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Li-beam developments

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Introduction

Energetic (few $10keV$) Li atom beams are routinely used to measure various parameters of magnetically confined fusion plasmas. Measuring the intensity of the Li2p line excited by plasma electrons one can determine the plasma density and its fluctuation along the beam path. Measurement of the line shape gives information on the magnetic field in the observation volume. Charge exchange with plasma impurity ions gives the possibility of the determination of impurity ion concentrations, [2, 3, 4]. The usual applications of Li-beam diagnostic can work with the presently available $1-2mA$ beam current but some require well above that. In this contribution we describe studies aiming at to understand limiting factors of current Li-beam sources and developments of a new thermionic ion source with higher ion emission capability.

Experimental setup

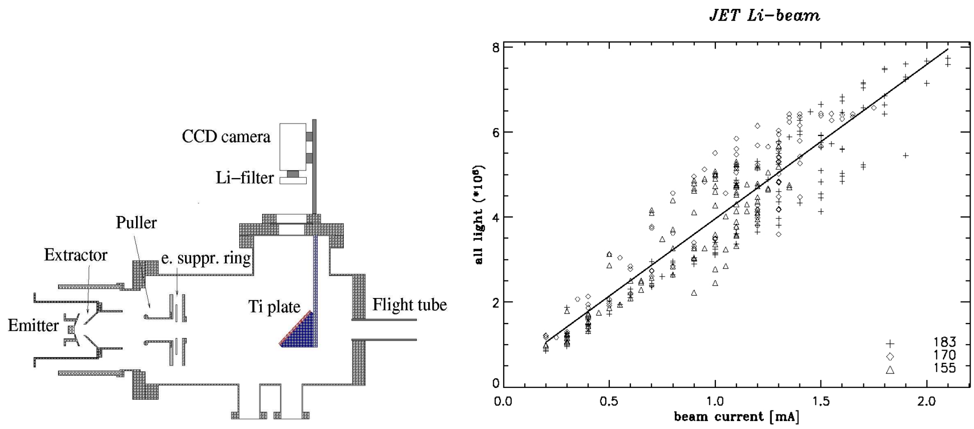

Figure 1: *Experimental setup (left). Total detected light vs beam current(right).*

The JET duplicate Li-beam injector was tested in IPP Garching. The testing set-up consisted of the gun section, a flight tube and a diagnostic chamber at the end of the flight tube. The gun follows the original ASDEX design [1] as shown in the left plot of Fig. 1. Thermal ions are emitted from a heated emitter (HeatWave Labs. Model 101072, emission surface is $1.32cm^2$) and accelerated by the ion optic which consist of three elements referred to as the emitter, the extractor and the puller. The puller is connected to ground, the emitter is on high positive potential (beam energy) and the extractor is biased negatively relative to the emitter (extraction voltage). At a fixed geometry, focusing of the ion optic is determined by the ratio of the extractor-accelerator and emitter-extractor voltage which we call voltage ratio. The beam formed in the ion optic is neutralised in Sodium vapour. Similar test was made with the TEXTOR Li-beam injector at KFKI-RMKI.

The new diagnostic method for beam profile measurement

The beam profile was measured by intersecting the beam path with a Titanium plate. The beam ions get neutralized on the surface and some of them become excited to the 2p state. On transition to the ground state the atoms emit visible radiation at $670.8nm$. This radiation was observed by a digital camera (PCO) through an interference filter ($670.8nm$). The beam current and the total detected light emission intensity were compared to verify the applicability of the new method, see the right plot of Fig. 1. On the basis of this result the beam current density distribution ($J(r)$; beam profile) was determined.

Li-beam tests

To find the limiting factor of the beam current the JET Li-beam was tested in detail. The beam profiles - measured at the neutraliser chamber - were normalised to their maximum and were contour plotted as a function of radius and voltage ratio at different beam energies, see Fig. 2. The most obvious trend is the decrease of the beam diameter with increasing voltage ratio. Increasing the beam energy, which in turn incraeses the beam current, the beam profile becomes slightly hollow towards the center. This hollow profile is most probably caused by the space charge in the acceleration region because it appears at higher ion currents. Beam focusing is shown at the end of the flight tube (2100 mm from the source) both for ion and neutral beam at 34 keV beam energy and 180 W heating power as the function of voltage ratio on Fig. 2.

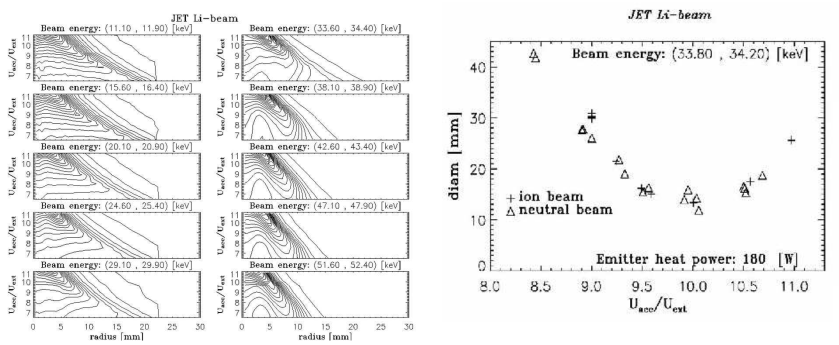

Figure 2: *Beam profile plotted as a function of voltage ratio (left). Beam diameter vs. voltage ratio (right).*

One clearly sees that the minimum beam diameter is around 15 mm and it can be achieved at about a voltage ratio of 10. It is very remarkable to see that the two curves are very similar, that is the space charge defocusing during free flight, i.e. after the electron suppression ring is not important. The reason of this could be that the beam space charge is balanced by electrons pulled into the beam channel from the surrounding.

The left side of Fig. 3 shows the beam current vs. extraction voltage. The tendency is clearly visible: the beam current increases faster than linear below 3 kV, above it it converges to the saturation. The increase approximately follows the Child-Langmuir law ($I \sim U^{3/2}$, the solid line on Fig. 3) up to 3 kV. This indicates that above 3 kV the saturation is caused by reaching the ion emission capacity of the emitter. From the plotted curve one can see that in this geometry at 6 kV extraction voltage, over 3 mA beam current would be achievable, provided the emitting material is capable of that. A similar test of the TEXTOR Li-beam source revealed 2mA maximum current at 35 keV beam energy.

Development of a new emitter

As it was shown the beam current is limited by the emitter, and as it was quoted in the introduction, the applications of Li-beam diagnostic would require higher beam current. Experiments have been started 2 years ago using a new emitter design and various materials and a new (cylindric) ion-extractor geometry to measure simultaneously the temperature of the surface of the emitter and the beam current, see the right plot of Fig. 3. The reflector electrode is develed cylinder with a 20?? mm diam. hole in the middle. The extracted ions are accelerated towards the reflector which deflect them to the wall. The secondary electrons resulting from the ion impacts on the wall are gathered by (and measured on) the reflector.

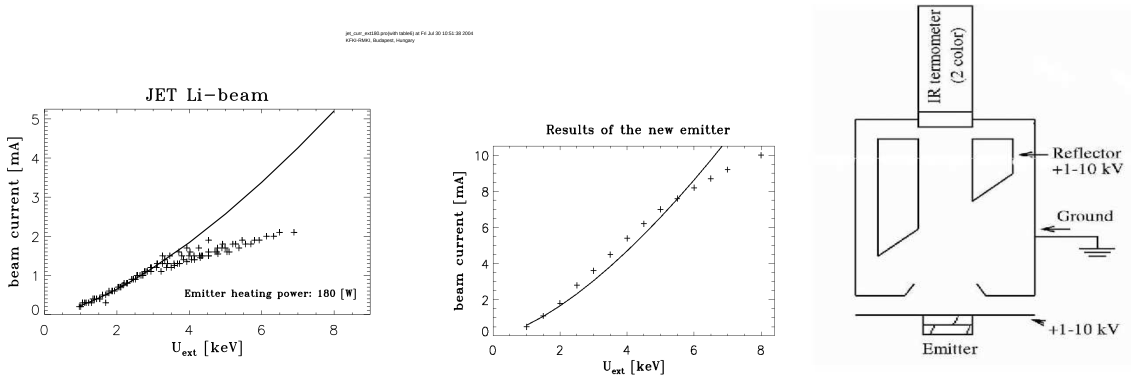

Figure 3: *Beam current vs. extraction voltage and the fitted Child-Langmuir law (left). Beam current vs. extraction voltage for the new emitter (middle). Experimental setup of the testing geometry (right).*

The new type of emitter is manufactured by pressing and heat treating Tungsten powder to form a solid disc. The rest porosity of this is about 30%. Two different ceramic materials, – a basic and a surface ceramic – are molten into the Tungsten disc. For ion emission the most important are the crystal structure and the temperature, consequently we need a micro crystaline structure which is stable and solid on high temperature as well. (The process is being patented.) Heating of this disk up to 1400 ^{o}C is done by radiation of a heated tungsten filament behind it or by electron bombardment. The measured current can be seen on the middle plot of Fig. 3. The maximum extracted current is at about $10mA$, the current density is about $7mA/cm^2$.

Beam simulation at high beam current

To know whether the usually used ion optic geometries can focus higher beam current or not computer simulations have been started a year ago using the AXCEL [5] beam simulation code. The code can calculate the space charge effect of the ion beam. Simulation were done for the TEXTOR Li-beam source geometry. It has to be noted that the principle of the ion optic for many of the recently used Li-beams (JET, ASDEX UPGRADE, TEXTOR) is the same. Consequently the results are useful for all of these guns as well. The outcome is notable: the beam diameter increases with increasing beam current, but it has a maximum at about 25*mm*, see Fig. 4, and this point corresponds to the beam emittance as well. The reason of this could be the increasing electric field when the ions approach the electrodes. A limiting factor for the ion beam diameter is the 40*mm* hole of the accelerator tube. In these simulations the space charge was fully compensated behind the electron suppression ring (free flight region) to take into account the experimentally observed behaviour.

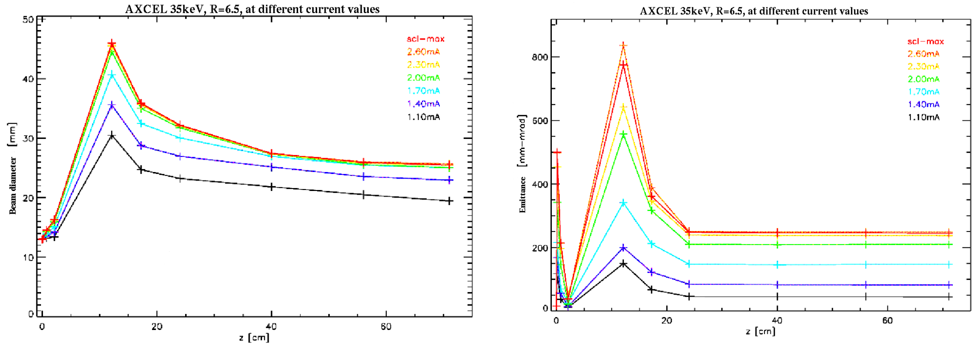

Figure 4: *Beam diameter along the z-axis at different current values (left). Beam emittance at the z-axis at different current values. (right).*

Discussion

Laboratory tests of the JET and TEXTOR Li-beam sources showed that - with the currently used ion source - these guns can achive only about 2*mA* and 1*mA* beam current, respectively, but in the given geometry and extractor voltages considerable more current would be extractable in both cases. The new emitter has $7mA/cm^2$ emission capacity, and it has been tested at IPP Garching in the JET duplicate Li-beam injector. The measured beam current followes the Child-Langmuir law. Beam simulations show that the presently used Li guns can focus higher beam current with a slightly larger beam diameter. Subsequently we have the opportunity to increase the beam current of the Li-beams, and thus to evaluate the data with more accuracy and with higher time resolution.

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