Decrease of plasma perturbations caused by Langmuir probes

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Abstract: New source of perturbations caused by Langmuir probes using screened probe holders has been disclosed. The report shows that direct “screen-plasma” contact turns the screen into a short-circuited, asymmetric double macro-probe which lowers plasma current (discharge or diffusion one) and therefore reduces plasma ionization degree. Understanding physics of the said mechanism gives a way to decrease plasma perturbations of this new type.

Keywords: Langmuir probe, charged particle collection, plasma potential, plasma floating potential, self-matched currents, electron concentration, ion bombardment.

1. Introduction

Probe plasma diagnostics is a contact method introducing definite perturbations into plasma that distort plasma parameters and result in measurement errors.

The main perturbations of plasma caused by Langmuir probes are well known [1, 2]: a) increased drain of electrons to a thick probe tip and/or a probe-holder that lowers electron density ne; b) in the case of RF plasma it is an increased level of RF interference on a probe sheath of space charge usually decreasing ne and lifting electron temperature Te. In the present work one more source of probe perturbations has been disclosed that is brought into plasma by a bare screen of a probe holder. To our knowledge this type of probe plasma perturbations has not been discussed in literature before.

2. The concept of the new type of probe perturbations

Perturbations of new type may arise when a bare metal screen of a probe-holder is incorporated to protect probe circuit against RF noise. Such kind of probe measurement arrangement is not excessively unusual, for example see [2-4]. Authors of the present report noticed that galvanic contact of the metal screen with plasma corresponds to a well known case of a large conducting body immersed in plasma that has been studied in numerous works [5-9]. In these publications it has been shown first phenomenologically [5, 6] and then experimentally [7-9] that in this situation a conducting body behaves like an asymmetric, short-circuited double “macro-probe”. According to [5, 6] this “macro-probe” acquires floating potential close to a minimal value of plasma floating potential range spanned by a body. Besides its short-circuit current is directed against plasma current lowering it and thus reducing plasma ionization degree and therefore electron concentration ne. Plasma density reduction in this case appears deeper than in the absence of probe screen when charged particles are lost due to only ambipolar diffusion to a ceramic probe holder being driven by floating potential of plasma contacting this dielectric rod. Metal screen is heated not only by short-circuit current in its bulk, but also by ion bombardment under the potential difference larger than floating potentials. This heating consumes some plasma energy content which also tends to reduce ne.

In the present work the phenomenon of “plasma-metal body” contact has been connected with probe measurements technique for the first time. Therefore it seems necessary to consider physical notions [5-9] to understand the nature of this new type of probe perturbation and get familiar with arguments for the correctness of the approach developed in these works.

3. Phenomenological analysis

In a general case space distribution of plasma potential is non-uniform: in a gas discharge it is its positive column and in quiescent plasma it is the area of ambipolar diffusion. Schematic of phenomena arising when a conducting body of length L is immersed in plasma (that initially was shown in [5]) is presented now in Fig. 1:

![Fig. 1 Behavior of a conducting body immersed in plasma](image-url)
Let this body (shown as a hatched strip) span plasma area where plasma potential varies in the range $V_{p1} - V_{p2}$. While its floating potential changes from $V_{1}$ through $V_{2}$. It seems evident that a single floating potential of the conducting body $V_{b}$ should belong to the range $V_{1} - V_{2}$. Then the right part of the body in Fig. 1 becomes more negative than plasma and it collects current of positively charged ions. The left part of the body becomes more positive than plasma and it collects electron current. Both currents should be closed in the body and in plasma forming a current loop with short-circuit current $I_{sc}$. That is why both currents have to be equal to each other. Such leveling off should happen automatically with the boundary separating two parts of the body that corresponds to the floating potential $V_{b}$. This boundary should shift to the left part of the body cutting electron collecting surface to a size that is less about $10^{2}$ times than another one ($10^{2}$ is approximately the ratio of electron and ion mobilities). Therefore the body’s floating potential $V_{b}$ appears a little higher than $V_{1}$ and in practice it can be considered to be nearly equal to this lower limit of plasma floating potential spanned by the body $V_{b} = V_{1}$. In this situation the conducting body behaves as the kind of peculiar asymmetric short-circuited double “macro-probe” [5]. Physical essence of this approach was cleared out introducing a notion of imaginary single-probe characteristics for two unequal parts of the conducting body – short-circuited “macro-probes” [6]. These two imaginary single-probe characteristics can be summarized in the form of an imaginary double-probe characteristic:

![Image](image.png)

Fig. 2 Imaginary single-probe characteristics for two highly unequal parts of the conducting body and their imaginary double-probe characteristic

As a result nearly all surface of the conducting body should be subject to ion bombardment due to its negative bias relative to plasma potential while in the bulk of the body short-circuit current $I_{sc}$ should flow closing in plasma and reducing plasma current $I_{p}$. Effect of this plasma perturbing phenomenon may really be significant as it will be seen in the next section of the report, and this fact justifies the efforts to obtain an experimental proof for the correctness of this approach.

4. Indirect experimental checkup

It has been carried out on the request of microelectronics technology specialists as a purposeful modification of the traditional process of plasma chemical etching in oxygen plasma of photoresist film (transparent organic coating) deposited on weakly conducting monocrystal silicon substrates. Schematic of the reactor of the industrial system for plasma chemical etching of photoresist 08ITXO-100T-001 (similar to the American LFE system) is presented in Fig. 3:

![Image](image.png)

Fig. 3 Schematic of the indirect experiment: group 1 – conventional etching; group 2 – its soft modification

According to the conventional technology silicon substrates with photoresist films were loaded as group 1 (50 wafers) into a quartz barrel in which barrier CCP diode was inserted using two external longitudinal electrodes. Reactor was pumped out through an end face sleeve along arrow 1 and plasma forming gas, oxygen was supplied along arrow 2. In the presence of MOS (metal-oxide-semiconductor, kind of a capacitor) structures on the substrates they did not react in plasma processing as long as oxide thickness remained more than $\delta$~100 nm. When oxide films of MOS structures became thinner electrical break-downs of these films started and at $\delta$~20 nm nearly all MOS devices were broken.

Solution to this problem was proposed by authors [6-8]: barrier reactor of Fig. 3 was modified so that its substrates were turned $90^\circ$ to be disposed across the discharge as group 2 (Fig. 3). As a result no more break-downs of MOS structures were observed. More than that, curing effect for previously failed structures appeared [7, 8]. Explanation of this effect followed from our understanding of the situation: plasma potential differences along turned substrates were reduced signifi-
cantly because now they were disposed nearly along the CCP discharge equipotentials. Therefore floating potentials of MOS external electrodes differed very little from the common floating potential of their silicon base - substrate itself. This result confirmed correctness of our understanding of the phenomenon nature and underlined the significance of this knowledge.

5. Direct experimental checkup

This experiment was arranged using free plasma flow in low vacuum conditions at the dynamic pressure 3–5 mbar [9]. The flow of very clean argon-air plasma was created by a high durability DC arc plasmtron [10]. Its schematic is shown in Fig. 4:

![Schematic of the high durability DC arc plasmtron](Image)

**Fig. 4** Schematic of the high durability DC arc plasmtron and probe arrangement to study plasma floating potential distribution along the flow axis

Teflon plate with a longitudinal array of four flat, disc shaped wall probes 4 mm in diameter was installed at the distance of 2 mm from plasma flow axis. Floating potentials of the wall probes were measured relative to a grounded cathode of the plasmtron. Results of these measurements are shown schematically in Fig. 4 and in a precise form are given in Fig. 5:

![Floating potentials of wall probes 1-4](Image)

**Fig. 5** Floating potentials of wall probes 1-4

Initially marginal probes Nos 1 & 4 were shorted through an ammeter. Thus an asymmetrical short-circuited macro-probe was formed. Its short-circuit current was about 100 μA and floating potential turned out to be nearly equal to the potential of probe No. 1 that showed minimal value for this pair of probes (as the matter of fact it was a little higher than $V_{w}$, which is shown schematically in Figs 1, 2 and can be seen in Fig. 5). Therefore these data represented the direct experimental confirmation of the fact that our understanding of the considered physical phenomena was correct.

Then the Volt-Ampere characteristic of this probe was registered. It is presented in Fig. 6:

![Double-probe potential difference $V_{w}$](Image)

**Fig. 6** Double-probe characteristic of probes 1 & 4

Comparison of this experimental characteristic with the imaginary one of Fig. 3 shows that they look quite similar. Their qualitative agreement confirms that this direct experiment ultimately proved the correctness of our general conception of the phenomena tentatively described nearly 30 years ago [5, 6].

6. Conclusions

Thus achieved understanding of the physical nature of the new type of probe perturbations in plasma immediately shows two ways to decrease their negative influence:

1) the screen of a probe holder should be insulated externally for example by deposition of some dielectric film or by inserting the holder into a ceramic tube; such an external dielectric layer will acquire plasma floating potential distribution that will remain unchanged due to the absence of migration currents in non-conducting material;

2) in case of some difficulties with screen insulation one should select such direction for probe measurements along which plasma potential variation is minimal (just like in the above mentioned process of photoresist etching where MOS structures behaved as small probes separated from silicon base by thin oxide and their security de-
pended on the orientation of a flat substrate relative to CCP discharge).

Acknowledgment

The authors are thankful to Prof. V. A. Godyak for friendly support of this work and fruitful discussions of its contents.

This work was carried out in the frames of the Russian Federation Government’s Grant of November 25, 2010 No. 11.G34.31.0022 for state support of scientific investigations headed by high rank foreign scientist – Professor H. W. Loeb of Giessen University, Germany.

5. References