RECENT AND FUTURE DEVELOPMENT OF ION SOURCES FOR ON-LINE IRIS FACILITY

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On-line electromagnetic isotope separators have proven to be the most efficient instruments in production and investigation of nuclei far from the region of β-stability, as well as for detailed study of more familiar nuclei. The IRIS (Investigation of Radioactive Isotopes on Sinchrocyclotron) mass-separator facility [1] has operated on-line to the proton accelerator at Gatchina since 1976. Meanwhile, technical development has been aimed at extending and improving the original facility according to demands and experiences arising from its application to a variety of nuclear physics experiments as well as at design and investigation of different types of target-ion source systems for efficient on-line isotope production. The detailed construction of targets used at IRIS was presented in the last issue of "Methodic and applied experiments of LNPI" [2]. In the present article the technical development of ion sources for IRIS facility will be summarized.

An ideal ion source for production of ions of nuclides far from stability should satisfy the following conditions:

1. High efficiency of ionization.
2. Production of ions of all periodical table elements.
3. Selective ionization of isobars.

However up to now there is no universal method which would meet all these requirements. A lot of types of ion sources have been developed and each of them allows to produce ions of some elements or groups of elements with more or less identical physical-chemical properties.

There are five types of ion sources used at IRIS facility.

1. High temperature positive surface ionizers.
2. Negative surface ionizers.

3. Selective laser ion source.
4. High temperature ion source with electron beam ionization.
5. Positive surface ionizer with bunched ion beams.

1. High temperature positive surface ionizers

This type of ion sources is the most simple one and works very stable for many hundreds hours of operation. If the surface work function and temperature of an ionizer is high enough it ensures the efficiency from 1 up to ~100% for different elements depending on the ionization potential.

At IRIS on-line mass-separator original construction of high temperature surface ionizers [3] made of some layers of thin (20–50 μm) tungsten or tungsten-rhenium foils has been worked out that ensures a very high operating (~2500°C) temperature and allows to produce on-line a large set of different nuclides. Making use of this type of positive surface ionizers, isotopes of *Rb*, *In*, *Cs*, *La*, *Pm*, *Eu*, *Sm*, *Gd*, *Tb*, *Dy*, *Ho*, *Tm*, *Yb*, *Lu*, *Tl*, *Fr* lying far from stability were produced and investigated [1, 4, 5].

2. Negative surface ionizers

The main principle of the ion source for negative ion production is based on the fact that an atom with high electron affinity can absorb an electron from a surface with low work function. The most effective source for halogen negative ion production was developed at ISOLDE. Pellets of LaB_6 have been found to be the most suitable material for this kind of ion sources. Providing rather high value (1–40%) of ionization efficiency this type of ion source ensures a very high selectivity of halogen isotope separation. At IRIS facility a modified version of the ISOLDE construction has been used for on-line produciton of neutron deficient isotopes of *Br* and *J*. During experiments the value of ionization efficiency for *J* and *Br* atoms 5–30% was obtained. The future development of negative ion production method lies in use of some metal carbides (ZrC_x, NbC_x, TaC_x) which are stable against high temperature (2300°C) heating and have a very low ($\leq$3 eV) work function. In this case the ion source could be used for negative ionization of many periodical table elements.

3. Selective laser ion sources

For studies of nuclei far from beta-stability and for other applications it is often necessary to produce intense mass-separated ion beams uncontaminated by isobars from neighboring *Z*-elements. At IRIS facility a new highly efficient selective laser ion source [6, 7] based on the resonant laser ionization was proposed and developed[1].

The selective laser ion source is schematically shown in Fig.1. The multistep resonance photoionization of the atoms of the given element takes place in a hollow niobium tube heated to a rather high temperature by passing a *dc* current through it. The tube is 50 mm long and has inner diameter of ~1.5 mm. Two or three laser rays from the tunable pulsed lasers are merged into one beam and are introduced in the ion source through inlet opening 1. The formed ions are extracted through outlet hole 2.

[1]Experiments were carried out in the collaboration with the group from Institute of Spectroscopy (Moscow).

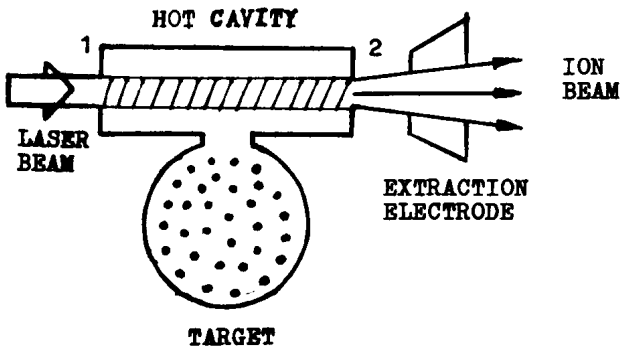

Fig.1. Schematic drawing of selective laser ion source. Dashed area is region of ionization. Proton beam goes through target along its axes perpendicular to plane of drawing

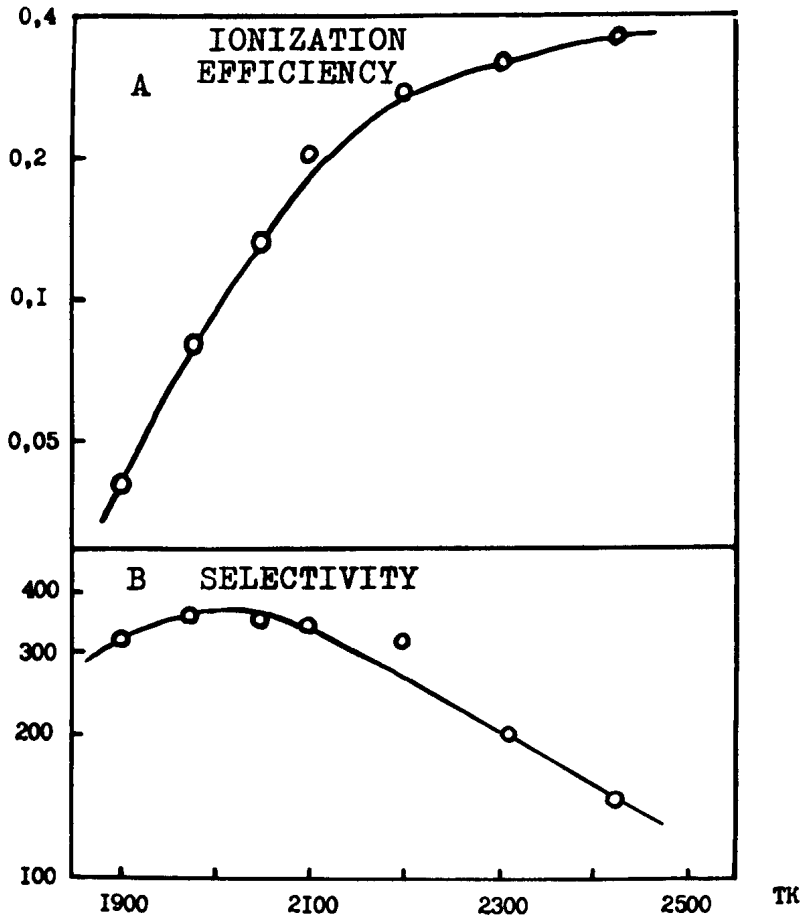

Fig.2. Temperature dependence of efficiency (A), and of selectivity (B) of laser ion source in off-line experiment with Yb

A maximum efficiency of the laser ion source about 35% was achieved for Yb atoms. The optimum regime of the ion source corresponding to high values of the efficiency and the selectivity was obtained at temperatures 2100–2200°K (Fig.2), the efficiency of ionization and the selectivity being 27% and 300 respectively. Making use of the laser ion source, neutron deficient isotopes of Ho and Yb have been on-line selectively produced and investigated. It has been shown that this source can be used as a new high-efficient method for on-

line measuring isotope shifts and hyperfine structures in optical transition of nuclides lying extremely far from stability [8].

This method of a highly efficient selective laser ionization is also being prepared for production and investigation of nuclei far from stability at some other nuclear research centers (ISOLDE-CERN, UNILAC-Darmstadt, IAERI-Japan), and for some very important and precise experiments, such as determination of the solar neutrino flux by measuring $^{97,98}Tc$ content of the molibdenum ore [9, 10].

4. High temperature ion source with electron beam

Being a very good instrument for selective ionization of many elements, laser ion source cannot ensure effective ionization of elements with rather high ($\geq$7 eV) ionization potentials because of difficulties with production of high intensive ultraviolet laser beams. Up to now there is no method which would allow to obtain ions of refractory elements with high potential of ionization effectively enough. At IRIS mass-separator a new version of a high temperature ion source with electron beam ionization was designed and off-line tested [11]. This method is very similar to the method of selective laser ionization in a hot metal cavity, but instead of laser beams the electron beam is used and niobium tube is changed into tungsten one. It makes possible to obtain the heating temperature of ion source up to ~3000° K. First experiments of stable isotopes of Li, Ca, Ba, Yb, Ti, Fe, Co, Ni, Mo, Nb, Ta, W ionization have been carried out and gave values of ionization efficiency 2–60%. At IRIS at present a new version of high current and high temperature plasma ion source is being worked out. The important property of this ion source is the possibility of production very intensive (up to some mA) ion beams without loss of efficiency and resolution. This type of ion source may be very useful when working with targets containing large amount of not very stable against high temperature target material. Probably these methods with additional technical development will turn out very useful in on-line production of radioactive isotopes of refractory and not well volatile elements with high ionization potentials.

5. Positive surface ionizer with bunched ion beams

Very often during the experiments at ISOL systems the necessity of bunching mass-separated radioactive ion beams arises. Making use of bunched beams allows to ensure better background conditions and to increase efficiency of measurement for short lived isotopes. The bunching of ion beams would be very useful for collinear laser spectroscopy where after its neutralization bunched ion beam is irradiated by pulsed laser light synchronized with the ion bunches.

A new method of bunching ions emerging from a surface ion source has been elaborated and tested on the mass-separator of the IRIS facility [12].

The main idea of the method is similar to that of laser ion source where the property of a high temperature surface to form inside the source volume negatively charged plasma with a sharp potential drop ΔU at the walls is used. The potential imprisons positive ions inside the volume of the ionizer. Due to this potential drop the ionized atoms with the kinetic energy less than $e\Delta U$ cannot get on the walls of the source and thus they may not be neutralized on the surface.

The system for accumulation and time forming on ions consists of a usual mass-separator surface ionizer fabricated of refractory metal and of an additional electrode under different

sign potential situated in front of the exit opening of the ion source-tube.

It is shown that in a rather wide range of time parameters of bunching (accumulation time = 10^{-4}–10^{-1} s, bunching time = 10^{-6}–10^{-3} s) the average ion current from the ion source in the bunching mode differs insignificantly from that in the continuous mode of work (Fig.3), the pulsed current of ions being dozen times more than the everage one. The measurements were carried out for high temperature ion sources fabricated of niobium, tantalum and tungsten with ions of stable isotopes of *Li*, *Na*, *K*, *Ba* and some rare earth elements.

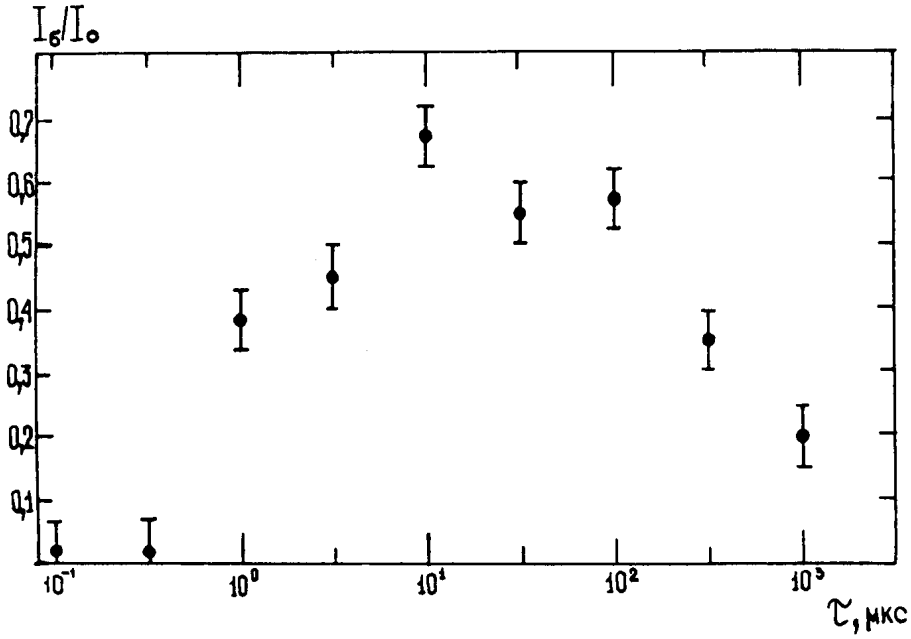

Fig.3. The I_b/I_o ratio (I_b —ion current in bunching mode, I_o —ion current in normal conditions without bunching) versus duration of opening pulses

REFERENCES

1. *Alkhazov G.D., Berlovich E.Ye., Blinnikov Yu.S. et al.* Preprint LNPI-1004. Leningrad, 1984. 57 p.
2. *Alkhazov G.D. et al.* //Metodicheskie i prikladnye raboty LIYAF. Leningrad, 1988. P.53.
3. *Panteleev V.N., Romanov V.I.* Preprint LNPI-1936. Leningrad, 1988. 22 p.
4. *Akhmonen A.A., Panteleev V.N., Polyakov A.G.* Preprint-935. Leningrad, 1984. 47 p.
5. *Bolshakov V.N., Dernyatin A.G., Mezilev K.A. et al.* //Nucl.Instr. and Meth., 1992. V.B70. P.69.
6. *Alkhazov G.D., Berlovich E.Ye., Panteleev V.N.* //Nucl.Instr. and Meth., 1989. V.A280. P.141.
7. *Alkhazov G.D., Batist L.Kh., Bykov A.A. et al.* //Nucl.Instr. and Meth., 1991. V.A306. P.400.
8. *Alhkazov G.D., Barzakh A.E., Denisov V.P. et al.* //Nucl.Instr. and Meth., 1992. V.B69. P.517.
9. *Cowan G.A., Haxton W.C.* //Science, 1982. V.216. P.51.
10. *Ames F., Brumm T., Jäger K. et al.* //Appl.Phys., 1990. V.B51. P.200.
11. *Panteleev V.N.* Preprint LNPI-1790. Leningrad, 1992. 9 p.
12. *Alkhazov G.D., Panteleev V.N., Romanov V.I.* //Pisma Zh.Tekn.Fiz., 1990. V.16. P.73.