IONIZATION EFFICIENCY OF A COMIC ION SOURCE EQUIPPED WITH A QUARTZ PLASMA CHAMBER

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Abstract

Increased ionization efficiencies of light noble gases and molecules are required for new physics experiments in present and future radioactive ion beam facilities. In order to improve these beams, a new COMIC-type ion source with fully quartz made plasma chamber was tested. The beam current stability is typically better than 1 % and beams are easily reproducible. The highest efficiency for xenon is about 15 %. However, the main goal is produce molecular beam including radioactive carbon (in CO or CO_2), in which case the efficiency was measured to be only about 0.2 %. This paper describes the experimental prototype and its performance and provides ideas for future development.

INTRODUCTION

The ISOLDE facility at CERN produces a wide range of radioactive ion beams due to a long history on target and ion source development. Because the radioactive isotope production is very limited, the most important ion source parameters are high ionization efficiency, selectivity and reliable operation under intense radiation. Currently used ion sources (mainly laser (RILIS [1]) and arc discharge –type ion sources (VADIS [2])) do not efficiently ionize light noble gases, such as helium, and molecules, such as CO, CO_2, N_2 and NO. These beams were previously planned to be produced with 1+ ECR ion sources operating at 2.45 GHz (for example MINIMONO [3]). However, due to new and more efficient RF coupling of COMIC-type ion sources [4], we expect to advance in 2.45 GHz ECRIS utilization for radioactive beam production.

Q-COMIC

The new COMIC source (Fig. 1) designed by LPSC/Grenoble incorporates special features such as a plasma chamber fully made of quartz (Q-COMIC), which should provide chemically favourable conditions for molecular ion beam production, especially for CO_2. The beam is mainly formed between plasma (hole diameter 3.1 mm) and intermediate electrodes, which have 1.5 – 3 kV potential difference over 10 mm gap. The intermediate electrode is important in minimizing the effect of using different operation voltages to the beam formation and shape. Comprehensive emittance measurements will be performed in near future. Results are expected to be similar to those of standard COMIC [4].

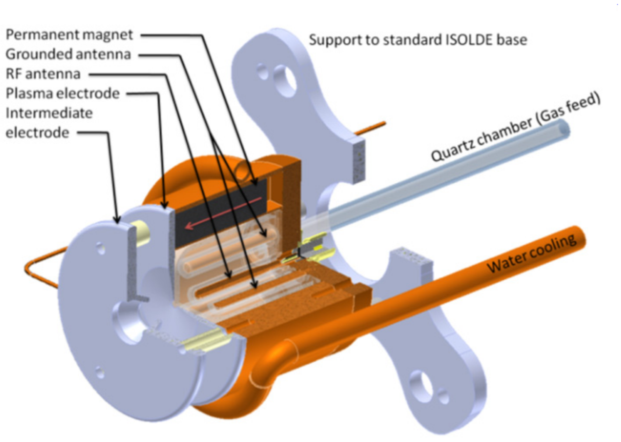

Figure 1: Schematic of Q-COMIC.

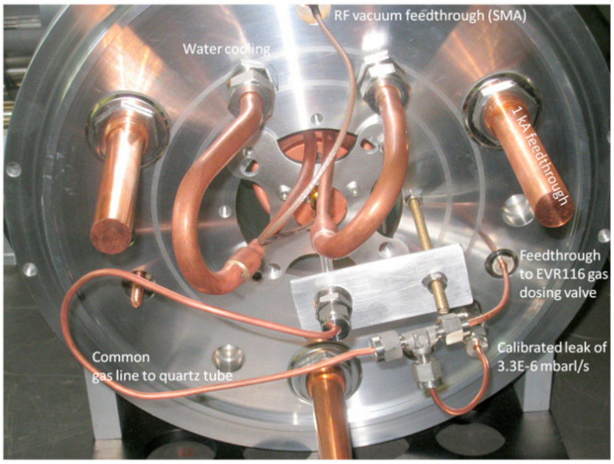

Figure 2: Q-COMIC setup and gas injection system

The source is placed inside a standard ISOLDE target base (Fig. 2), in vacuum. Consequently, a water cooling system is necessary to protect the NdFeB -permanent magnets from overheating. In this prototype unit there is no target container (between 1 kA current feedthroughs, Fig. 2) and the gas of interest (simulating a radioactive gas from target) is injected through a calibrated leak of 3.3E-6 mbarl/s (value corresponding air). The buffer gas is injected into the system by using a Pfeiffer EVR116 gas dosing valve operated by a RVC300 controller unit. Gas injection system calibration was verified with a calibrated helium leak detector.

The microwave power generator is Kuhne Electronic GmbH “KU SG 2.45-30A” operating at 2.45 GHz and capable of injecting up to 30 W microwave power. The plasma ignites typically at the pressure level of about 5E-5 mbar (at the extraction) when employing the full microwave power. However, at higher pressure of to 1E-2 mbar the ignition can be achieved already at 10 W. After the plasma is ignited the power can be decreased down to 2.7 W still maintaining the plasma. All the experiments were performed at ISOLDE off-line mass spectrometer using 30 kV acceleration voltage. An example of measured spectrum is shown in Fig. 3.

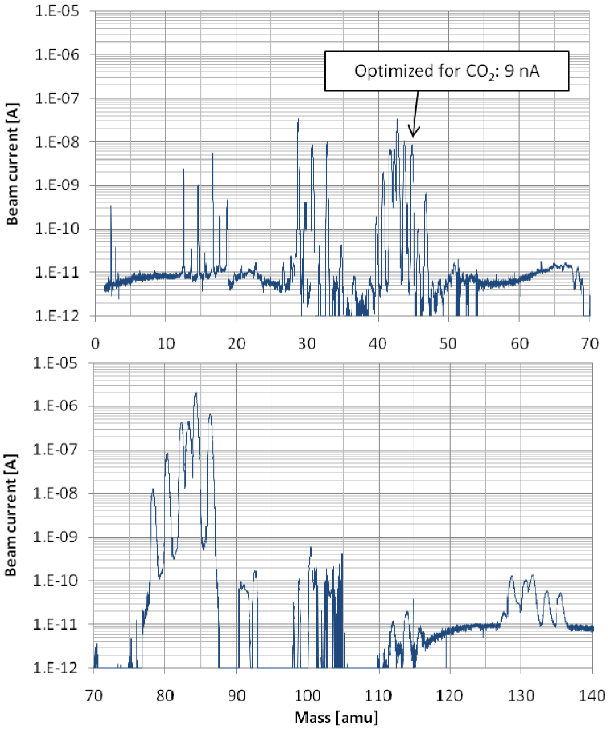

Figure 3: Spectrum when injecting 11.3 pμA of CO_2 in to the source with krypton as a buffer gas.

GAS EFFICIENCY

Experiments were performed by a) injecting only one gas and b) injecting CO_2 through a calibrated leak (simulating radioactive CO_2 from target) and a buffer gas for igniting and maintaining plasma.

A. *Injection of one gas*

In order to measure the influence of pressure (leak) on the gas efficiency, krypton was injected through the buffer gas dosing valve. The highest gas efficiency achieved was 6 % when injecting 62 pμA (4E-5 mbarl/s over 1.2 bar) of natural krypton (where ^{84}Kr abundance is 57 %). Comparable measurement was done also for argon and nitrogen. Results are shown in Fig. 4. In the case of nitrogen, it should be noted that this is a molecular beam of N_2 (atomic nitrogen beam current is typically 10 % of molecular N_2 beam with 28 W of forward microwave power).

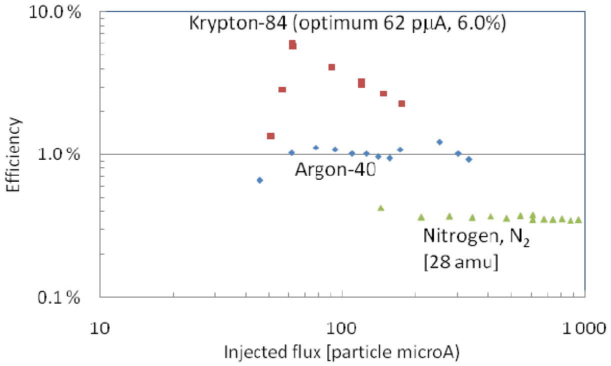

Figure 4: Gas efficiency as a function of injected flux

B. *Injection of CO_2 with a buffer gas*

Buffer gases tested with CO_2 were: nitrogen (N_2), argon, krypton and xenon. To verify the origin of monitored peak, the pressure of CO_2 injection line was altered from 0.5 bar to 1.5 bar (corresponding CO_2 injection from 5.1 pμA to 15.4 pμA). In the case of nitrogen the "CO_2 beam" was almost independent of CO_2 injection pressure. Possible explanation could be the formation of N_2O molecule having a same mass with CO_2. In the case of argon, krypton and xenon CO_2 beam intensity was a function of the pressure and the measured gas efficiency remained constant. The summary of the results is shown in table 1.

Table 1: CO_2 gas efficiency for different buffer gases

Buffer gas	**CO_2 gas efficiency**
Argon	0.09 %
Krypton	0.12 %
Xenon	0.22 %

DISCUSSION AND SUMMARY

Fig. 5 shows a summary of the gas efficiencies as a function of mass. All the measurements, except CO_2, fit very well on the dashed trend curve. The values for helium, neon and xenon were not measured with a single gas injection, but by injecting a gas-mixture of 20%-xenon, 20%-krypton, 20%-neon and 40%-helium. Krypton efficiency in this case was 5.9% (separately measured 6 %) indicating that the other compounds were not drastically affecting to the measured efficiency.

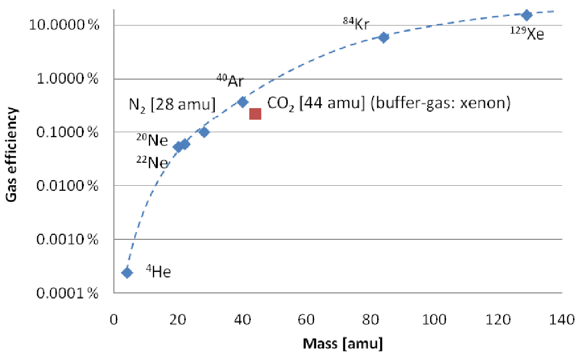

Figure 5: Summary of the measured gas efficiencies

It seems that the higher masses are ionized and extracted more efficiently than lower masses. This behaviour looks very similar to the kinetic theory of gases where $v_{rms} \propto \sqrt{(1/M)}$.

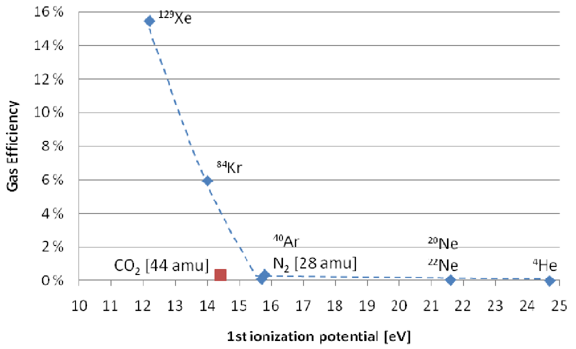

Figure 6: Gas efficiency as a function of the first ionization potential

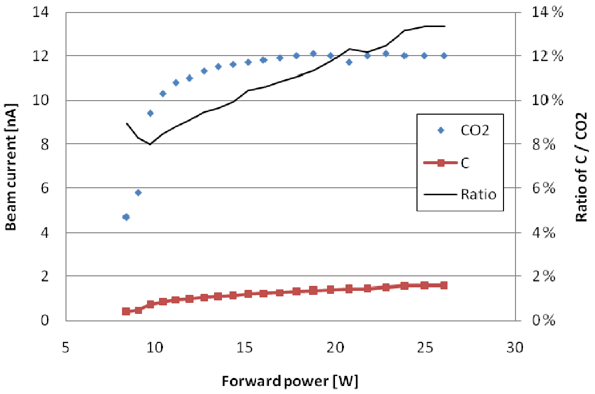

Figure 7: CO_2 breaking to C

Fig. 6 shows efficiencies plotted as a function of the first ionization potential of the ion. Also in this case CO_2 does not follow the tendency of the other tested gases. Possible explanation is that the CO_2 molecule is breaking in the plasma (C=O bond energy is only 8.3 eV). This was studied by measuring the CO_2 and C ion production as a function of microwave power. Fig. 7 shows that above 15 W of microwave power, the production of CO_2 saturates while the production of C increases with the power.

Table 2: Molecule dissociation and recombination

Ion	Mass [amu]	Beam current [nA]
C	12	2.4
O	16	5.6
O_2	32	10
CO_2	44 (also N_2O)	8.7
N	14	1
N_2	28 (also CO)	34
NO	30	8.7
NO_2	46	0.65
Kr	84	2 200
H_2O	18	0.47

Table 2 summarizes the relevant peaks of the spectrum shown in Fig. 3. Calculation of the total amount of oxygen in peaks O, O_2, NO and NO_2 suggests that some of the carbon is missing. However, after opening the source no visible carbon contamination was found on the quartz chamber.

The next step is to use oxygen (O_2) as a buffer gas, which is expected to improve C + O_2 recombination and therefore the CO_2 beam production. Additional plan is to test a plasma electrode with 0.3 mm extraction hole. This should increase the pressure inside the plasma chamber and reduce the amount of neutrals lost to vacuum pumps.

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