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Diagnostic Arc Source of Neutral Lithium Beam

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Abstract
The paper describes a small diagnostic source of Li, Mg and Al atoms. Atoms are produced by a controlled arc discharge using a hollow cathode to prevent the emission of microparticles released from the cathode spots into tokamak plasma. Using an electrostatic and time-of-flight analyzers, the mass and energy of the atoms were determined.

Key words:
corpuscular diagnostics, arc discharge, lithium beam, time-of-flight analysis.

1 Introduction

Probing of the tokamak plasma by beams of lithium atoms is an efficient tool for determination of basic plasma parameters. In particular, registration of a resonant line intensity along the path of the low energy Li beam allows to determine the edge density profile [1]. Such information is essential e.g. for studying of the particle transport in this region, which plays an important role in the global confinement.

Probing of the edge plasma by a thermal beam of Li atoms has already been performed on CASTOR tokamak [2]. However, to avoid technical difficulties connected with the operation of the oven heated to temperatures more than 500^oC and moreover, to have a more flexible source, an attempt to develop a small compact impulse source of low energy Li beam was carried out, see Sec. 2. The source is a modification of the hollow cathode arc discharge with electrodes made from Li-Mg-Al alloy (Li:Mg:Al=2.2:5.0:91.1; Al allows in principle to determine the edge electron temperature). Due to its small dimensions the source can be used for probing of the edge plasma practically in all directions. The primary application on the tokamak CASTOR should be the determination of density changes in the front of lower hybrid grill antenna.

Because the knowledge of injected beam properties is a primary requirement before the source application for diagnostics purposes [1], the Sec. 3 is devoted to the determination of composition and energy distribution of particles in the beam escaping the source. Sec. 4 summarizes the results and the experience with the source operation.

2 Description of the source

As it has been already shown on tokamak CASTOR with a controlled arc source [3], the particles are generally released from such source in the form of neutral atoms and microparticles. The microparticles, however, represent in tokamak an additional, undefined source of neutral atoms due to their ablation by the plasma electrons. Using a hollow cathode as a discharge chamber in our case [4] the penetration of the microparticles in tokamak plasma has been successfully prevented. Ions released in this case are removed from the beam during the diagnostic application on the tokamak due to the strong magnetic field. However, their existence in the arc plasma can change the energy spectrum of escaping neutral atoms substantially and existence of a group of neutrals with energy up to or even more as arc voltage can be expected.

The schematic arrangement of the source with the electrical supplies is given in Fig. 1. As a source of arc energy is used a condensor bank up to $1.6mF$. Triggering of the arc is realized by an auxiliary high voltage (15kV) low energy spark. The inductance $20\mu H$ is used for achieving a more quasistationary course of the discharge parameters, see Fig. 2, where time evolutions of arc voltage and current under conditions $C = 600\mu F$, $U_a = 300V$ are given. It may be seen that typical parameters of the arc discharge during its quasistationary phase are following: $U_a = 25V$, $I_a^{max} = 940A$, the arc duration $\tau \leq 450\mu s$. It must be noted, however, that there is a relatively high dispersion in these parameters and so the poor reproducibility of the discharges maybe, without further improvement, a major drawback for utilization of this source on the great tokamaks.

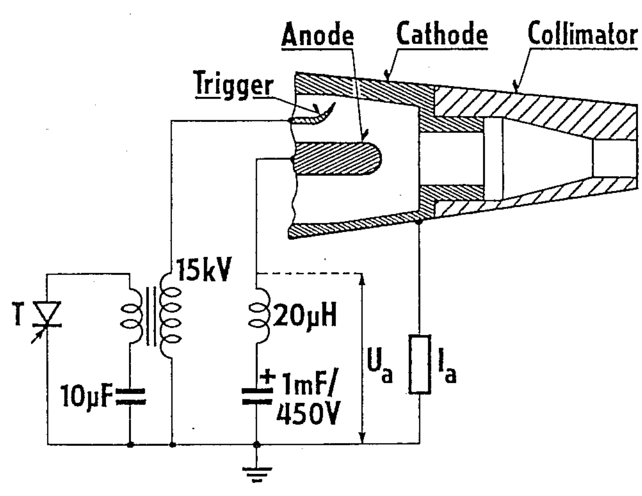

Figure 1: Schematic arrangement of the impulse arc source with the electric supplies.

The source has been preliminary tested on CASTOR tokamak, without any knowledge of Li atoms velocity distribution. Using CCD camera, the radial profile of resonant line LiI (607.8 nm) was registered (with integration time 1 ms). Fig. 3 shows radial electron density profile enumerated from LiI intensity under assumption of (i) thermal velocity distribution with one temperature 1500K only, (ii) existence

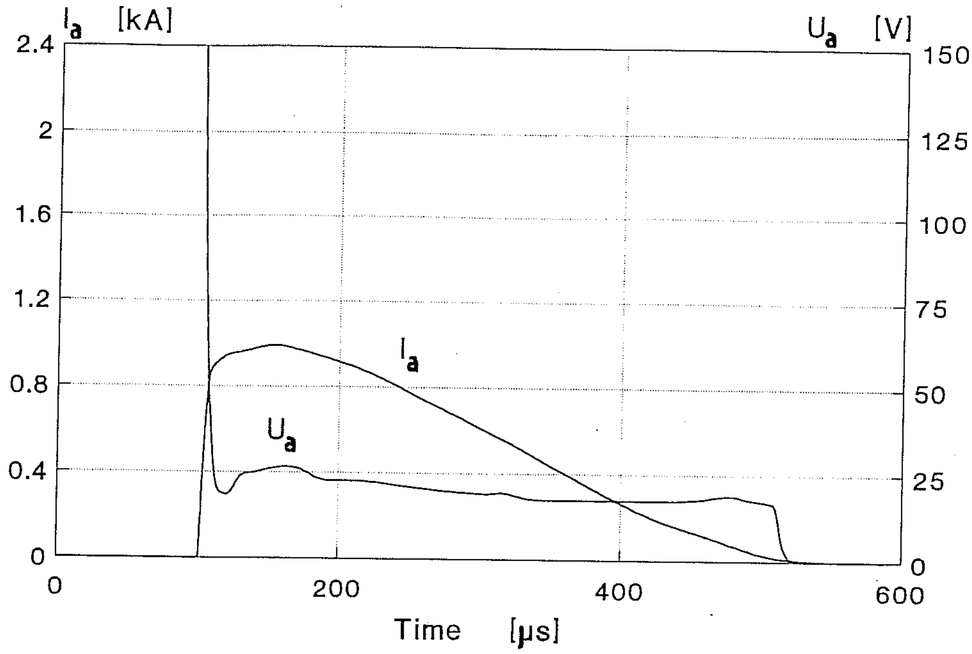

Figure 2: Time evolutions of arc voltage and current.

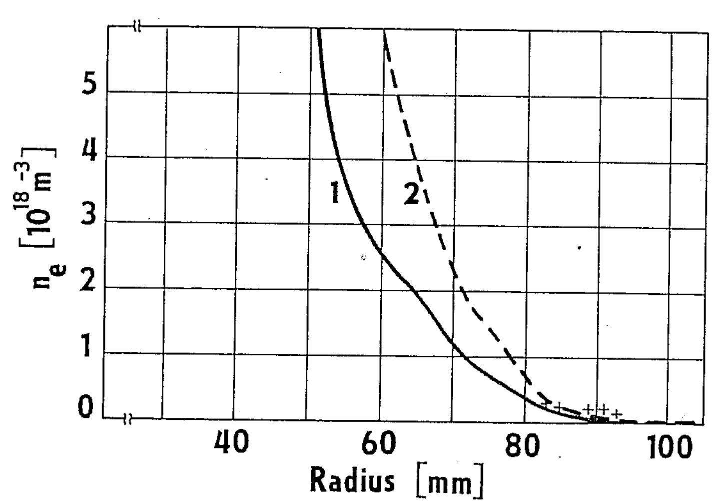

Figure 3: Radial electron density profile on CASTOR tokamak enumerated for the maxwellian distribution of the Li atom beam with temperature 1500K (curve 1) and for two-temperature distribution with 1500K and 40eV (curve 2). The crosses are data obtained by Langmuir probe.

of two groups of thermal particles with the same density and temperatures 1500K and 40eV. The probe data obtained in limiter shadow are given for comparison in the figure as well. The importance of the real velocity distribution of the beam particles can be deduced from the figure.

3 Analysis of the beam properties

A determination of the beam composition and particles velocity distribution represents in the case of impulse arc source rather complicated task. Because it may be supposed that neutral and ion components in the beam are in close relation, we have begun with the measurement of the ion component using an electrostatic analyzer in combination with time-of-flight analyzer [5], see paragraph 3.1. Afterwards, using a time chopper (rotating slot) and deflecting plates, some estimates concerning the neutrals has been made, see paragraph 3.2.

3.1 Ion component

The experimental arrangement is schematically shown in Fig. 4. The pulsed electrostatic analyzer determines the energy of registered ions (twice ionized ions have double energy) and the time of injection of the ions into the drift tube (i.e. gives a possibility to measure the spectrum time evolution). The time of flight through the drift tube (length 1.7m) determines the ion mass. Using an acceleration of the ions in the detector to the energy 3kV, the low energy ions are registered as well (on the contrary to the neutrals).

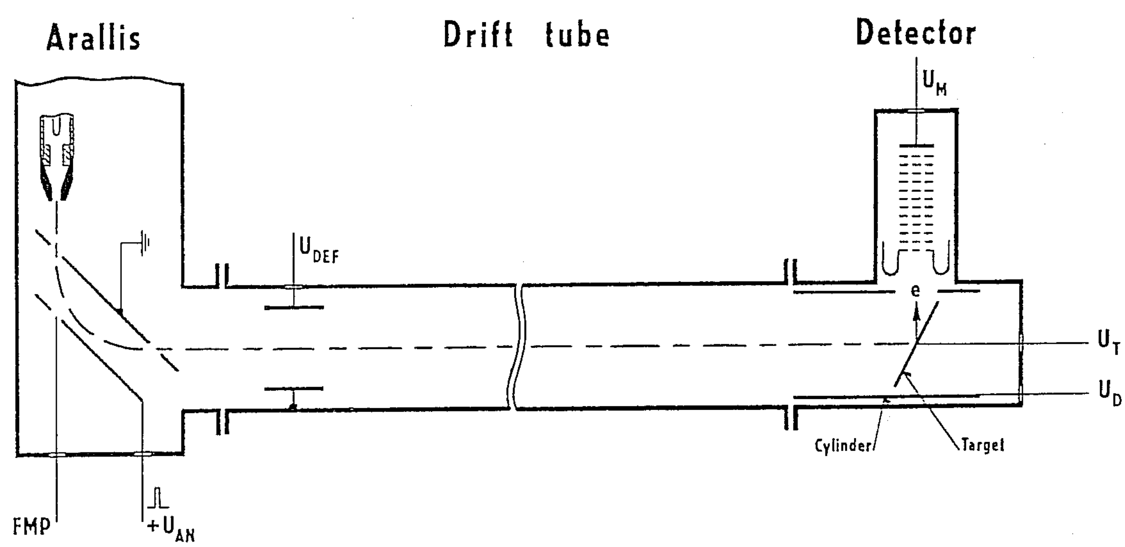

Figure 4: Schematic arrangement of the stand measurement with electrostatic and time-of-flight analyzers.

An example of the ion mass spectrum for energy 40eV is given in Fig. 5. The spectrum was obtained in the quasistationary discharge phase (40μs after the arc start-up). The following mass number, in concordance with the cathode composition, are registered: Li^+ (M=7), Al^+ and Al^{++} (M=27) together with Mg^+ and Mg^{++} (M=24).

The Fig. 6 gives rough range of all energies occurring in the beam, regardless on the mass of ions. This result was obtain from shot to shot, varying the DC voltage applied to the electrostatic analyzer. It may be seen, that the energies comparable or even greater than the arc voltage are present predominantly (the limits of the energy region are taken as decrease of the signal ten-times). This fact can be explained by existence of twice ionized ions of Al and Mg [6,7] and by electrons collisions and gas dynamic forces [8].

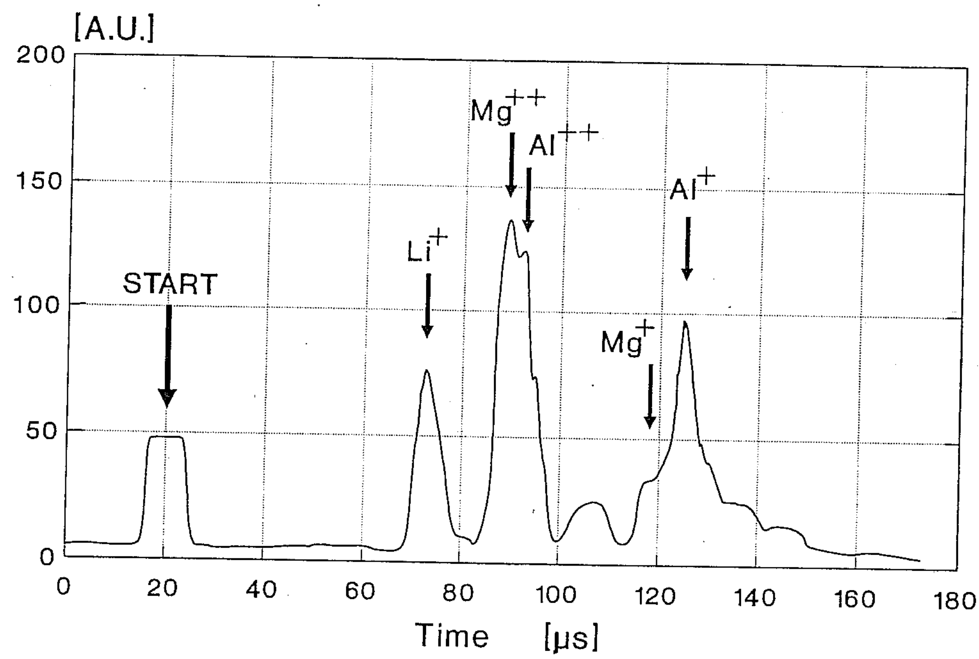

Figure 5: Ion mass spectrum of the beam in the moment $40\mu s$ obtained with apparatus shown in Fig.4 for energy 40eV.

3.2 Ion and overthermal neutral components

For this purpose only time-of-flight analyzer equipped, however, by a time chopper was used, see Fig. 7. By the biasing of the deflection plates the ions can be removed from the beam and the neutral component can be analyzed. In this case, however, the lowest detectable energy, sufficient to produce a secondary electron in detector, is $E \geq 20eV$ only. Energy resolution of the analyzer $\Delta E = 2(\Delta t/t)E$ is given by the shutter opening time Δt (about $10\mu s$ in our case). The results are given in Fig.8 and 9. The time-of-flight analysis is performed in the maximum of the arc discharge current approximately. Fig. 8 shows the detector signal produced by ions and neutrals together, Fig. 9 represents the signal produced by neutrals only. It may be seen, that in both cases the energies up to 100eV are present in the analyzed beam. In comparison with chemical composition of cathode material, however, the concentration of Li ions seems to be favourably enhanced by a factor of about 5.

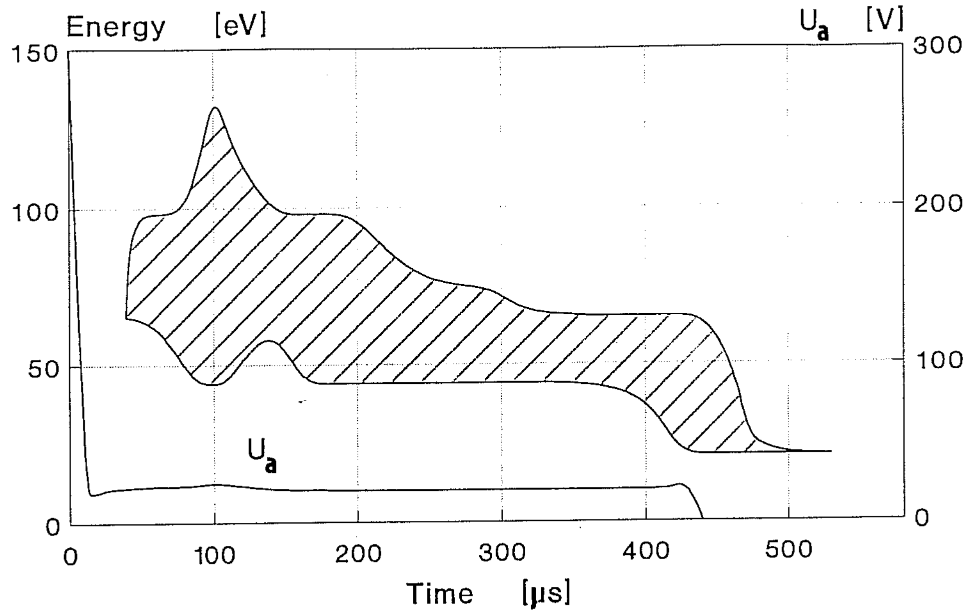

Figure 6: Time development of the range of beam ion energies during the arc discharge.

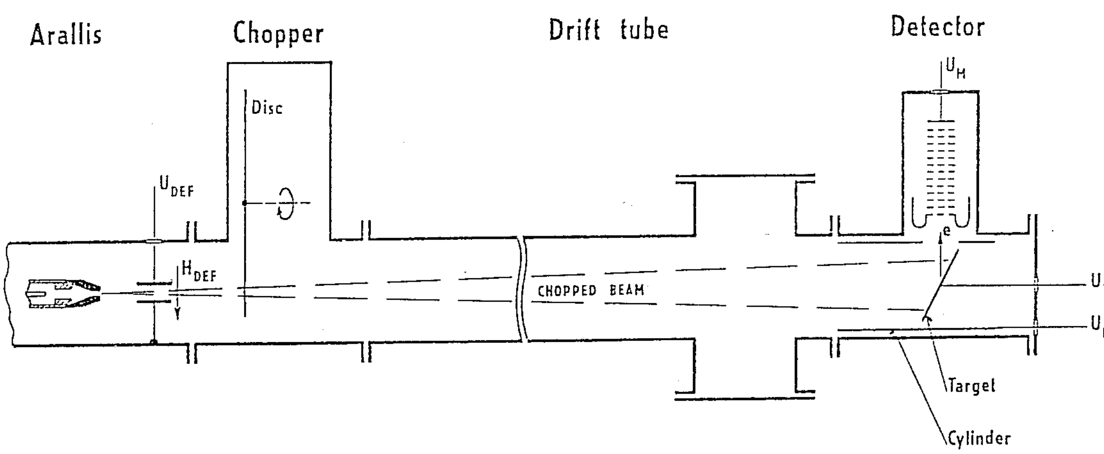

Figure 7: Schematic arrangement of the stand measurements with time-of-flight analyzer equipped by a time chopper.

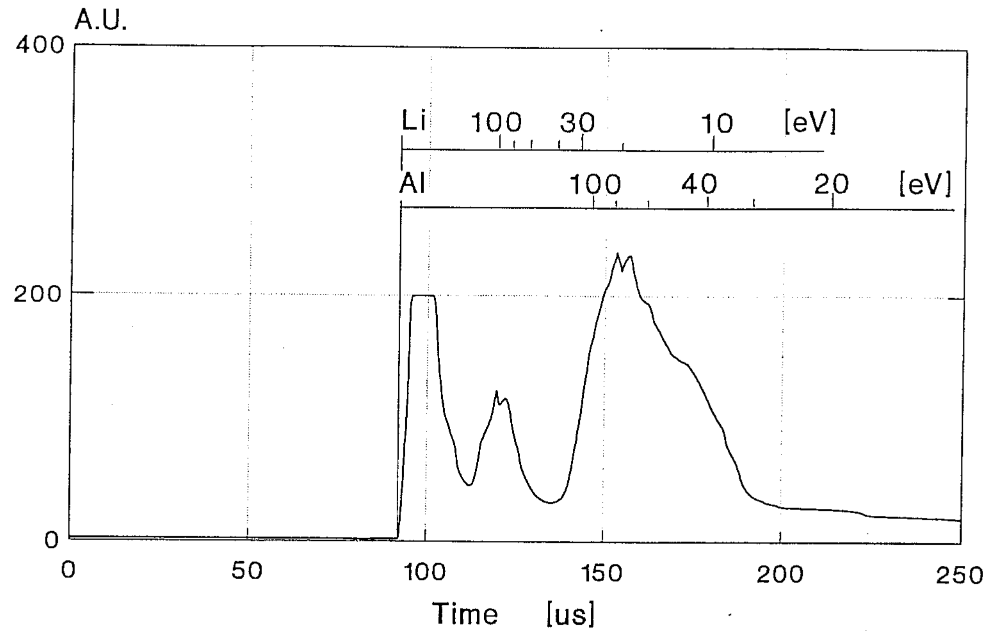

Figure 8: Detector signal from the time-of-flight analyzer produced by both ions and neutrals.

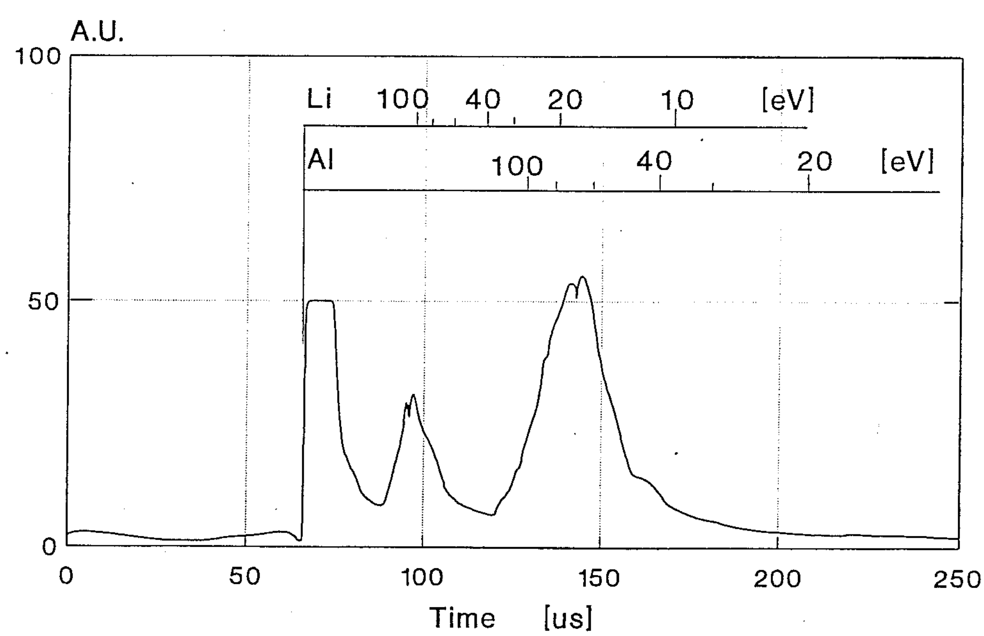

Figure 9: Detector signal from the time-of-flight analyzer produced by neutrals only.

4 Conclusion

The results of the mass and energy analysis of the particle beam generated by the described diagnostic source can be summarized as follows:

- the ion beam component consists of $Mg^+, Mg^{++}, Al^+, Al^{++}$ and Li^+ ions, i.e the elements of cathode alloy [9]; it seems, however, that in comparison with the alloy composition the density of Li^+ ions is favourably enhanced;
- these ions have a broad energy spectrum with the energies even exceeding the arc voltage;
- together with Li^+ ions a relatively well detectable amount of Li neutrals with energy up to 100eV has been found; this fact complicates the electron density evaluation and the ratio of these energetic neutrals density to the thermal neutrals density must be still quantitatively determined.
- unfortunately, the operation parameters of the arc discharge are not quite well reproducible; the reproducibility depends in some extent on the regularity of the shots repetition and moreover it achieved an optimum after certain number of shots.

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