CYCLOTRON BASED COMPLEX IC-100 FOR SCIENTIFIC AND APPLIED RESEARCH

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Abstract

The complex based on the cyclotron IC-100 of the Laboratory of Nuclear Reactions of Joint Institute for Nuclear Research in Dubna (Russia) provides industrial fabrication of nuclear filters. The cyclotron is equipped with super-conducting ECR-ion source and axial injection system. The specialized beam channel with two coordinates scanning system and equipment for irradiation of polymer films is installed in the implantation part of the complex. High intensity beams of Ne, Ar, Fe, Kr, Xe, I, W are accelerated to energy of 1 MeV/A. The investigation of irradiated crystals features, irradiation of different polymer films is provided. Few thousands square meters of Trace Membranes (TM) with pores in the wide range of densities were produced. Facility is capable to solve different kinds of scientific and applied problems

INTRODUCTION

The facility for nuclear filters production based on IC100 cyclotron has been developed at LNR in 1985 [1,2]. The internal PIG ion source installed at IC100 has defined possible range of ions from Carbon ($^{12}C^{2+}$) to Argon ($^{40}Ar^{7+}$) [3]. Beam energy was fixed to 1.2 MeV/A at 4th acceleration harmonic and to 0.6 MeV/A at 6th harmonic of RF. To improve performance and realize industrial production of nuclear filters it was proposed to irradiate films by heavier ions like Kr and Xe [4].

CYCLOTRON UPGRADE

In 2003÷2006 the applied research facility has been equipped with Superconducting ECR Ion Source (DECRIS) and axial injection system (Fig.1). Intensive beams of high-charge state ions of heavy element are supplied from Ion Source [5]. Beam tests have been performed with $^{86}Kr^{15+}$ and $^{132}Xe^{23+}$ ions. Extracted beam current exceeds 2 μA. Ions accelerated at IC100 are presented in Table 1.

During commissioning original design was tailored to improve performance of cyclotron. Additional solenoid was installed close to median plane. The position and the shape of central region electrodes were rearranged and optimized. The electrostatic deflector and two magnetic channels were installed. Magnetic field distortions have been compensated by shimming plates. Field deviation from isochronous profile was reduced to an acceptable level and imperfection first harmonic was suppressed to few Gauss. The beam centring was improved. Independent power supply for each resonator from two RF generators essentially improves cyclotron tuning and

Figure 1. IC100 cyclotron. Shown are the SC ECR source, injection line, magnet and resonance cavity.

provides guarantee of long term beam stability. With new 3/2βλ drift buncher beam current was increased in three times. The specialized beam channel and equipment for film irradiation as well as box for applied research were installed. Two coordinates beam scanning system provides homogenous ion implantation on to large surface polymer films [6]. Influence of different factors on beam quality has been investigated. IC100 operating parameters are close to designed values (Table 2).

Superconducting ECR Ion Source was designed for SRF frequency range up to 24 GHz and axial magnetic field up to 30 kGs [4,5]. 18 GHz SRF Generator of 1 kW

Table 1: Ions accelerated at IC100

Element	Ion	A/Z	Current, μA
Neon	$^{22}Ne^{4+}$	5,5	0,7
Argon	$^{40}Ar^{7+}$	5,714	2,5
Iron	$^{56}Fe^{10+}$	5,6	0,5
Krypton	$^{86}Kr^{15+}$	5,733	2
Iodine	$^{127}I^{22+}$	5,773	0,25
Xenon	$^{132}Xe^{23+}$	5,739	1,2
Xenon	$^{132}Xe^{24+}$	5,5	0,6
Tungsten	$^{182}W^{32+}$	5,6875	0,015
Tungsten	$^{184}W^{31+}$	5,9355	0,035
Tungsten	$^{184}W^{32+}$	5,75	0,017

Table 2: IC100 parameters

Parameter	Designed	Realized
Accelerated ions	Ar, Kr, Xe	Ne, Ar, Fe, Kr, I,Xe,W
A/Z range	5,3÷6,0	5,5 ÷ 5,95
RF harmonic	4	4
Ion energy, MeV	1÷1,25	0,9÷1,1
Field, kGs	18,8÷20,1	17,8 ÷ 19,3
RF frequency, MHz	20,4÷20,9	19,8÷20,6
Injection voltage, kV	12,5	14÷15
Injection vacuum, Torr	$5\cdot10^{-7}$	$1,5\cdot10^{-7}$
Cyclotron vacuum, Torr	$5\cdot10^{-7}$	$5\cdot10^{-8}$
RF Dee voltage, kV	50	45 ÷ 55
Emitt.inject.beam, π mm·mr	250π (4RMS)	~250π
Inject.line Accept, π mm·mr	225π	~220π
$^{86}Kr^{15+}$ beam intensity	~10^{12} pps 2.5 μA	$8\cdot10^{11}$ pps 2 μA
$^{132}Xe^{23+}$ beam intensity	$2.6\cdot10^{11}$ pps 1 μA	$3\cdot10^{11}$ pps 1.2 μA
pores density uniformity	± 10%	± 10%
Long term beam stability	± 10%	± 4÷10%
Total beam transmission	8%	7%

power is employed at IC100 DECRIS-SC. Up to 60 μA of $^{86}Kr^{15+}$ and 30 μA of $^{132}Xe^{23+}$ are injected into the cyclotron.

The axial injection line is accomplished with analyzing magnet AM, three focusing solenoids S1-S2-S3, single quad lens Q and correction magnets (Fig.2) [7].

The vertical gap between sectors in the cyclotron was reduced to 20 mm in order to provide high level magnetic field (19 kGs). Isochronous field profile was formed by shaping of plate shims attached to sector edges.

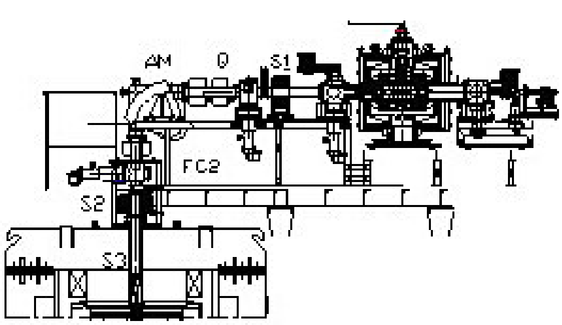

Figure 2. Axial injection channel (length ≈5 m). DECRIS – superconducting ECR Ion source, AM – analyzing magnet, S1,S2, S3 – focusing solenoids, Q – correction quads, FC2 – Faraday cup.

The gap between Dee-ground electrodes in the centre was reduced to 7 mm. To minimize transit time effects of $3/2\beta\lambda$ drift buncher the gaps between ground and potential grids were reduced to 3 mm and distance between wires to 4 mm.

BEAM MEASUREMENTS

A/Z range of ions and RF frequency in the IC100 cyclotron might be slightly varied [8]. Distribution of beam current for Ar^{7+}, Kr^{15+} and Xe^{23+} ions during acceleration in the cyclotron is presented in Fig.3. The RF phase selection of ions takes place up to ~150 mm. RF capture efficiency of DC beam (Buncher is OFF) is close to 10% of injected current (RF phase band is ~40°). With buncher ON the extracted beam current is increased in three times [9]. Cyclotron operates at vacuum level of $4\cdot10^{-8}$ Torr which is provided by two sets of Cryo- and turbo-pumps [10]. Distribution of beam current during acceleration for ions with different charge state does not depends on ion charge (Fig. 3).

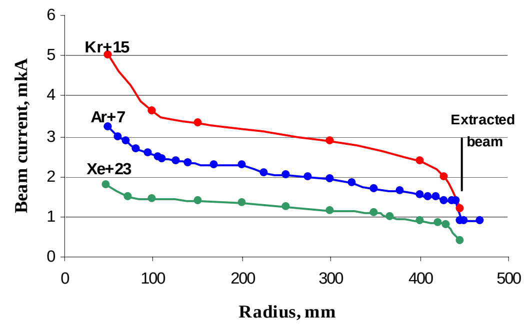

Figure 3. Beam current distribution of Ar, Kr, and Xe ions during acceleration in the cyclotron.

No significant vacuum losses were observed. Ions of $^{184}W^{32+}$ with current up to 17 nA ($3\cdot10^{9}$ pps) have been delivered to the target. Technology of composite hexa-carbonyl tungsten powder $W(CO)_6$ sublimation was used for ion production in ECR source [11]. For production of Fe ions Vapors of metallotzen $Fe(C_5H_5)_2$ composite unit have been injected into the discharge chamber of ECR source. Injected current of Fe ions of +9, +10,+11 charge states is equal to 3÷5 μA. Extracted beam of $^{56}Fe^{10+}$ ions is almost 0.5 μA ($3\cdot10^{11}$ pps).

Beam stability

Special measures have been undertaken in order to improve long term stability of beam current and provide uniform distribution of beam on target of 300×200mm² area. Two RF generators are used for independent feed of two RF resonators. Back loop phase stability system ensures precise tuning of RF phase and independent amplitude variation. Faraday Cups displaced on both sides of radiation area and central collector intercepting part of beam are used to monitor beam during film irradiation.

CHANNEL FOR PRODUCTION OF TRACE MEMBRANS

Film is rotating in the vertical direction. Beam is shaped as elongated ellipse in vertical direction and spread out in horizontal direction by scanning magnets with repetition rate of 100 Hz. Special attention was paid to symmetry of beam current on both sides of film. Production cycle usually takes about 2÷4 hours providing the film rotation speed from 5 to 10 $cm \cdot s^{-1}$.

Beam current on target is stabilized by tuning of injection line solenoid S1 as well as by variation of buncher voltage or change of ECR source power. With automatic tuning system ON long term stability of beam current is better than ±5% (Fig.4).

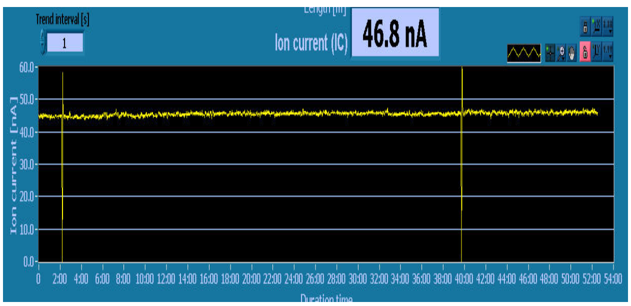

Figure 4. Long term stability of 132Xe23+ beam measured on target. Irradiation period one hour.

To guarantee uniform density distribution of pores as well as to reduce influence of sparks in cyclotron film is irradiated for few times. Differential pumping system installed in the 10 m long beam channel separates cyclotron volume from irradiation chamber and consists of four turbo-pumps and two for-vacuum lines (Fig.5). Three high speed turbo-pumps are attached to film rewinding chamber (Fig.6).

Figure 5. Beam line to device for TM production.

Figure 6. Chamber for film irradiation.

CONCLUSION

Intense beams of 1 MeV/A heavy ions of Ne, Ar, Fe,Kr, Xe, I., W elements have been successfully accelerated at IC100 cyclotron. Parameters of irradiated crystals have been studied. Industrial production of different kinds of polymer films was performed. Tens of thousands of square meter of TM in the wide range of hole densities from $5 \cdot 10^5$ to $3 \cdot 10^8$ cm^{-2} were produced at IC100 cyclotron. Facility is well fitted for scientific and applied research programs including nanotechnologies. Modifications and improvement of different subsystems are under way. Special attention is paid to expand range of accelerated ions, to increase beam intensity, to improve beam stability, to modify vacuum system of irradiation channel etc. Authors are greatly appreciate to LNR staff and all people who helps to improve facility performance.

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