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PROCEEDINGS

Status of the Warsaw ECR ion source and injection line

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Abstract A room temperature home built 10 GHz ECR ion source delivers beams of B, C, N, O, F, Ne, S, Ar to the Cyclotron U200-P. The same ion source has also been used for surface irradiation of the solids. To upgrade the ion source and increase the ion current in the cyclotron an oven for evaporation of solid materials has been constructed and a two gap buncher has been installed in the injection line. Some new observations on the influence of the extraction system on the ion beam current will be presented.

Key words axial injection • Electron Cyclotron Resonance (ECR) • highly charged ions • implantation • ion source • ion transport

Introduction

Energy per nucleon of the ion beam extracted from the last orbit of a cyclotron is proportional to the square of the radius of a magnet, square of magnetic field and square of the ion charge to mass ratio $\{E/\mathrm{A} = 48.24(\mathrm{B}\rho)^2(q/\mathrm{A})^2, E[\mathrm{MeV}], B[\mathrm{T}], \rho[\mathrm{m}]\}$. Increase of the magnetic field and magnet dimensions is expensive and sometimes impossible. The production of highly charged ions by the ECR sources was the reason for the application of ECR sources as external ion sources for cyclotrons. The properties of ECR sources allow for surface and atomic physics research with the low energy, highly charged ion beams of stand-alone ECR sources.

The Warsaw ECR ion source (Fig. 1) with 10 GHz generator was built at Heavy Ion Laboratory (HIL) in 1996, as the first one in Central Europe. Axial injection line, guiding ion beam from the source to the median plane of the cyclotron, was completed in 1997 [3]. This system works almost continuously, delivering to the cyclotron very stable (intensity fluctuations in the order of 2%) beams of B, C, N, O, F, Ne, S and Ar. Recently, the stand-alone ECR ion source has also been used for irradiation of samples for solid state investigations. In order to increase the variety of available beams, an oven for evaporation of solid materials has been constructed. To increase efficiency of ion beam injection into the cyclotron, a two gap buncher has been constructed and installed on the axial injection line. Some new investigations on the influence of plasma phenomena on extraction efficiency have been performed.

Ion source and injection line

The Warsaw ECR ion source is a small, room temperature one. Electron Cyclotron Resonance discharge takes place in a chamber (made of stainless steel, 50 mm of inner

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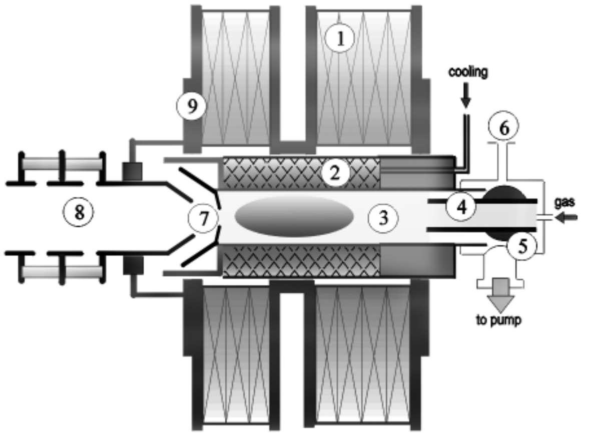

Fig. 1. ECR ion source. 1 – coils; 2 – hexapole; 3 – discharge chamber; 4 – coaxial line; 5 – tuner; 6 – RF injection; 7 – exit hole; 8 – Einzel lens; 9 – yoke.

diameter, 250 mm long) placed in a magnetic field at a strength fulfilling resonance conditions. The chamber is supplied with a working (and sometimes also supporting) gas and RF power. RF power is transmitted from the generator to the discharge chamber via a rectangular wave-guide. The wave-guide is coupled with the coaxial part of the chamber using a home made matching transformer. The magnetic field is created by 8 water cooled coils, fed by 4 power supplies, and an oil cooled hexapole consisting of 12 NdFeB segments. This configuration allows to obtain relevant magnetic profile, tuned for maximum beam current. Created by this way the magnetic trap, keeps the plasma long enough in time to obtain highly charged ions.

Main parameters of the ion source: RF – 9.6 GHz; extraction voltage – 10 kV; max. magnetic field on the axis – 0.65 T and 0.55 T (extraction side); min. – 0.24 T; RF power – up to 300 W.

The 6 m long injection line (Fig. 2) has been designed with a minimum number of optical elements. The first order calculation have been done using TRANSPORT and POISSON codes for the beam emittance of 300 mm·mrad and m/q ranging from 8 to 2. Only axially symmetric elements – Glaser lenses (magnetic field of the lens, from the ion source to the cyclotron: 0.05 T, 0.3÷0.45 T and 0.2 T, respectively) and solenoid (0.13 T), are used. The beam is analyzed and bent by double focusing magnet. In the channel of the cyclotron yoke additionally some passive magnetic elements are applied. To inflect the ion beam on the median plane of the cyclotron, a gridded electrostatic mirror [3] has been designed and used.

In order to decrease or compensate the influence of the stray magnetic field (80 mT under the cyclotron, 5 mT on the ion source level) on the ion beam, the ion-guides are made of magnetic steel and two sets of steering coils are used. The vacuum system of the injection line, consisting of two cryogenic (400 l/s) and four turbomolecular pumps (240 l/s), provides an operating pressure of $10^{-8}\div10^{-7}$ Torr. Transmission from the ion source to the inflector varies from 60 to 80%. Ion beam diameter on the inflector is about 3 mm.

All mechanical elements of the injection line, apart from the analyzing magnet, have been designed and manufactured at HIL.

Recent work

Irradiation of samples

The small set-up for irradiation of samples by ion beams from the ECR ion source has been installed in a diagnostic chamber of the injection line under the bending magnet (see Fig. 2). Polymer membranes [1, 2], stainless steel surface and iron in the form of metallic glass were irradiated using beams of He, C, Ar, N and B. Experiments were performed in order to collect data for investigating the influence of ion beams on electrical and mechanical properties of the solid materials surface.

Oven

The successful tests of home made oven with an external heater were carried out outside and then inside the ion source. The oven is designed for evaporation of materials with low melting temperature (about 500°C). The oven

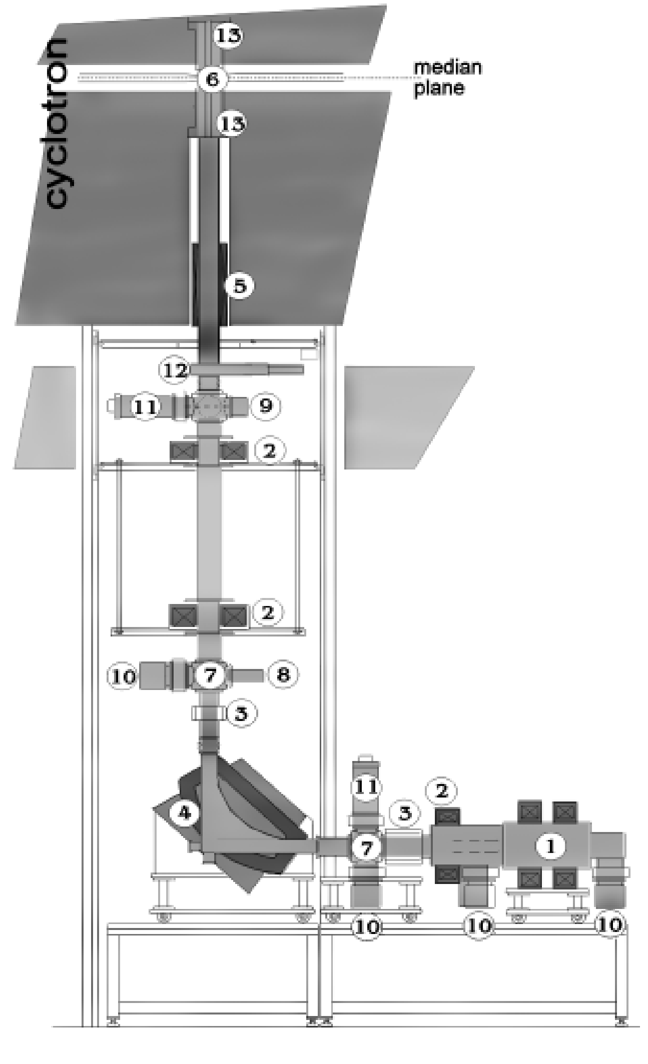

Fig. 2. The injection line. 1 – ECR ion source; 2 – Glaser lenses; 3 – steering coils; 4 – double focusing analyzing (and bending) magnet; 5 – solenoid; 6 – inflector – electrostatic mirror; 7 – slits; 8 – movable Faraday cup and wire detector; 9 – buncher; 10 – turbomolecular pumps; 11 – cryogenic pumps; 12 – main valve; 13 – plugs.

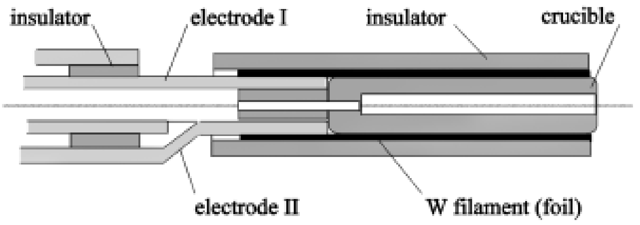

Fig. 3. Schematic view of the oven.

suitable for evaporation of metals with higher melting point (Fig. 3) was manufactured and checked outside the ECR source. The temperature over 1200°C was reached in the crucible. The measurement made by a thick crystal detector indicated that the material deposition was about 2–3 mg/h for Al and about 1 mg/h for Na. Solid angle of the stream of evaporated metal was about 0.5 sr.

First tests with a plasma contact method were performed. The beam of Al ions (over 20 eμA of Al^{3+}, 9 eμA of Al^{4+} and 2 eμA of Al^{5+}) was obtained using He mixed with O as supporting gases.

Buncher

To increase the ion beam intensity of the cyclotron, a two-gap buncher, constructed at HIL [6], has been installed in the axial injection line. The buncher is a sine wave type with a fixed geometry.

Studies of the extraction system

Some observations concerning extraction system (Fig. 4) were done during generation of ion beams of B, N, O and Ne [5]:

– there is a strong relationship between ion beam current and Einzel lens voltage. The influence of this voltage is much stronger than one can estimate using electron optics rules;

– the change of ion beam current with Einzel lens voltage is discrete (Fig. 5). During the beam "breaking" (when decreasing Einzel lens voltage) the profile does not change – so, this is not caused by optical divergence;

– this phenomenon is stronger for lower charge states for all the ion beams listed above, but does not occur for hydrogen. The hydrogen beam current was changed only few percents when decreasing the Einzel lens voltage, but the beam was not "broken";

– this effect is stronger for worse vacuum, so probably it is connected to the impurity level.

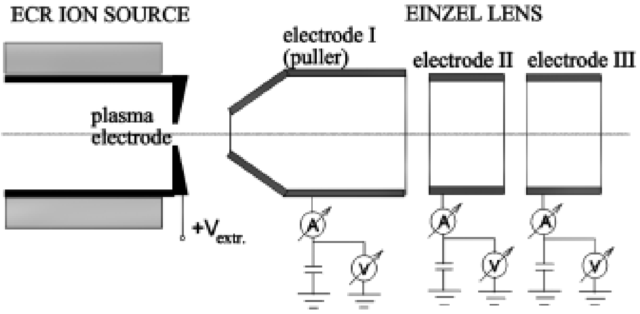

Fig. 4. Extraction system of the Warsaw ECR ion source.

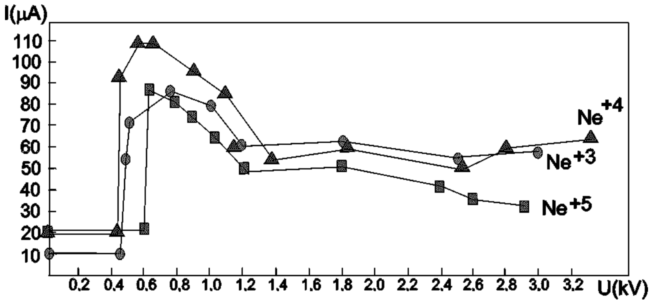

Fig. 5. Ion beam current *vs*. Einzel lens voltage.

The ion source performance depends on plasma conditions, but also on the extraction system. We think that the influence of the extraction system on the ion beam cannot be explained by the one-particle model [4]. In our opinion, the observed phenomenon is caused by the residual plasma discharge generated in the system.

Conclusions

The Warsaw ECR ion source and injection line are operational since 1997. Performance of the ion source (Table 1)

Table 1. Ion beams available from the Warsaw ECRIS: currents in eμA, measured on the Faraday cup (Fig. 2 item 8), *q* – charge state. Transmission between the Faraday cup and the inflector: 60÷80%.

q	3+	4+	5+	6+	7+	8+	9+	10+	11+	12+	13+
^{11}B	57	21									
C		55	6								
N	180	116	65								
O	130	150	85	32							
F	65	80	47	22	10	2					
Ne	120	140	160	90	47	5					
S			70		60	30	10	4			
Ar				70	65	58	15		5		
Kr					30	32	27	20	14		4

and transmission of the injection line are good enough to produce ion beam of intensity sufficient for a cyclotron. The ion source does not produce high intensity beams of very highly charged ions but high charge states are not necessary since the extraction of ions from our cyclotron is by stripping. The set-up is working almost continuously for the cyclotron, so it seems to be necessary to have a second ECR ion source as a back-up for the existing one and, stand-alone, as a tool for surface and atomic physics research, tests of ovens etc.

References

1. Dworecki K, Hasegawa T, Sudlitz K, Wasik S (2000) Modification of electrical properties of polymer membranes by ion implantation. Nucl Instrum Meth Phys Res B 166/167:646–649
2. Dworecki K, Hasegawa T, Sudlitz K, Wasik S, Slezak A (2001) Modification of electrical properties of polymer membranes by ion implantation (II). Nucl Instrum Meth Phys Res B 185:61–65
3. Sudlitz K, Kulczycka E (1999) 10 GHz ECRIS for Warsaw Cyclotron. In: Proc of the 14th ECRIS Workshop, 3–6 May 1999, CERN, Geneva, Switzerland, pp 205–207
4. Sudlitz K, Kulczycka E (2000) Influence of the extraction system on ion spectrum emitted by ECRIS. In: Proc of the Workshop on the Production of Intense Beam of Highly Charged Ions, 24–27 September 2000, Catania, Italy. Italian Physical Society 72:89–95
5. Sudlitz K, Kulczycka E (2002) Status of the Warsaw ECR ion source. In: Proc of the 15th ECRIS Workshop, 11–14 June 2002, Jyväskylä, Finland, pp 46–48
6. Sura J, Kulczycka E, Bracha T, Daniel B (2002) Design and commissioning of the prototype buncher. In: Annual Report 2001 of Heavy Ion Laboratory, Warsaw University, Warsaw, pp 13–14