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# EXPERIMENTAL STUDIES ON THE GAS MIXING EFFECT ON DECRIS-14-2

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# 1 Introduction

The gas mixing effect in ECR ion sources consists in a substantial increase to the ion beam intensity with high charge states when a second lighter gas is mixed into the plasma. The gas mixing effect has been used widely in many ECR ion sources over the world[1,2]. But its mechanism has not been very clear. In order to improve the highly charged ion production on DECRIS-14-2 [3] and study the gas mixing effect experimentally, a set of experiments were performed on DECRIS-14-2 with the first stage, negatively biased electrode [3] (no first stage), and the first stage together with negatively biased potential. Different support gases ( helium, oxygen, neon) were tested to the different main gases (oxygen, argon, xenon).

# 2 Experimental Procedures

DECRIS-14-2 is a 14 GHz compact ECR ion source particularly developed for the multiply charged ion production which will be coupled to FLNR U-400M cyclotron. The structure of this source is shown in Fig.1. The details of DECRIS-14-2 were described in Ref.[3].

All experiments about the gas mixing effect were done on DECRIS-14-2 with 10 Kv extraction voltage and 8 mm extraction hole. The source was optimized at a constant RF power-level of 200 W for all the highest available charge states. The main gas (beam-gas) and support gas (mixing-gas) are fed by two seperated piezo valves. The main gas is mixed up with the support gas at the common exit of the piezo valves from where the mixed gas is fed into the source through the coaxial line. The gas consumption and flow rate can be estimated by the two calibrated valves which are controled by the high voltage around 1 KV. The typical gas pressure for the bottle of the main gas and support gas is approximately 200 $\sim$ 300 mbar. All the ion currents were measured by a Faraday-cup situated about 90 cm downstream the exit of a 90 degree analyzing magnet, no any slits in the beam line.

The experimental procedures are always same no matter what kind of ions are optimized, and no matter with the first stage and the





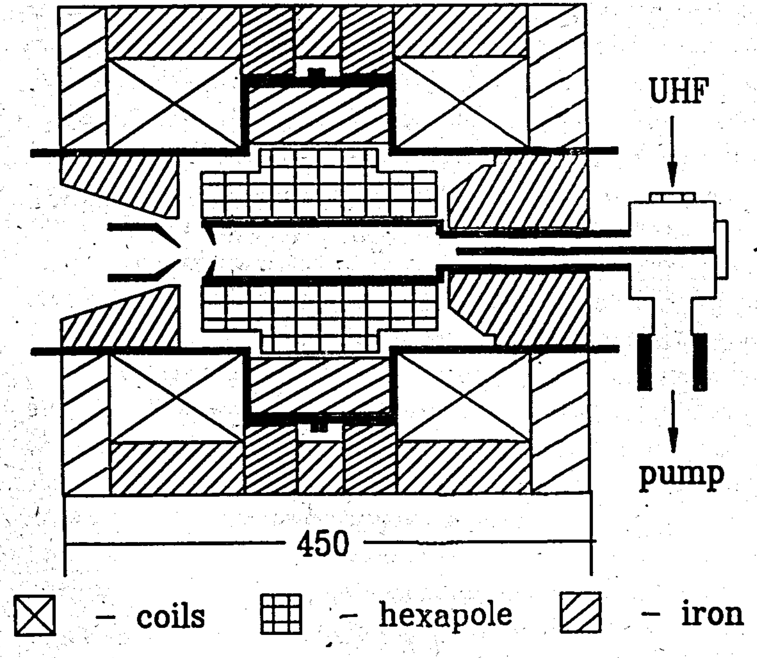


Fig.1 Schematic form of DECRIS-14-2

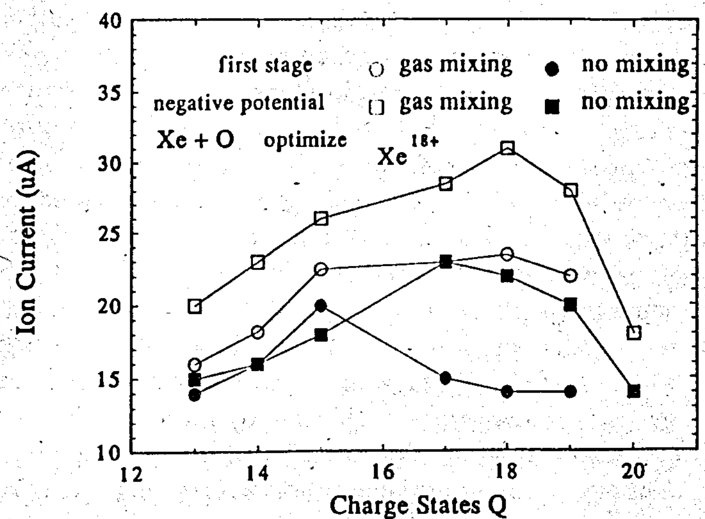


Fig.2 The gas mixing effect to highly charged ions of Xenon mixing with oxygen with the first stage and the negatively biased electrode.

negatively biased electrode. The source always begins to be tuned with pure gas by optimizing certain high charge state, and then the support gas is injected and the ion with the same charge state is optimized. All the results compared between the gas mixing effect and no gas mixing were obtained at the best optimization regime of the source so that we could understand the real and practical effect of the gas mixing to the enhancement of highly charged ion currents. We usually do the experiments like the following procedure.

A little bit of main gas is fed into the source firstly after the currents of the magnetic mirror coils and high voltage of the source are applied to, and then about 50 $\sim$ 100 W RF power is coupled to the source. The plasma is ignited and the ions are extracted from the source which can be seen from the total load current , the profile monitor and the current of the Fraday-cup. The currents of the lens and the analyzing magnet have to be optimized so that the ions with the high charge state that we want to optimize can be transported and selected efficiently. After that we increase the rf power little by little up to 200 W and fix it at this level. What is the most important next is to optimize the gas flow rate and the currents of the two magnetic mirror coils in order to get the best optimization regime. The negatively biased potential also has to be optimized if with the negatively biased electrode. We have to pay attention that the axial magnetic field, the gas flow rate and the rf power don't always match very well. Several good regime often occur, but we have to find the best one to make the current of the optimized ion maximum and stable by the best compromise between all those tuned parameters of the source. All the parameters, ion currents and spectrum can be recorded when we are sure that we get the best regime. After completion of a set of charge state measurements we have to check the reproducibility of the beam current for the selected ion. At this moment, the second gas (support gas) can be fed into the source and we begin to tune and optimize the same ion charge state with the gas mixing. The optimization procedures are similar to that mentioned above. The mixing ratio between main gas and support gas plays a very important role and we have to tune it very carefully to get a optimum mixing ratio.



# 3 Experimental Results

The gas mixing effect to highly charged ions of oxygen, argon and xenon was studied with support gases helium, oxygen and neon. $O_{16}^{6+}$ , $Ar_{40}^{11+}$ and $Xe_{132}^{18+}$ were always as typically optimized ions respectively during all experiments.

The comparison of the gas mixing effect with the first stage and the negatively biased electrode for the typically optimized ions is presented in Table 1. The results of the gas mixing effect to highly charged ions of Xenon mixing with oxygen are summarized in Fig.2 with the first stage and the negatively biased electrode.

We can see from Table 1 that the enhancement factors of the gas mixing effect with the negatively biased electrode are much less than those with the first stage. In other words, the gas mixing effect is restrained by the negatively biased electrode compared with the first stage.

Only argon mixed with oxygen was tested when the first stage together with a negatively biased potential. No any gas mixing effect was found when we optimized $Ar^{11+}$ and $Ar^{9+}$.

The experiments indicate that helium and oxygen have almost same gas mixing effect to $Ar^{11+}$. There is no much effect to $Ar^{11+}$ and $Ar^{9+}$ when neon as a support gas. With neon as support gas, the gas mixing effect to the high charge states of xenon is obvious, but the effct is less than oxygen (at least $Q \leq 20$ ). The current of $Xe^{18+}$ increases from 21 $\mu$ A to 28 $\mu$ A by the gas mixing of neon with the negatively biased electrode.

The consumptions of the main gases oxygen, argon and xenon at different conditions are shown in Fig.3 which were obtained when we optimized $O^{6+}$ , $Ar^{11+}$ and $Xe^{18+}$ respectively. All of the gas consumptions in Fig.3 are estimated from the two calibrated piezo valves. The calibrated curves for the two valves are shown in Fig.4.

The gas mixing effect was also studied theoretically on the base of a simple balance model [4]. The calculated charge state distributions for argon and xenon mixed with oxygen are fitted with the experimental results from DECRIS-14-2, as shown in Fig.5 and Fig.6. In order to fit with the experimental results, in our calculations the hot

Table 1 Comparison of the gas mixing effect with the first stage and the negatively biased electrode for the typically optimized ions ($\mu A$).

| | The First Stage | | | Negatively Biased Electrode | | |
|---|---|---|---|---|---|---|
| | no gas mixing | with gas mixing | $f$ | no gas mixing | with gas mixing | $f$ |
| $O^{6+}_{16}$ | 60 | 90 | 1.5 | 116 | 135 | 1.16 |
| $Ar^{11+}_{40}$ | 11 | 16.5 | 1.5 | 17 | 25 | 1.47 |
| $Xe^{17+}_{132}$ | 15 | 23 | 1.53 | 23 | 28.5 | 1.24 |
| $Xe^{18+}_{132}$ | 14 | 23.5 | 1.68 | 22 | 31 | 1.4 |
| $Xe^{19+}_{132}$ | 14 | 22 | 1.57 | 20 | 28 | 1.4 |

*: Helium was used as support gas for $O^{6+}_{16}$ . The support gas of the others was oxygen.
$f$ means enhancement factor



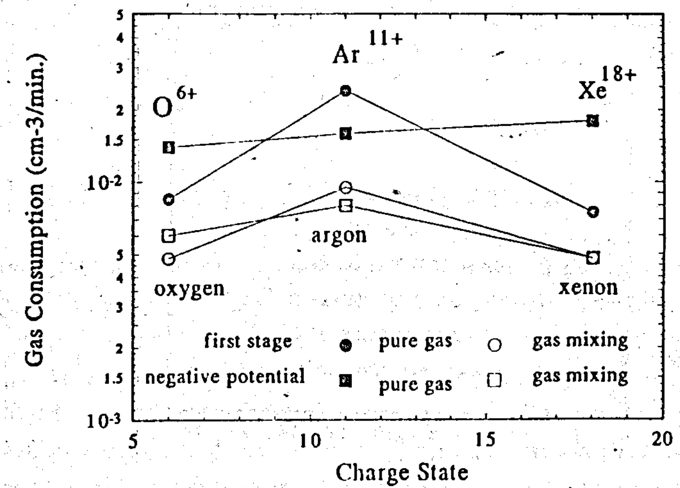


Fig.3 The consumption of the main gases oxygen, argon and xenon with and without the gas mixing.

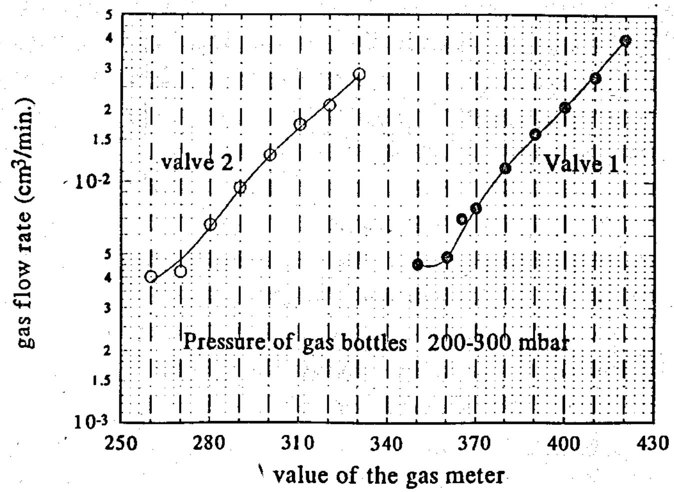


Fig.4 The calibrated curves of the two piezo valves used in the experiments.

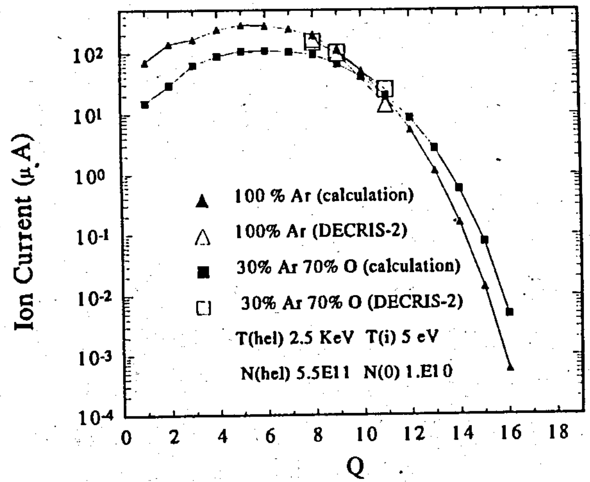


Fig.5 The fitting between the calculated charge state distributions for argon mixed with oxygen and the experimental results from DECRIS-14-2.

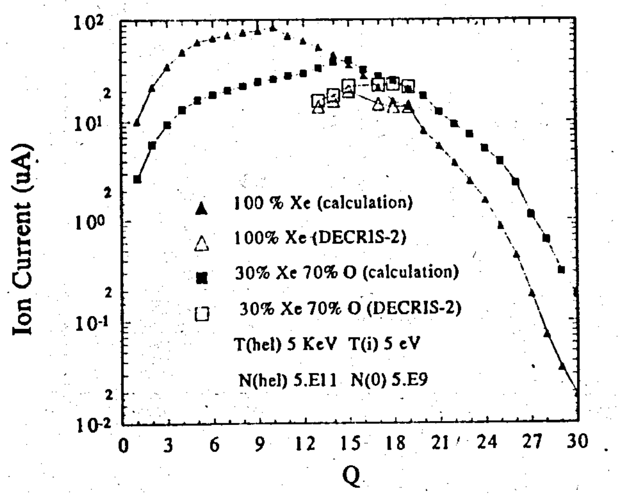


Fig.6 The fitting between the calculated charge state distributions for xenon mixed with oxygen and the experimental results from DECRIS-14-2.



electron temperature and density are relatively low because the microwave power that we used in our experiments was very low ( less than 250 W ). Fig.5 and Fig.6 indicate that the calculations are in good agreement with the experimental results.

## 4 Discussion and Conclusion

By means of the gas mixing effect, the beam intensity of the typically optimized ions ( $O^{6+}$ , $Ar^{11+}$ and $Xe^{18+}$ ) are improved averagely by more than 1.3 times with the negatively biased electrode and more than 1.5 times with the first stage. The gas mixing effect not only improves the currents of the highly charged ions, but also decreases the main gas consumption by more than 60% on average which is very promising and interesting to the radioactive ion production. Oxygen is the best support gas and very effective to the high charge states of xenon and argon. The mixing ratio between main gas and support gas is different for different ions and different support gas with the first stage and the negatively biased electrode. For DECRIS-14-2 in optimization of $Ar_{40}^{11+}$, the mixing ratio changes from 20% argon , 80% support gas to 40% argon , 60% support gas with negatively biased potential and with first stage when oxygen and helium are used as support gas.

The experiments indicate that the gas mixing effect is restrained by the negatively biased potential. The negatively biased electrode works as a plasma cathode to collect ions and repel the plasma electrons into the central plasma, meanwhile, it also provides electrons from secondary emission of impinging plasma particles. That means the additional electrons are injected into the ECR plasma with a negatively biased potential. When an ECR ion source works at the best optimum regime, the density of the electrons might reach the value near the cut-off density (a constant value) . when additional electrons are injected into the ECR plasma with a negatively biased potential, the gas mixing effect must be limitted if we think one of functions for the gas mixing effect is the increase of the electron density. If one of mechanisms for the gas mixing effect were not the increase of the electron density, then it would be very difficult to explain this experimental phenomina. It is obvious that this phenomina can not be explained by the previous interpretation to the gas mixing effect (ion cooling). From this interpretation it seems that the increase of the electron density should be one of dominant reasons for the gas mixing effect.

# 5 References


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**Экспериментальное исследование эффекта смешивания газов в DECRIS-14-2**


Экспериментально исследован эффект смешивания газов. Проведена серия экспериментов на источнике DECRIS-14-2 с первой ступенью, с отрицательно смещенным электродом (без первой ступени) и с первой ступенью вместе с отрицательно смещенным электродом. Различные балластные газы (гелий, кислород, неон) были испытаны вместе с различными рабочими газами (кислород, аргон, ксенон). В соответствующих экспериментах измерялся расход рабочего газа и коэффициент смешивания. Эксперименты показывают, что эффект смешивания газов проявляется сильнее в случае использования отрицательно смещенного электрода без первой ступени по сравнению с совместным использованием отрицательно смещенного электрода и первой ступенью. При использовании смешивания газов расход основного газа уменьшается более чем на 60%. Эффект смешивания газов увеличивает интенсивность пучка ионов, на который оптимизируется источник, более чем в 1,3 раза с отрицательно смещенным электродом и более чем в 1,5 раза при работе с первой ступенью.



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**Experimental Studies on the Gas Mixing Effect on DECRIS-14-2**


The gas mixing effect has been studied experimentally. A set of experiments were performed on DECRIS-14-2 with the first stage, negatively biased electrode (no first stage), and the first stage together with negatively biased potential. Different support gases (helium, oxygen, neon) were tested to the different main gases (oxygen, argon, xenon). The main gas consumption and the mixing ratios were measured for the corresponding experiments. The experiments indicate that the gas mixing effect is restrained by the negatively biased potential compared with the first stage. The main gas consumption are decreased by more than 60% due to the gas mixing effect. By means of the gas mixing effect, the beam intensity of the typically optimized ions ($O^{6+}$, $Ar^{11+}$ and $Xe^{18+}$) are improved averagely by more than 1.3 times with the negatively biased electrode and more than 1.5 times with the first stage.



The investigation has been performed at the Flerov Laboratory of Nuclear Reactions, JINR.

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