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Introduction

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Dealey Plaza in the historic West End district of downtown Dallas, Texas

The assassination site; the mark on the road where John F. Kennedy was hit.

The Texas School Book Depository; at the rooftop of that building, the assassin shot at JFK.
Background

Plasma potential $V_p$ • • • Decision of electron temperature, ion accelerations between bulk plasma and sheaths

Measurement of $V_p$ → **Probe diagnostics**

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Disadvantage</th>
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<td>Simplicity</td>
<td>Plasma perturbations</td>
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Noncontact measurement of $V_p$ → **Measurement of electrode voltage**

Electrode voltage = DC self bias voltage ($V_{dc}$) + RF voltage ($V_{rf}$)

($V_{dc}$ • • • Decision of ion energy in the sheaths)
Relation between $V_{dc}$ and $V_p$

Plasma Equivalent Circuits

(a) DC or low frequency plasma, (b) High frequency plasma, and (c) Simplification of (b) by considering $R_p << R_{S1}, R_{S2}$, and most ions moving to electrodes

Potential diagram of $V_p$ and $V_{dc}$\[^1\]

\[ \frac{V_1}{V_2} = \left( \frac{A_2}{A_1} \right)^a \quad (a \leq 2.5) \quad (1) \]

Substituting $V_1 = V_p$, $V_2 = V_p - V_{dc}$ in the equation (1) and arranging, we obtain

\[ V_p = \frac{\left( \frac{A_2}{A_1} \right)^a}{\left( \frac{A_2}{A_1} \right)^a - 1} V_{dc} \quad (2) \]

\[^1\] ttp://timedomaincvd.com/CVD_Fundamentals/plasmas/capacitive_plasma.html
\[^2\] Principles of Plasma Discharges and Materials Processing
Relation between electrode voltage and $V_p$

Experimental\[^3\]

\[ R = \frac{A_2}{A_1} \]

FIG. 3. Approximate target and plasma voltage waveforms in a glow discharge with grounded walls ($R$ is the ratio of target area to wall area).

We can find more accurate $V_p$ by comparing one calculated from $V_{dc}$ with one obtained from electrode voltage waveforms.

\[ V_1 = V_p, \quad V_2 = V_p - V_t \]

\[ \frac{V_1}{V_2} = \left( \frac{A_2}{A_1} \right)^a \]

(0.98 < $a$ < 1.4 when 0.09 < $A_2/A_1$ < 0.29.)

Objective

- \(V_{dc}\) measurements
  - Construction of a circuit to measure DC component.
  - Dependence of \(V_{dc}\) as a function of the electrode position.
  - \(V_p\) calculation from outputs

- \(V_{rf}\) measurements
  - Construction of a voltage divider circuit
  - Dependence of \(V_p\) as a function of the electrode position.
Experimental

Liquid injection plasma system

Ar gas flow rate : 20 sccm
RF power: 1 - 20 W  Gas pressure : 16 Pa

\( h \) (the electrode position) : 0, 2.5, 5.0 cm

\( A_2/A_1 : 0.017 \ (h = 0 \ \text{cm}), \ 0.015 \ (h = 2.5, 5.0 \ \text{cm}) \)

\( A_1 \) : Area of the grounded chamber  
\( A_2 \) : Area of the energized electrode
Dependence of $V_{dc}$ on the electrode position

Circuit diagram to measure DC component

- Increase in $|V_{dc}| \rightarrow$ Increase in discharge voltage
- Decrease slightly in $|V_{dc}|$ with changing $h$
**V_p calculation with V_{dc}**

\[
\frac{V_1}{V_2} = \frac{C_{sh2}}{C_{sh1}} = \frac{A_2 s_1}{A_1 s_2}
\]

- $C_{sh1}, C_{sh2}$: sheath capacitances
- $s_1, s_2$: sheath thicknesses

In RF plasma, ion sheaths can’t follow the RF voltage.

→ $s_1/s_2 \sim 1$ (also as reported\textsuperscript{[3]})

→ In the equation (2), it is assumed that $a = 1$.

\[
V_p = \frac{A_2}{A_1 A_2 - 1} V_{dc} \quad (2')
\]

Decreases in averaged $V_p$ and $|V_{dc}|$ with changing $h$

→ Decrease in the electron temperature

Measurement of electrode voltage

Methods of measuring electrode voltage \((V_{rf} + V_{dc})\)

High voltage probe
Voltage divider

RF high voltage have to be divided into measurable voltages.
→ Voltage divider circuit

Equivalent circuit of general electric element for RF voltage

ex. \(R=1\ \text{MΩ}, L=0.1\ \text{μH}, C=0.1\ \text{pF}\)

\(f=10\ \text{Hz}\)
→ \(j\omega L << R, 1/j\omega C >> R \rightarrow Z \sim R\)

\(f=10\ \text{MHz}\)
→ \(j\omega L << R, 1/j\omega C << R \rightarrow Z \sim 1/j\omega C\)

For RF voltage, influences of inductance and capacitance are critical.
Evaluation of $V_p$ by measuring $V_{rf}$

RF voltage divider circuit

Theoretical

$V_{rf} \approx 1114 \times V_O$

$V_{rf}$: amplitude of RF discharge voltage
$V_O$: amplitude of measured RF voltage

Actual measurement

$V_{rf} \approx 71 \times V_O$

Incorrect values on capacitors and inductors.

The behaviors of $V_p$ were obviously incorrect.

Induced voltages or RF noises in MN $\rightarrow$ Inaccurate $V_{rf}$
Summary

$V_p$ in the RF capacitively coupled plasma was determined by measuring $V_{dc}$ with changing the electrode position.

- Decreases in averaged $V_p$ and $|V_{dc}|$ with changing $h$
  \[ \rightarrow \text{Decrease in the electron temperature} \]

$V_p$ was determined by measuring $V_{rf}$ with changing the electrode position by using a voltage divider circuit.

- Correct $V_p$ was hardly obtained because of induced voltages or RF noises.

Future works

- More accurate measurements of $V_{rf}$ by getting circuit lines as short as possible.
- Identification of frequency dependencies of electric elements.
- Comparisons of electron density, electron temperature, and $V_p$ with other techniques.
Thank you for your kind help and support!