Plasma Potential Determination in RF Capacitively Coupled Plasma by Measuring Electrode Voltage.

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Introduction

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Introduction

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**

Advantage	Disadvantage
Simplicity	Plasma perturbations

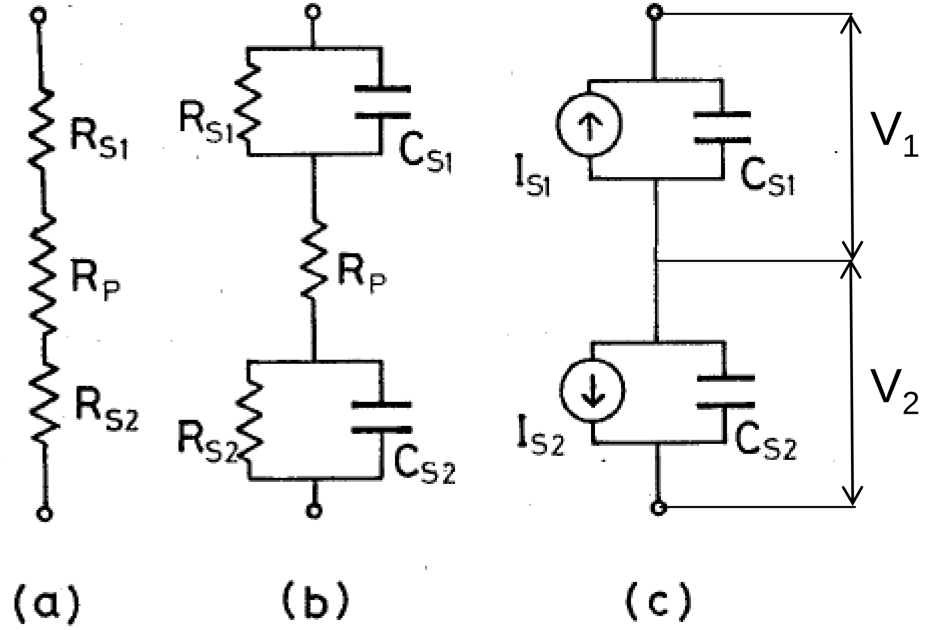
Noncontact measurement of V_p
→ **Measurement of electrode voltage**

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

(V_{dc} ･･･ Decision of ion energy in the sheaths)

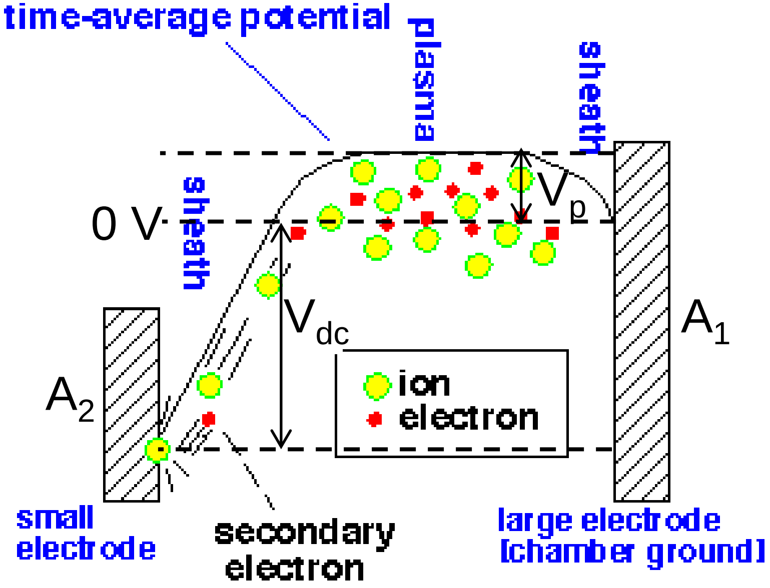
Relation between V_{dc} and V_p

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

$V_1 = V_p$, $V_2 = V_p - V_{dc}$



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

$$\frac{V_1}{V_2} = \left(\frac{A_2}{A_1}\right)^a \quad (a \leq 2.5)^{[2]} \quad (1)$$

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

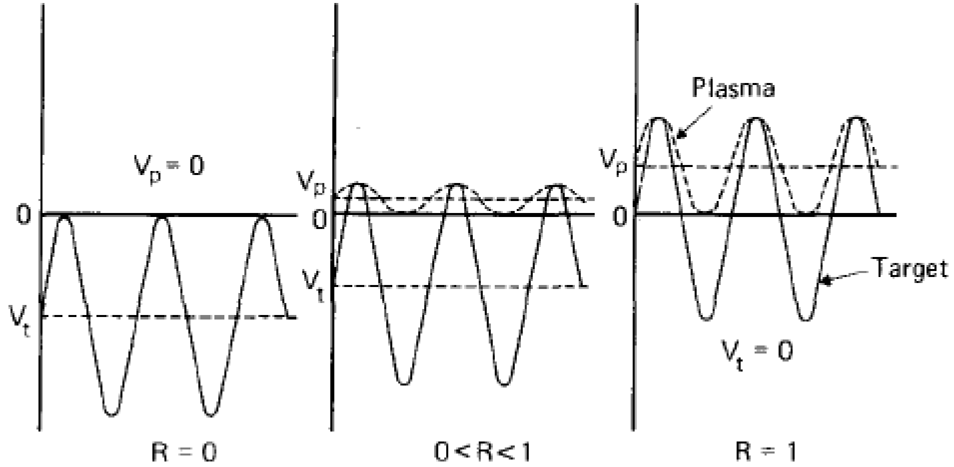
$$V_p = \frac{\left(\frac{A_2}{A_1}\right)^a}{\left(\frac{A_2}{A_1}\right)^a - 1} V_{dc} \quad (2)$$

[1] ttp://timedomaincvd.com/CVD_Fundamentals/plasmas/capacitive_plasma.html

[2] Principles of Plasma Discharges and Materials Processing

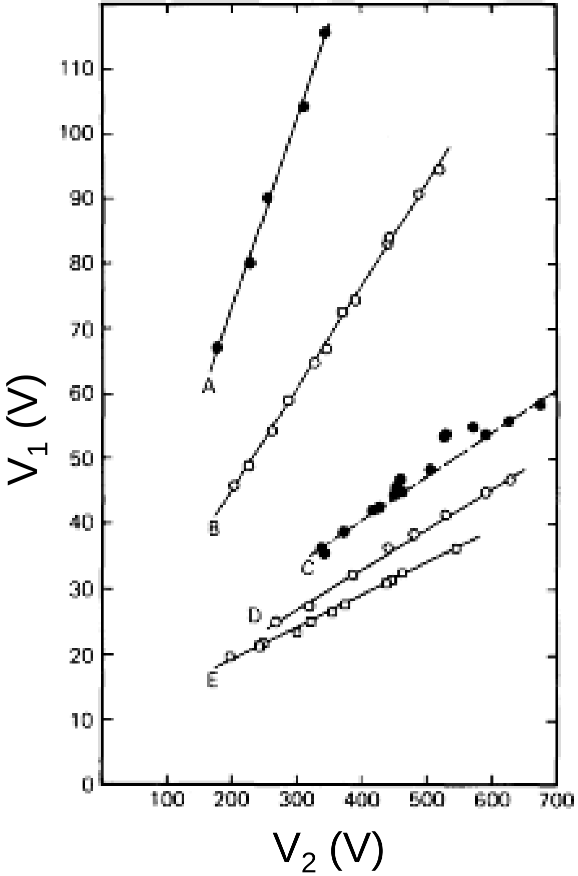
Relation between electrode voltage and V_p

Experimental[3]



$R = A_2/A_1$

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.

$V_1 = V_p$, $V_2 = V_p - V_t$

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

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

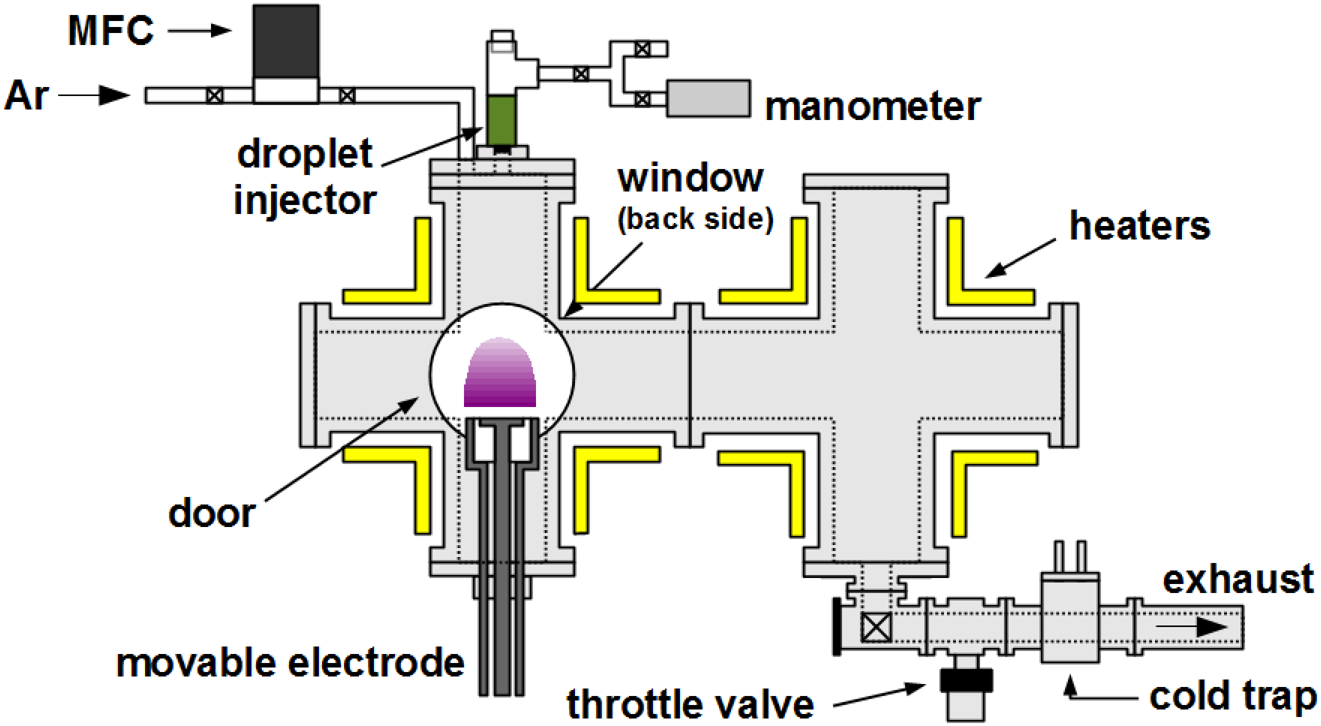
[3] J. W. Coburn and K. Eric, J. Appl. Phys. **43** 4965 (1972).

Objective

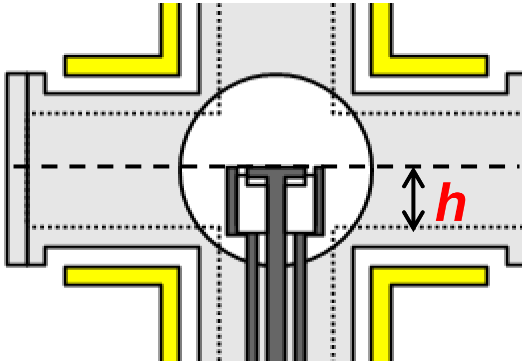
- V_{dc} measurements
  - Construction of a circuit to measure DC component.
  - Dependence of V_{dc} as a function of the electrode position.
  - V_p calculation from outputs

- 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



<u>Ar gas flow rate</u> : 20 sccm

<u>RF power</u>: 1 - 20 W <u>Gas pressure</u> : 16 Pa

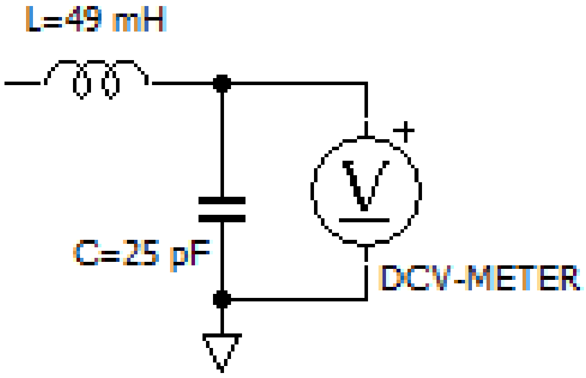
<u>*h* (the electrode position)</u> : 0, 2.5, 5.0 cm

<u>A_2/A_1</u> : 0.017 (*h* = 0 cm), 0.015 (*h* = 2.5, 5.0 cm)

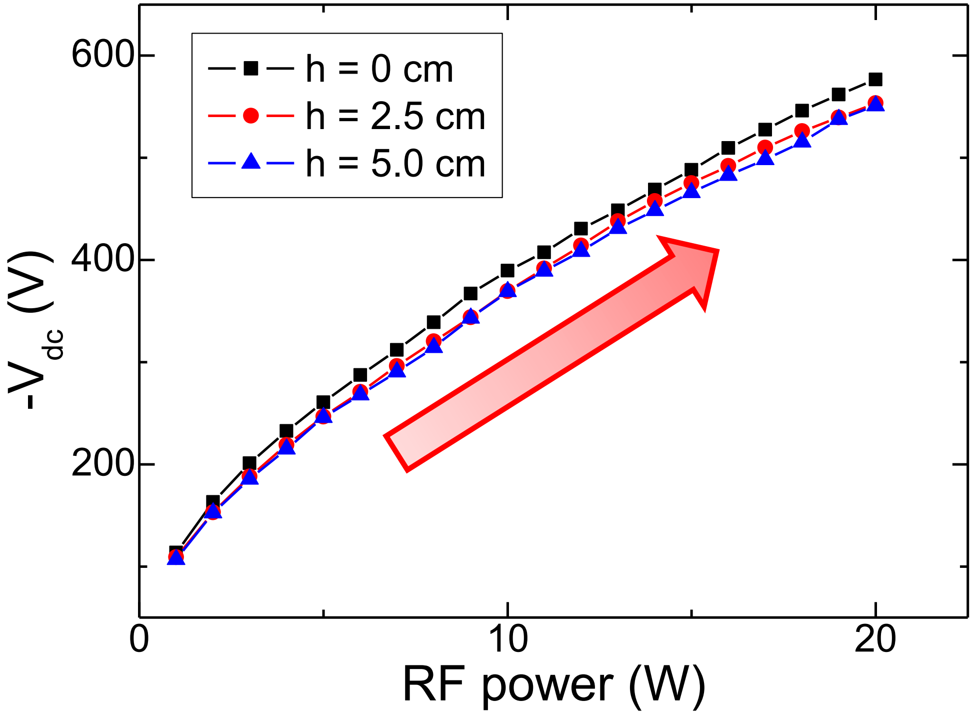
A_1 : Area of the grounded chamber

A_2 : Area of the energized electrode

Dependence of V_{dc} on the electrode position



Circuit diagram to measure DC component



Dependence of V_{dc} on *h* as a function of RF power

- Increase in $|V_{dc}|$ → Increase in discharge voltage
- Decrease slightly in $|V_{dc}|$ with changing *h*

V_p calculation with V_{dc}

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

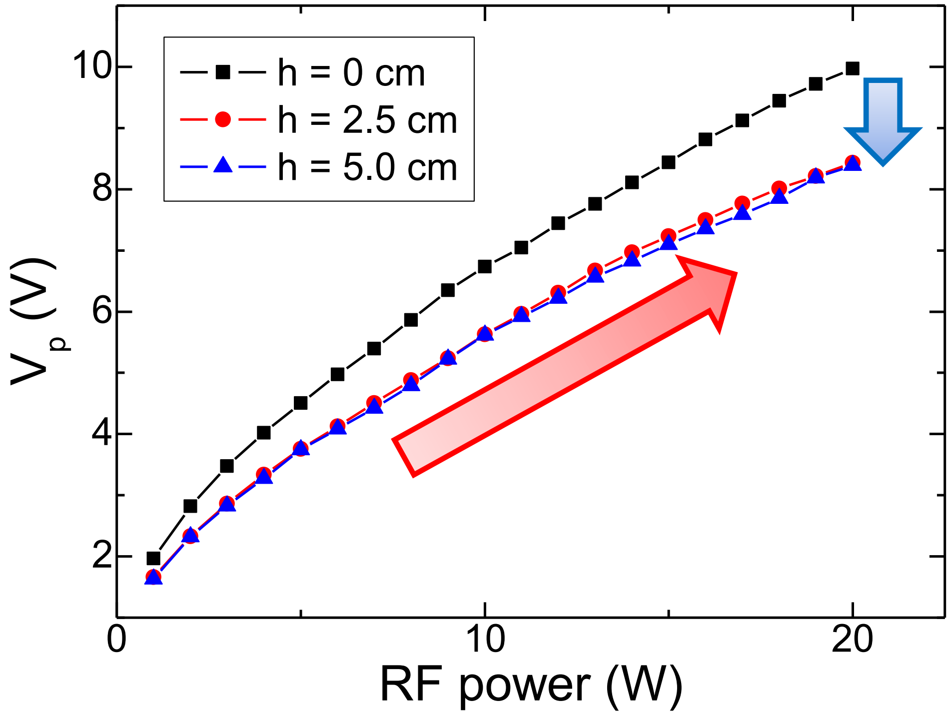
C_{sh1}, C_{sh2} : sheath capacitances
s_1, s_2 : sheath thicknesses

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

→ s_1/s_2 ~ 1 (also as reported[3])

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

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



Dependence of V_p on *h* as a function of RF power

Decreases in averaged V_p and $|V_{dc}|$ with changing *h*
→ Decrease in the electron temperature

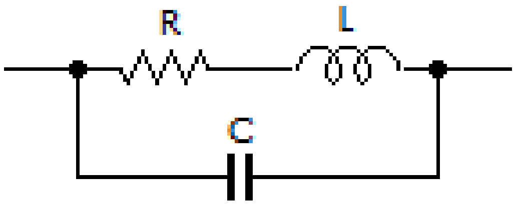
[3] J. W. Coburn and K. Eric, J. Appl. Phys. **43** 4965 (1972).

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

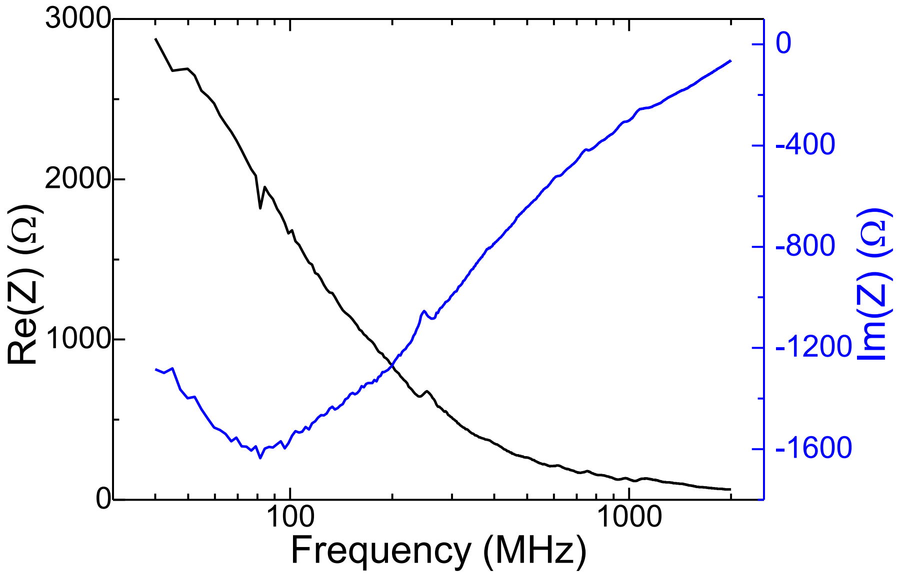
ex. R=1 MΩ, L=0.1 μH, C=0.1 pF

f=10 Hz

→ jωL << R, 1/jωC >> R → Z~R

f=10 MHz

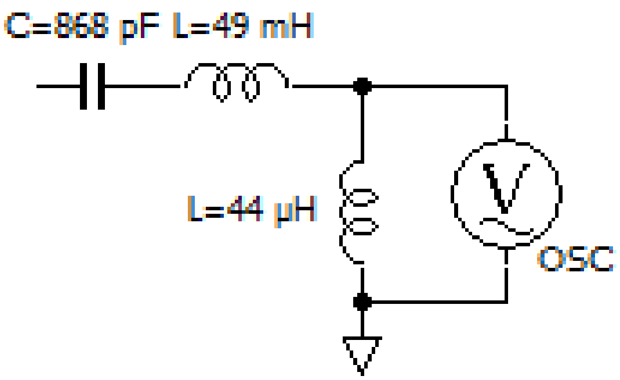
→ jωL << R, 1/jωC << R → Z~1/jωC



Dependence of 5.4 MΩ resistor on frequency

For RF voltage, influences of inductance and capacitance are critical.

Evaluation of V_p by measuring V_{rf}



RF voltage divider circuit

<u>Theoretical</u>

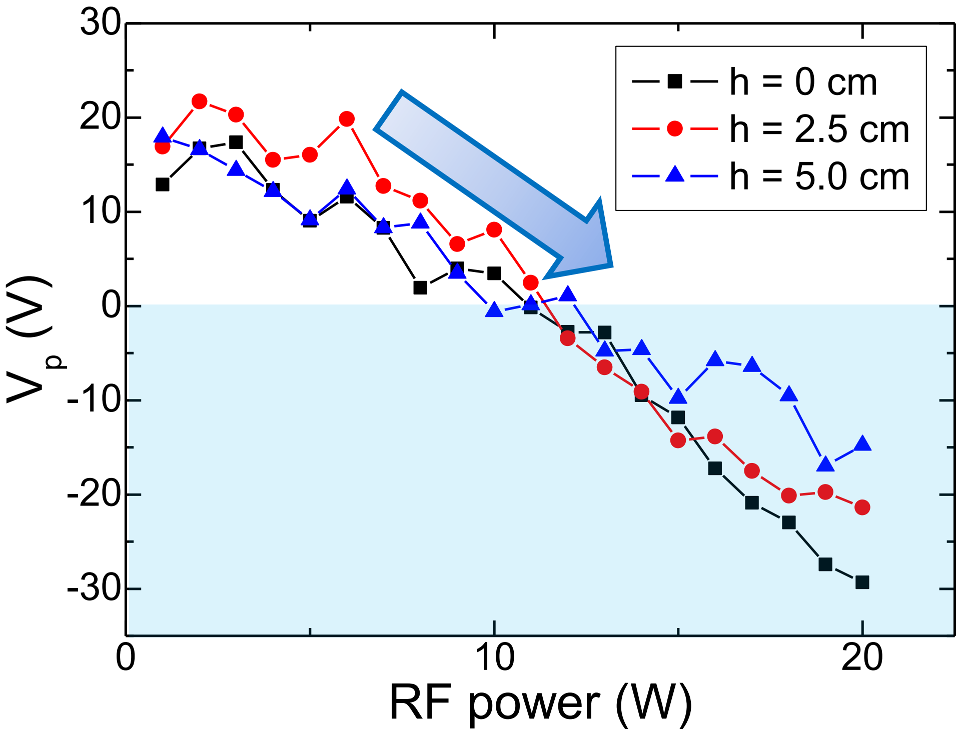
$$V_{rf} \approx 1114 * V_O$$

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

<u>Actual measurement</u>

$$\boldsymbol{V_{rf} \approx 71 * V_O}$$

Incorrect values on capacitors and inductors.



Dependence of V_p on *h* as a function of RF power

The behaviors of V_p were obviously incorrect.

Induced voltages or RF noises in MN
→ 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
  → 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!