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THE FIRST EXPERIMENTAL RESULTS ON LASER ION LOADING INTO SUPERCONDUCTING **ECR** ION SOURCE AT **RIKEN**

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Introduction

The recent development of electron cyclotron resonance (ECR) ion sources shows an enlarging of experimental and theoretical interest on the ECR source loading with neutral or ionic flows from laser ion source (LIS) [1-7]. The loading of solid and refractory materials and the searching of ways to improve the highly charged ion production are the main reasons of laser produced neutral or ion injection into the ECRIS. A series of experimental investigations of pulse injection of Mg, Zn and Cd neutrals into the 14 GHz ECR ion source at the Frankfurt University has been performed during a couple of recent years [3, 4].

The presented research is aimed at production of highly charged heavy ion beams in pulsed mode by means of the coupling laser ablated fluxes of neutrals and low energy ions with the ECR plasma in the new helium free 18 GHz superconducting ECR source at RIKEN. The coupling efficiency between a laser ablated fluxes of particles and ECR discharge strongly depends on the initial energy of neutrals and ions in the laser plasma. The theory and numerical simulations predict that the lower is the energy of ablated particles (tens to few hundreds of eV) the higher is efficiency of coupling and the higher is probability to produce higher charge state pulsed ion currents by an ECRIS [1, 5, 7]. This condition can be provided at the laser beam energies not much above the ablation thresholds for solid targets: ablated fluxes of particles mainly consist of neutrals and low charge state ions.

Experimental Setup

The detailed design of the ECR ion source (RAMSES) using a liquid-He-free superconducting magnet is given in ref 8. The super-conducting solenoid coils are cooled to below 5 K by a small Gifford-McMahon type refrigerator. It maintains the superconductivity of solenoid coils without supplying liquid He. In our experiments we used oxygen gas in the ECR chamber at the pressure about $(2\text{-}4)\times10^{-7}$ mbar. Though the maximum available radio frequency (rf) power is about 2 kW at RAMSES, we started our investigations from 100 W up to 200 W at the extraction voltage 7 kV of the source throughout all experiments. The typical magnetic strengths of beam extraction side (B_{ext}), minimum magnetic field of mirror magnetic field (B_{min}) and rf injection side (B_{inj}) are 1.8, 0.5, and 1.1 T, respectively.

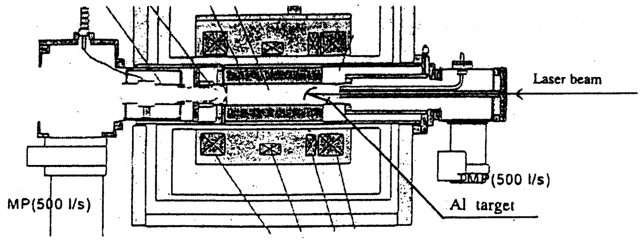

Fig 1. Layout of experimental set-up at RIKEN

A Q-switched Nd:YAG laser LS-2134 (max energy 250 mJ, pulse width 12ns) was operating at the basic wavelength 1.06 μm at the pulse repetition rate 2 Hz. The layout of the experimental set-up is shown in Fig 1. The laser beam entered the chamber through a vacuum window and focused on the Al target located at the microwave injection side by the means of the home-made stainless steel folding mirror with F = 50 mm focal length. Unfortunately the quality of the utilized mirrors surfaces was not of a high level which results in an untypical and not regular focal spots. Nevertheless, the roughly estimated power density was about $4x10^9$ W/cm^2 at the beam energy 80 mJ in a pulse.

Experimental results

In our preliminary test experiments carried out at the zero value of the rf power the charge state distribution (CSD) of Al ions at the laser pulse energy 80 mJ consists mainly of Al^{1+} as well as of very unstable Al^{2+} ions. Switching on the rf power on 100 W results in production of highly charged states up to Al^{8+} in an oxygen plasma at the gas pressure $4x10^{-7}$ mbar in the source. The shapes of the pulses for two various charge states are illustrated in Fig 2. The lower is the charge state the shorter are the rise and fall times of the ion currents.

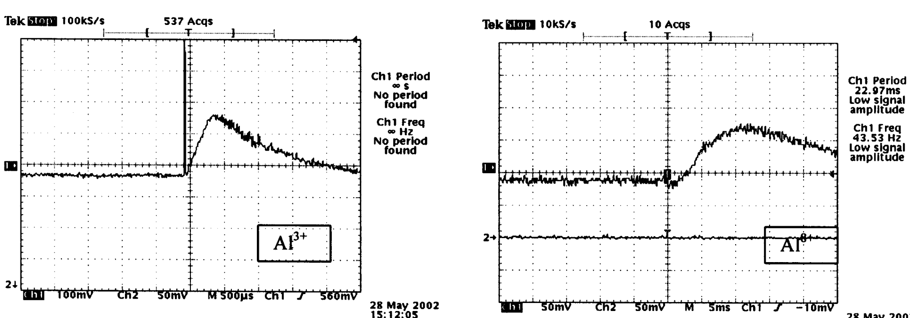

Fig 2. Pulsed ion currents for Al^{3+} (pulse width about 1 ms) and Al°' (pulse width 20 ms)

One can see from the figure 2 that two groups of ions (fast and slow) are remarkable for the low charge state. Though the origin of the fast group is the subject of our further exploration, the behavior of the CSD pulse shapes in slow component is in rather good agreement with numerical simulations carried out by our group (Fig 3). These simulations were carried out for the following ECR oxygen plasma and Al neutral flow parameters: $N_e = 3x10^{11}$ cm^{-3}, Te = 2keV, $N_{0Al} = 10^{10}$ cm^{-3}, $\tau = 20$ μs (where N_e and T_e - are the electrons density and temperature respectively, N_{0Al} - Al neutral flow density, τ - pulse width of neutrals).

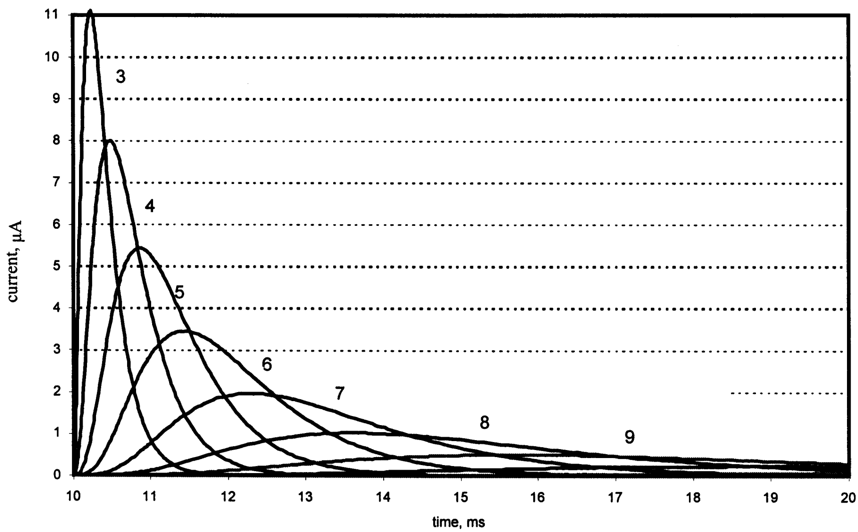

Fig 3. Numerical simulation of ECRIS ion production ($3^+ \rightarrow 9^+$) after the injection of Al neutral flux at the time of 10 ms

Increasing the rf power up to 200 W results in shortening of the ion current pulses in **a** different way: for lower charge states up to Al^{5+} shortening was stronger compared to those for highly charged ions.

Summary

The first experimental results carried out on the laser injection of neutrals into the 18 GHz RIKEN SC ECRIS have demonstrated its viability and perceptiveness to produce highly charged metal ions in the pulsed operation mode. Besides, one can use this method to explore various parameters of ECR plasma: temperature and density of electrons, ion confinement times etc. In our further experiments we consider to replace the folding mirror on lens located outside of the chamber, which will provide more stable and reliable conditions.

The first experimental results at RIKEN as well as recent results at Frankfurt [3, 4] have shown advantages of laser loading of different solid and refractory materials into the ECR source. A relatively simple solid state laser of about 100 mJ in pulse is quite enough to produce a dense flow of neutrals with an energy of tens eV and pulse width of about 10-20 μs.

A cw mode operation of accelerators requires the continuous injection of ions and correspondingly the cw mode of material loading into the ion source. This problem needs special investigations with a cw laser or a high pulse repetition rate (1-25 kGz) laser. Such an approach may have a special sense as a very promising way for production of neutral flows of heavy metallic elements (Cu, Pb, Au, U and etc) into the next superconducting ECR source for Radioactive Ion Beam Factory at RIKEN.

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Первые экспериментальные результаты по лазерной инжекции ионов в сверхпроводящий ЭЦР-источник ионов в RIKEN

Представлены первые экспериментальные результаты по лазерной инжекции ионов и нейтралов из металлической мишени в 18 ГГц сверхпроводящий источник ионов на электронно-циклотронном резонансе (ЭЦР) в RIKEN (Япония). Из источника получены импульсные токи ионов алюминия вплоть до Al^{8+}. Зафиксированы различия форм импульсов ионных токов разных зарядностей.

Работа выполнена в Лаборатории физики частиц ОИЯИ и в Институте физических и химических исследований (RIKEN, Япония).

Сообщение Объединенного института ядерных исследований. Дубна, 2002

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The First Experimental Results on Laser Ion Loading into Superconducting ECR Ion Source at RIKEN

The first experimental results on ions and neutrals injection by means of laser ablation from metal targets into the RIKEN 18 GHz superconducting electron cyclotron resonance ion source (SC ECRIS) are presented. Pulsed aluminium ion currents up to Al^{8+} were generated in the source. The difference in pulse shapes of various charge states of the extracted ion currents is registered.

The investigation has been performed at the Laboratory of Particle Physics, JINR and at the Institute of Physical and Chemical Research (RIKEN, Japan).

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