Development of Lithium Beam Probe Systems for the Diagnostics of Cold and Hot Plasmas

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1. INTRODUCTION

Beam emission spectroscopy based on monoenergetic neutral lithium beam has become a standard diagnostic technique in advanced plasma confinement devices to measure their density profiles in the high temperature plasma edge, with good space and time resolution [1,2]. More recently, density fluctuations and impurity concentrations at the edge region of ASDEX-U tokamak has also been determined by this method [3,4]. The success of these measurements rely on high intensity and good optics lithium beams and complex calculation codes with elaborate atomic data base. Edge transport barrier properties so important for a successful fusion reactor are determined by these plasma parameters.
On the other hand, this lithium beam probe technique has been suggested also for cold plasma characterization [5], however, with much relaxed beam qualities and simpler data analysis procedure.
We are developing a 3-10 keV lithium beam diagnostics systems to be applied in both hot and cold plasma in our laboratory. Meanwhile, optimizations of the lithium ion source, of the beam optics and its neutralization are underway to provide improved neutral lithium beam probe system for plasma diagnostics.

2. LITHIUM BEAM PROBE (LBP) FOR PIII TARGET PLASMA

The schematic drawing of the LBP system for the PIII (Plasma Immersion Ion Implantation) plasma characterization is shown in Fig.1. We have successfully generated PIII plasmas both by microwave and glow discharge methods [6], the first plasma having densities of $5x10^{10}$ cm^{-3} and the second with $1x10^{10}$ cm^{-3} (both measured with Langmuir probes). Plasmas with these densities are adequate to be probed with LBP and when PIII is operated in the presence of H.V. (10 - 20 kV typically), this technique which provide local plasma densities $n_e(r,t)$ with high space and time resolution will be useful for the studies of sheath propagation and PIII dynamics.

3. LITHIUM BEAM PROBE FOR ETE TOKAMAK DIAGNOSTICS

The diagnostic set-up of LBP in ETE tokamak [7] is being planned as shown in Fig.2. A beam line of about 3 m from the source to the observation point is being anticipated. Therefore, good lithium beam optics and high beam intensity will be crucial in this LBP application. Furthermore, shielding of stray magnetic fields near the lithium ion source and propagation regions will be essential to avoid beam losses. And the backflow of beam neutralizing Na vapours to the tokamak chamber will have to be hindered using fast gate valves which will be actuated only during the probing of the plasma generated in the tokamak. Hence automation of LBP system is being considered using PLC platform. The profiles of the beam photon emission will be obtained by a multichannel data acquisition system based on VME modules. The diagnostics beam optics and intensity optimizations to be implemented in the LBP systems for the tokamak application are being conducted in a presently operating LBP system, the results of which will be described next.

4. OPTIMIZATION OF THE LITHIUM SOURCE INTENSITY AND BEAM OPTICS

Previously, we have shown significant improvements in the ion emission intensity from the lithium ion source by transforming the pasty β-eucryptite emmiter to its glassy state[8]. However, large beam intensity for low energy beams (2 kV) resulted in the degradation of the beam optics[9].

Hence various attempts were made to keep the improved emission in good beam optics mode. Glassy β-eucryptite source prepared 3 months before this experiment was set-up in a lithium gun described elsewhere [9], and mounted on a new drift tube with better geometry for beam propagation (beam closer to the walls). The emission characteristics of this source is shown in Fig.3, for which a large area detector (6 cm diameter) was used near the gun (15 cm away). The majority of the emitted lithium ions were collected and for source operating temperatures of about 1100°C an output of about 80 μA was obtained for extraction voltages of 1.5 kV. Much larger currents could be drawn at higher crucible temperatures but with the risk of damaging the source.

We systematically characterized the glassy source with respect to the lithium gun extraction voltage, focusing electrode voltage, source electrode voltage as well as heater voltage and current. In Fig.4(a), we show how is the collected beam current behavior near the gun, det1 (d=15 cm) and far from it det2 (d=80 cm) when we change the extraction voltage (Vext) with fixed focusing electrode voltage (Vfocus) of 2.3kV. The optimum output for Vext is about 1.7 kV when considering the beam divergence despite the smooth current output for up to Vext = 2.3kV.

In Fig.4(b) we show the corresponding currents for the case with fixed Vext=1.7 kV while varying the Vfocus from 0.1 to 2.6 kV. The obtained beam HWHM width at this optimized condition is about 1.0 cm at a downstream position of 80 cm from the source, as seen in Fig.5, when we achieved about 20 $\mu A/cm^2$ at that point. This is about ½ of the width seen before under similar conditions but with lower beam energy.Therefore, a more carefully designed drift tube and the increase of the beam energy helped to improve the beam optics significantly.

Additionally, an electron shower system based on hot filament was used for the attempt to reduce the excess space charge in the beam which possibly caused the degradation of the beam divergence for the high current density beam extractions previously. However, instead of improving the beam characteristcs, the broad swarm of electrons started acting as a defocusing lens (Vfil=55V) and hence degrading the beam optics as we show in Fig.6. When too large quantities of electrons are thrown in the beam path (Vfil>60V), the performance of the source itself is strongly affected, probably due to their migration into the source region. Hence a more adequate scheme of electron injection into the space charge dominated beam has to be devised.

We also found that the ion collectors themselves charge up if floating and can influence strongly the beam optics during the measurements.

5. CONCLUSIONS

Lithium beam probe systems for cold (<10 eV, 10^{10} - 10^{12} cm^{-3}) and hot (10 -100 eV, 10^{10} - 10^{14} cm^{-3}) plasmas are being developed in our laboratory. The first system is very simple and practically ready for the measurements in the PIII plasma device and the photon signals in this case can be promptly translated into a high space and time resolution density mapping of that plasma. The second system is presently being designed, taking into account the required high beam intensity and improved optics for large S/N ratio necessary for the tokamak edge plasma density profile measurements.

Experiments aiming at high intensity, high quality optics beams are being carried out to back up these experiments and the new set-up with improved drift tube as well as higher energy (3 keV) beam operation have shown the achievement of 1 cm HWHM width beams with >20 $\mu A/cm^{-2}$, comparable to low energy lithium beams attained in advanced plasma laboratories. For ETE tokamak applications higher intensity beams with energies of 10 keV are being developed.

6. REFERENCES

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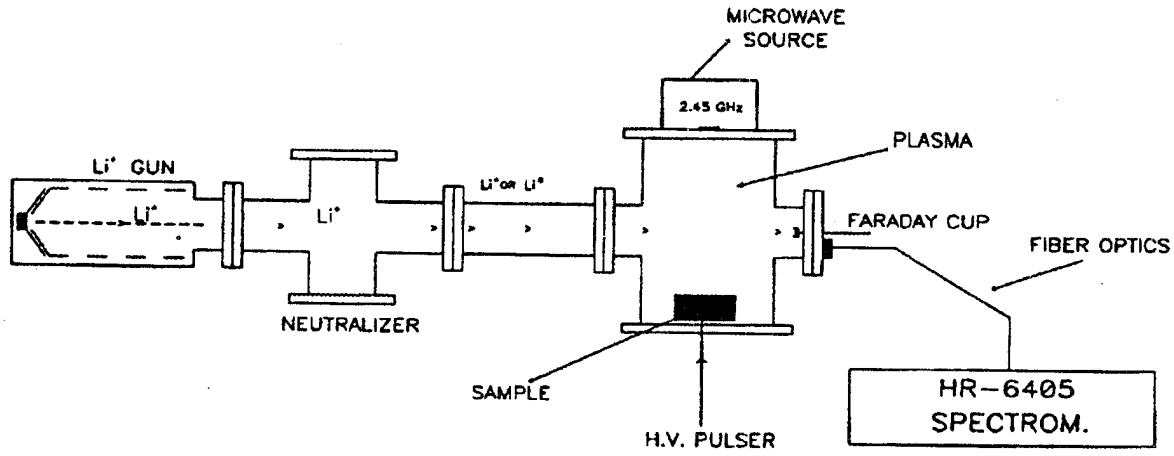


Fig.1 Experimental set-up for Lithium Beam Probing of PIII plasma

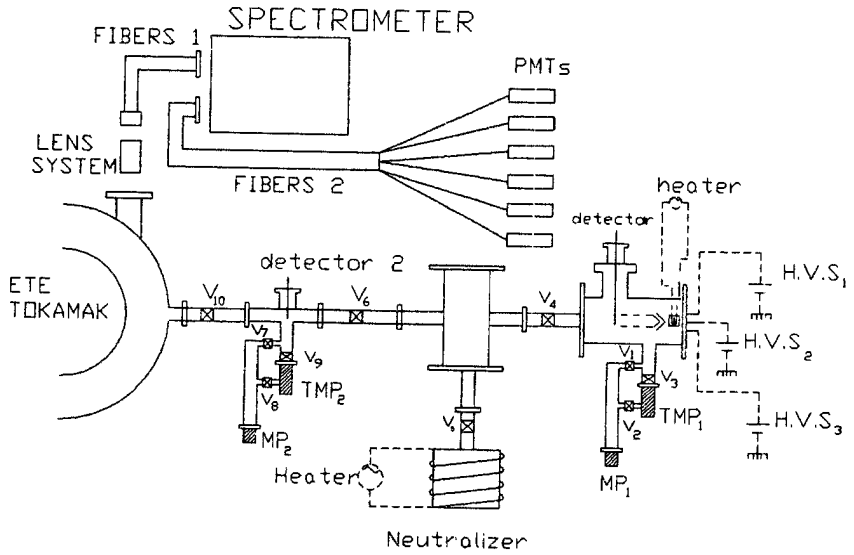


Fig.2 Experimental set-up for Lithium Beam Probing in the ETE tokamak

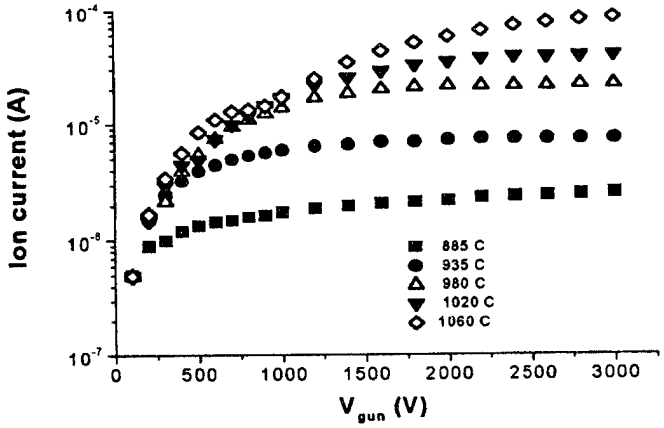


Fig.3 Lithium ion emission characteristics of the glassy β-eucryptite source for different temperatures

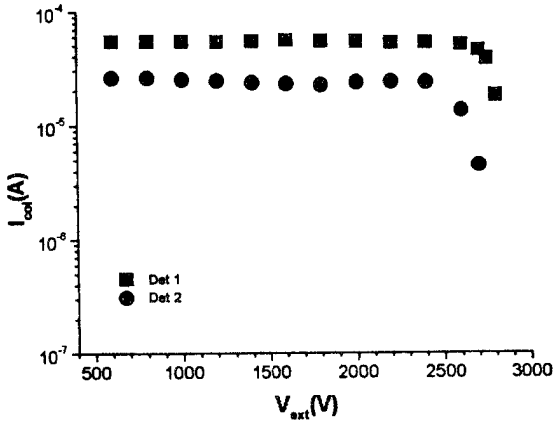


Fig.4(a) Li^+ current versus extraction voltage (Vfocus=2.3 kV) for different detector positions

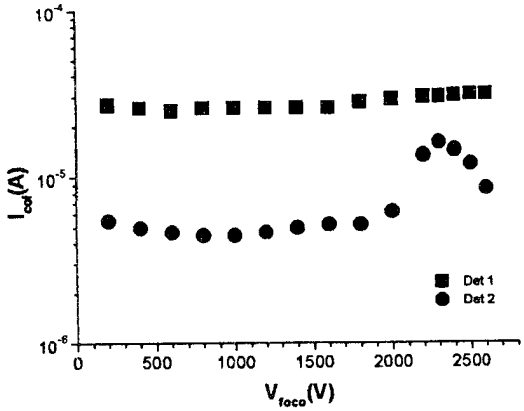


Fig.4(b) Li^+ current versus focusing voltage (Vext= 1.7kV) for different detector positions

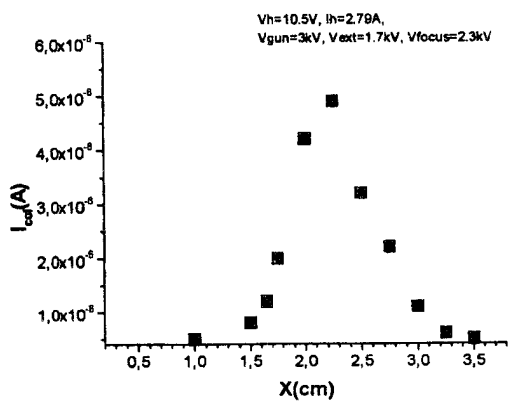


Fig.5 Beam width under source optimized conditions at 0.8m distance from the source

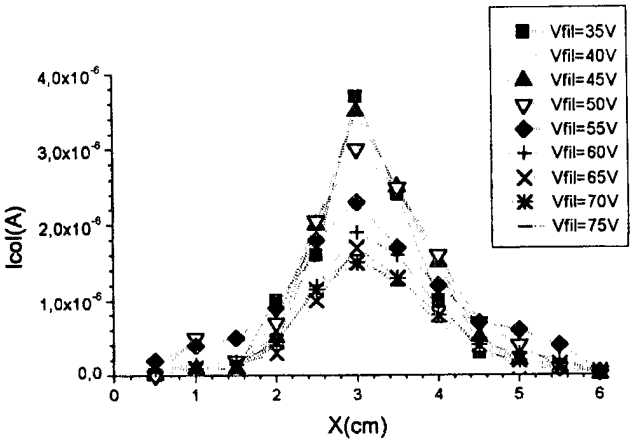


Fig.6 Beam width variation for different electron shower filament voltages