First Electron Temperature Profile Measurements on the Lithium Tokamak Experiment

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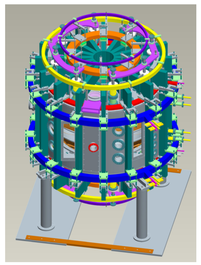
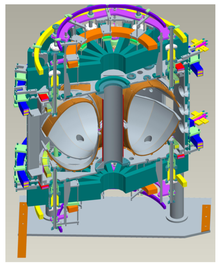
Abstract

The Lithium Tokamak Experiment (LTX) is a spherical tokamak designed to study the low-recycling regime through the use of a liquid-lithium coated shell conformal to the last closed flux surface. A low recycling rate is expected to flatten core electron temperature profiles, raise edge temperatures, and strongly affect electron density profiles. A Thomson scattering diagnostic uses a 15 J, 30 ns FWHM pulsed ruby laser (694.3 nm) to measure T_e and n_e at 9 radial points on the horizontal midplane, spaced from the plasma axis to the edge at a single temporal point for each discharge, with two background light channels. Scattered light is imaged though a spectrometer into an intensified CCD. T_e values have been observed from 50 to 150 eV. T_e and n_e profiles under various wall conditions are presented. Calibrated n_e and P_e profiles are used to constrain equilibrium reconstructions. Details and progress regarding an upcoming 5 channel, 5 mm resolution edge polychromator system are presented.

The Lithium Tokamak Experiment



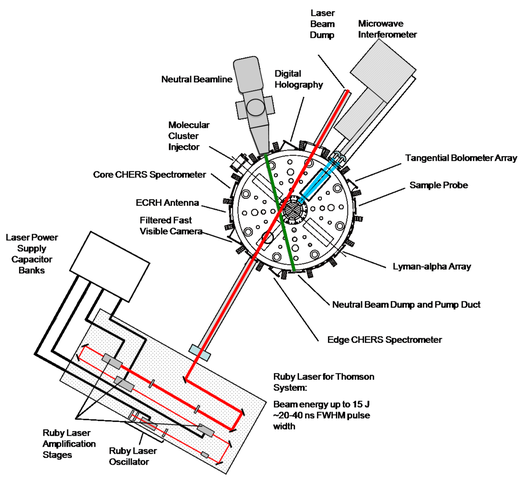


- Spherical torus designed to nearly eliminate wall recycling
- Liquid lithium coated shell conformal to LCFS covers 85% of the plasma
- Shell resistively heated to keep lithium in liquid state
- Shell has two toroidal and two poloidal breaks to prevent the formation of large scale currents and allow diagnostic views

Parameter	Value
R_0	0.40 m
a_0	0.26 m
B_T	3.4 kG
I_P	400 kA
κ	1.55
$T_{e,\max}$	> 300 eV
τ_{flattop}	> 100 ms

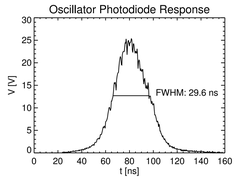
Thomson Scattering System

- Scattering intensity is directly proportional to n_e
- Width of the scattered line gives T_e
- Thomson scattering has a very low cross section
- An intense light source and sensitive optics are necessary



Beam

- Ruby laser (694.3 nm)
- 15 J maximum pulse design, 17 J achieved
- 20-40 ns duration
- Single pulse per plasma shot
- Horizontal polarization
- HeNe beams used for alignment



Stage	Ruby Rod	Flashlamps	Charge	Capacitance	Energy
Oscillator	6 mm	4	1880 V	320 μF	520 J
Preamplifier	9 mm	4	1820 V	1800 μF	3000 J
Amplifier 1	18 mm	6	1900 V	1840 μF	3300 J
Amplifier 2	25 mm	8	1900 V	1280 μF	2300 J

Viewing Optics

- 5 element lens set, $f/3.8$, 59 cm from beam line
- Polarizer in place to reduce background light levels
- 1 mm diameter quartz-core fibers (0.9 mm cladding diameter, 0.8 mm core diameter, Fiberguide Industries) in a curved holder above collection lens (25 grooves)
- 11 spatial channels
- Background light can be characterized using multiple exposures
- New system is configured with 2 background light channels viewing off the beam axis

Measurement Locations

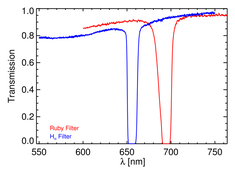
- A rigid rod with a ruler is placed along the beam path
- Fibers are back-illuminated with a halogen light
- Viewing optics are aligned
- Measurement locations are recorded
- Locations are mapped from 'ruler' to machine coordinates using CAD
- Argon breakdown during Rayleigh scattering determines mapping to CCD
- Vignetting blocks a portion of the CCD and limits system to 11 channels

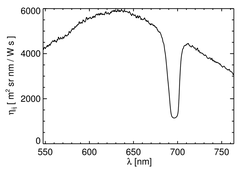
Ch	R [cm]	r [cm]	r/a	Pixel
1	40.8	0.8	0.031	-
2	41.8	1.8	0.069	-
3	42.7	2.7	0.104	-
4	44.9	4.9	0.188	-
5	46.8	6.8	0.262	52-60
6	48.8	8.8	0.338	74-98
7	50.8	10.8	0.415	111-133
8	52.9	12.9	0.496	148-173

Ch	R [cm]	r [cm]	r/a	Pixel
9	54.7	14.7	0.565	184-211
10	56.7	16.7	0.642	222-245
11	58.7	18.7	0.719	259-283
12	60.8	20.8	0.800	298-323
13	61.8	21.8	0.838	336-357
14	62.8	22.8	0.877	370-396
15	64.0	24.0	0.923	408-427
16	65.0	25.0	0.962	-

Spectrometer

- Kaiser Optical Systems HoloSpec VPT System spectrometer (HS-f/1.8i-VIS)
- Transmission grating sees light from 547 to 764 nm (Kaiser Optical Systems HFG-650)
- Laser light and H_α lines blocked by internal filters (Kaiser Optical Systems HSPF-694.3-2.0 and HSPF-656.6AR-2.0)
- Princeton Instruments IMAX Intensified CCD (512 by 512 pixels, 19 μm by 19 μm pixel size, ST-133)
- Stanford Research Systems Digital Delay Generator (DG-535) controls timing (70 ns exposure time)





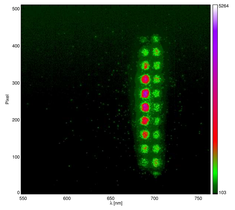
Density Calibration

Motivation

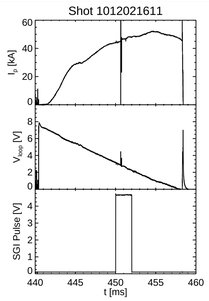
- n_e is measured by the intensity of scattered light
- Absolute n_e measurement requires knowledge of the system optical transmission

Methods

- Calibrated Light Source (Labsphere URS-600) for spectrometer measurements
- Rayleigh Scattering (Ar) for overall system measurements
- Raman Scattering (N_2) for pre-Li only system measurements



Plasma Evolution Study

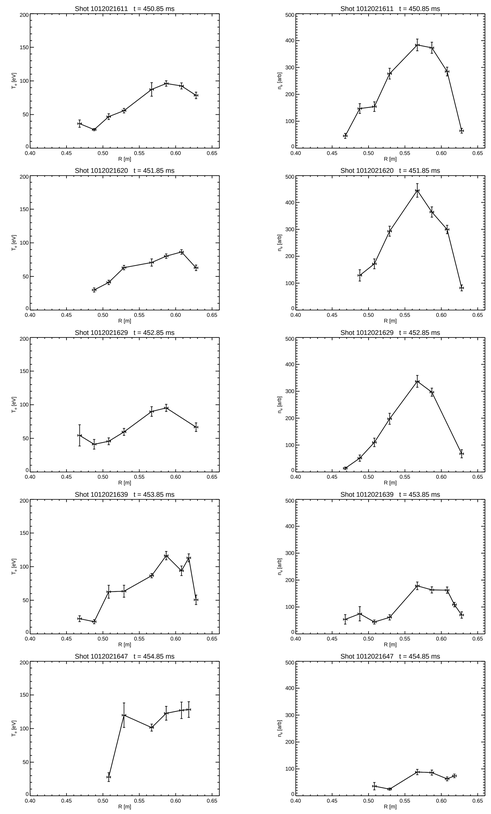


Experimental Setup

- Cold Li wall conditions
- Same coil programming repeated for a series of shots, plasmas very reproducible
- Gas injection at midplane from 450.0 ms to 452.0 ms
- Firing time of Thomson laser changed to look at T_e and n_e profile evolution

Results

- Plasma appears to be centered outboard
- Peak T_e values around 100 eV
- T_e profile changes little over time
- n_e profile exhibits relaxation after gas injection



Upcoming Edge Thomson Scattering System

Objective:

- Measurement of edge T_e and n_e with high spatial resolution

Approach:

- Observe edge plasma along beam path of laser from core Thomson scattering diagnostic
- Five channels arranged to provide 5 mm spatial resolution

Viewing Optics:

- Lens with 35 cm focal length designed and fabricated by Academia Sinica Institute of Plasma Physics (ASIPP) in Hefei, China
- Five 1 mm-diameter (900 μm cladding, 800 μm core) fibers bring light to spectrometers

Spectral Resolution:

- Five polychromators constructed by General Atomics (GA)
- Each polychromator holds up to six filters with different wavelength bands to determine spectral line broadening
- Filterset designed for maximum edge temperature of 250 - 300 eV
  - 694.3 $\pm$ 0.3 nm
  - 699.8 $\pm$ 0.6 nm
  - 707.8 $\pm$ 0.9 nm
  - 718.3 $\pm$ 1.2 nm
  - 734.3 $\pm$ 1.5 nm
- Light in each filter channel detected with avalanche photodiode (APD) coupled to transimpedance amplifier designed by PPPL

Data Acquisition:

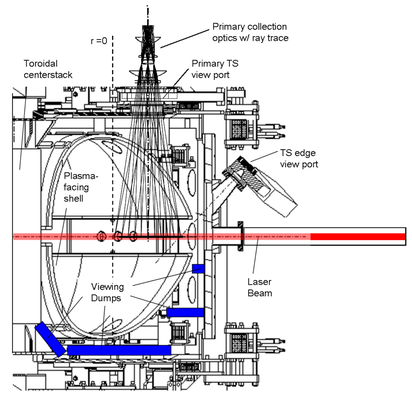
- Waveform of detected light recorded with CAEN Technologies digitizers
- Four Model V1720 modules digitize at 1.25 megasamples per second in each of thirty-two 12-bit channels

Schedule:

- Final installation of components: early spring
- First data: late spring

Additional Possibilities for Diagnostic:

- Edge fluctuations
  - Use bright emission from lithium (670.8 nm)
  - Look for changes in fluctuation levels as lithium coatings affect recycling
- Edge neutral density measurements
  - Use laser-induced ionization
  - Take advantage of high laser power and short distance between collection optics and beam path



Future Work

- Determine the electron temperature and its profile as a function of recycling
- Correlate the electron temperature profile peaking and the confinement
- Correlate the recycling and the edge temperature using a combination of Thomson scattering and Langmuir probe data
- Determine if the edge temperature correlates with the recycling predicted by UEDGE or other models

Supported by US DOE contract DE-AC02-09CH11466