EXPERIMENTS ON A 14.5 GHZ ECR SOURCE

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Abstract

The 14.5 GHz ECR4 source supplied to CERN in the framework of the Heavy Ion Facility collaboration provided Pb^{27+} operational beams to a new custom built linac in 1994. This source, which operates in the pulsed "afterglow" mode, quickly met its design specification of 80 eμA and now provides currents >100 eμA regularly. Early source tests showed the existence of extremely stable modes of operation. In the search for higher intensities a number of experiments have been performed on plasma gas composition, RF power matching, extraction, beam pulse compression and a biased dynode. The results of these tests will be presented along with further ideas to improve source performance.

Introduction

CERN's original proton linac was shut down in 1992 after a final light ion period with sulphur ions. It was dismantled and construction started, on the site, of a new heavy ion linac (Linac3) intended for the acceleration of lead ions. This machine was built by an international collaboration involving GANIL, Caen (ion source); INFN, Legnaro (low energy beam transport and RFQ); GSI, Darmstadt (Interdigital-H linac and some RF systems); INFN, Torino (high energy transport and filtering); IAP, Frankfurt (debuncher), and CERN and assistance from Sweden, Switzerland, the Czech Republic, India. In June 1994 the first beam was passed to the next accelerator in the injector chain, (the booster synchrotron) and in October beam was given to the physics experiments for a nine week operational period.

An ECR (Electron Cyclotron Resonance) ion source was chosen for the project. Although the ECR was originally developed for continuous operation, the afterglow phenomenon can be exploited to give short pulses suitable for synchrotron operation of high charge state ions [1]. In the optimisation of the design of the new facility the output energy of the linac was defined to be 4.2 MeV/u for Pb^{53+}, a charge state that is beyond the reach of normal ECR sources. Thus stripping at the end of the linac was necessary. Further design optimisations indicated that at least 80 eμA of Pb^{25+} would be required from the source.

GANIL performed tests on their ECR4 (Fig. 1) source and showed that enhanced intensities of highly charge lead ions could indeed be obtained at 2.5 keV/u (approximately 20 kV total) in the afterglow mode of operation which satisfied the criteria of:- a) intensity >80 eμA; b) adequate useful beam length; c) pulse to pulse stability; d) emittance. In fact, to limit the X-ray emission from the linac cavities which were designed for 25+, the charge state 27+ was chosen for operational purposes whilst still meeting the intensity criterion.

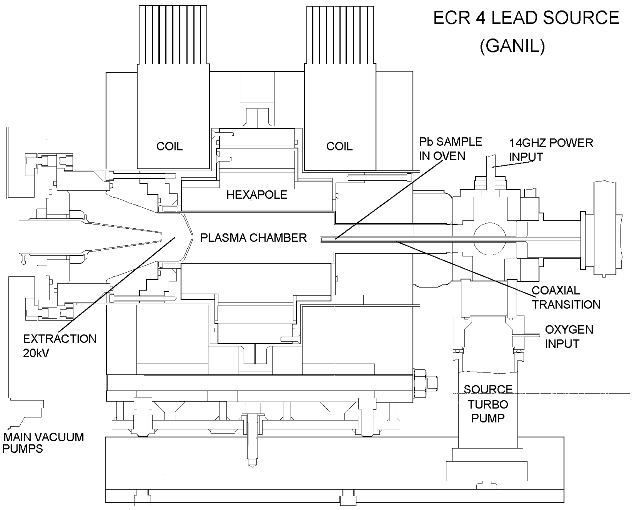

Fig. 1. The ECR4 source used at CERN.

Early Tests

After commissioning of the source at CERN using the GANIL test settings, 65 eμA of Pb^{27+} was measured in a Faraday cup after analyser magnets. Improvements to the vacuum of the beam line and an extensive optimisation of the source showed that about 100 eμA could be obtained (Fig. 2(a)). During a search of the source parameter space, a new operating point was found. At lower magnetic fields, the

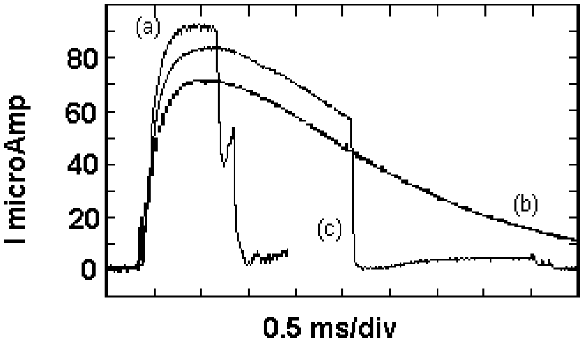

Fig. 2. Different types of afterglow: a) optimised initial, b) stable mode, c) typical operational beam

afterglow pulse became very smooth and stable with a decay tail of several milliseconds (Fig. 2(b)). The pulse rise time was of the order of 500 µs and the plateau acceptable Although the intensities were somewhat lower than the GANIL mode, a compromise could be found which retained the extreme stability on a pulse to pulse basis whilst keeping a good plateau (Fig. 2(c)). This stability proved to be invaluable in the setting up of the following accelerators [2]. A reproducible operating current of around 80 eµA was adopted as standard during the first (1994) physics run.

Extraction Gap

Initially an extraction gap of 42 mm was used in the source. Various tests have been carried out to investigate the optimum gap. In each case the source, and beam transport, was optimised for maximum intensity and stability of the beam. The results of these tests are summarised in figure 3. During the 1995 physics run the 47 mm gap, with 120 eµA of Pb^{27+}, was retained. Further tests on the gap are needed for other extracted currents and charge states.

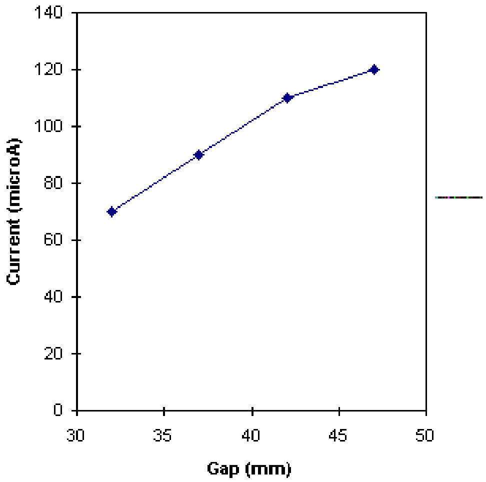

Fig. 3. Pb^{27+} current variation with extraction gap.

Gas Mixing

It had been suggested [3] that the replacement of oxygen as the pilot gas by neon should give rise to an improved intensity and an increase in the mean charge state. Extensive tests showed that the current of Pb^{27+} could not be increased using neon. Currents approaching those obtained with Pb/O_2 operation could be reached, however the stability and duration of the afterglow pulse were reduced.

After a long period of operation with pure neon it became evident that at least a small amount of oxygen is required for Pb/Ne operation: after approximatly 24h it was not possible to start the discharge at the pressure required for high charge state production.

A significant difference between Pb/O_2 and Pb/Ne operation was found when the source parameters were optimised on Pb^{30+} production (Fig. 4). In both cases the current of Pb^{30+} was 70µA. The maximum of the CSD was increased to 29+ for neon operation, while it remained at 27+ for oxygen. Initially a similar result was found for an optimisation on the Pb^{32+} peak. The maximum of the CSD was moved to Pb^{30+} for Pb/Ne and to Pb^{29+} for Pb/O_2 operation. However, after a period of four weeks of operation with oxygen it could be shown that the maximum of the CSD can be shifted to 31+ for Pb/O_2 operation (discharge optimised for 32+). The Pb^{32+} current was 80µA in this case while the best result for Pb/Ne was 50µA.

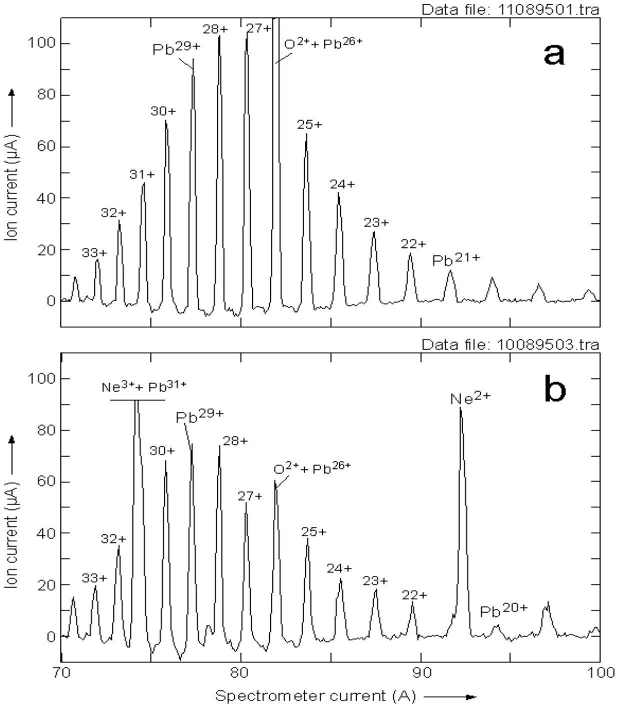

Fig. 4 . Comparison of charge state distributions (CSD) of lead ions a) using oxygen as carrier gas, b) using neon and residual oxygen as carrier gas. (Source parameters optimized for maximum current of Pb^{32+} in both cases)

RF Tuning Effects

Microwave power is injected into the source via a tuned waveguide to co-axial transition. To obtain the best output and stability from the source, the optimum tuning of the transition was not necessarily that which gave the minimum reflected power. Additionally, other tuning points could be found which either gave similar, or reduced, performance within the range of the tuner. Certain operating points also gave rise to increased X-ray emission from the source.

Fig. 5 shows a comparison of the current during the afterglow with the current during the main pulse for the full tuning range. In a first approximation the two curves are complementary, i.e. if a high afterglow peak is obtained the current is low during the heating phase and vice versa. This is especially pronounced at position 4920 in Fig. 5. The

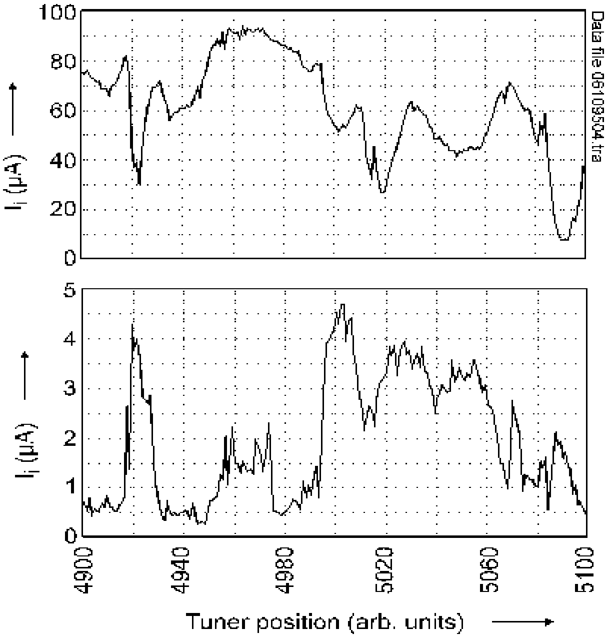

Fig. 5 Pb^{27+} current as a function of tuner position: a) current during afterglow, b) current during main pulse

maximum for the afterglow is found at position 4968, although the base current also goes through a maximum at this position.

It should be noted that the shape and duration of the afterglow are also a function of the tuner position, so that a peak on Fig. 5 does not necessarily indicate a stable operating point. Furthermore the curve is influenced by the various source parameters and it changes with time, so that an optimisation is required at regular intervals.

Dynode Bias

The inner conductor of the co-axial transition which contains the sample oven and which penetrates into the plasma chamber (see Fig. 1) is known as the dynode. In another ECRIS for sulphur ions, the presence of a biased electrode in the plasma gave improved performance and stabilised the afterglow [4]. It had been reported that biasing the dynode in an ECR4 source also enhanced the yield of ions [5]. The original lead source dynode was a 6/8 mm copper tube but became a 10/8 mm tube in a biased configuration. Initial tests showed that it was impossible to control the source output using the oven heating as a parameter. The oven temperature is influenced by RF losses on the dynode, RF heating of the oven and resistive heating. There were indications that the lead neutral pressure in the source was too high and examination of the sample showed that it had been overheated, giving rise to a too high lead vapour pressure in the plasma chamber.

The dynode bore was reduced to 6 mm, as in the original electrode, and a much improved control of the oven was obtained. The source was optimised with zero bias, new RF tuning points and magnetic fields had to be found. It was immediately obvious that the source was much more temperamental and that all parameters had a very much reduced tolerance. The optimum RF tuning was now very sharp and just off the limit of stability. Satellite tuning points whilst more stable gave only 50% of the peak intensity.

Although it proved possible to optimise the source under these conditions, no gain in Pb^{27+} current was observed. Application of a negative bias to the dynode resulted in a loss of current, an increase in instability and beam breakup and a change in beam shape when the bias exceeded 50 V. These instabilities were also present in the microwave reflected power. As the bias increased above 200 V, the current appeared to climb again but isolation and sparking limited the bias that could be used reliably. Positive bias reduced the beam dramatically. However, it did prove possible to find a low magnetic field setting which reduced instabilities but without an improvement in intensity.

It was noted that for O^{2+}, the current in the afterglow, which is not very pronounced relative to that in the main discharge, tended to decrease whilst the main discharge current increased. It may be asked if the bias was insufficient relative to the ionisation potential of Pb^{27+} (874 eV).

Future Plans

Further tests are desirable (subject to operational restrictions) to examine the effects of various ideas to increase the yield of the Pb^{25+} and Pb^{27+} ions. Experiments are only interested in particles not electrical intensity so an increase in charge state from the source is not of interest unless the intensity gain is dramatic. Going to lower charge states is excluded in the linac design. Investigations that could be of interest are:- extraction gap with current and ion species, continuation of the biased electrode tests, plasma chamber wall materials, sample composition and plasma gas effects.

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