Measurement of Plasma Density of Fluorescent Lamp using 94-GHz Interferometer System*

정진현, 배영순, 이한구, 조무현, 남궁 원

Pohang University of Science and Technology

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Abstract

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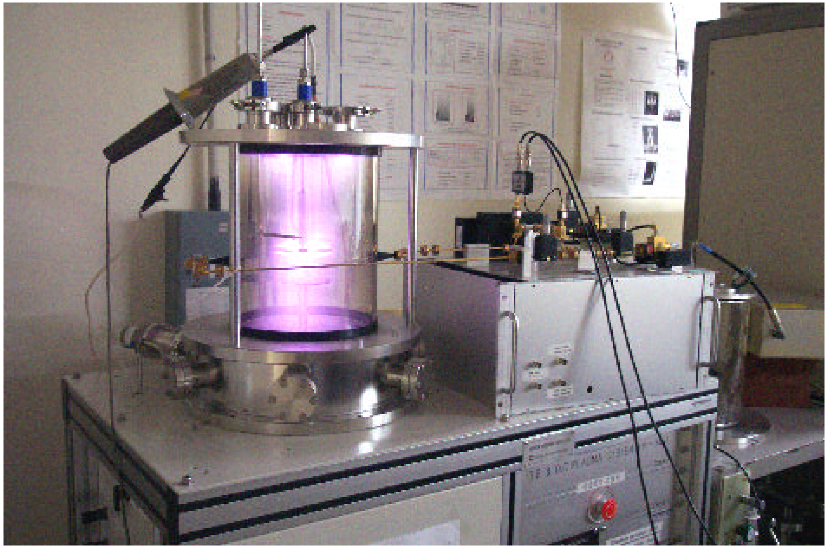
- The microwave interferometer system is a well-established technique for measurements of line-integrated plasma densities without perturbing plasma. The plasma density of a fluorescent lamp is measured by a 94-GHz interferometer system. We used 94- and 94.2-GHz Gunn oscillators, and a balanced mixer with down conversion. We observed a density modulation of 60 Hz in the output voltage of the phase comparator. The results are compared with the data measured with the network analyzer considering collisional effect. The line-integrated plasma density of the fluorescent lamp was about $5 \times 10^{11}/cm^{-3}$.

* Supported by KSTAR Project at KBSI.

Schematics of Microwave Interferometers

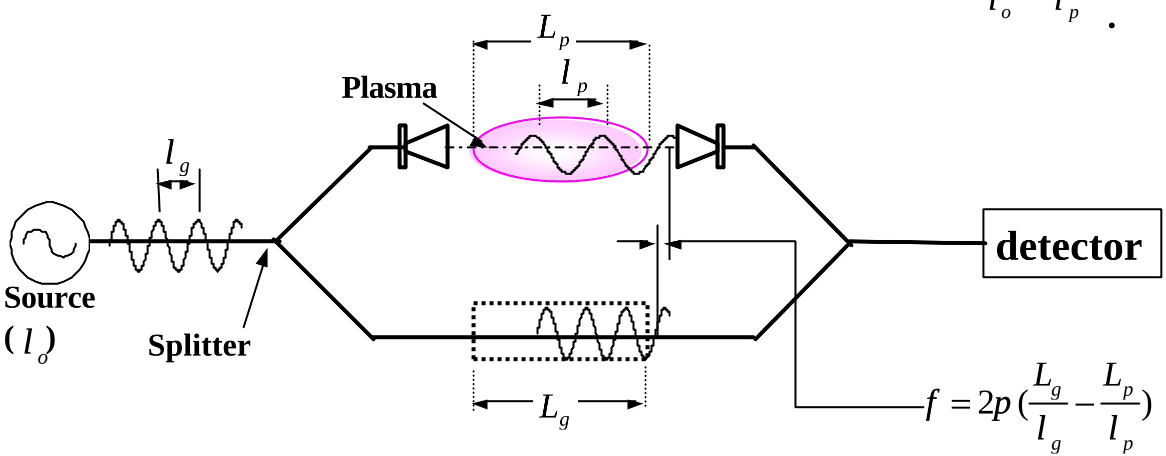


The wavelength in the plasma is always longer than in vacuum

$$l_p = l_o(1-\frac{w_p^2}{w^2})^{-1/2} .$$

The phase difference between when there is a plasma and when not is then

$$\Delta f = 2p L_p(\frac{1}{l_o} - \frac{1}{l_p}) .$$



Microwave Interferometers *(Heterodyne type)*

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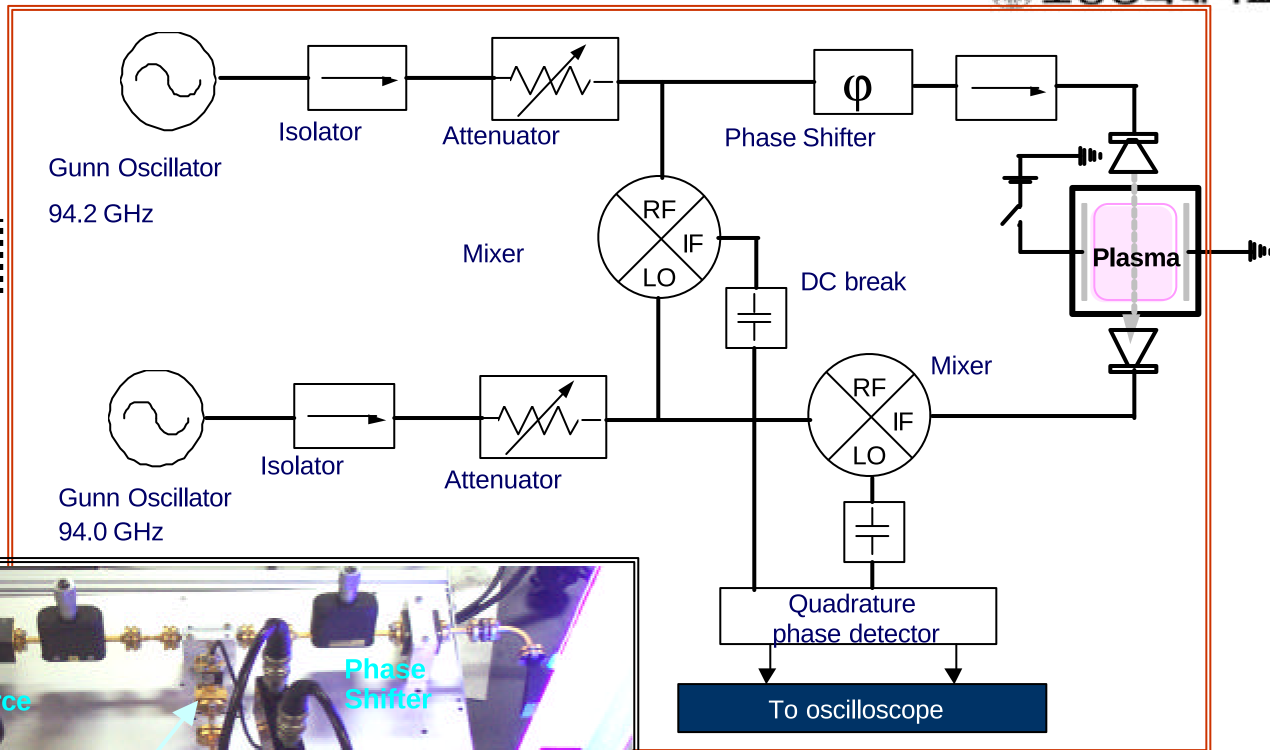
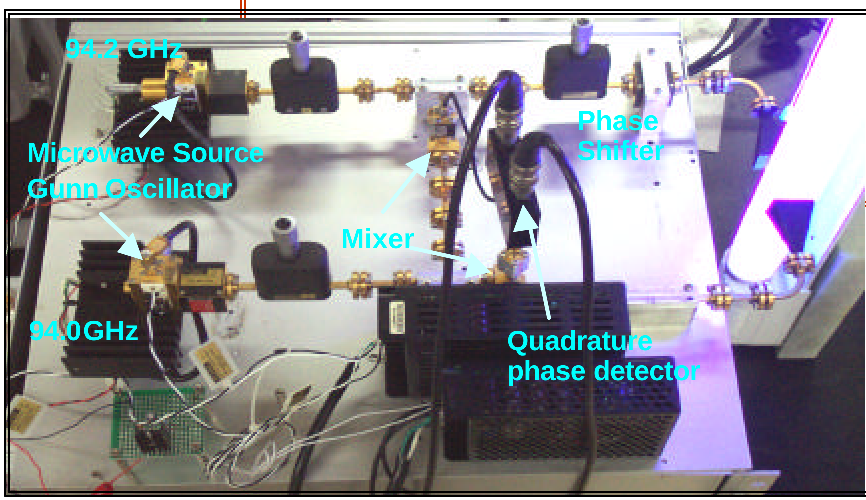
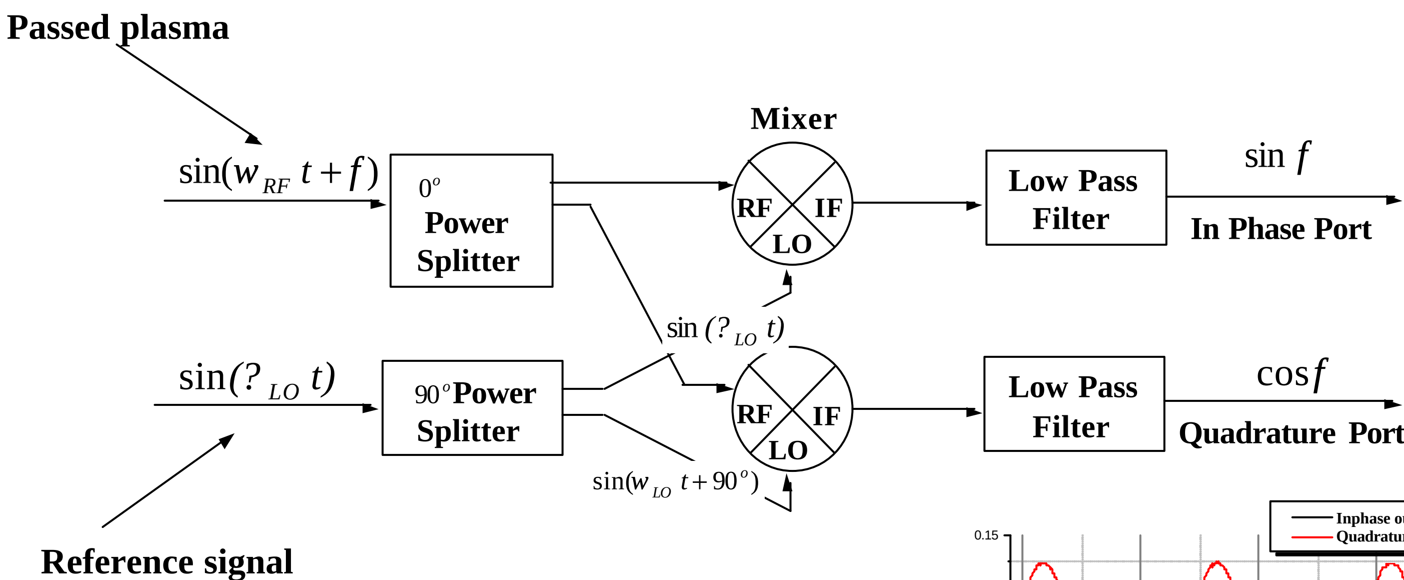
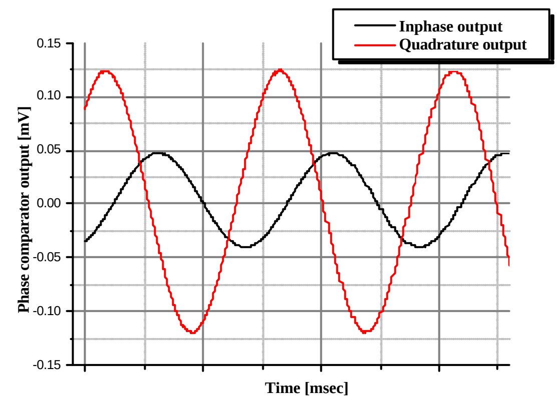
WR10 waveguide





Quadrature Phase Detector (Phase Comparator)





Plasma density calculation

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- **Because of the non-linearity of the phase quadrature phase detector, the digitized value (I and Q) should be corrected before the phase shift calculation.**

$$I = K_I \sin[2p(f_{RF} - f_{LO})t] + V_{OI}$$
$$Q = K_Q \cos[2p(f_{RF} - f_{LO})t + \varphi_o] + V_{OQ}$$

where, $2\pi(f_{RF} - f_{LO})$ is $\varphi(t)$,
K_I, K_Q are output amplitudes ,
V_{OI} and V_{OQ} are dc - offset,
and φ_o is phase balance.

$$\varphi(t) = tan^{-1}\left(\frac{cos(\varphi_o)}{M + sin(\varphi_o)}\right) \quad \text{where, } M = \frac{Q - V_{OQ}}{I - V_{OI}} \frac{K_I}{K_Q}$$

- **Phase shift due to plasma**

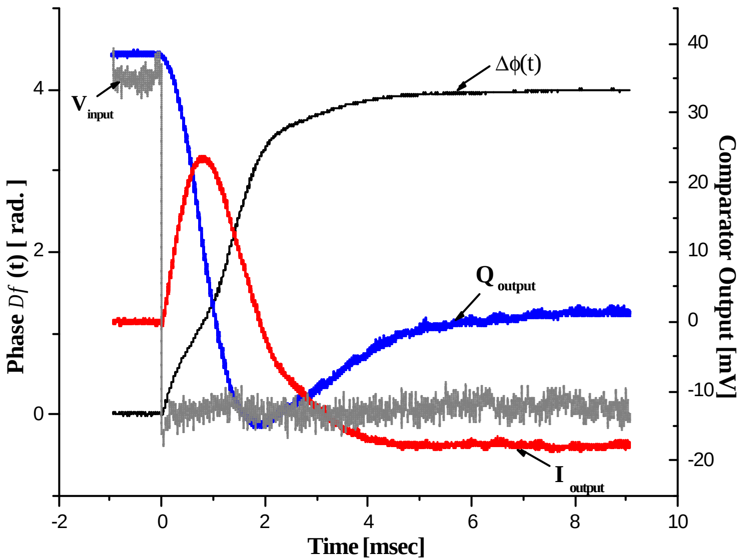
$$f(t) = \frac{?}{c}\int_{-a}^{+a}[1 - \frac{?_p^2}{?^2}]^{1/2}\, dr$$
$$\cong 8.42 \times 10^{-16} \frac{1}{f_o(GHz)} \int n_e(r,t)\, dr(m^{-3}), \text{ for } ?_p^2 \langle\langle ?^2 \quad \text{where, } f_o \text{ is } 94.2 \text{ GHz}$$

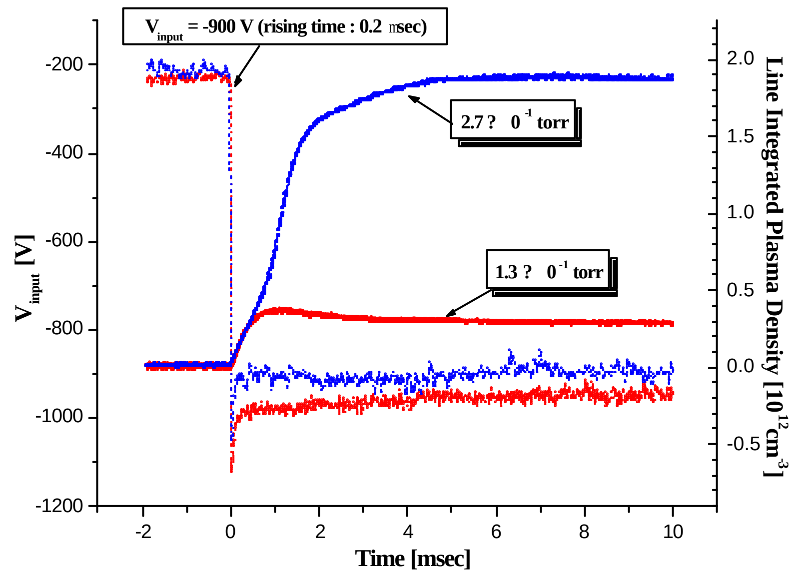
- **Therefore, the line-averaged electron density is**

$$< n(m^{-3}) >= \frac{1}{L} \times 1.18 \times 10^{15} f(GHz) \times \varphi(t)$$

Variation of Plasma density over the DC input

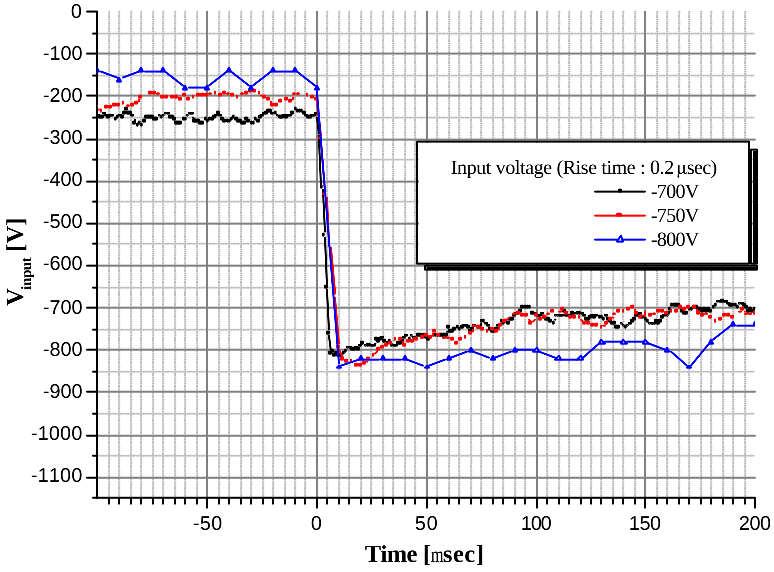
Case I : Variation of pressure

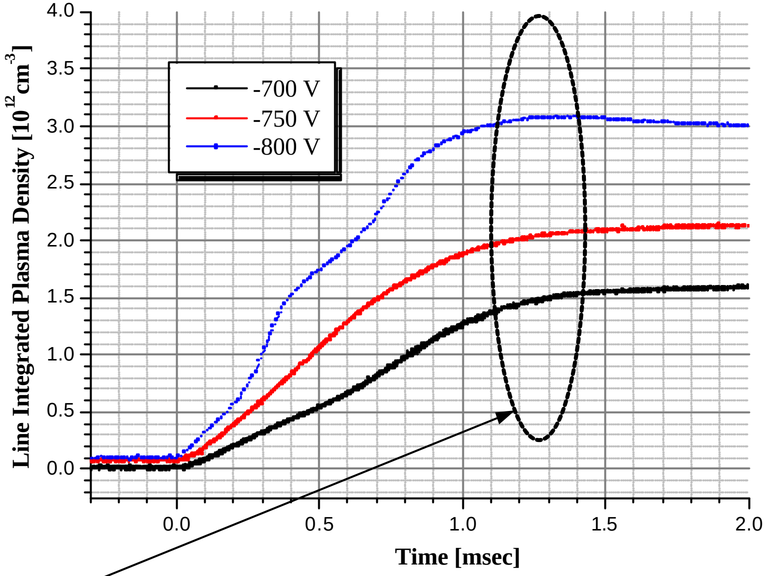




Variation of Plasma density over the DC input

Case II : Variation of voltage





The plasma density reaches a maximum almost the same time.

Variation of Plasma density over the DC input

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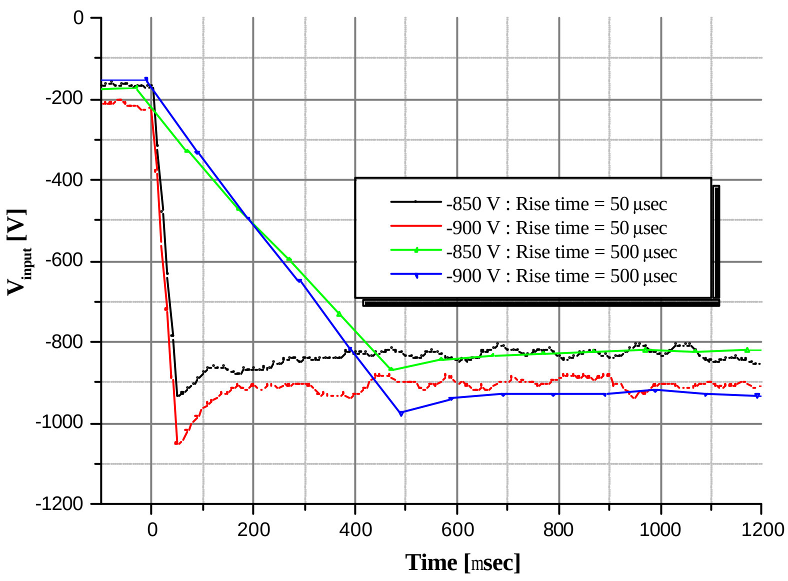
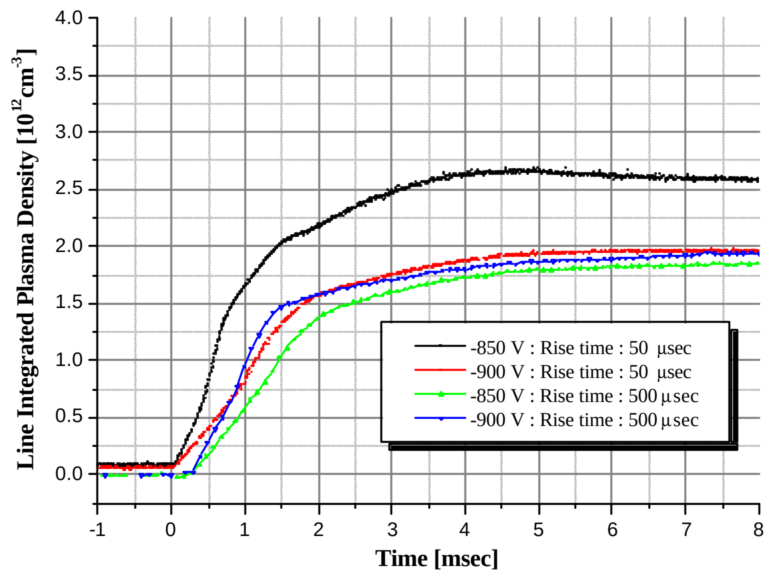
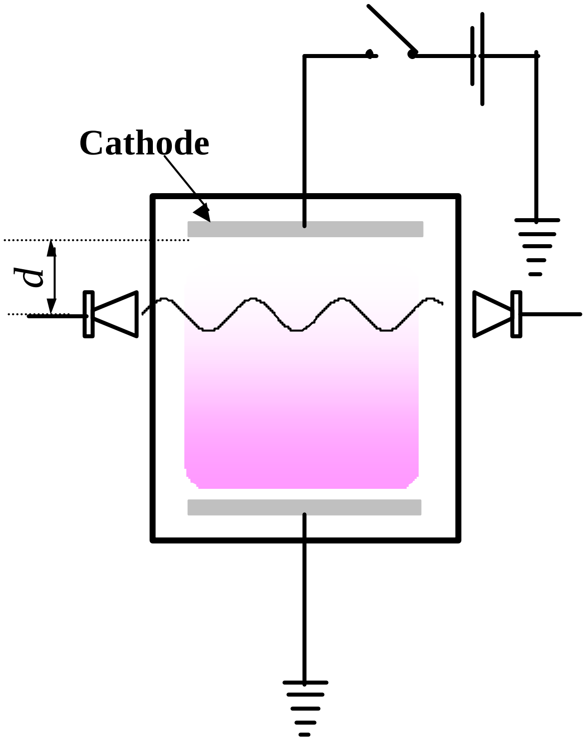
Case III : Variation of rising-time

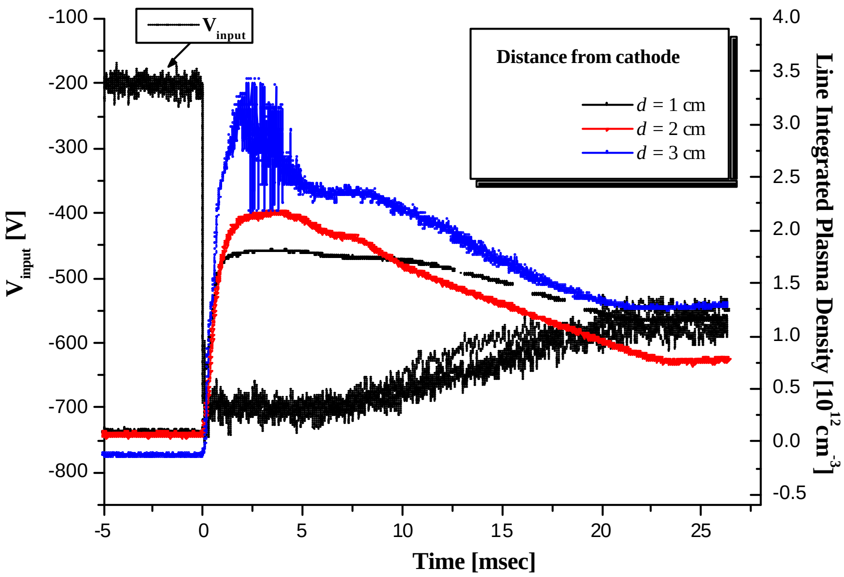




Variation of Plasma density over the DC input

Case IV : Variation of distance from the cathode





Measurement of Plasma Density of Fluorescent Lamp

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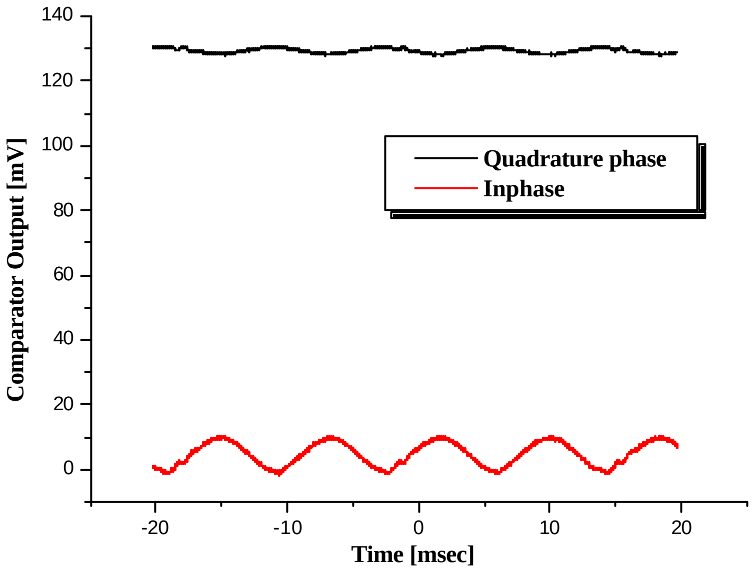

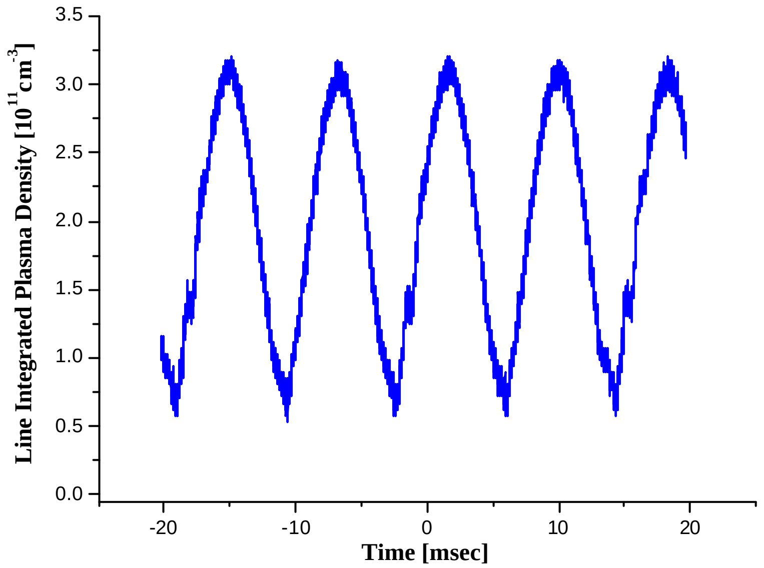

Conclusions

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We have studied the fundamental properties of the plasma generated from DC operation.

- At the beginning of the pulse, plasma density increase steadily, and after that, the density decreases as the charged particles are lost to the surrounding electrodes and recombine into neutrals.

- The time that plasma density reaches a maximum point is determined by pressure.

- The stable state of the plasma is determined by the pulse voltage and pressure (and will be determined by other parameters such as pulse width and duty cycle).

- The line-integrated plasma density of the fluorescent lamp was about $3 \times 10^{11}/cm^{-3}$.