (300 W reflected), and 3) plasma-on at 110 W incident microwave power. No rf bias was applied for the plasma-on tests. For the condition of plasma-on at 110 W incident, the microwave power was partially transmitted to the wafer since the reflected power was near zero (<5 W) and a potential difference was induced on the rf bias circuit with rf bias off. The results for each wafer cycled under each condition are shown in Figure 4. Two observations are noted: 1) both plasma-on conditions show high first wafer counts, and 2) in addition to the first wafer tested, the 110 W plasma-on test had two high excursions. To test for statistical differences in these results, a Wilcoxon test was performed on the means and an F-test was performed on the variances. The test for the means showed no statistical difference for the three conditions. The test on the variances showed no difference between gas-only and plasma-on at 1100 W. The variance of the plasma-on, 110 W condition is different from the other two conditions, due to the two outliers of test 13 and 22. The results are illustrated using box plots in Figure 5. An important conclusion from these plots is that the presence of a plasma in the system seems to increase the number and the extremity of the outliers (excursions).

5.2 Effect of rf bias on particle addition to wafers

The effect of rf bias on particle behavior was studied for the conditions of gas-only, 140 W rf bias, and 0 W rf bias. Incident microwave power was 800 W and reflected power was 160 W for the plasma-on tests. The 140 W rf bias resulted in an average peak-to-peak rf voltage of 260 V. The results for each wafer cycled under each condition are shown in Figure 6. The results show a dramatic increase in the number of particles added to the wafers from the bell jar surface for the condition of plasma-on with rf bias. A time-dependent effect, possibly due to heating of the bell jar, is also evident for this condition with the first several wafers adding a factor of 20 more particles to wafers than for the gas-only or 0 bias conditions. Although the particle counts stabilize for the 140 W condition after about 13 wafers, note that this level is still a factor of two higher than for the other conditions. For these tests, the external bell jar temperature at the beginning of each test sequence was 21, 22, and 25 °C for the conditions gas-only, 140 W bias, and 0 W bias, respectively. Statistical tests of the means and variances show no difference in the gas-only and 0 W bias conditions. The result for the test on the means is consistent with the results of the microwave power study (Section 5.1). The box plots for these results, Figure 7, show the impact of the 140 W rf bias condition. Although there is no statistical difference in the means or variances of gas-only and 0 W rf bias, note that there are more extreme outliers of greater extremity for the plasma-on condition, again consistent with the results of the microwave power study.

5.3 Effect of electrode temperature on particle addition to wafers

Among the forces influencing particle behavior in plasmas is drag due to collisions of the particles with neutral gas molecules [9]. One way in which neutral drag can influence particles is by imparting a thermophoretic force due to thermal gradients [6 and references therein]. Graves, *et al.* [6] demonstrated that gradients on the order of 3 K/cm are sufficient to balance the gravity force on 0.5 μm carbon particles at 500 mT in a parallel plate source and the authors suggest that thermophoretic forces may be important in low temperature etching applications.

For the ECR source used here, previous experiments showed that wafer surface temperatures are on the order of 10 to 20° C higher than the electrode temperature when exposed to plasma with an electrode temperatue of 20° C. If we assume that the same is true at electrode temperatures of -50° C and +80° C, then wafer temperatures would be about -30° C and +100° C, respectively. For the case of a gas-only condition, the wafer is only mechanically, not electrostatically, clamped and therefore the wafer surface temperature is expected to be warmer when the electrode is at -50° C and cooler when the electrode is at +80° C. Therefore, wafer-to-wall temperature gradients, ∇T, on the order of +7 K/cm and greater are possible with an electrode temperature of -50° C and gradients of down to -8 K/cm may be realized with an electrode temperature of +80° C. Since thermophoretic force varies with the square of the particle diameter [13], $F_{th} = f(d_p^2)$, and gravity force varies with the cube of the particle diameter, $F_g = f(d_p^3)$, the effect of thermal gradients should be larger with smaller particles. Assuming a particle density of 2 g/cm^3 and a particle temperature less than 500 K, calculations of the thermophoretic forces [13] on 0.32 to 0.5 µm particles (the smallest particle size range measured here) in Ar at 5 mT and ∇T = -8 K/cm (electrode temperature of +80°C) give $F_{th}/F_g = 1\text{x}10^{-5}$. No thermophoretic effect is expected, therefore, at the low pressures used in an ECR source, even with a hot electrode and a cold chamber wall. This was verified by measuring particle additions to wafers for gas-only and plasma-on conditions at electrode temperatures of -50° C and +80° C. Results of the effect of electrode temperature on particles 0.32 to 28 µm and 0.32 to 0.5 µm in size are shown in the form of box plots in Figure 8. As expected, there is no observable thermophoretic effect in the ECR source indicating that this force is negligible with respect to ion drag, electrostatic, and gravitational forces.

6. Particles added by the electrostatic wafer chuck

Electrostatic wafer chucks can shed large numbers of particles because brittle, ceramic materials are used to coat the chuck. Although particles may be added to the backside of a wafer, most are subsequently removed in a wet clean. When the wafer is electrostatically clamped, the backside is pressurized with up to 10 torr of He to promote heat transfer from the wafer to the chuck. The resulting pressure differential from the wafer backside to the source region causes some He to leak into the chamber. The He flow is pulse width modulated at 1 sccm, giving a time averaged leak rate of about 0.1 sccm, to maintain the correct backside pressure. Consequently, the possibility exists that particles are blown from the backside of the wafer and land on the wafer frontside. This phenomenon has been investigated and no added particles were observed in a clean system under normal operation. If the backside He is pulsed instantaneously with 10 sccm or if the clamping voltage is suddenly removed, however, particles can be added to the wafer under a variety of source conditions due to a shockwave which carries the particles around the edge of the wafer and into the chamber (Figure 9). The geometry of the electrode cover and mechanical clamp ring are such that flow is directed towards and over the wafer, rather than away from it. The He burst (release point) originates at a fixed point around the circumference of the wafer. The larger particles land closer to the release point and the smaller particles are carried farther away.

The finding relavent to particle behavior in an ECR source is that there is a consistent order of magnitude increase in particles (0.32 to 28 μm) added to wafers for any given plasma-on condition (several thousand particles added) compared to a gas-only condition (several hundred particles added). We believe this is strong evidence that ion drag is the dominant force influencing particle transport in this source.

7. Discussion

The presence of an ECR plasma clearly can cause the ejection of particles from a chamber surface, validating earlier observations in an SiO_2 plasma deposition system [4]. This behavior is seen most dramatically in the rf bias study described in Section 5.2. Thermal stress of the polymer film on the bell jar is a reasonable explanation for this phenomenon. The consistent observation of high plasma-on particle counts in a cold (room temperature) ECR system, even when gas-only counts are low, is evidence that thermal stress plays an important role. Even a short idle period for the system will cool the bell jar to a point where a subsequent exposure to plasma will eject particles. Thermal stress is less attractive, however, as the explanation for high plasma-on particle counts in a system which is hot. External bell jar temperatures can reach a peak of 110° C during plasma-on periods of processing and cool by 15 to 20° C between wafers. Assuming that the interior bell jar temperatures are on the order of 10 to 20° C hotter than the external temperature, this represents a reduction by more than 100° C of the temperature drop across the polymer film relative to a cold system. A direct plasma/wall interaction may then explain particle ejection from a hot wall.

The effect of system induced mechanical stress on particle ejection from walls is less clear. The fact that no mechanical perturbation of the system occured *during* the particle test indicates that the plasma alone causes the ejection of particles. This does not imply, however, that system induced mechanical stress (such as gate valves opening/closing, etc.) has no effect: mechanical stress may condition the film such that it is more likely to eject particles upon exposure to a plasma, as suggested in Reference 4.

In light of the results with large neutral thermal gradients and the observation that particles ejected from the backside are driven to the wafer in the presence of a plasma, ion drag appears to dominate thermophoretic and gravity forces in this ECR source. The role of electrostatic force remains unclear. *In situ* laser light scattering results revealed no particle trapping during the HBr etching of polysilicon in this tool in the regions over the clamp ring or several mm above the wafer surface. The plasma/sheath boundary region above the wafer could not be observed because of obscuration caused by the clamp ring.

8. Acknowledgements

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1. R.M. Roth, K.G. Spears, G.D. Stein, and G. Wong, Appl. Phys. Lett., **46**, 253(1985).

2. G.S. Selwyn, J. Singh, and R.S. Bennett, J. Vac. Sci. Technol. A, **7**, 2758(1989).

3. G.M. Jellum and D.B. Graves, J. Appl. Phys., **67**, 6490(1990).

4. G.S. Selwyn, J.S. McKillop, K.L. Haller, and J.J. Wu, J. Vac. Sci. Technol. A, **8**, 1726(1990).

5. G.S. Selwyn, J.W. Heidenreich, and K.L. Haller, J. Vac. Sci. Technol. A, **9**, 2817(1991).

6. G.M. Jellum, J.E. Daugherty, and D.B. Graves, J. Appl. Phys., **69**, 6923(1991).

7. G.S. Selwyn, J. Vac. Sci. Technol. A, **9**, 3487(1991).

8. J.S. Logan and J.J. McGill, J. Vac. Sci. Technol. A, **10**, 1875(1992).

9. M.S. Barnes, J.H. Keller, J.C. Forster, J.A. O'Neill, and D. K. Coultas, Phys. Rev. Lett., **68**, 313(1992).

10. M.D. Kilgore and D.B. Graves, unpublished.

11. G.S. Selwyn, Proceeding of the 1992 Dry Process Symposium, The Institute of Electrical Engineers of Japan, Tokyo, 123, (1992); G.S.Selwyn, K.L. Haller, and E.F. Patterson, Proceedings of the 9th Symposium on Plasma Processing, ed. by G.S. Mathad and D.W. Hess, Proceedings Vol. 92-18, The Electrochemical Society Inc., Pennington, NJ, 236, (1992).

12. G.D. Tipton, M.G. Blain, P.L. Westerfield, L.S. Trutna, K.L. Maxwell, to be published in the proceedings of the 2nd Workshop on High Density Plasmas and Applications, J. Vac. Sci. Technol.

13. Equation (1) in Reference 6.

Figure captions.

Figure 1. Configuration of close-coupled ECR plasma reactor.

Figure 2. Comparison of particles (0.23 - 1.6 μm) added to wafers for plasma on and gas only particle tests (using the conditions shown) during a stability test of an optimized, 200 mm etch process. Aging refers to a 15 minute *in situ* plasma, chamber cleaning process.

Figure 3. Box plot of the plasma on and gas only particle test data shown in Figure 2. White bar indicates the median value. Shaded area represents the inner quartile range (25th - 75th percentile). Enclosures (connected by dotted lines) indicate the 2.5 and the 97.5 percentiles. Horizontal lines indicate outliers.

Figure 4. Comparison of particles added to 150 mm wafers (0.32 - 28 μm) for wafer runs with gas only, 900 W plasma, and 90 W plasma for the conditions shown. The order of the runs was the same as the order in the legend.

Figure 5. Box plot of the gas only, 900 W plasma, and 90 W plasma data shown in Figure 4. Meaning of the symbols is as described in the caption of Figure 2.

Figure 6. Comparison of particles added to 150 mm wafers (0.32 - 28 μm) for wafer runs with gas only, 140 W rf bias plasma, and 0 W rf bias plasma for the conditions shown. The order of the runs was as indicated in the legend.

Figure 7. Box plot of the gas only, 140 W rf bias plasma, and 0 W rf bias plasma data shown in Figure 6. Meaning of the symbols is as described in the

caption of Figure 2.

Figure 8. Box plot of 0.32 to 28 μm particles and 0.32 to 0.5 μm particles for the gas-only and 850W Ar plasma runs at electrode temperatures of +80°C and - 50°C. Meaning of the symbols is as described in the caption of Figure 2.

Figure 9. Schematic of the electrostatic wafer electrode and the mechanical clamp.

Table I. Plasma-on and gas only particle tests during the etching of polysilicon wafers using an etch process known to deposit polymer on chamber surfaces.

Number of wafers etched	Number of particles (0.32 to 28 μm) Plasma-on	Gas-only
0	8, 13	2, 13
10	36, 15	11, 15
10*	678, 10*	600, 31*
20	50, 151	44, 37
30	222, 115	213, 80
40	404, 215	339, 157
50	577, 263	369, 214

*Cold system test results.

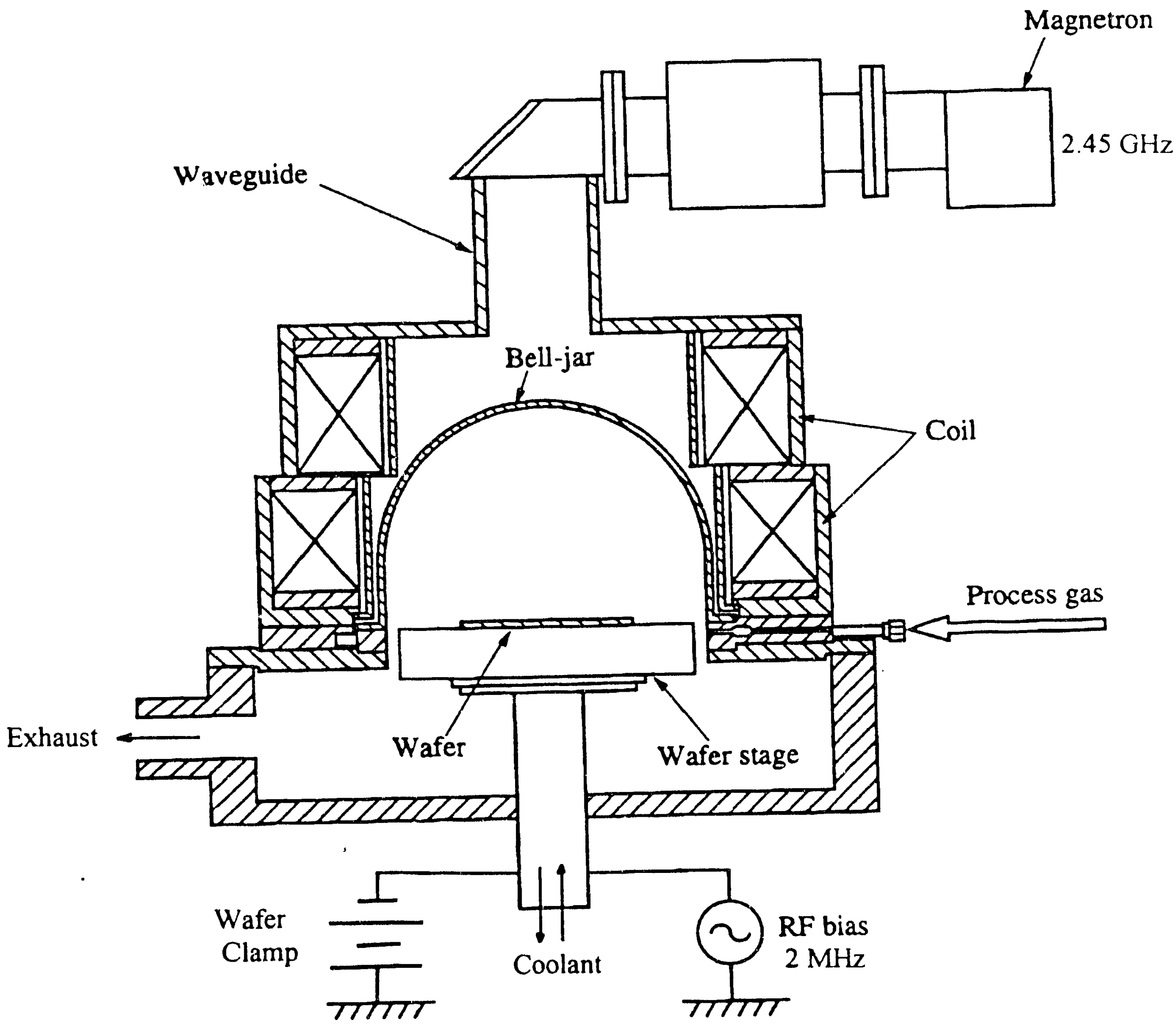

Magnetron
2.45 GHz
Waveguide
Bell-jar
Coil
Process gas
Exhaust
Wafer
Wafer stage
Wafer
Clamp
Coolant
RF bias
2 MHz

Figure 1

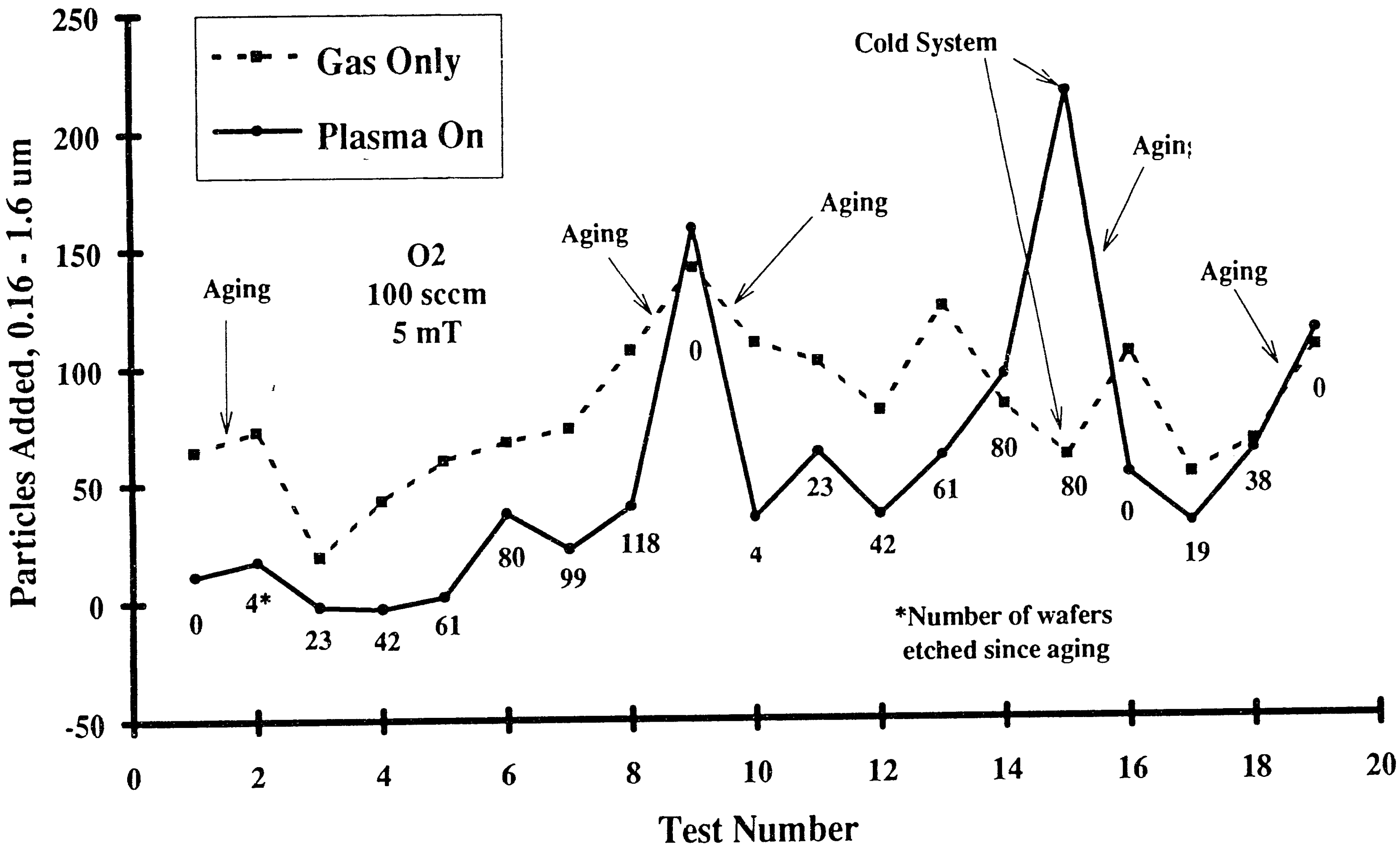

Gas Only
Plasma On
O2
100 sccm
5 mT
Aging
Aging
Aging
Cold System
Agin;
Aging
*Number of wafers
etched since aging
Particles Added, 0.16 - 1.6 um
Test Number
250
200
150
100
50
0
-50
0
2
4
6
8
10
12
14
16
18
20
4*
23
42
61
80
99
118
23
42
61
80
80
19
38

Figure 2

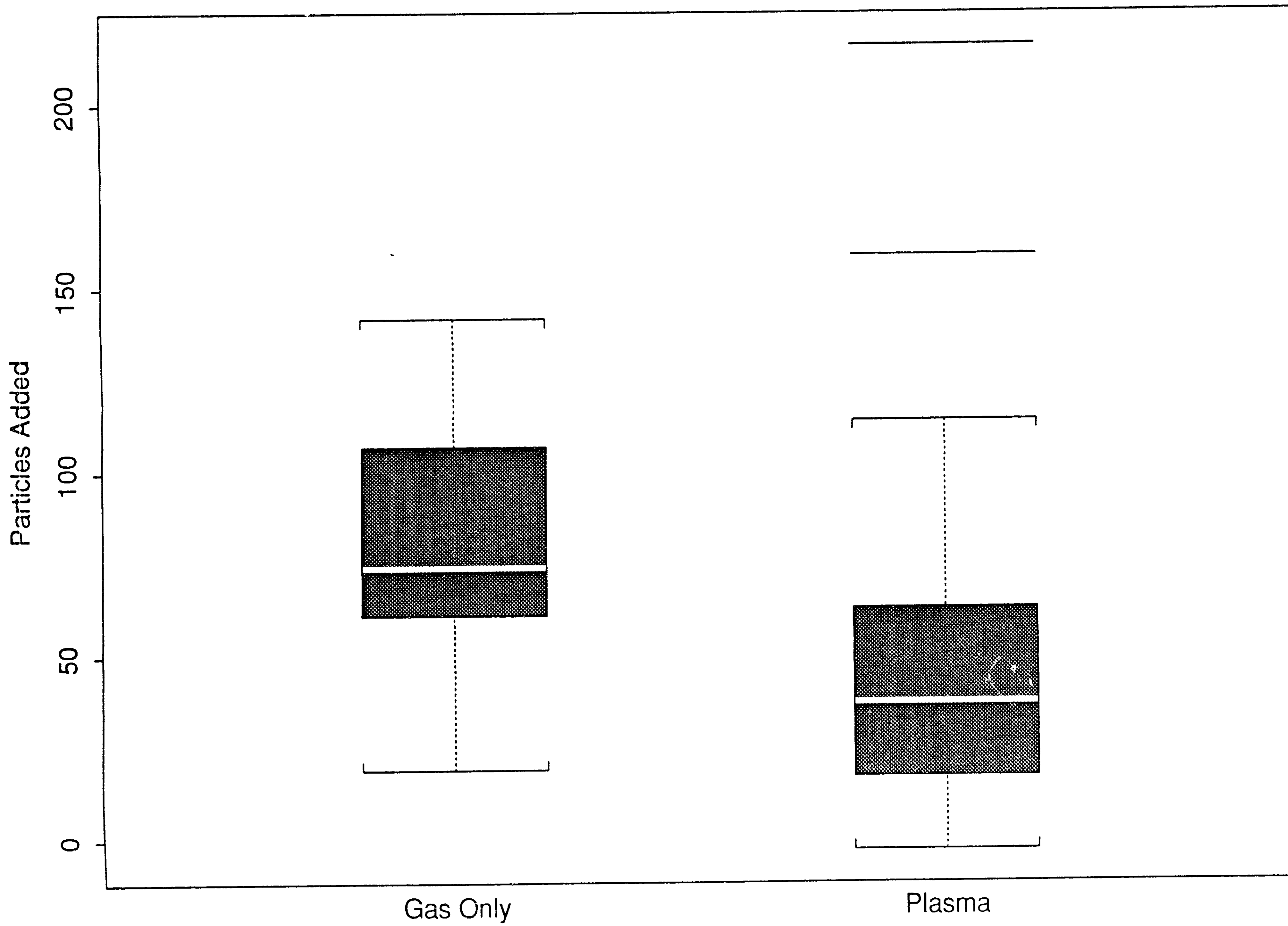
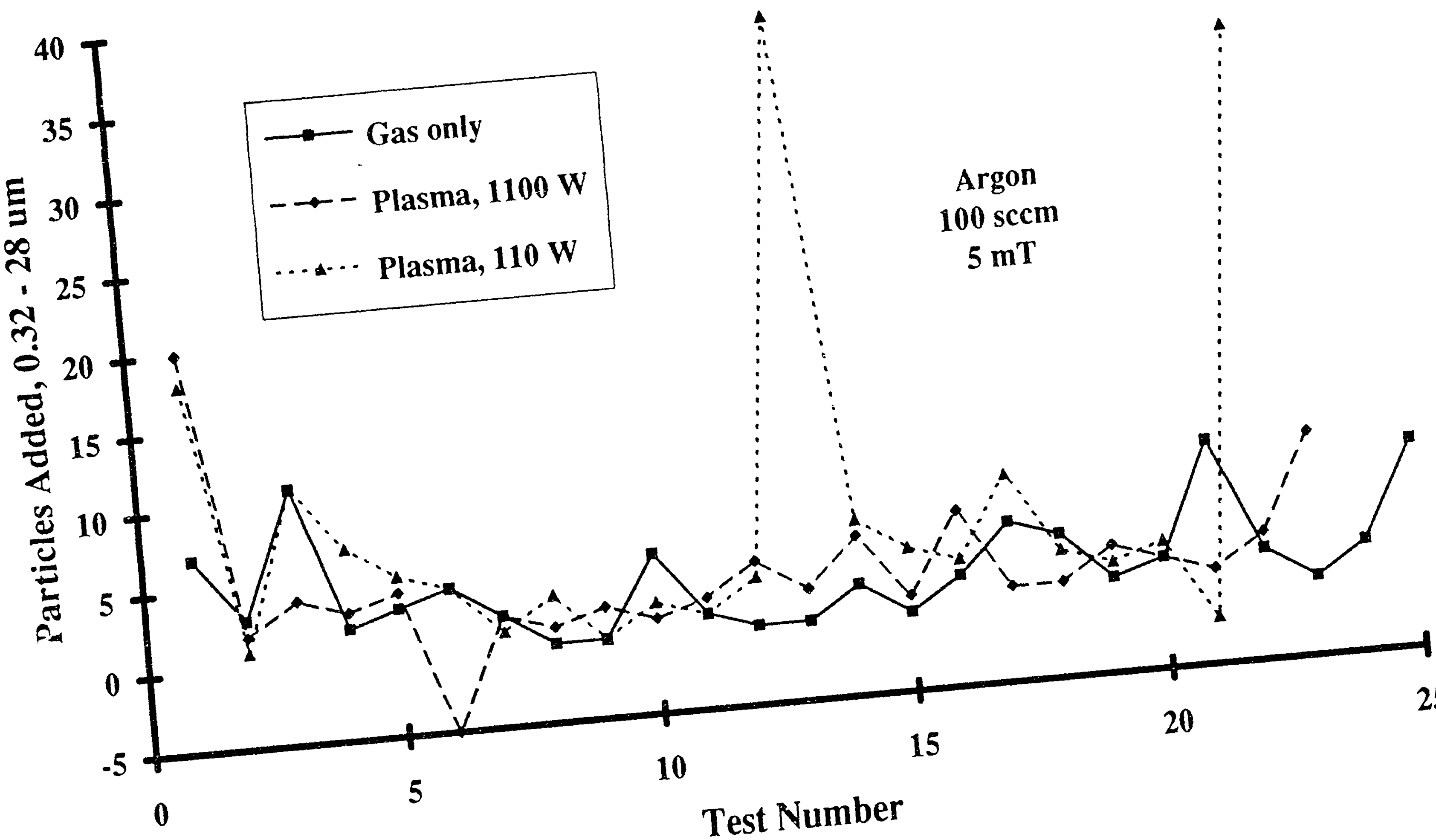


Figure 3



Gas only
Plasma, 1100 W
Plasma, 110 W
Argon
100 sccm
5 mT
Particles Added, 0.32 - 28 um
Test Number
40
35
30
25
20
15
10
5
0
-5
0
5
10
15
20
25

Figure 4

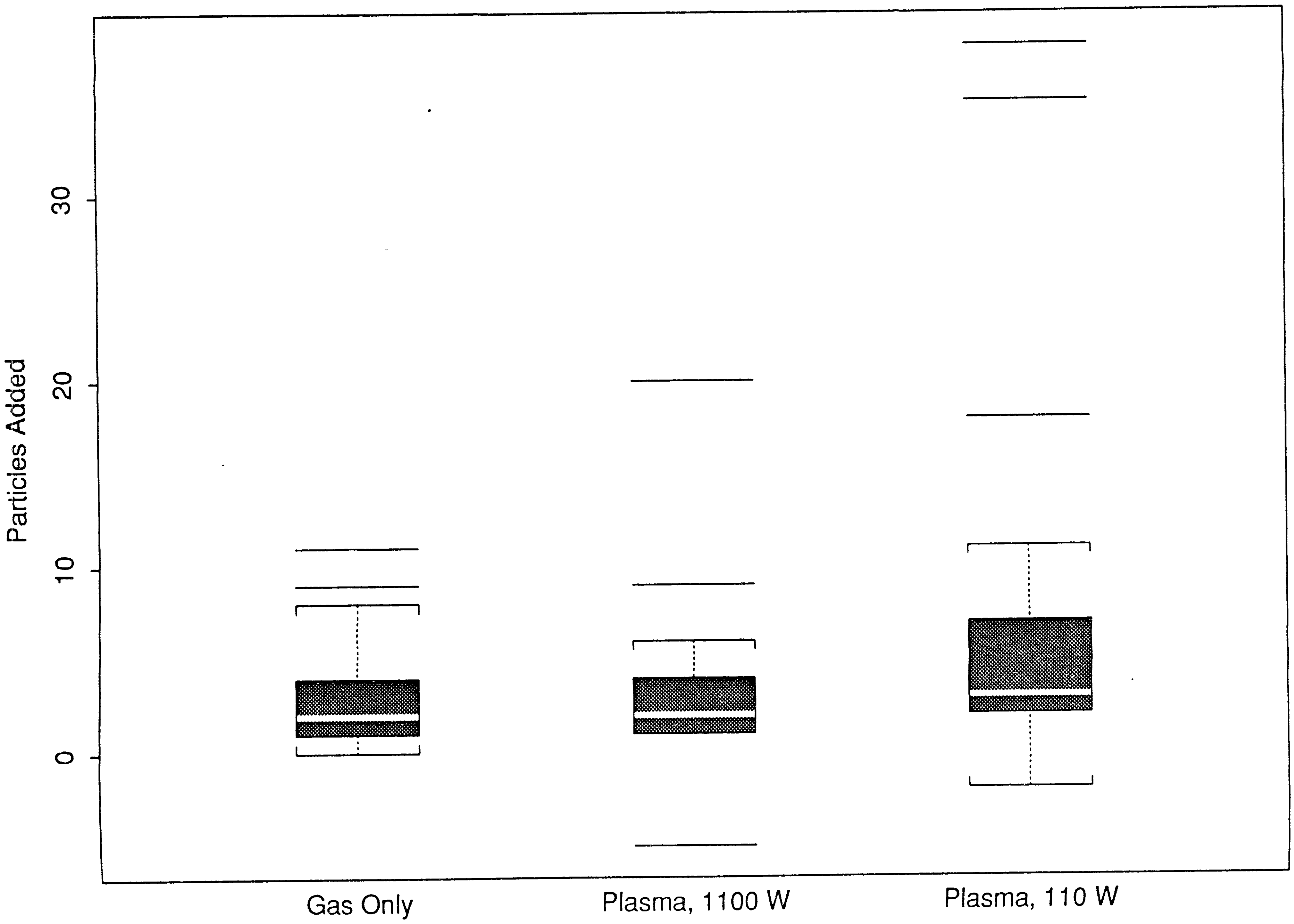
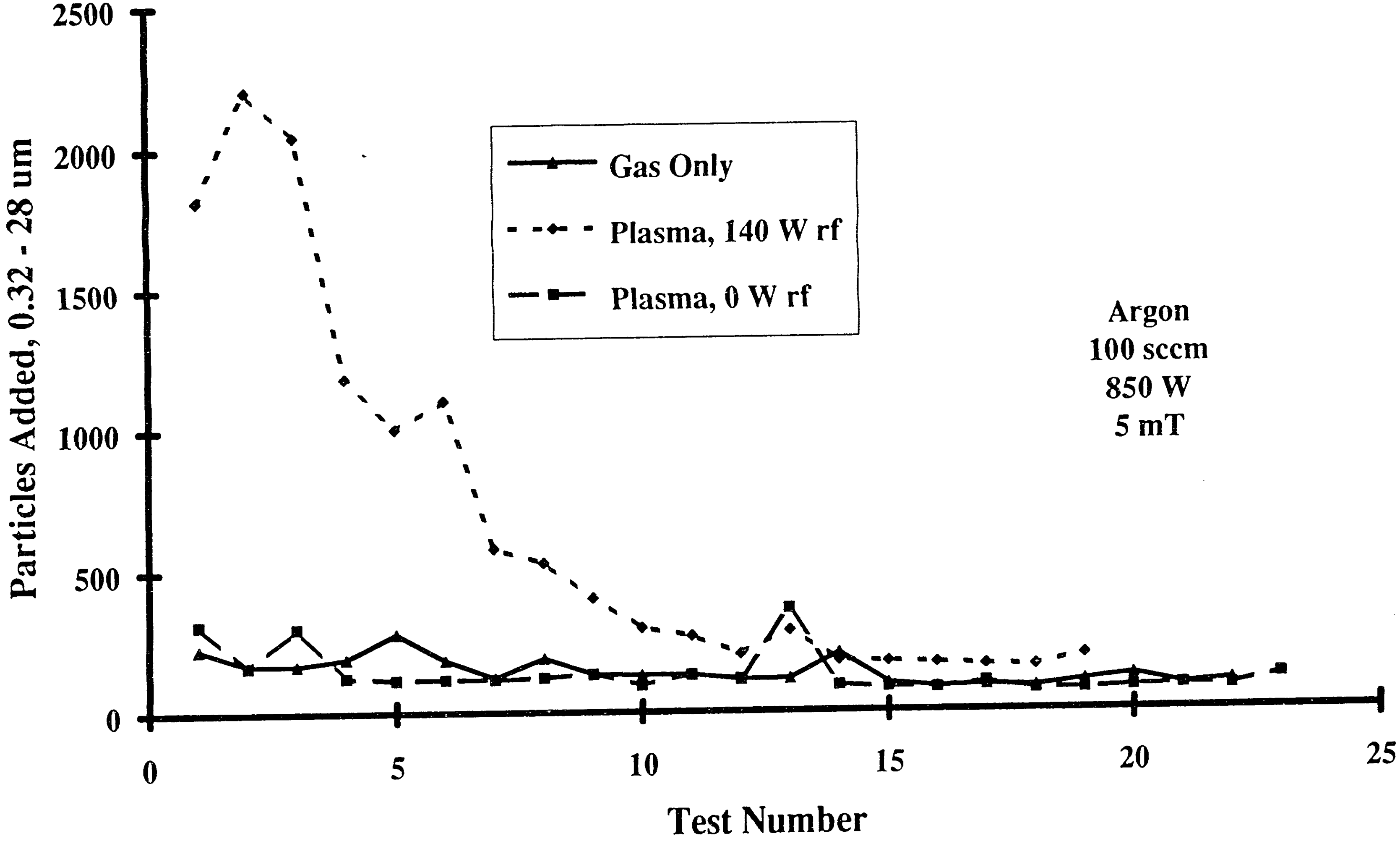


Figure 5



2500
2000
1500
1000
500
0
Particles Added, 0.32 - 28 um
0
5
10
15
20
25
Test Number
Gas Only
Plasma, 140 W rf
Plasma, 0 W rf
Argon
100 sccm
850 W
5 mT

Figure 6

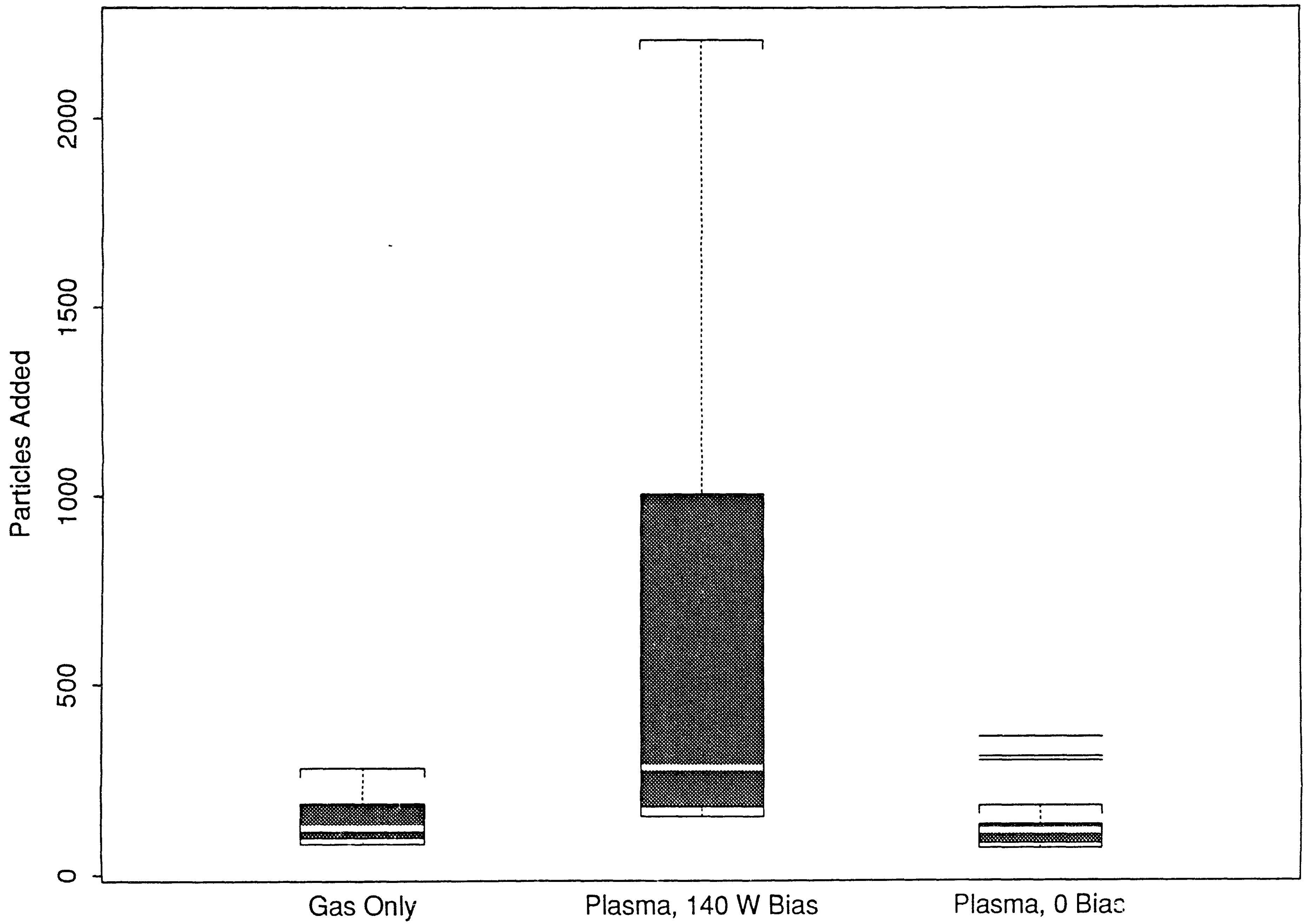
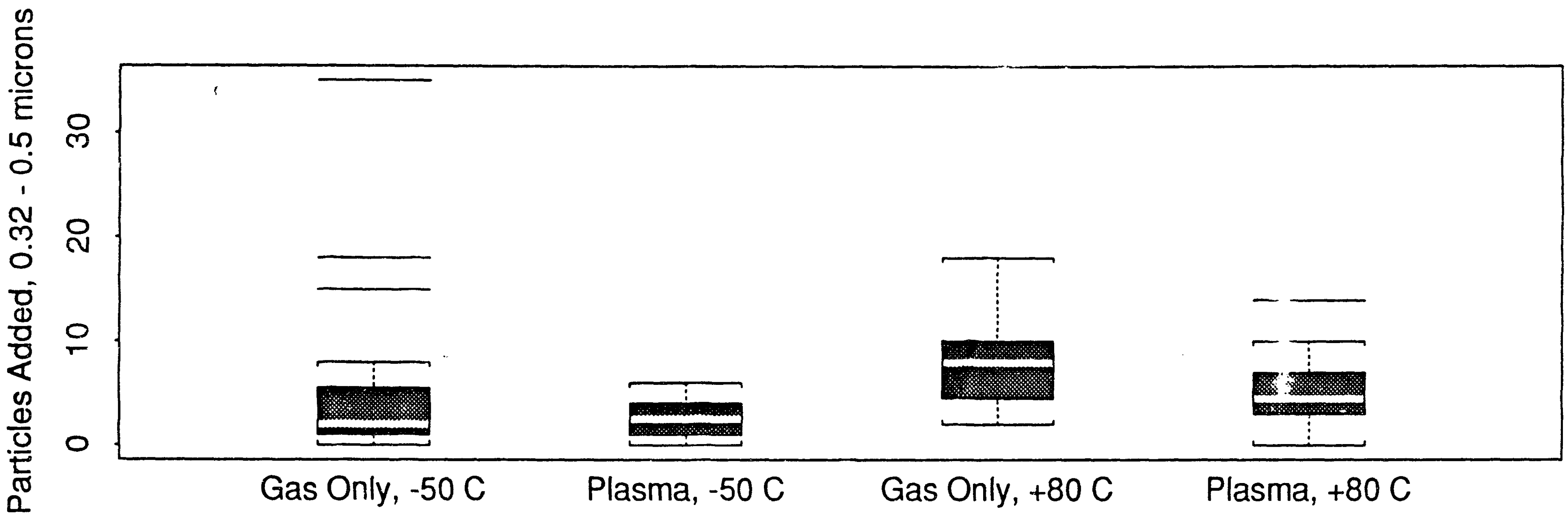
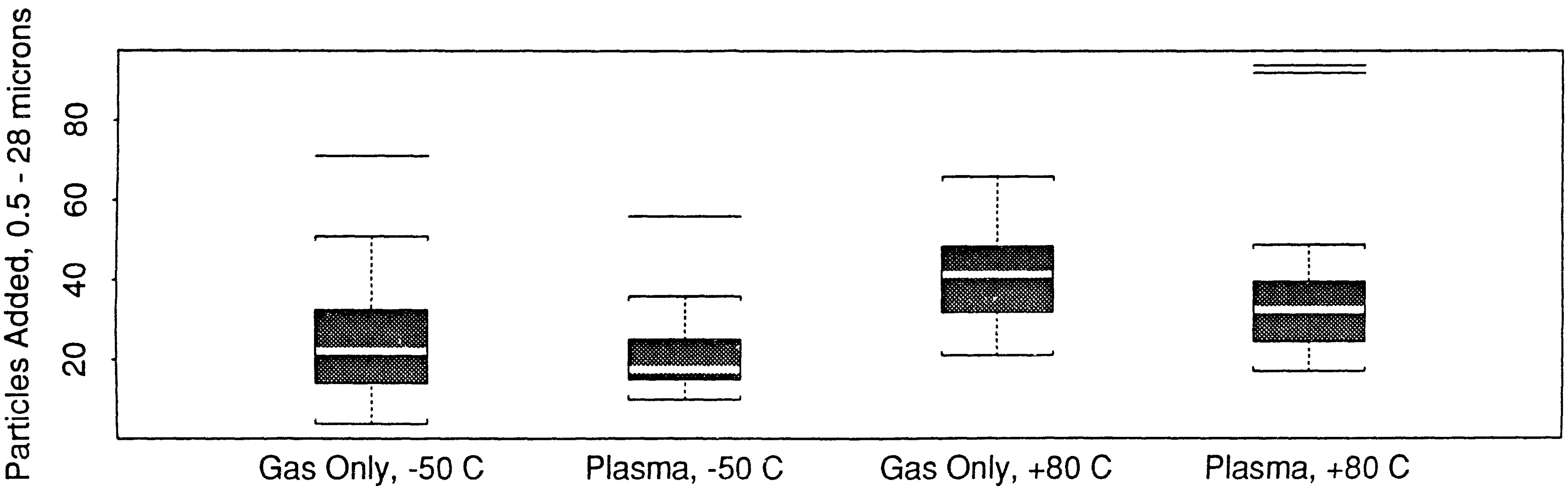

Particles Added
2000
1500
1000
500
0
Gas Only
Plasma, 140 W Bias
Plasma, 0 Bias

Figure 7



Particles Added, 0.32 - 0.5 microns
0
10
20
30
Gas Only, -50 C
Plasma, -50 C
Gas Only, +80 C
Plasma, +80 C



Particles Added, 0.5 - 28 microns
20
40
60
80
Gas Only, -50 C
Plasma, -50 C
Gas Only, +80 C
Plasma, +80 C

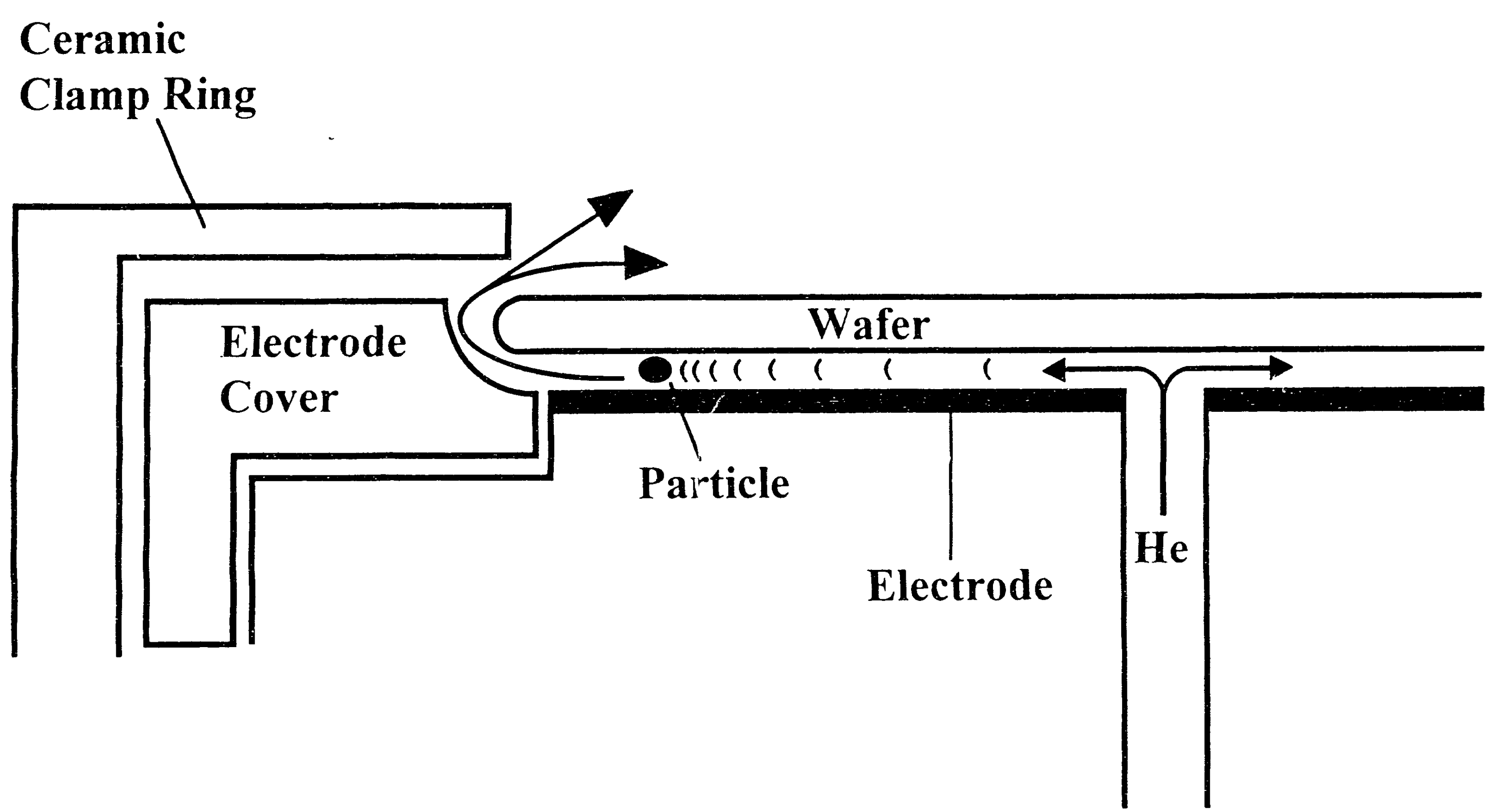

Ceramic
Clamp Ring
Electrode
Cover
Wafer
Particle
Electrode
He

Figure 9

END

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