First Plasma Formation in Glass Spherical Tokamak (GLAST)

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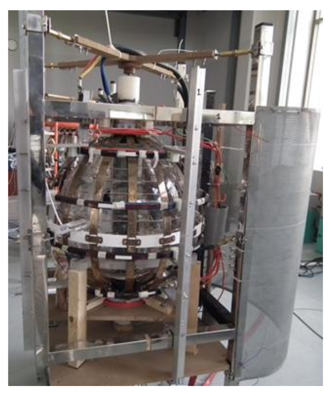
Abstract

The first plasma formation in GLAST is presented. GLAST is a small spherical tokamak having vacuum vessel of dielectric material (Pyrex glass). A plasma current of 2kA was produced for about 0.5msec using ECR assisted plasma startup. A small vertical field was then added to enhance the peak of plasma current up to 5kA. The variation of plasma current with the applied vertical field was also studied and the optimum values of the vertical magnetic field were experimentally determined to be between 40-50 gauss. A high speed camera was used to study the plasma behavior during the whole discharge scenario. The diagnostic systems such as Rogowski coil, flux loop, fast photo-diode, and spectrometers were also used to record the signatures of plasma current and to estimate some plasma parameters. The edge electron temperature was estimated to be 13eV from the measurement of the variation in the loop voltage during the plasma current formation.

Tokamak Devices at NTFP


GLAST-1


GLAST-2

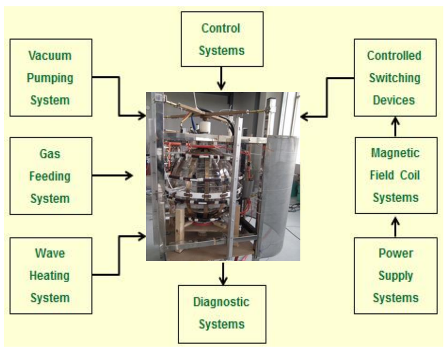

GLAST-3

Design Parameters

Physical Parameters			
Device	GLAST-1	GLAST-2	GLAST-3
Vacuum Vessel:	Glass	Glass	Glass
Central Tube	Steel	Glass	Glass
Major Radius	15 cm	15.5 cm	20 cm
Minor Radius	10cm	9.5 cm	10 cm
Aspect Ratio	1.5	1.6	2.0
Solenoid	0.7mH 279mΩ	1.4mH 900mΩ	1.3 mH 320mΩ
Compensation Coils	4	4	2
Number of TF Coils	16	16	12
VF Coils	6	6	6

Plasma Parameters		
Device Name	GLAST-1,2	GLAST-3
Toroidal Field at Center	0.2 - 0.4 T	0.5 -0.7T
Plasma Current	40-50 kA	30-80kA
Elongation	2	2.1
Central Electron Density	~ 10^{20} m^{-3}	~ 10^{20} m^{-3}
Central Electron Temp.	400 eV	400 eV
Edge Electron Density	~ 10^{16} m^{-3}	~ 10^{16} m^{-3}
Edge Electron Temp.	5-10 eV	5-10 eV
Edge Safety Factor	6	8
Maxi. Pulse Length	5-10 ms	5-10ms

Experimental Setup



Experimental Schematic

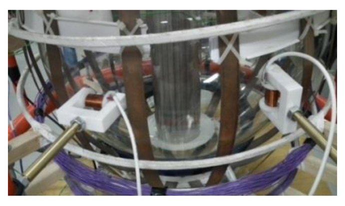

Power supply System

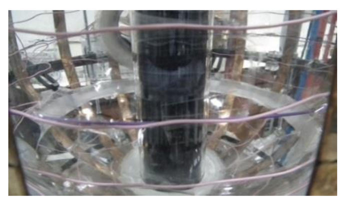
Microwave Pre-ionization

- Domestic microwave oven magnetron at 2.45 GHz based waveguide system
- Generation of microwave pulse of 4msec with output power of 1.5kW
- Maximum absorption at toroidal magnetic field of 875 gauss
- Pre-ionization during Tokamak startup

Diagnostic Systems


Rogowski


Magnetic Probes


Flux Loops


RGA300


High Speed Cameras

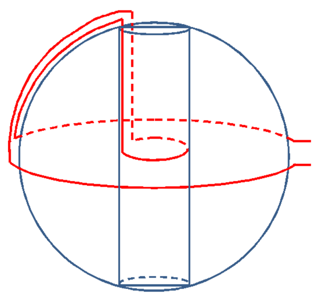

Spectrometers

Vessel Cleaning and Outgassing

- Cleaning with acetone and alcohol
- Base vacuum of 8×10^{-7} mbar using turbomolecular pump
- Under-vacuum heating at ~80 °C for several hours
- Glow discharge conditioning at higher pressure of neon
- Impurity monitoring using Residual Gas Analyzer (RGA)

Vertical Flux Null Generation

- Generation of flux null is extremely important for the plasma current startup in small tokamaks
- Presence of net vertical magnetic field (error field) due to the central solenoid and other coil systems greatly affect the requirements for the induced electric field during the startup phase
- Adopted a simple technique to minimize the net vertical magnetic flux inside the whole vacuum vessel
- Two pairs of vertical field coils (compensation coils) were used in series with the central solenoid to generate null magnetic flux inside the vessel with the help of a differential loop (one part around the central solenoid while other around the vessel)

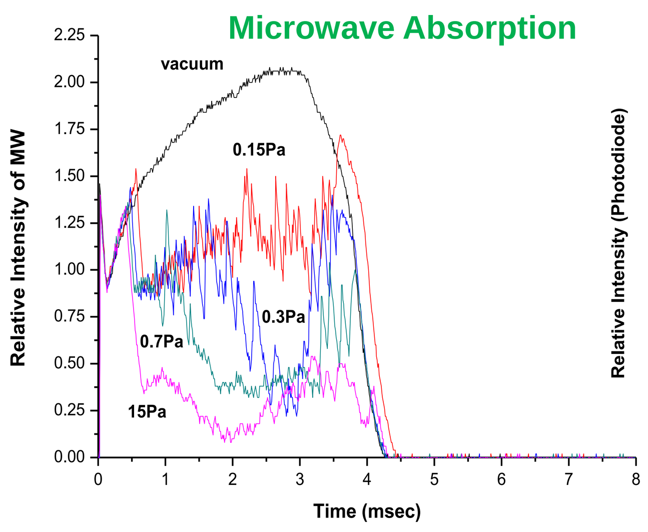

Differential Loop

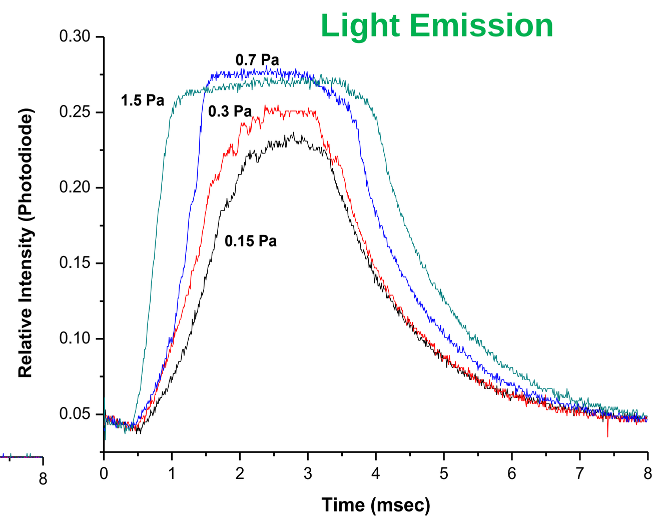
- The minimum net flux at a particular instant was achieved by varying the number of turns and also the position of the compensation coils

Tuning of Vertical Coils

- Tuning of vertical field coil system i.e. to minimize the induced effect of central solenoid on the vertical coils system is also necessary for the tokamak startup
- This was done by firing the central solenoid at small voltage (~100 volts) and measuring the induced voltage across the vertical system
- The induced voltages were reduced to the minimum possible value by adjusting the number of turns and the direction of current in each of the coils

Optimization of ECR absorption

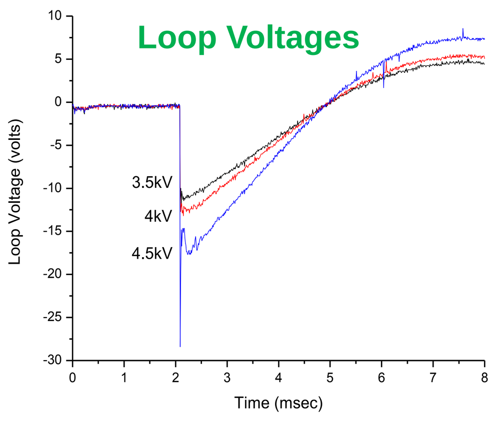


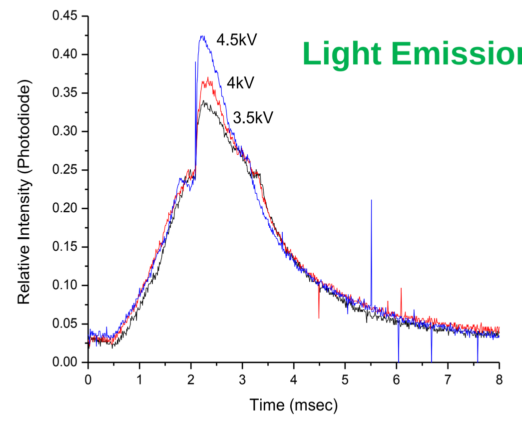


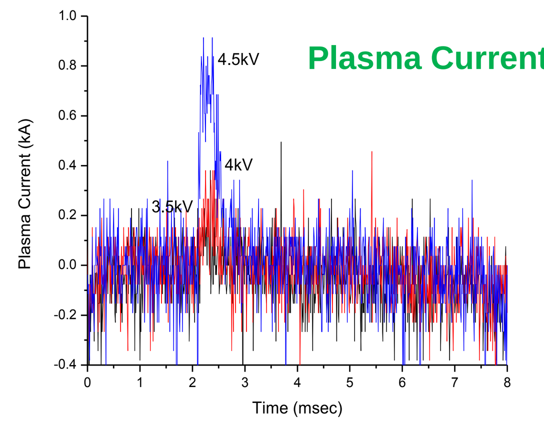
- Electron cyclotron resonance absorption was optimized to provide a base for plasma current startup
- The microwave pulse was launched into the vessel filled with neon gas at pressure of about 10Pa in the presence of toroidal magnetic field (875gauss) to generate the ECR layer at the inboard side
- The width and the intensity of resonance layer were optimized by changing the gas pressure, orientation of the waveguide and relative delay between TF and the microwave pulse
- A microwave photodiode was used to record the temporal intensity changes in the microwave pulse while an optical photodiode was used to record the light emission from plasma as a result of ECR absorption at different gas pressures
- The width and also the intensity of the optical emission decrease with the decrease in neon gas pressure as shown in above figures
- The operating pressure range for neon gas was found to be 3×10^{-3} mbar---5×10^{-4} mbar

Plasma Current Studies

- After preliminary optimization of gas pressure and other operating parameters, it was tried to generate plasma current
- Neon gas was filled at pressure of 3×10^{-3} mbar and suitable loop voltages were applied in the presence of microwave pulse and the toroidal magnetic field
- The three pulses i.e. microwave, toroidal field and the central solenoid were fired with suitable relative delays between them
- A small value of plasma current (0.15kA) was observed at loop voltages of about 11volts by charging the central solenoid at 3.5kV
- The plasma current was increased with increase in the applied toroidal loop voltages. The temporal evolution of plasma current at three values of loop voltage along with the corresponding changes in light emission signals are shown in figure below



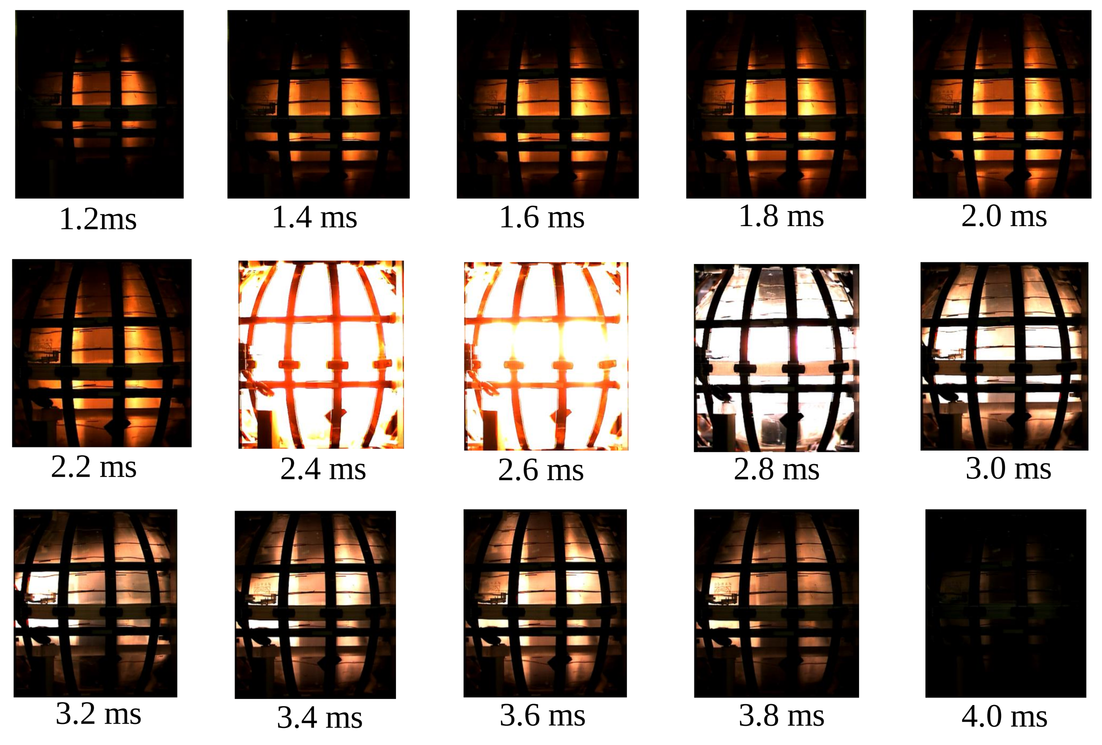


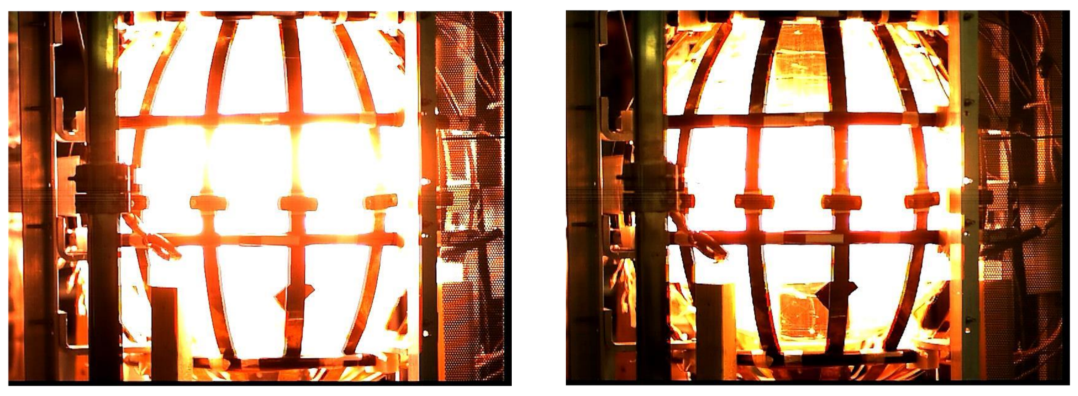


- A plasma current of about 2kA was produced for about 0.5msec. A fast photodiode and a flexible Rogowski coil of about 1.7m long encircling the whole cross section of vessel was used to record the signatures of plasma current

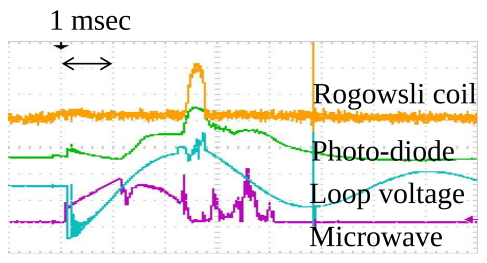
Effect of Vertical Field

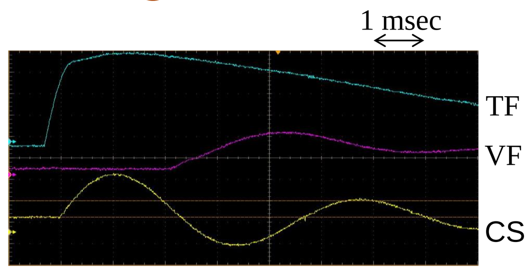
- An increase in plasma current from 2kA to 5kA was observed with addition of a small vertical field
- Plasma current was optimized by scanning the vertical field in both directions and also by varying the field from 10 to 100 gauss
- The optimum values of the vertical magnetic field were found to be between 40-50 gauss
- A change in the direction of plasma current was also observed with changing the direction of vertical field that confirmed the enhancement of plasma current due to the vertical field drift effect
- Temporal evolution of plasma current recorded with a high speed camera (5000fps) is shown below
- The first visible layer appears at time 1.2ms after the firing of microwave at t=0. The intensity and the size of resonant layer increase with time up to about t=2.2ms. The plasma current formation starts at about t=2.4ms, maximum is at t=2.6ms and then starts to decay and ends at t=3ms while the visible glow ends at t=4ms




Central frame with and vertical field

Experimental Signals





Conclusions

- Successfully generated the plasma current in GLAST
- Efforts to increase width and amplitude of plasma current
- Development of diagnostics and adiabatic compression studies are future task