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Abstracts

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KP6 ELECTRON OPTICS SIMULATIONS FOR RHIC EBIS AT BNL*

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Based on the successful experience of the BNL test EBIS, the RHIC EBIS design utilizes a 10A electron beam to produce the required ion source the output intensity 3.4×10^9 of Au^{32+} ions per 10-40 μs pulse. In order to provide increased cathode lifetime and reliability at the required 10A, and accommodate future upgrade of RHIC EBIS ion intensity, it is desirable to upgrade the electron gun. Simulations have been made for a new electron gun and an electron collector capable of generating and dissipating the electron beams with current up to 20 A. The method of forming the electron beam using magnetic compression and inverse magnetron structure of the electron gun are the same as has been tested successfully on EBTS. The new gun has higher perveance (2.9×10^{-6} $A/V^{3/2}$) and partially shielded spherical cathode. A bell-shaped radial current density distribution with reduced current density on a periphery of the beam, combined with a modified shape of the electron collector magnet shim, yields a simulated power density on the surface of the electron collector below 400 W/cm^2 for electron beam currents up to 20A.

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SP3 **NEGATIVE ION SOURCE IMPROVEMENT BY SHUTTER MASK INTRODUCING**

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Multicusp sources with cesium seed are widely used for negative ion production. Study of large multicusp source was done recently at National institute for fusion science by plasma grid masking. Large external-filter-type multicusp source with directly heated filaments and the triode beam extraction/acceleration system was used. The movable molybdenum shutter musk was attached to plasma grid at the plasma side. A complete opening or closing of emission apertures was obtained with the shutter musk fast moving. H^- beam production with current of about 3 A, energy up to 90 kV and pulse duration 0.6-1.3 s was studied.

Maximal H^- ion yield is about 1.4 times larger for the shutter musk case, than that for source operation without shutter mask. The emission apertures closing by shutter musk during the interval between the beam extraction pulses produces an essential decrease of cesium escape to accelerator and an improvement of injector high voltage conditioning and operation. Duration of injector high voltage starting conditioning was decreased 2 times. Number of shots with breakdowns in the accelerated circuit was 30% less in the operation with mask shuttered for 3 sec, as compared with the opened mask case. An increased thickness of composite plasma grid + shutter musk structure (3+2 mm) provides the better suppression of extracted accompanying electron flux. It permits to operate with the negative plasma grid biasing and produces an increased ion beam in this case.

No cesium deposition to the vicinity of plasma grid emission apertures takes place at the shutter mask closed position. It permitted to separate the income of plasma grid emission apertures area and of the shutter mask surface to the H^- surface production. Negative ion current evolution during the first cesium seed to the plasma chamber evidenced that about 60% of negative ions are produced on the shutter musk surface, while about 30% – on the edges of plasma grid emission hole, exposed by cesium only after the start of mask shutting.

TI2 CW H^- ION SOURCE FOR MEDICINE ACCELERATOR USE

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A compact cw hydrogen negative ion source having reliable operation and a simplified maintenance is developed at Budker Institute of nuclear physics for tandem accelerator of boron capture neutron therapy installation. The source uses a Penning discharge with a hydrogen and cesium feed through the hollows in the cathodes. Discharge voltage is about 60-80 V, current up to 8 A, hydrogen pressure 4-5 Pa, magnetic field 0.05-0.1 T, cesium seed <1 mg/hour. Negative ion are mainly produced on the cesiated anode surface due to conversion of hydrogen atoms. An optimal anode temperature 250-350 C. Negative ion beam current is directly proportional to the discharge current and to the emission hole area. The triode system for the beam extraction and acceleration system is used. The flux of accompanying extracted electrons was decreased by filtering in the transverse magnetic field. This electron flux was intercepted to the special electrode, biased at 3 kV potential with respect to the anode.

Source stable cw operation for several hour runs was multiply tested. H^- ion beam with current up to 8 mA, beam energy 23 keV was produced regularly. Negative ion current of heavy impuruties had value of about 3% of the total beam current. Beam normalized emittance is about 0.3 π mm·mrad, emission current density - 0.1 A/cm^2. A build-in cathode heater provides the operation quick start.

UI2 NEUTRAL BEAM INJECTORS FOR PLASMA DIAGNOSTICS

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Narrow, low-divergent neutral beams are often applied in modern magnetic fusion devices as a diagnostic tools providing unique information about plasma parameters. Series of injectors of focused neutral beams with beam energy ranging from 5 to 50 keV, equivalent beam current of 1-20 A, angular beam divergence of ~ 10^{-2} rad, equivalent current density in focus of beam more than 1 A/cm^2, pulse duration of 10^{-4}- 10 s is developed in Budker Institute of Nuclear Physics.

A specific approach to formation of high brightness ion beams is used in short pulse versions of the injectors. The low transverse ion temperature of plasma emitter is achieved by use of plasma emitter formed by the collisionlessly expanding plasma jet. The highly ionized plasma jet is produced by a cold cathode arc discharge plasma generator. Ion beams are extracted from the plasma emitter by precise multi-aperture four-electrode ion optics systems.

Two methods of beam focusing have been tested and successfully applied. In the first one the formed ion beam is focused by a magnetic lens and partially neutralized in a pulse gas target. The second method is based on geometrical focusing of the beam by spherically bent electrodes of an ion optics system. To profit better use of the nonuniform plasma jet, the developed ion optics systems with geometrical beam focusing have gaps extending with radius that ensures optimal beam formation from enlarged surface.

To provide a beam for active beam emission spectroscopy measurements in large fusion devices the injector was developed to be operated at energy 50 keV, equivalent beam current (for hydrogen) up to 1 A, pulse duration of up to 10 s and capability of beam modulation with frequency of up to 500 Hz. In the injector ion source the emitter plasma is produced by an inductively exited RF discharge. Distinctive feature of the ion source is that in order to simplify injector design, a thermal inertia-type ion optics system with "thick" electrodes [1] is used. With grids formed to focus the beam 4m downstream from the source the integral angular divergence of the beam, measured at 1/e level in the focus, of 10^{-2} rad was obtained.

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WP3 HIGH POWER HYDROGEN INJECTOR WITH BEAM FOCUSING FOR PLASMA HEATING

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High power neutral beam injector is developed with the atom's energy 25 keV and beam current 60 A. The 6 or 8 of such injectors will be used for modernization of the atomic injection system at Gas Dynamic Trap (GDT) device. The purpose of modernization is: increasing of the injecting power; increasing pulse duration from 1 to 5 ms and provide the possibility of beam focusing. The power injector includes the arc discharge plasma source, expansion chamber with peripheral multipole magnetic wall and 4-electrodes ion optical system (IOS).

The 1 kA arc discharge channel of 1 cm in diameter generate a plasma flow which spread in expansion chamber and forms the plasma emitter of 200 mm in diameter. The multipole magnetic wall with permanent magnets is used to increase the efficiency of plasma source and to provide the uniform emission at the 1^{st} grid of the IOS. The homogeneity of ±15% is obtained over the extraction region of 200 mm in diameter.

The molybdenum grids of the IOS has more than 3000 holes of 2.5 mm diameter, the holes form the regular hexagonal structure which manufactured with the accuracy of 10 mcm. The grids have spherical curvature for geometrical focusing of the beam. The optimal IOS geometry and electric fields were calculated. The measured beam divergence is ≈0.8°, the focal length was 110-350 cm depending on the radius of the grid curvature. The measured beam profile has the 1/e radius 2.5 cm at focal point. The neutralizer efficiency was ~73%. A good reliability is sufficient requirement for injector, which operates in a system of many injectors. The required probability of failure ~ few percent was demonstrated at test.

WP11 CHARACTERIZATION OF ION SPECIES MIX OF THE TEXTOR DIAGNOSTIC HYDROGEN BEAM INJECTOR WITH AN RF AND ARC-DISCHARGE PLASMA BOX

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The hydrogen diagnostic beams are now widely exploited in magnetic fusion devices [1] to provide the local plasma parameters. In particular, the diagnostic neutral beam injector of TEXTOR device is envisaged to measure the ion temperature and impurity profiles via active charge-exchange recombination spectroscopy [2]. As well as the beam angular divergence and current density, the beam species mix is critically important for this diagnostic. The ion specie fractions of the beam have been determined by making use of a H_α -light Doppler shift spectroscopy [3,4]. This spectroscopic technique has been first applied to neutral beam for plasma heating [3,5], and recently to the diagnostic neutral beams [6,7]. In the data analysis we followed the standardized procedure, which is described in [5]. It has been adopted that observed intensities of the light emitted by the beam species are governed by a Corona model. Alternatively, the beam species mix was measured by using magnetic mass-spectrometer. Both methods provided similar quantitative assessment of the ion species mix. The measurements have been done for the fixed beam energy of 50keV and beam current variable upto 2.5A. In these experiments, the ion source was alternatively operated with two different type of plasma boxes. Namely, an RF and arc-discharge based plasma boxes have been used, which operated at the same ion current density. According to the measurements, the full energy beam component for the RF plasma box amounts to ~50% by the particle density and to more than 75% for arc-discharge plasma box. Optimal conditions, for which the full energy specie is maximal for both plasma boxes studied, have been thus determined.

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WP16 DIAGNOSTIC NEUTRAL BEAM INJECTOR FOR LARGE PLASMA DEVICES.

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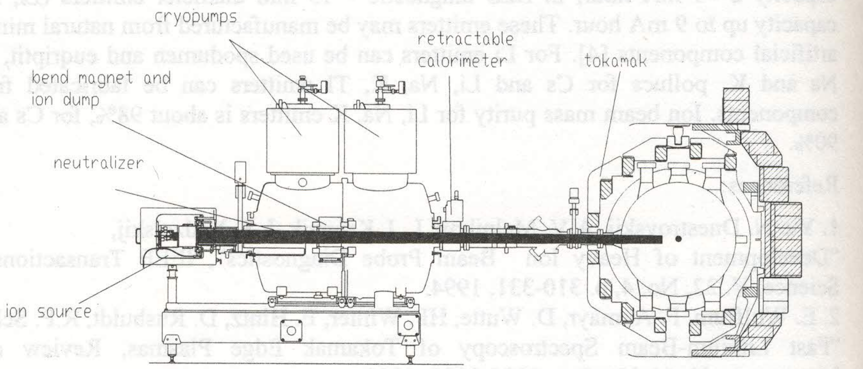
A diagnostic beam system has been developed for the Alcator (MIT, Boston). The system is primarily used for measurement of the ion temperature in plasma by charge-exchange recombination spectroscopy (CHERS) and for magnetic field measurements via motion Stark effect (MSE). The system consists of ion source, vacuum pumps and various diagnostics of the beam. The ion source creates 50 keV, 5A hydrogen beam. Ions are extracted from a plasma created by an arc discharge source and, after accelerating and focusing, neutralized in gaseous target. A low ion perpendicular temperature at the plasma emission surface, achieved via plasma expansion cooling, results in low (0.01 rad) intrinsic beam divergence. The spherically curved electrodes of the ion optic system provide geometric focusing of the beam on distance 4 m with beam current density up to 100 mA/cm^2 in focus. Arc discharge plasma source provides high content (85%) of the main fraction (protons of full energy) in the beam. The injector provides 50 msec duration pulse each 5 min. In order to increase the signal to noise ratio the beam can be modulated with a frequency variable up to 250 Hz.



WP28 STUDY OF LARGE H$^-$ ION SOURCE WITH DISTRIBUTED PLASMA INJECTION FROM SEVERAL CESIATED HOLLOW CATHODES

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Large negative ion sources are developed and operated for the high-power neutral beam injection to the experimental fusion devices in the National Institute for Fusion Science and Japan Atomic Energy Research Institute[1]. The operated sources use the hot filaments for primary electron emission, and the filament lifetime limits an experimental cycle. It is needed to develop the durable ion source with multisecond pulse length or cw operation. Possible decision is to use the distributed plasma injection to the large source from the several hollow cathodes. The cesiated hollow cathode with the small orifice, exploring the hydrogen and cesium seed was developed at Budker Institute of Nuclear Physics, and the multicusp source operation using one hollow cathode was tested for the plasma and negative ion production in the NIFS[2].

The first results of distributed plasma production from simultaneously operated several hollow cathode units are presented in this paper. The operation of 1/6 rd scale source with two hollow cathodes and of 1/3rd scale source (plasma chamber volume 35W x 62H x 20L cm^3) with up to four hollow cathodes were tested on the test stand facility of the National Institute for Fusion Study. The hollow cathode units were installed through the filament feedthrough port on sidewalls of the plasma chambers. Two different designs of hollow cathodes, developed at BINP, were tested, including the novel one, having an isolated cathode body and a cascade discharge structure. The independent hydrogen, cesium and power supply systems for every cathode were used. Power supplies and discharge parameters were controlled by the data acquisition system. The reliable discharge ignition and operation with current up to 50 A per hollow cathode unit and pulse duration up to 5 s was tested. H$^-$ beam production with multi-aperture extraction and acceleration from the source driven by several hollow cathodes was studied.

The authors would like to acknowledge the Director-General Prof. O. Motojima for his continuous support of this collaboration in NIFS.

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WP33 RESULTS OF UPGRADE OF THE DIAGNOSTIC NEUTRAL BEAM INJECTOR FOR THE TCV TOKAMAK

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The diagnostic neutral beam injector (DNBI) [1,2,3] has been developed at BINP for beam emission spectroscopy measurements in the TCV tokamak. The DNBI has been commissioned at the tokamak in 1999. It operates with the beam energy up to 50 keV, equivalent neutral beam current (for hydrogen) up to 1A and pulse duration up to 2 s. Plasma in the ion source is produced by inductively-coupled 4.6 MHz RF discharge. Ions are extracted and accelerated by a four-grid ion optical system with 163 circular 4 mm i.d. apertures.

The DNBI is to provide local measurements of plasma ion temperature, velocity and impurity densities through active charge exchange recombination spectroscopy (CXRS). The beam parameters of the diagnostic injector enabled to carry out the measurements at plasma density in tokamak up to 5×10^{19} m^{-3}.

In order to further increase the active to passive signal ratio of the CXRS measurements and extent the operational density up to $10^{20} m^{-3}$, the diagnostic injector has been upgraded in 2002. The technical upgrade was undertaken to obtain an increase of the neutral beam current density in observation region of the CXRS diagnostic by a factor of ~1.5÷2. A new ion source was installed on DNBI with corresponding changes in the power supplies. The diameter of RF cylindrical plasma box was increased from 10 to 12 cm, an extraction area was increased from 7.2 to 9.2 cm in diameter. Correspondingly, the number of apertures was increased from 163 to 241.

This paper describes the results of the beam parameters measurements after upgrade.

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WP42 ION GENERATION VIA RESONANTLY-ENHANCED TWO-PHOTON PHOTOIONIZATION

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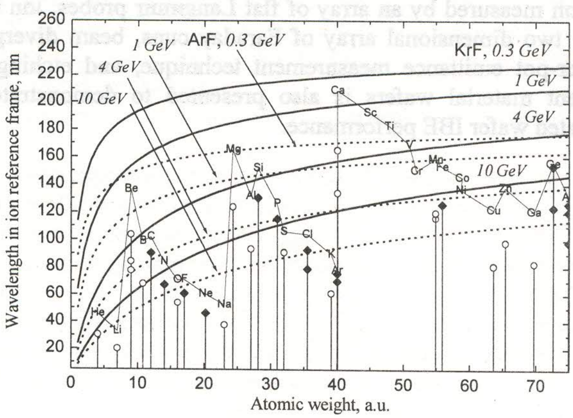
Charge-exchange or stripping method of ion injection into accelerators and storage rings has essential advantages compared to other conventional methods as this technique has no restrictions imposed on the storage ions on orbit by Liouville's theorem. Ion injection by means of the charge-exchange on a material target has been developed by A. J. Dempster [1], L. Alvarez [2], and G. I. Budker, G. I. Dimov et. al. [2]. At present, charge-exchange injection is widely employed on many accelerators and storage rings. In particular, the charge-exchange injection is a subject of special interest for projects of heavy ion driven inertial confinement fusion (see, *i. e.* [4]). A non-Liouvillean injection technique based on ion stripping by hard vacuum ultraviolet radiation via direct photoionization [5] or through an autoionization state [6] has been recently proposed by Rubbia and Hofmann. Implementation of this method requires using an HVUV-laser that does not exist yet.



We suggest a resonantly enhanced two-photon photoionization (RETPI) as a technique for stripping ions, moving on an equilibrium orbit, to the next charge state. An intense UV laser beam crosses at some angle a high-energy singly charged ion beam. Varying ion beam energy and the angle, one can match photon energy ε_φ in the ion beam reference frame (solid and dotted lines in the figure) to the energy of one of the ion resonance transitions $E^* = \varepsilon_\varphi > I/2$ (circles and diamonds in the figure). Wavelengths corresponding to half of the ionization potential I for the lightest elements are shown in the figure with a thin line. Intermediate excited state is populated to saturation and then is ionized by following photons. For most elements this technique can be realized with conventional excimer lasers and employed for ion injection, stacking, or diagnostics. High ionization efficiency, rather low photon flux (0.01-2 J/cm^2 for KrF and ArF lasers), which is necessary for complete ion beam ionization, as well as absolute selectivity are advantages of this method. Detailed description of the technique is provided in Ref. [7].

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