Development of an ECR Ion Source for Accelerators and Plasma Processing Applications

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Abstract

Performance of the ECR source and its applications in heavy ion implanters, powerful neutron generator and plasma processing setups are presented. An extracted beam current density of about 150 mA/cm^2 for one 4-mm-diameter emissive hole and about 100 mA/cm^2 for seven holes have been obtained, when gaseous ions, like oxygen or hydrogen, are produced. More than 70% atomic ion ratio in a beam is achieved. The in- and out-of-discharge chamber furnace versions have been tested when generating ions of metals. A beam current of $Ti^+$of several milliamps has been achieved with $TiCl_4$ as a charge material. More than 50% ratio of Ti^+ in a beam is available. The microwave PCVD experimental setup intended for diamond and DLC films deposition is briefly described.

At present, microwave ion sources are finding ever-widening application in various accelerators and plasma installations [1, 2]. Alongside with sufficiently complicated ECR sources, comprising a number of cavities located in series, intended for production of ions with large charge number, a variety of compact single-stage sources, operating both in the electron-cyclotron resonance (ECR) and in off-resonance modes are constructed thus far. Such sources are designed for production of ions with Z=1, 2 and beam currents in the miliampere range. Microwave ion sources offer the following advantages: a wide range of operating pressures inside the discharge chamber, the possibility to deal with agressive substances, to produce homogeneous large cross-section plasma of high density in the ECR operation mode, to provide satisfactory phase characteristics of extracted beams. The designers of accelerators and installations for plasma technologies demonstrate the ever increasing interest to microwave sources.

For several years researches into microwave sources, to be applied to high-voltage ion accelerators and installations for plasma-chemical vacuum deposition (PCVD), have been performed at the Efremov Institute. One of the modifications of the ECR source, designed for application to powerful neutron generator and oxygen ion implanters, is shown in Fig.1. As it is seen from the figure the source is installed directly onto the accelerating tube without preliminary beam separation. Such a layout is determined by high content (more than 70%) of atomic ions in the beam. As a microwave generator we employ a magnetron with an output power up to 600 W and operation frequency of 2.45 GHz. The microwave circuitry includes a three-stub attenuator and a block of directional couplers intended for control of incident and reflected waves. To provide more uniform radial distribution of the plasma density, a microwave discharge is initiated at the TE_{11} mode. The microwave power is input into the discharge chamber through a vacuum quartz window. To protect the window against a flow of accelerated electrons backscatted to the discharge chamber from the area of the initial beam shaping and from the accelerating tube, a disk of silicon nitride (Si_3N_4) is installed on it. In addition, an intermediate disk of alumina (Al_2O_3) also is applied to reduce the reflection of microwave power. A longitudinal magnetic field is induced by two structurally united solenoid coils. The optimal magnitude of the magnetic field and its axial distribution are provided by way of separate current control in the coils and their movement along the source axis.

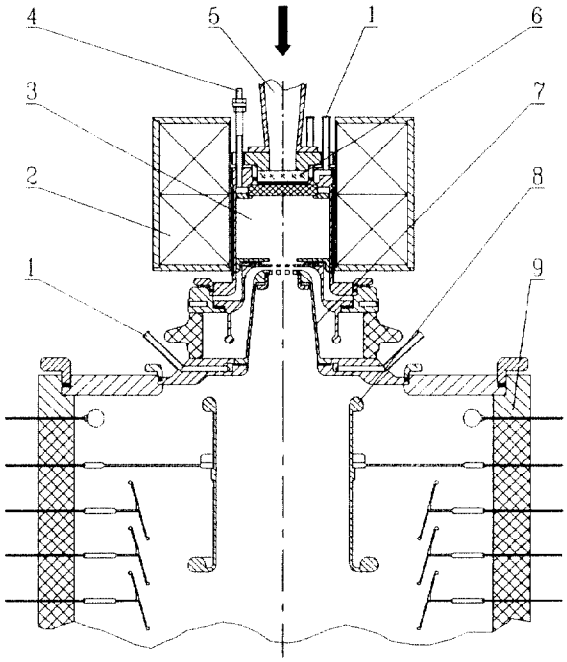

Figure 1. ECR ion source connected with accelerating tube. 1 - cooling water; 2 - magnet coils; 3 - discharge chamber; 4 - gas inlet; 5 - rectangular waveguide; 6 - microwave window; 7 - extracting electrode; 8 - focusing electrode; 9 - accelerating tube.

A feed gas is supplied to the source from the side of vacuum window. A movable diaphragm, dictating the active length of the discharge chamber is placed in front of the emission electrode. An ion beam is extracted through one, four or seven holes 3 - 6 mm in diameter, depending on a particular application. The beam is initially shaped by means of an immersion lens structurally combined with the accelerating tube.

Such a version is realized in the high voltage accelerator for powerful neutron generator and provides production of accelerated ion beams ($^1H_1^+$ and D_1^+) with current at the Ti-T target up to 60 mA and energy up to 300 keV. The atomic ions' content in the extracted beam is about 70% [3].

A similar version is used in the oxygen implanter for the SIMOX technology. The beam is extracted through 4 holes

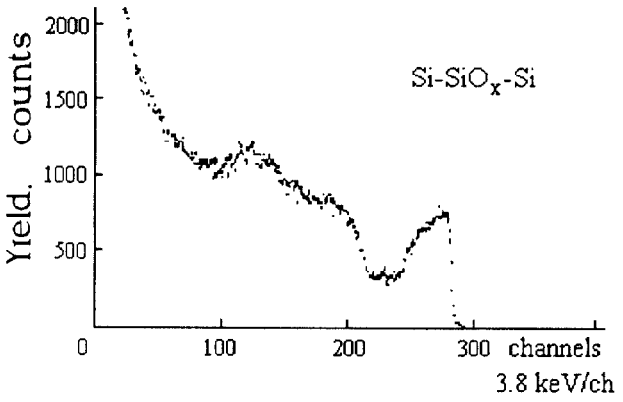

Figure 2. Backscattering spectrum of 2.0 MeV He^+ from Si implanted with O^+ (ECR ion source, E_{beam} = 190 keV, D = $1.8*10^{18}$ cm^{-2}).

4 mm in diameter. The O^+ beam current at the end station is 15-20 mA at an energy ranging from 150 to 250 keV. The atomic ions' content when operating with oxygen and nitrogen is more than 70%. Fig.2 displays the backscattering Rutherford spectrum for a silicon wafer implanted with oxygen (O^+) ions.

Preliminary studies of metal ions production using an ECR source have been conducted. To produce $^{48}Ti^+$ ions we have tested the versions with the furnace located outside the source and directly inside the discharge chamber. In the second case the TiF_4-powder is used as a feed substance. The discharge is initialed in the support gas (^{40}Ar) and when the source is forced into the operating mode the discharge is maintained only with TiF_4-vapours. When the furnace is installed outside the source we employ $TiCl_4$-liquid as the feed substance. The vapours are puffed to the discharge chamber through the gas inlet. The support gas is not applied. Fig. 3 demonstrates the changes in the mass composition of the extracted beam when the source, operating with $TiCl_4$, is forced into the operation mode. It is seen that at the initial moment (a) the main components of the beam are chlorine ions. With the source warming up and

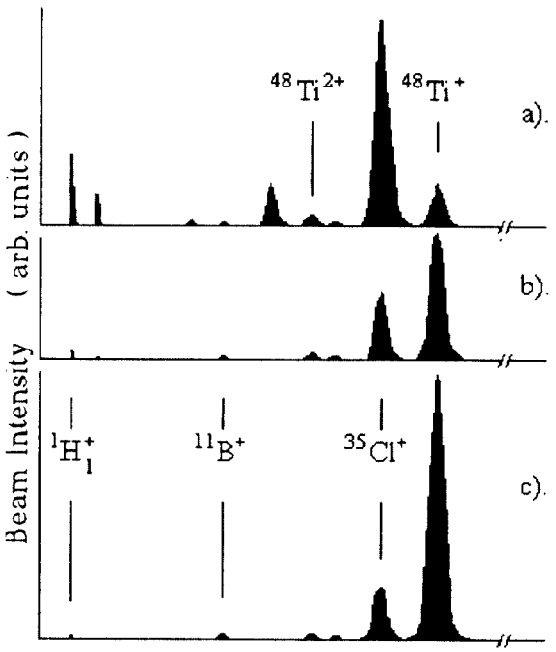

Figure 3. Time variation of ion mass spectrum from ECR source using $TiCl_4$ feed gas when the source is forced into operating mode. (E_{beam} = 150 KeV, $I_{beam\ total}$ = 4 mA).

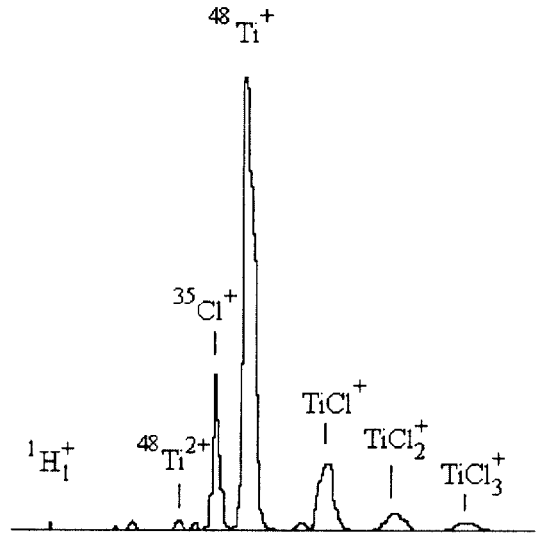

Figure 4. Ion spectrum from ECR source using $TiCl_4$ feed gas (E_{beam} = 180 keV, $I_{beam\ total}$ = 4 mA).

optmiization of $TiCl_4$ vapour pressure, the fraction of $^{48}Ti^+$ ions increase (b) and it amounts to about70% (c). Fig. 4 displays the mass spectrum of the ion beam produced by an ECR source, operating with $TiCl_4$, and accelerated up to 150 keV. The beam is extracted through a single hole 4 mm in dia. The time of continuous source operation with $TiCl_4$

vapour depends on the plugging of the emission hole with chlorine compounds and it is of the order of 20-30 h. To increase this time we should modify the source to higher temperatures.

This source was employed on the experimental setup for implantation of $^{48}Ti^{+}$ ions into quartz glasses with the aim to increase the glass strength. The $^{48}Ti^{+}$ beam current up to 2mA at the end station was provided in 150 - 250 keV energy range. The extraction and initial beam shaping system is similar to that shown in Fig.1. The used electro-magnetic scanner provides the dose uniformity about 1% for single sample irradiation.

Fig.5 shows the backscattered Rutherford spectrum for a quartz glass implanted with $^{48}Ti^{+}$.

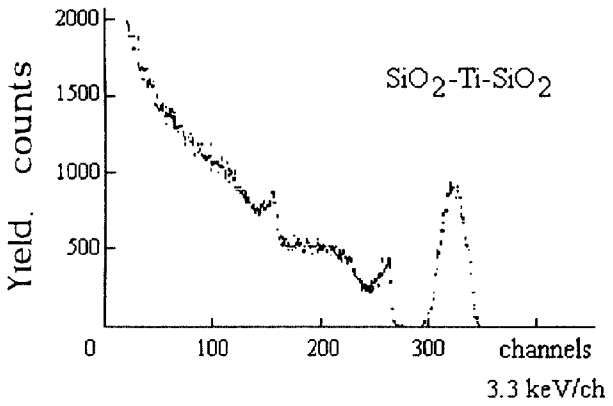

Figure 5. Backscattering spectrum of 1.8 MeV Hc^{+} from SiO_2 implanted with Ti^{+} (ECR ion source, E_{beam} = 185 KeV, $D = 2*10^{17}cm^{-2}$).

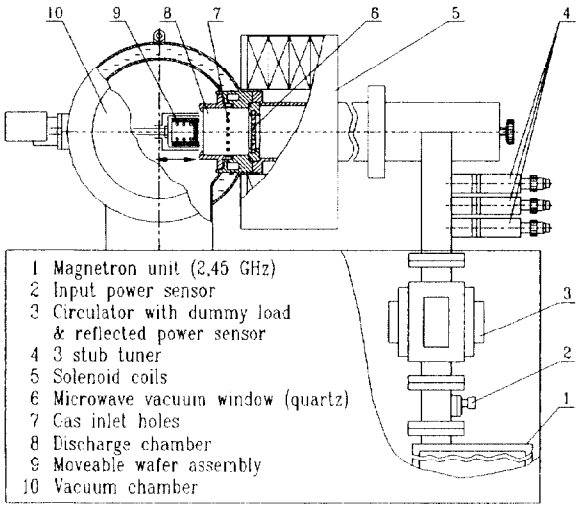

Figure 6. Schematic view of experimental microwave setup "AGAT" for plasma chemical vacuum deposition (PCVD) of diamond and DLC films.

Along with the use of ECR sources in accelerators they find wide application in equipment for ion etching, polishing, plasma chemical deposition [4, 5]. Fig.6 shows the experimental microwave setup AGAT designed and constructed at the Efremov Institute for plasma chemical vacuum deposition of diamond and diamond-like carbon (DLC) films onto different materials. It consists of microwave circuitry, discharge chamber, with the magnet system similar to that shown in Fig.1, and vacuum chamber with a movable block to locate the irradiated samples. The possibility for heating the substrate up to 1000 ^{0}C and to change its potential up to ±300 V is provided. The mixture of 0.5-5.0 % of CH_4 and 99.5-95.0 % of H_2 is used as the feed gas for the microwave source. The microwave discharge allows to accomplish the deposition processes in a wide range of pressures (from 10^{-5} torr to 10^{+2} torr) in different operation modes. This offers wide potentialities for optimisation of deposition technologies for each particular case.

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