Spectroscopic Studies on GLAST-III Varying the Inductance and Charging Voltage of Vertical Field Coils

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Abstract. Optical emission spectroscopy is applied as a diagnostic tool to investigate the plasma in GLAST-III (glass spherical tokamak). It is a small limiter device having aspect ratio (R/a = 2) with major radius R = 20 cm and minor radius a = 10 cm. Spectral analysis is performed to study the plasma induced optical emission and the electron temperature for different values of charging voltage, and inductance of vertical field (VF) coils. The inductance of the VF is changed by varying number of inductors in series systematically. HR-4000 spectrometer is used to record the spectrum in the visible range (280-750 nm). The electron temperature is determined from the emission intensity of argon (Ar is used as feed gas) lines by using Boltzmann plot method. The optical emission is also recorded using photodiode BPX65. H_α line impurity is monitored using Monochromator with fixed position of grating at 656.28 nm, and intensity follows the plasma current during discharge. The results indicate that the emission intensity decrease with increase of the inductance of VF coils. Consequently, with addition of inductors the plasma current, and electron temperature both are reduced. The effect of charging voltage of VF coils on the plasma current and hence electron temperature is also calculated. It is observed that with the increase of charging voltage of VF coils, the plasma current increases, attain a maximum value and then after a critical value of charging voltage the plasma current starts decreasing

1. Introduction

Glass Spherical Tokamak named GLAST-III is a small tokomak having Pyrex glass vacuum vessel and provides clear visibility of the discharge dynamics and obviate the need of optical window. The major radius is (R=20 cm) and minor radius is (a=10 cm) thus making its aspect ratio (A=2). A toroidal magnetic field B_T =0.1 T is produced using 12 toroidal field coils connected in series. A radio frequency magnetron (2.45 GHz, 800W) is used as pre-ionization source to assist and initiate the tokamak discharge. Several diagnostic like rogowski coil, loop voltage, differential loop voltage, triple Langmuir probe, monochromator, high speed camera (1000f/s) and spectrometer are installed on GLAST-III for different kind of measurements.

Optical emission spectroscopy is an appropriate and inventive technique to determine the plasma parameters such as electron temperature, electron number density. Many diagnostics based on emission spectroscopy have been employed to investigate the plasma parameters, impurity influx, wall recycling and plasma wall interaction mechanisms [1-2]. Radiation in the visible spectral range originates from atomic and molecular electronic transition [3]. Basically the electron temperature from the spectroscopy is an averaged temperature of the plasma discharge. In the present analysis the spectroscopic measurements have been made using HR 4000 ocean optics spectrometer with Toshiba CCD detector which is a linear array with 3648 pixel element and external trigger. This spectrometer has spectral resolution (FWHM) of 0.75nm and integration time is 3.8ms. Light is collected from the system through optical fibre which is connected with fixed entrance slit of 25 μm of spectrometer. The emission spectrum is acquired with the installed Spectrasuite software. At the current phase of GLAST operation, the emission spectrum integrated over the whole discharge duration is recorded and labelled by using NIST data [4]. The electron temperature is also measured from the Spitzer's resistivity formulation [5-6].

2. Experimental Setup

The photographic view of the GLAST-III experimental setup is shown in figure 1.

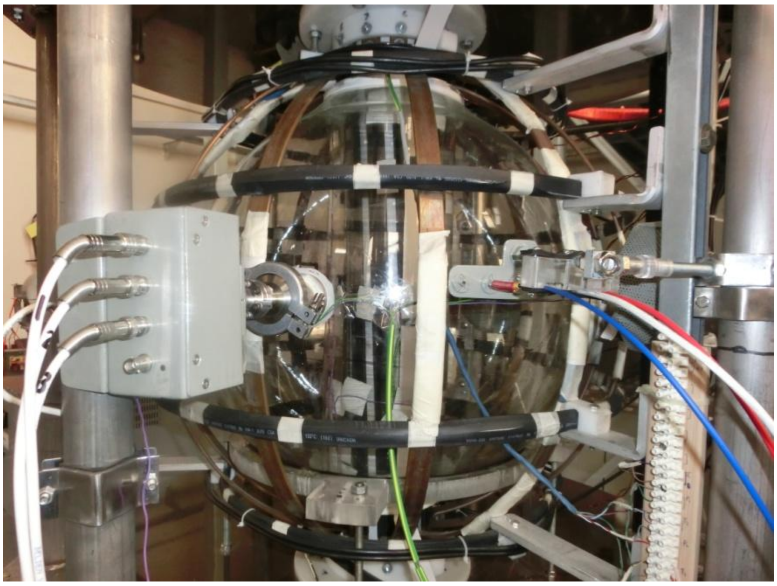

Fig-1. Overview of GLAST-III

The magnetic field configuration consist of the twelve toriodal field (TF) coils, ohmic heating centre solenoid (CS) having 295 turns, single layer, compensation coils and vertical field (VF) coil system. The GLAST chamber is evacuated at the base pressure to 4×10^{-7} mbar using turbo molecular pumping system. Argon gas filling pressure is 1×10^{-3}mbar. 2.45 GHz microwave source is used to assist the start-up prior to applying loop voltage through CS. A rectangular E-plane horn antenna in TE_{10} mode is used to inject RF waves in the perpendicular direction with the plasma torus for the benefit of pre-ionization. The TF coils are energized by a combination of fast bank (3 mF, 480 V) and slow bank (600 mF, 90 V) that produces a magnetic field in toroidal direction. This applied field is used to locate the electron cyclotron resonant layers within the plasma region at 875 Gauss necessary for 2.45 GHz microwave frequency. The plasma current is produced by discharging the capacitor bank (3.3 mF, 4.5 kV) across CS. With this configuration we are able to generate plasma current up to 1.0 kA for 1.2 ms time without energizing the vertical coils. The discharge analysis of this shot is shown in figure 2. The light emission from the plasma and the plasma current region are strongly co-related in the time domain. A dip in the loop voltage is also observed when the plasma current starts to build.

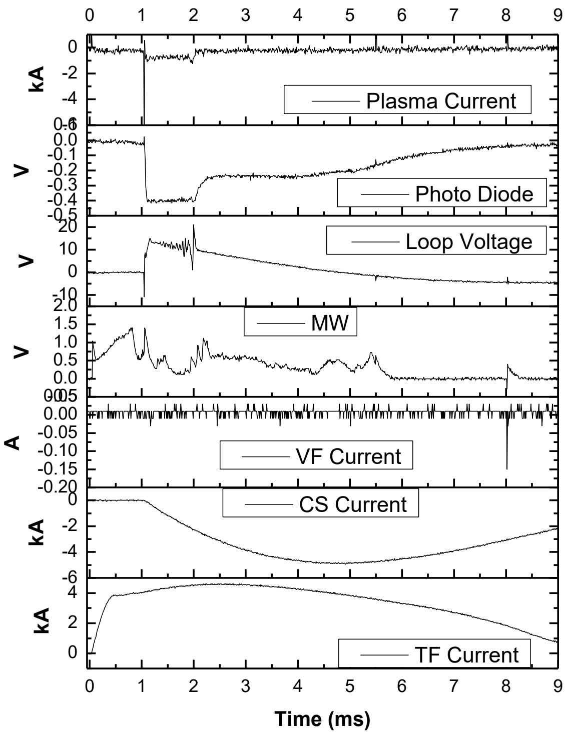

Fig-2. Plots of TF, CS, PF (=0) currents, Microwave, Loop voltage, photo diode and plasma current

2.1.1 Spectroscopic measurement of plasma current for different VF inductance

The radiations are the result of electron or ion interactions with other particles in the plasma. Due to higher velocity, electron interactions tend to dominate the collisional excitation and ionization processes [7]. The light emitted as a result of bound-bound transitions forms line spectra. Atoms and ions of the working gas emit radiation when transitions of electrons occur between the various energy levels of the atomic system. The spectroscopic analysis is done to study the plasma induced optical emission and the electron temperature for different values of vertical field coils (VF) inductance. The inductance of the VF is changed by varying number of inductors in series systematically. HR-4000 spectrometer is used to record the spectrums for various value of VF inductance.

Experiments are performed for the fixed value of VF charging voltage having capacitor bank (3 mF, 800 V) with time delays w.r.t TF and microwave. The inductance and resistance of the four inductors used in VF are given in table 1.

TABLE-1 RESISTANCE AND INDUCTANCE OF THE INDUCTORS

Sr.No.	Inductors	Inductance(mH)	Resistance (Ω)
1.	L_1	1.44	0.253
2.	L_2	0.218	0.1009
3.	L_3	0.710	0.216
4.	L_4	2.95	0.355

The emission spectrum recorded for VF without inclusion of any additional inductor in the circuit is shown in figure 3.

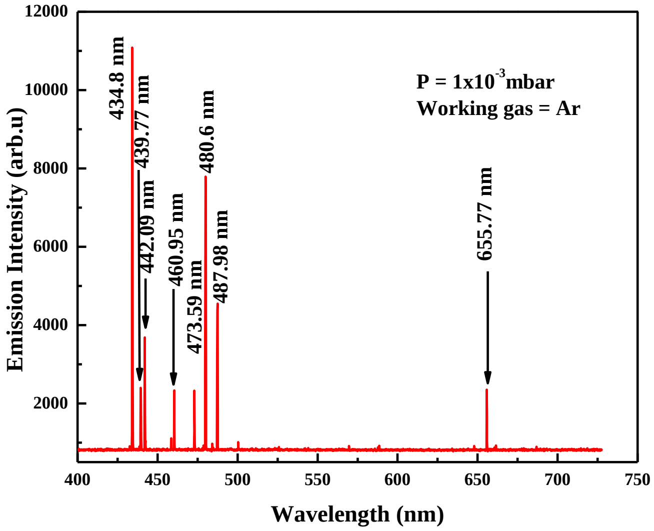

Fig-3. Optical emission spectrum from Argon plasma

The electron temperature is obtained from the slope of the Boltzmann plot [8] using the following equation.

$$\ln\left(\frac{I_{ki}\lambda_{ki}}{A_{ki}g_k}\right) = -\frac{E_k}{k_B T} + C$$

where λ_{ki} is the wavelength, I_{ki} is the measured intensity, A_{ki} is the transition probability, g_k is the statistical weight and C is the constant for a given atomic species. For the electron temperature measurement we have selected singly ionized Ar II spectral lines [9]. Table.2 shows Ar II spectral lines with corresponding energies.

TABLE-2 AR II SPECTRAL LINES WITH CORRESPONDING ENERGIES

λ(nm)	**Transition**	**A_{ki} g_k(s^{-1})**	**E_k(cm^{-1})**
434.80	$3s^23p^4(^3P)4s$ - $3s^23p^4(^3P)4p$	1.17E+08	157234.01
439.46	$3s^23p^4(^3P)4p$ - $3s^23p^4(^3P)4d$	6.00E+05	183797.44
442.09	$3s^23p^4(^3P)3d$ - $3s^23p^4(^3P)4p$	3.10E+06	155351.12
460.95	$3s^23p^4(^1D)4s$ - $3s^23p^4(^1D)4p$	7.89E+07	170530.40
473.59	$3s^23p^4(^3P)4s$ - $3s^23p^4(^3P)4p$	5.80E+07	155351.12
480.60	$3s^23p^4(^3P)4s$ - $3s^23p^4(^3P)4p$	7.80E+07	155043.16
487.98	$3s^23p^4(^3P)4s$ - $3s^23p^4(^3P)4p$	8.23E+07	158730.29
655.77	$3s^23p^4(^1D)3d$ - $3s^23p^4(^3P)5p$	1.00E+04	189654.84

With the inclusion of inductor in the VF coils system, the inductance and resistance of the coils is increased. This increased resistance and inductance affects the current profile in the coils and as a results magnetic field rise is slowed down in VF coils. Consequently plasma current is decreased and pulse length is increased. Figure 4 represents the comparison of emission intensities of spectral lines corresponding to wavelength with the variations of inductors at constant VF charging voltage (=800V). It is observed that the emission intensity decrease with increase of the inductance in the system.

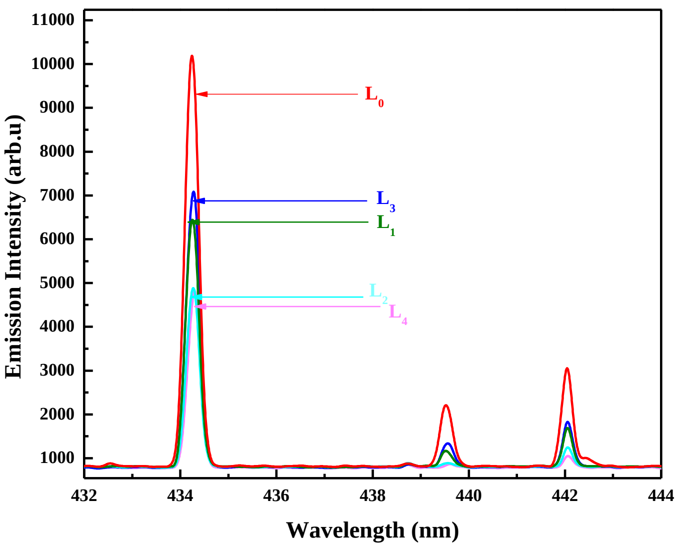

Fig-4. Influence of inductance on spectral intensity at 800V

The decrease in the emission intensity results in the reduction of electron temperature in the plasma. The electron temperature and plasma current both shows similar decreasing trend with addition of inductors. The electron temperature and the plasma current are plotted as a function of inductance and are shown in figure 5. Electron temperature (Te) values obtained are in the range of 0.44–0.55 eV. These results are much smaller than the measurements obtained by the triple Langmuir probe. Possible reason can be the integration time of spectrometer is 3.8ms where as plasma pulse duration is 1ms.

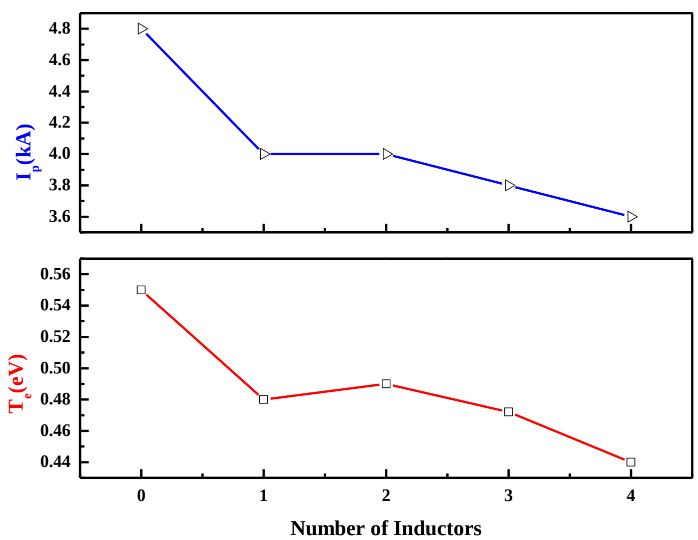

Fig-5. OES electron temperature and plasma current with changing inductance

The emitting light from the photodiode and H line impurity emission at 656.28 nm adjusted with the Monochromator follows the plasma current profile during discharge as shown in figure 6.

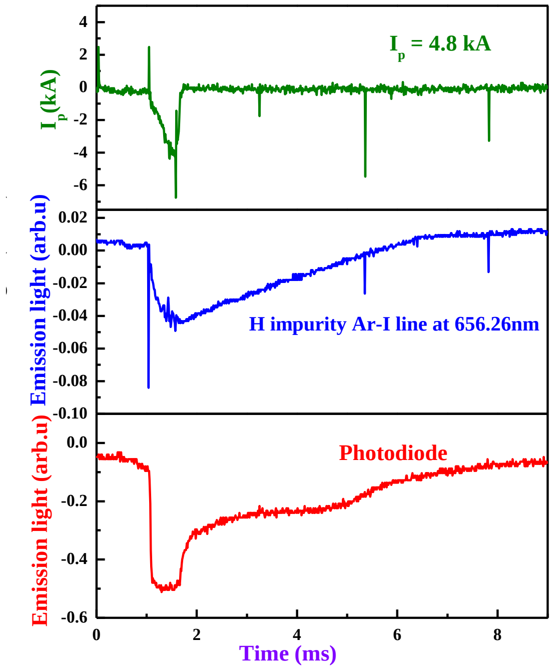

Fig-6. Photodiode signal and H line impurity with plasma current without inductor

3. Spectroscopic measurement for plasma current with different charging voltage of vertical field coils

The experimental setup is same as in the previous study. Only the effect of VF charging voltage on the plasma current, electron temperature and light emission is investigated by keeping the inductance constant.

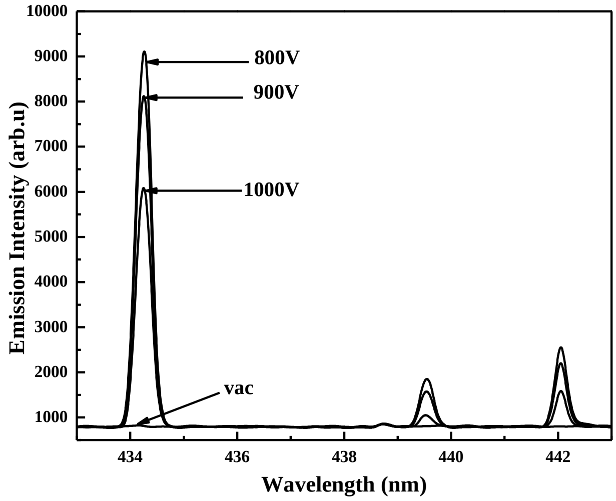

Fig-7. Intensities of spectral lines for different applied VF

The plasma current is increased if we increase the charging voltage of VF coils from (0-800 V), attains a maximum value at 800 V. Plasma is relatively in good equilibrium. Further increase in the charging voltage of VF results in decreasing trend in the plasma current as well as in pulse length and emission intensity. For the purpose of comparison the emission spectrum are recorded for different VF (800-1000V) and are presented in figure 7. The result shows that the intensity of the spectral lines decrease with increase of the applied VF. Figure 8 represents a slight decrease in the plasma current with increasing VF corresponding to pulse length also decreased.

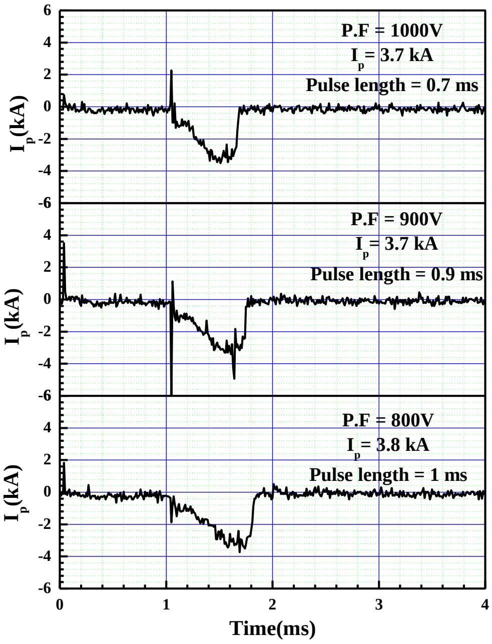

Fig-8. Plasma current for different VF

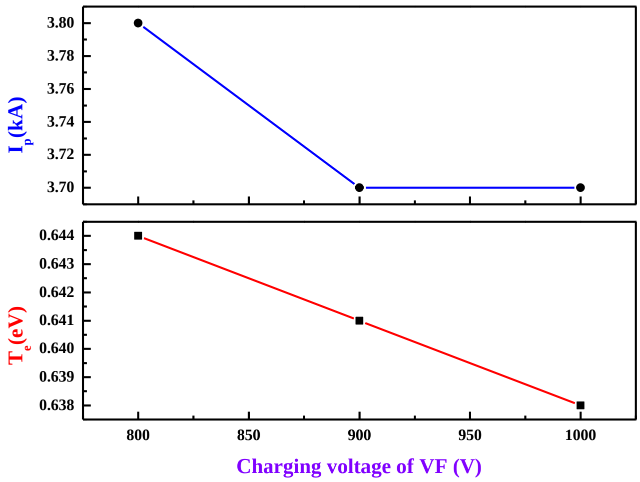

Fig-9. Variation of plasma current and electron temperature with different charging voltage of VF

Figure.9 shows that the plasma current and electron temperature both decrease with increasing VF showing the same trend. With increasing VF the electron temperature is also estimated from Boltzman plot for maximum current and found to be 0.64 eV.

4. Electron temperature with Spitzer resistivity

Plasma resistivity

$$\eta_p = 5.23 \times 10^{-5} T_e^{-3/2} Z_{eff} ln\Lambda(\Omega m, eV)$$

Using values for Tokamak plasma $ln\Lambda=17$, Z_{eff} for Ar =8, Plasma current 4.8kA, Loop voltage 14. The electron temperature is estimated to be ~20 eV.

5. Conclusion

Plasma induced optical emission spectroscopy has been carried out to investigate the plasma parameters in GLAST-III for different values of coil inductance in VF. The electron temperature is determined from Boltzmann plot method for varying values of inductance of VF coils. The results indicate that plasma current and emission intensity both are reduced in the same manner with increasing inductance. As a consequence the electron temperature is also reduced. The optical emission is also recorded using photodiode BPX65 and H line impurity is monitored and observed that intensity follows the plasma current during discharge. The effect of charging voltage of VF coils on the plasma current and hence electron temperature is also determined. It is observed that with the increase of charging voltage of VF coils, beyond certain limit plasma current starts decreasing and the electron temperature is reduced as well. Electron temperature is also calculated using Spitzer resistivity formula and is found to be 20eV.

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