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ACCELERATION OF Li^{3+} IONS AT THE INS 176 cm SF CYCLOTRON

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Abstract.- An internal cold-cathode Penning ion source has been developed at a cyclotron to accelerate Li^{3+} beams. A good intensity up to 2 μA has been obtained and used for nuclear physics experiments. Source design, experiences during operation and results of improvement tests are described.

1. Introduction.- Nuclear physics experiments by using Li-ion beam have been carried out extensively in recent years, because of the simple structure of the Li nucleus. Most of the experiments have been done with the beam energies around 30 MeV, delivered from tandem Van de Graaff accelerators. The emphasis in nuclear physics with Li-induced reactions, however, has been shifting to experiments requiring higher beam energies. In order to meet such experimental needs, fully stripped Li ions were to be accelerated in our cyclotron, since its maximum energies are limited by the magnetic field to K=68. For the acceleration of Li^{3+} ion, an internal heavy-ion source of cold-cathode PIG type with a sputtering anode was developed at the INS SF cyclotron.[1)] A block of single-crystal LiF was used for the charge material. The source can produce rather high intensity of Li^{3+} beam in spite of its simple structure and has been used for nuclear physics experiments[2)] over one year. Experiences during operation and results of some improvement tests are described and discussed.

2. Ion source design.- The source design used in the present work is shown in Fig. 1. Though it is similar to the source described in Ref. 1), it has been slightly modified to improve reliability for high charge-state performance. The bore diameter of the source shown in Fig. 1 is 6 mm, which is smaller than the previous one.[1)] Sources with anode bore diameters of 5 mm and 8 mm were also tested, and a comparison is described in the next section. The cathodes are made of Ta, 8 mm in diameter. The lower part of them is only put in the holder, while the upper part is sustained by a graphite ring set on the holder. Their loose contact with the holder without set screws permits better heat insulation of the cathodes and gives lower operating voltage, resulting in longer cathode life. The source slit is 3 mm in width and 10 mm in height. The beam intensity depends, to a large extent, on the width of the source slit, because of the RF back bombardment mechanism. Xenon was used as a supporting gas. Argon gas was also tested, but Xe was found to be better. A block of the source material to be ionized, $8\times6\times12$ mm^3 in size, is set in a copper holder and attached to the chimney facing the extraction slit. The holder is cooled only indirectly through the contact with the anode chimney. For the source material, we used lithium fluoride single-crystal. This material has a lot of advantages compared with the polycrystalline LiF powder which is commonly used as the source material for Li ions: high density, large heat conductivity and easiness of machining. The source material was carefully positioned to cover almost all impact area of the xenon ions accelerated back into the chimney. The source was operated normally in pulse-arc mode with a duty factor of 33 %, 1-msec pulse length and 3-msec period, which seems to be an optimum choice.[3)]

3. Performance and discussion.- The intensity of Li^{3+} ion beam extracted from the cyclotron depends on many parameters: conditions of the ion source itself, relative position between the ion source and the accelerating electrodes and tuning conditions of the cyclotron. It is rather difficult to extract unambiguously the dependence of the beam intensity on some of the parameters, especially due to the complex ionization process of the RF back bombardment mechanism.

In fact, although simple calculations of the orbits of Xe ions gave general agreement with the experiments,[1)] it is still hard to say that the optimum conditions have been fixed in detail for this source. In practical points of view, however, it is important to study the trend of the parameter

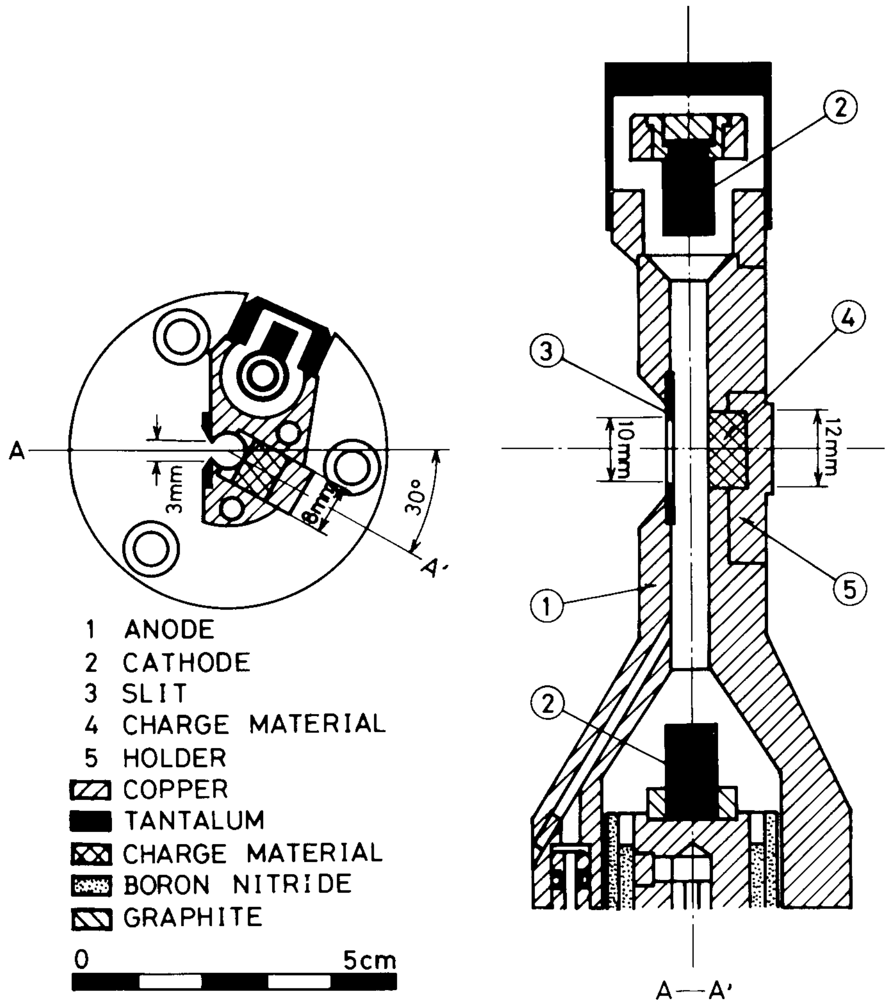

Fig. 1: Cross section views of the cold-cathode PIG source for solid material.

dependence of the beam intensity qualitatively and quantitatively if possible, for assuring and improving good source performance. In the following, examples of our heuristic trials and experiences are described.

There is an optimum arc power at a given gas flow rate. The optimum power depends not only on the gas flow rate but also on the time from the start of the arc. Figure 2 shows a comparison of the beam intensity obtained at different arc power for three different sources with anode bore diameters of 5, 6 and 8 mm. It is evident that the beam intensity at the optimum arc power is higher for the sources with a smaller diameter of the bore. The ratio of beam intensities is about 1(8 mm): 2(6 mm): 3(5 mm). The typical lifetime of the source with the 5 mm diameter, however, is shorter than those with larger diameters: they are about 5-8 hours for the sources with 6 and 8 mm bore diameter, while for the one with 5 mm is less than 5 hours. A compromise between the intensity and the lifetime may be a choice of a 6 mm diameter. The time of a complete consumption of LiF is much longer than the lifetime of cathodes.

The source is normally operated under pulse-arc condition. At present there is only limited experience with dc-arc conditions, but beam intensity for the pulse-arc mode is usually about two times larger than that for the dc-arc mode.

Optimum gas flow rate was found to be less than about 0.06 cc/min and gradually decreases with time.

When the supporting gas Xe was replaced by Ar, the intensity decreased slightly (by about 30 % or less). This difference seems to be caused by the difference of sputtering efficiency for both gases at a given condition.

The intensities for different maximum energies are compared at 50, 75 and 90 MeV. At 50 MeV, intensity decreased considerably in comparison with other energies. One of the reasons of the decrease seems to be due to the insufficient impact energy of Xe ions to produce sufficient sputtering, because our cyclotron is operated under a constant orbit condition and the dee voltage is decreased with decreasing energy.

Use of a larger source slit enhances

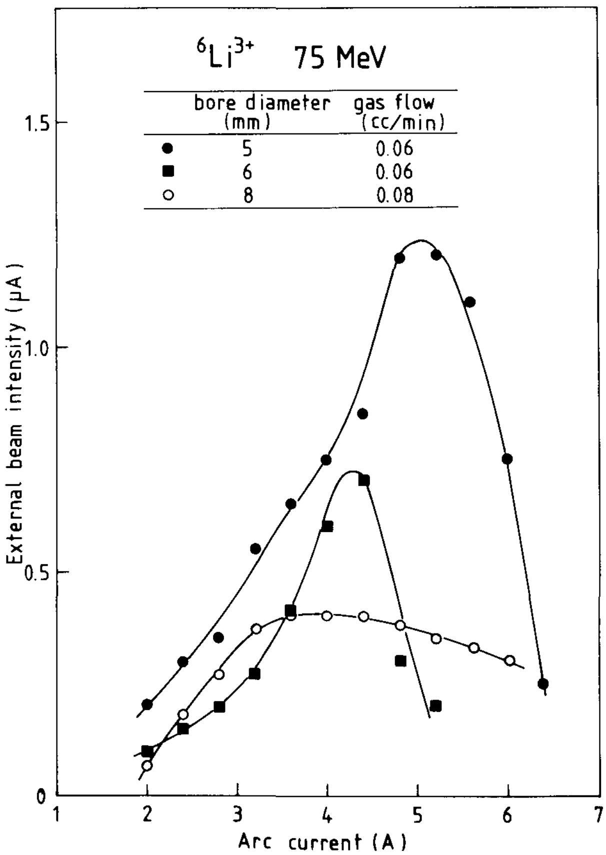

Fig. 2: Examples of the relation of external beam intensity versus average arc current for sources with different bore diameters. Average arc voltage for the pulse mode operation is about 250 V. Dee voltage is 61 kV. LiF crystal enriched in ^{6}Li (95 %) was used as the sputtering electrode and Xe gas was fed to the source.

intensities greatly in comparison with a gaseous ion source. The sensitivity of intensity on the slit width may be related to the trajectories of Xe ions: the returning position of Xe ion is different from the starting position on the slit.[1] The consumption of the Ta slit plate is quite heavy and it has to be changed every two runs of cathode change by a new one.

External beam intensity depends on the time from the start of the arc. At the early stage of the source, we sometimes obtain high external current up to 2 μA, but it usually decreases with time. The maximum intensities also change on various conditions. Axial rotation of the source relative to magnetic flux which we can not control seems to have an important role and further study might improve reproducibility of high intensity condition.

Under some operational conditions, the surface of the LiF is covered by sputtered Ta layer, which prevents erosion of the source material. The reason of this kind of behavior is still not well understood.

After running the source, the chimney was usually soiled heavily with sputtered Ta which was used as the cathode. The cleaning of the used chimneys is a difficult and laborious work. We normally clean them up by dissolving Ta in a solution of hydrofluoric acid (46 %). Since the dissolving speed of the sputtered Ta is much faster than that of copper, only the Ta can be removed almost completely from the chimney in half an hour. After this treatment, the chimney is washed in water. This is a very easy and reliable method.

Li ions were accelerated by using this ion source for about one month in total in the past one year. We had no serious damage on the cyclotron components by the Li except one case. In this occasion, the dee and the electrodes in the central region were contaminated with a considerable amount of Li atom. The dust on the earth plate in the central region was chemically analyzed and Li of about 0.6 % in weight was found in it. Sparkings on the dee electrode prevented to hold a dee voltage above 50 kV without ion loading, although dee voltages up to 80 kV are usually possible without great difficulty in our cyclotron. The reason of this contamination is not clear but it is suspected that the arc hitted directly the LiF block and a macroscopic amount of Li atom was sputtered or evaporated out of the source. The normal condition of the cyclotron was recovered completely by cleaning the electrodes. Except this trouble, no evident deterioration of the cyclotron components has been experienced so far.

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