Optical and Microwave Diagnostics in Atmospheric Pressure Plasma Jet

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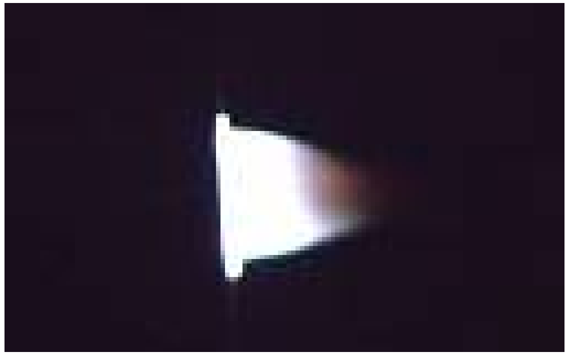
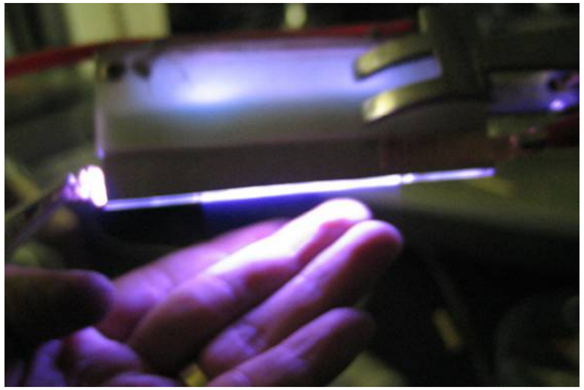
Introduction

➢ Atmospheric pressure plasma jet





– Characteristics –

- driven by RF (mainly 13.56 MHz)
- non-equilibrium, homogeneous discharge
- non thermal damage to material

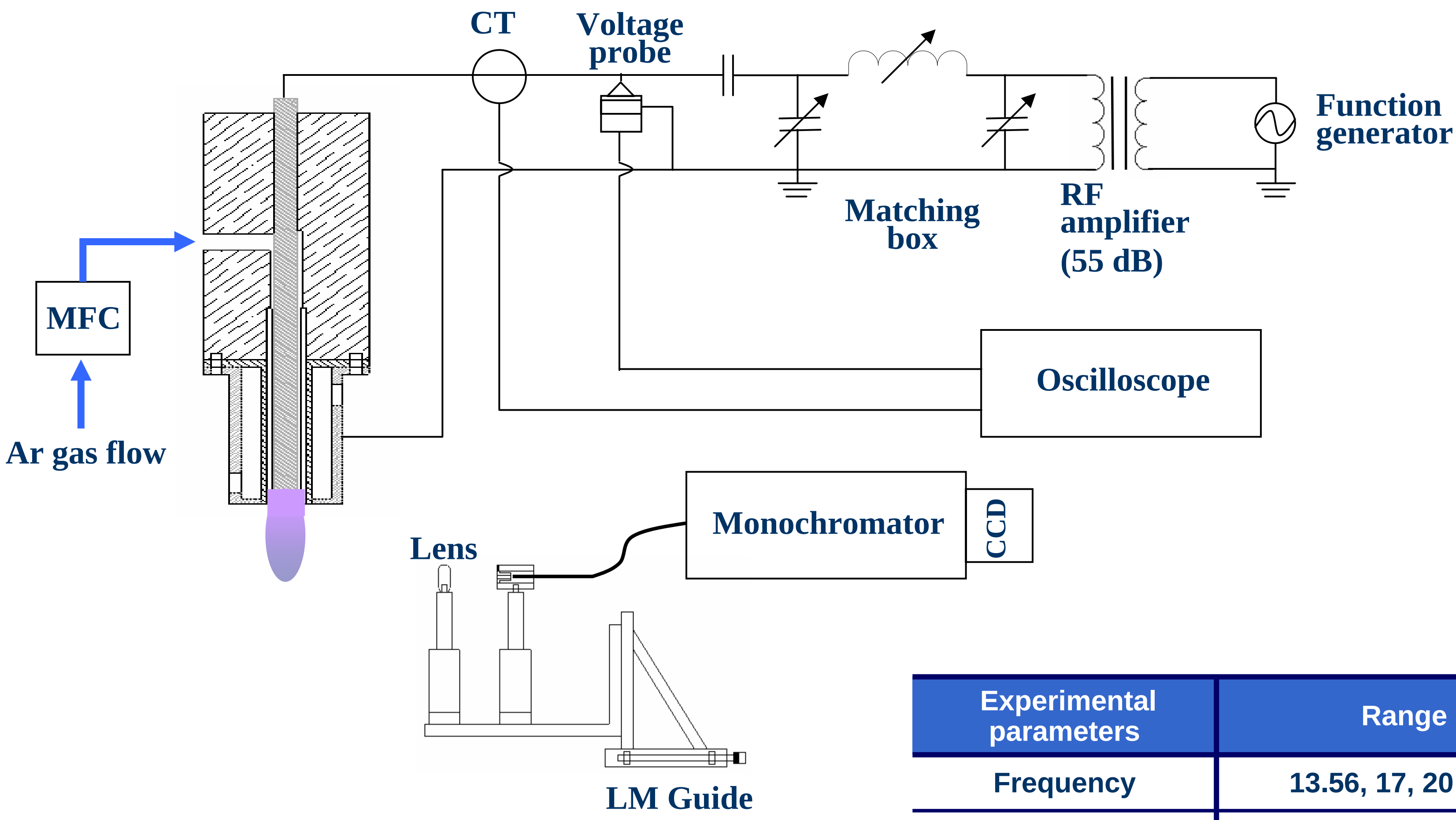
– Application –

- Etching : Polyimide, tungsten, tantalum, silicon-dioxide
- Deposition : SiO_2 film, TiO_2 film
- Decontamination of chemical and biological warfare agents : BG spore, plague, E coil

➢ Objective

- Vibrational and rotational temperature measurement analyzing optical emission spectrums.
- Electron density measurement using 94 GHz microwave interferometer system.

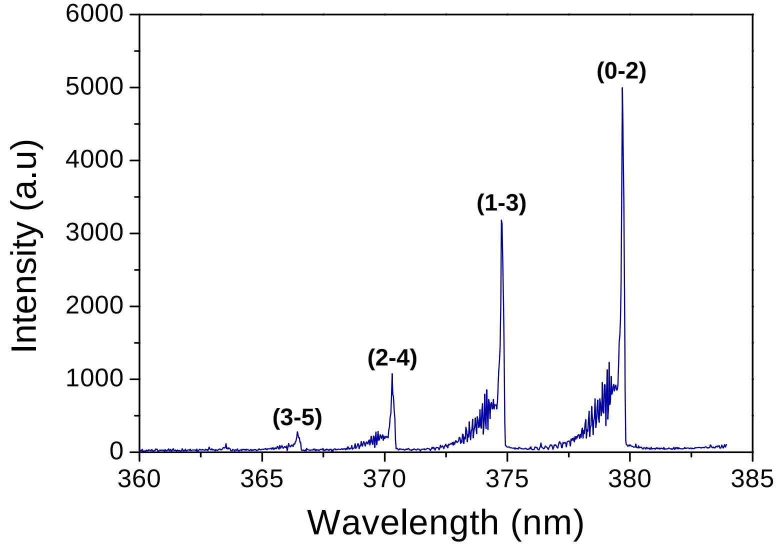
Experimental setup

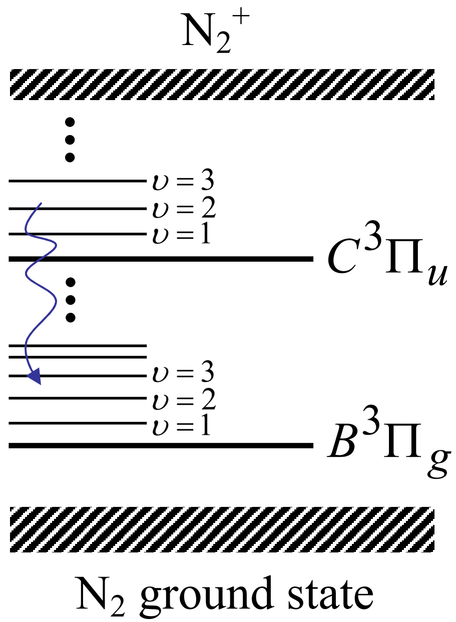


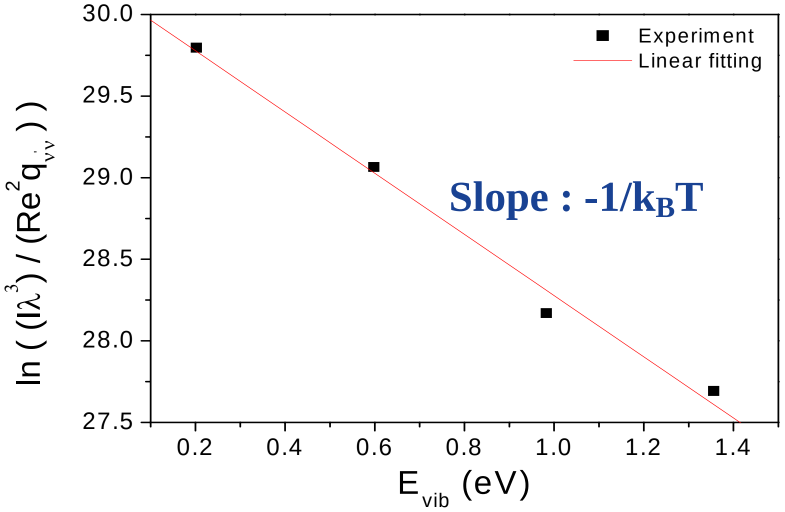
Experimental parameters	Range
Frequency	13.56, 17, 20 MHz
V_{rms}	200 ~ 400
Input power	10 ~ 70 W
Working gas	Ar
Flow rate	20 LPM

Vibrational temperature

$$N_2(C^3\Pi_u,\upsilon) \rightarrow N_2(B^3\Pi_g,\upsilon') + h\nu(2^+)$$





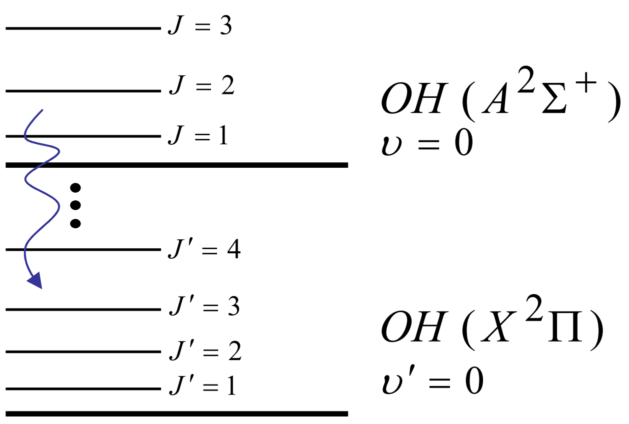


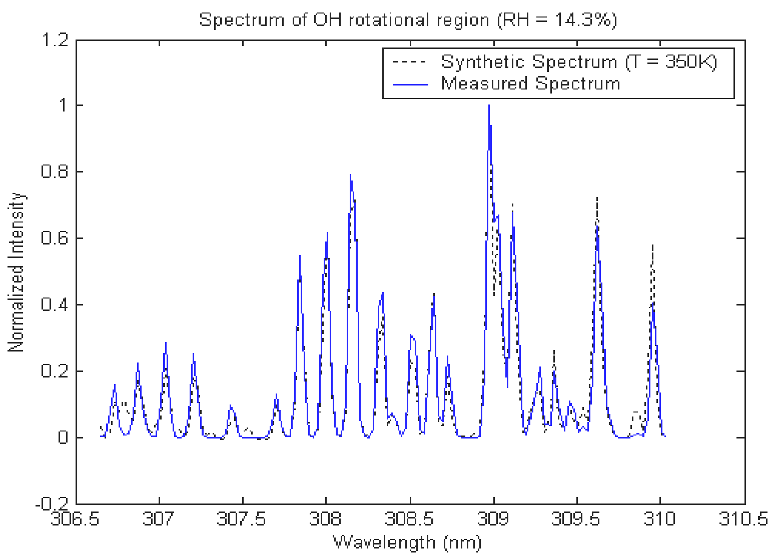
$$I_{\upsilon'\upsilon} = N_o R_e^{\,2} \frac{q_{\upsilon'\upsilon}}{\lambda^3} \exp\left(-\frac{E_{vib}}{k_B T_{vib}}\right)$$

$$\ln\left(\frac{I_{\upsilon'\upsilon}\,\lambda^3}{R_e^{\,2}\, q_{\upsilon'\upsilon}}\right) = -\frac{E_{vib}}{k_B T_{vib}} + C$$

Rotational temperature

$OH(A^2\Sigma, v=0 \rightarrow X^2\Pi, v'=0)$ band





- Synthetic spectrum method -

Modify ref. data for arbitrary temperature,

$$\frac{I_{JJ'}}{I_{JJ'}^{ref}} = \frac{Q(T^{ref})}{Q(T)} \exp\left(-\frac{E_J (T^{ref} - T)}{T^{ref} T} \right)$$

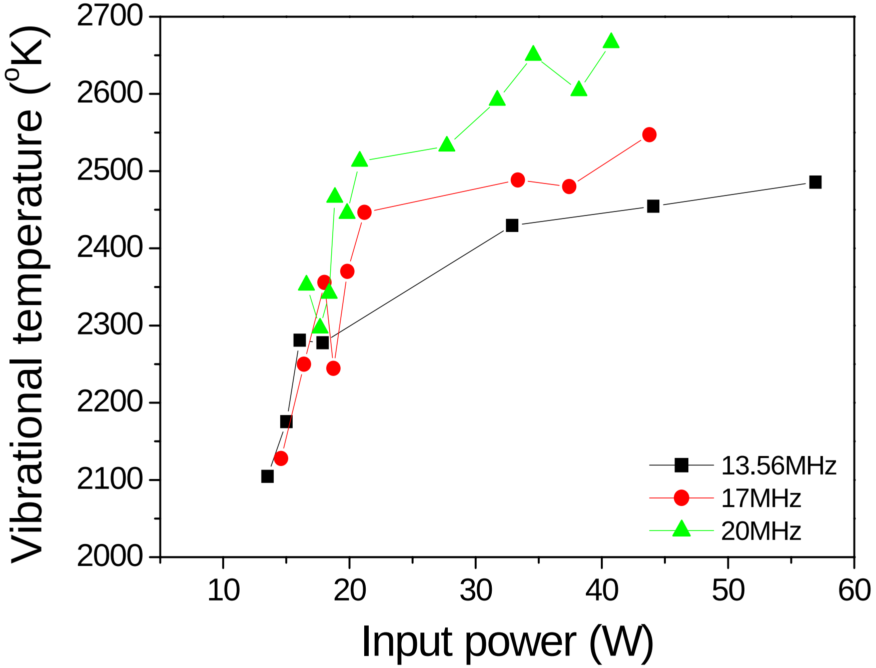
Considering instrument broadening,

$$I'_{JJ'}(\lambda) = \frac{I_{JJ'}}{\Delta\sqrt{\pi}} \exp\left(-\frac{(\lambda - \lambda_0)^2}{\Delta^2} \right)$$

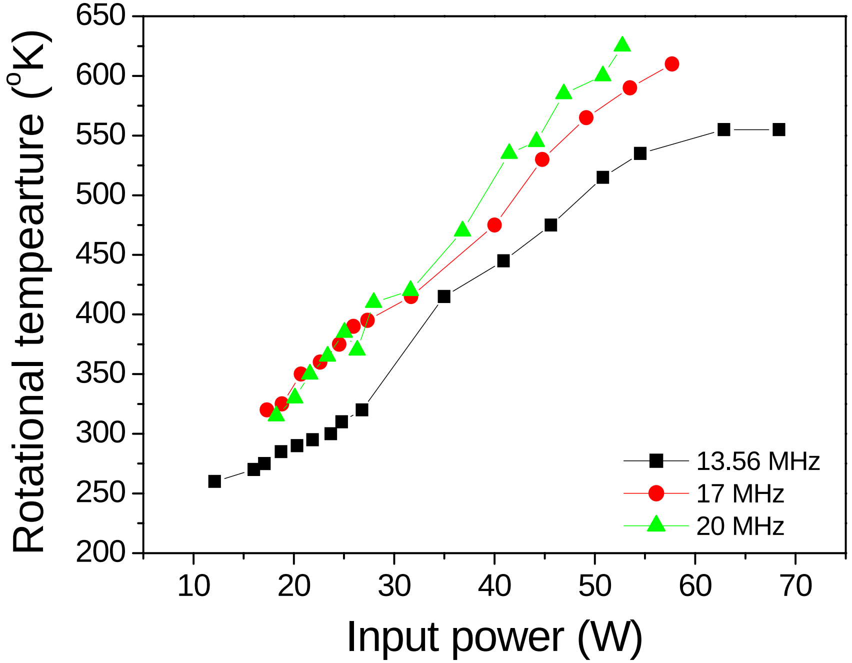
Compare measured spectrum with synthetic spectrum of various temperatures.

Plasma temperature

➢ vibrational temperature



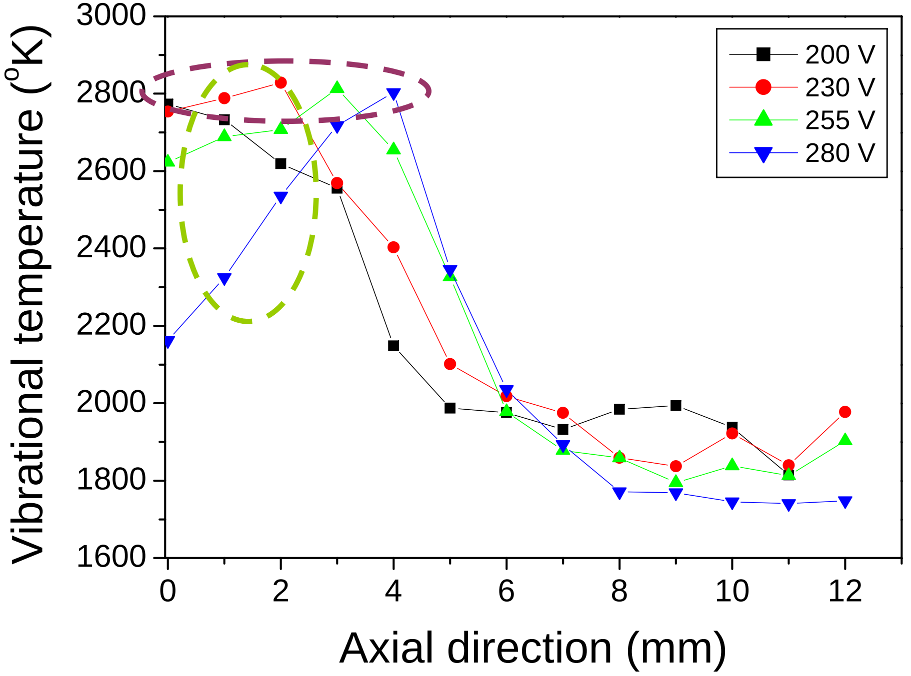
➢ Rotational temperature



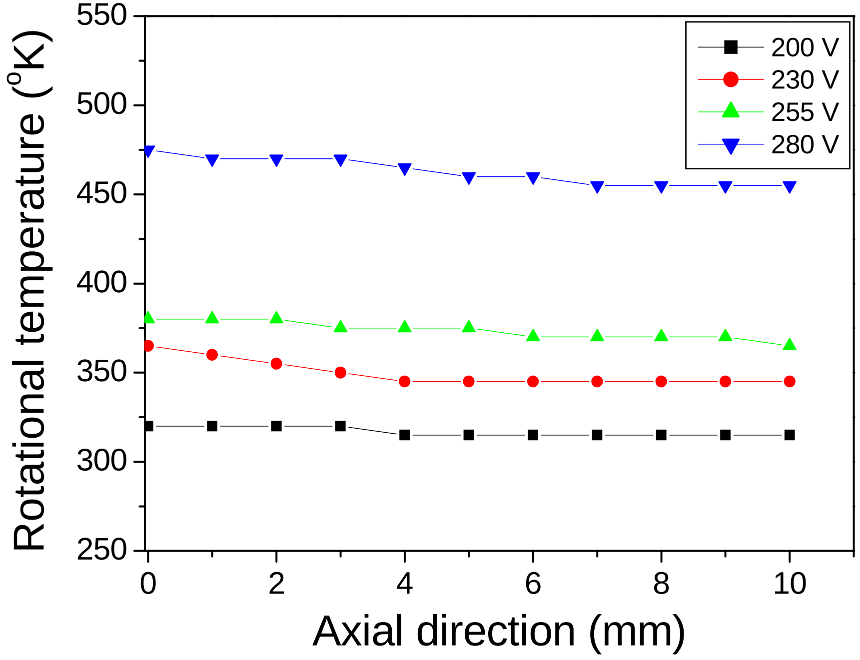
- In our experimental range, vibrational and rotational temperature increase as increasing input power.
- At the same input power, both vibrational and rotational temperature increase as increasing RF frequency.

Spatially resolved plasma temperature (axial direction)

➢ vibrational temperature

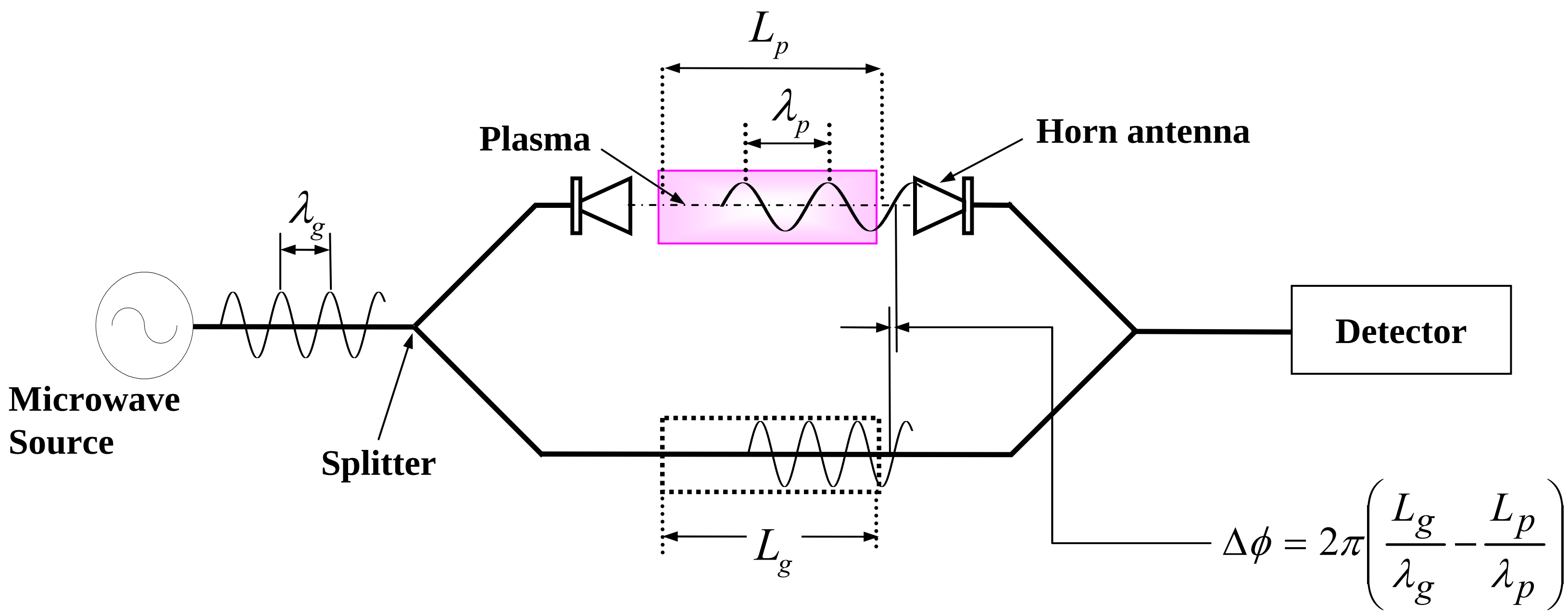


➢ Rotational temperature



- As increasing the input voltage, maximum T_{vib} position is shifted to the outer region.
- In the region of the RF electrode, plasma density increase as increasing the input voltage.
- Plasma jet show the good thermal conductivity

Principle of microwave interferometer



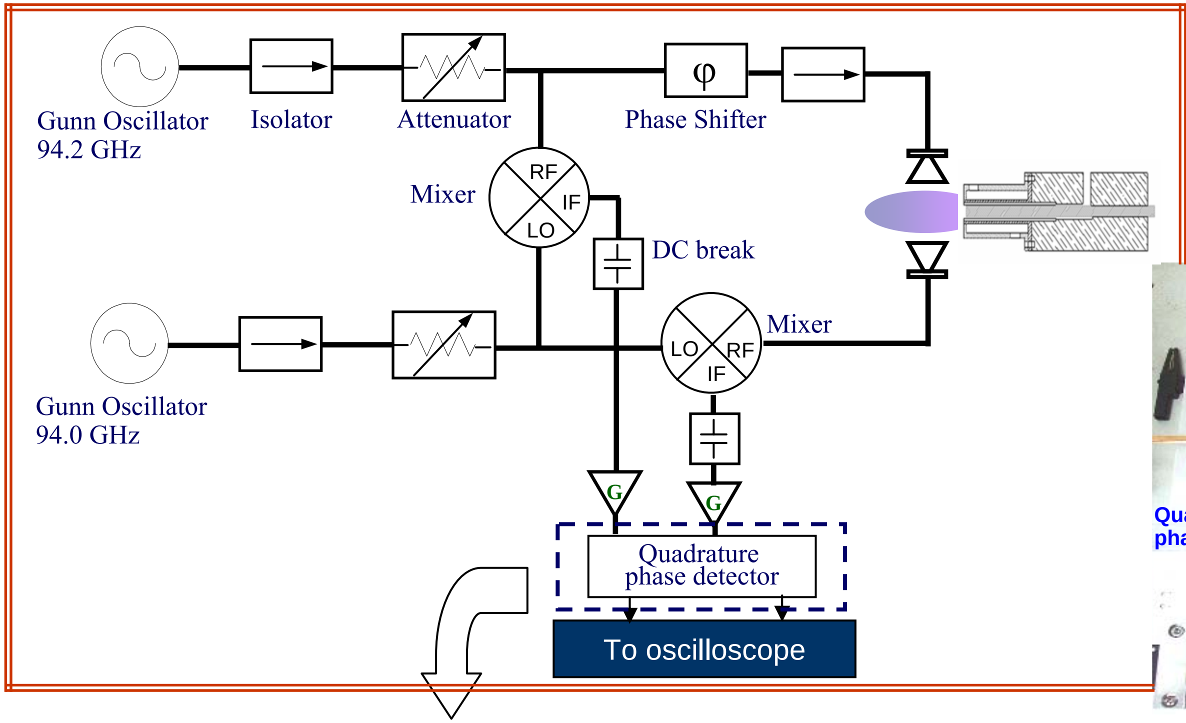
- Phase shift due to plasma : $\Delta\phi = 2\pi L_p\left(\frac{1}{\lambda_o} - \frac{1}{\lambda_p}\right)$

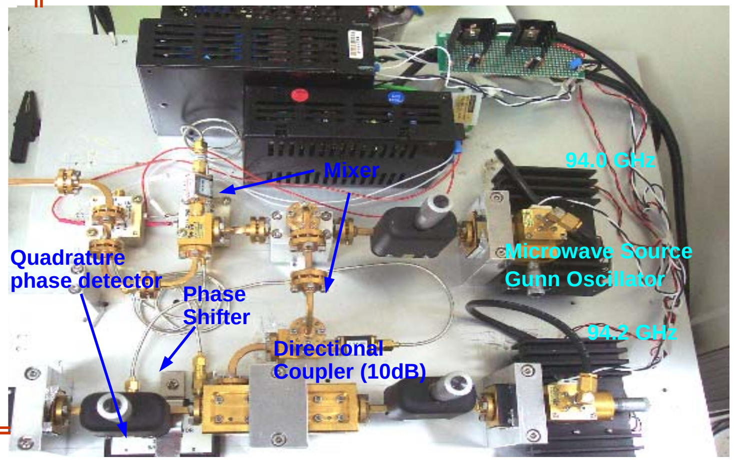
$$\varphi(t) = \frac{\omega}{c}\int_{-a}^{+a}\left(1-\left[1-\frac{\omega_p^2}{\omega^2}\right]^{1/2}\right)dr$$

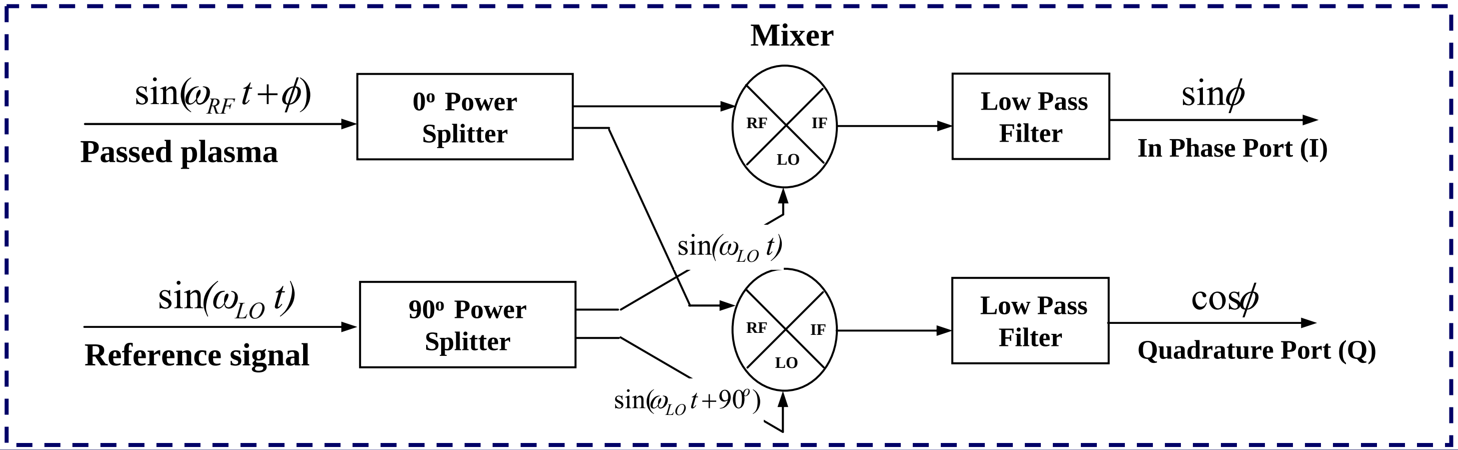
$$\cong 8.42\times10^{-16}\frac{1}{f_o(\text{GHz})}\int n_e(r,t)\,dr(m^{-3}),\ \text{for}\ \omega_p^2 \langle\langle \omega^2 \quad \text{where, } f_o\ \textit{is}\ 94.2\ \textit{GHz}$$

- Therefore, the line-averaged electron density is $<n(m^{-3})>=\frac{1}{L}\times 1.18\times10^{15}\,f(\text{GHz})\times\varphi(t)$

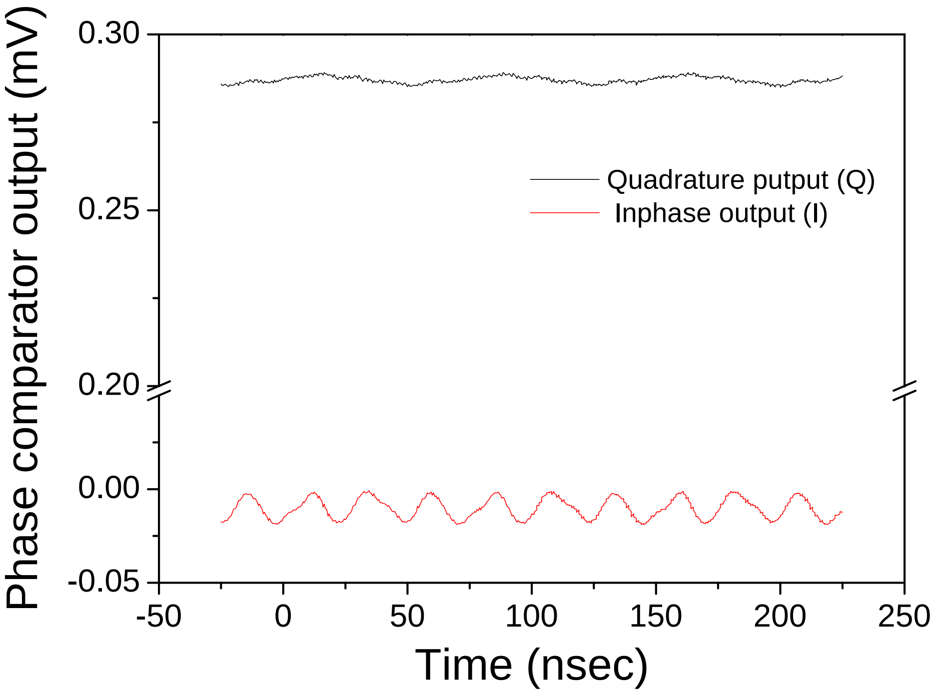
Heterodyne type Interferometer







Plasma density calculation

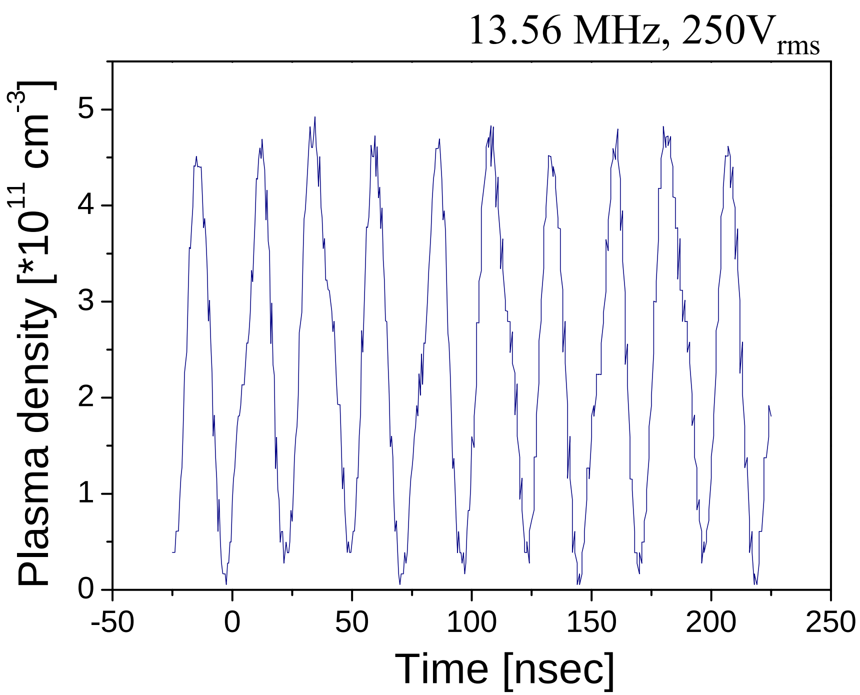


$$I = K_I \sin(\phi) + V_{OI}$$

$$Q = K_Q \cos(\phi + \varphi_o) + V_{OQ}$$

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

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



Conclusions

We have studied the fundamental properties of APPJ by optical and microwave diagnostics

- When same input power is applied to the APPJ varying RF frequency, the vibrational and rotational temperature increase as increasing frequency.
- We have measured spatially resolved plasma temperature. As a result, maximum vibrational temperature is shifted to outer region and density in the region of RF electrode increase as increasing the input voltage. The rotational temperature is maintained at constant value.
- Electron density measured by microwave interferometer is estimated to be in order of 10^{11} cm^{-3}