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J. Lettry, M Lindroos, F. Wenander

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TRANSVERSE EMITTANCE INVESTIGATION OF THE ISOLDE TARGET ION SOURCES

F. WENANDER†, J. LETTRY, M. LINDROOS

PS CERN, 1211 Geneva-23, Switzerland

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Abstract:

In order to produce target-ion sources allowing for a high isotopic resolution in the separator, CERN/ISOLDE (Isotope Separator On Line) has purchased a commercial emittance meter, capable of measuring transverse phase-space emittances for ion-beam intensities down to approximately 1 nA. It was installed at the ISOLDE off-line separator where targets are tested with respect to material purity and the ion-source efficiencies are determined. Now, also the emittance and brightness are measured for different stable elements. An extensive programme has been launched aiming at a complete survey of the emittance dependence on the various ion-source parameters. Results from the measurements on the different ISOLDE ion-source types, with associated analysis, are presented.

1. Introduction

1.1.Motivation

At the ISOLDE facility [1,2], the quest for ion sources with high chemical selectivity, efficiency and long lifetime still remains, but in recent times a stronger emphasis has been put on the beam-optical properties. With the increased use of the High Resolution Separator (HRS) [3], and the demand for highly mass resolved radioactive beams, the transverse emittance of the extracted ion beam becomes an important issue as the resolution is inversely proportional to the horizontal emittance. Furthermore, ion injection into charge breeding and trapping devices requires high brightness beams for a high efficiency.

Previously, the $\varepsilon_{95\%}$ was measured at ISOLDE PS Booster at 60 kV and found to be 32 π·mm·mrad for a surface ioniser [4]. More recent estimations based on the minimum waist-size and the divergence of the HRS beam gave 7±6 π·mm·mrad [5]. To clarify the picture, a commercial emittance meter was purchased, and the primary aim has been to re-examine the transverse emittance of the different ion sources operated under varying conditions.

1.2. Definitions

† *E-mail*: fredrik.wenander@cern.ch, fax: +41 22 7678990, phone: +41 22 7672630

The figures of merit are the emittance and the brightness values. The geometrical emittance, $\varepsilon_{95\%}$, denotes the phase-space area for 95% of the beam particles (in one dimension). The absolute experimental values depend on the background threshold adopted, and on the measurement errors (discretisation and border errors). These uncorrelated uncertainties are conservatively estimated at ±1 π·mm·mrad each. All values presented are non-normalised, for a total extraction voltage of 30 kV.

The brightness, specifying the peak flux available from a beam, is defined within this report as:

$$B_{95\%} = \frac{I}{\pi^2 \cdot \varepsilon_{95\%x} \cdot \varepsilon_{95\%y}} \text{ A/(m}^2 \text{ steradians)} \qquad (1)$$

where I is current and $\varepsilon_{95\%x,y}$ are assumed equal because of extraction symmetry.

1.3. Experimental set-up

The entire series of measurements has been carried out at the ISOLDE off-line mass separator. The ions are extracted from the ion source by an axially moveable extraction electrode (puller), which is followed by an einzel lens and a double focussing 55° dipole magnet. The emittance meter was positioned behind the magnetic focal plane, permitting measurements of mono-isobaric beams, with a total drift length between ion source and the emittance probing-plane of approximately 4500 mm. The isotope and total extracted currents were measured in a 30 mm diameter Faraday cup positioned 520 mm in front of the emittance meter entrance slit.

The off-line separator differs somewhat from the on-line one. For example, the on-line quadrupole lens is exchanged for an einzel lens. Secondly, the potential of the puller is variable between 0 and 30 kV relative to ground potential and is not grounded. Finally, the nominal extraction voltage is limited to 30 kV due to transformer insulation restrictions, as opposed to 60 kV for the on-line separator.

The emittance was measured using a commercial beam emittance analyser [6] of slit-grid type developed by NTG (Neue Technologien Gelnhausen).

1.4. Ion source description

Two standard ISOLDE ion-source types were investigated: surface ionising MK1 and plasma ionising MK7 sources. In the former type a high temperature cavity of tungsten (also tantalum or rhenium) very efficiently ionises the alkalis, rare earth elements and low ionisation potential molecules. In the plasma ion-source of FEBIAD type [7] the ionisation occurs in a high temperature cavity under low magnetic field by collision with 100-200 eV electrons. The electrons are produced by a hot cathode and accelerated via a grid into the 2.5 cm^3 plasma chamber. The ion sources are described in more detail in ref. [8,9].

2. Results

2.1. Surface ioniser

The emittance of the surface ioniser was first measured for a number of different operating conditions.

By varying the line current, while all other parameters were kept constant, the temperature of the cavity tube was changed. The emittance increases with the current, as seen in Fig. 1 for a K^+ beam. A similar tendency was found for a Na^+ beam, and for I_{target}=750 A. The increase is large, and the theoretical emittance estimation [10]:

$$\varepsilon_{4RMS} = 8.2 \cdot r \cdot \sqrt{kT_i} \ \pi\cdot\text{mm}\cdot\text{mrad}, \qquad (2)$$

where r denotes extraction hole diameter (mm) and kT_i the ion energy (eV), shows that the ion temperature T_i is not solely governed by the tube temperature (changing from 1870 to 2450 K), but is most likely influenced by a deeper plasma potential well[1].

The brightness, for this stable beam, is reduced as the line temperature increases, but it is not a limitation for spectroscopy experiments, ion implantation or sample collections at ISOLDE as the beam-line aperture allows for a sufficiently focused beam in most cases. Nevertheless, for acceptance limited devices, the particle throughput is determined by this value, and it should therefore be optimised.

In a similar way the target temperature was changed, resulting in a varying extracted current. In spite of this, the emittance remained constant (Fig. 2a) signifying that space-charge effects are absent up to at least I_{total}=3 μA. Thus, the brightness increased significantly with the target temperature (Fig. 2b).

No systematic variation in emittance with mass or ionisation potential for the different elements Na (A=23, W_i=4.34 eV), Al (A=27, W_i=5.99 eV) and K (A=39, W_i=5.14 eV) was recorded, as is illustrated in Fig. 3, however, the mass range was limited.

A scan of the puller voltage from −10 to −30 kV relative to the ion source (U_{HV} constant at 30 kV and D_{puller}=90 mm) showed no variation in either emittance or brightness. This confirms that the beam is far from emittance blow-up due to space-charge effects in the extraction region. An emittance blow-up due to over-focussing by the plasma meniscus was also not present.

Nevertheless, the emittance investigation revealed a strong dependence on the puller position. Fig. 4a shows that the emittance and brightness optima occur for an extraction distance of 85 mm; an identical optimum distance was found for a K^+ beam. The extracted current, Fig. 4b, remains almost constant over a wide distance range, but losses occur, either at the puller or in the separator line, for very short and long distances. The load current on the puller was unfortunately not recorded at this moment.

A similar measurement series carried out with a lower target current (700 A), and thereby at a lower extracted current (I_{total}~500 nA), exhibited a similar behaviour, with the emittance optimum occurring at the same distance. Nonetheless, the optimum distance may change for extreme current values. The phase-space ellipses orientation changed considerably with the distance.

The load current on a grounded puller was measured and found to be very high, 3-10 μA, compared with an analysed total current of some μA. The cause, however, is thermionic emission of electrons leaving the extraction electrode radially, and not ion current losses.

As was demonstrated above, the emittance is strongly dependent on the line temperature and the extraction electrode position. Nevertheless, it can be stated that a minimum $\varepsilon_{95\%}$ value of

[1] In fact, as the ionisation takes place on a single potential (the tube wall potential), one would not expect an ion temperature distribution as large as the plasma potential well. However, charge exchange, and collision processes within the tube volume redirecting the longitudinal energy spread to the transversal, could give rise to the large ion energy.

12-14 π·mm·mrad for a 3 mm inner diameter W line tube operated at 340 A (2450 K) and with an extracted current of a few μA is attainable. This translates to approximately 10 π·mm·mrad at 60 kV. Complementary measurements on two other surface ionisers agree with this value.

2.2. Plasma ion-source

Two MK7 plasma ion-sources were examined, starting with the cathode temperature. As the cathode current was increased from 340 to 400 A, the emittance increased by 2 units to 14 π·mm·mrad while the Xe brightness rose by a factor of 4. The emittance increase is most likely due to changed extraction conditions, as the change in electron temperature is negligible.

A small but significant emittance increase with the anode voltage was found. With the source tuned at U_{anode}=150 V and with D_{puller}=120 mm (not optimum), the $\varepsilon_{95\%}$ went up by 3-4 π·mm·mrad (

Fig. 5). Likewise, a combined increase of anode voltage and source magnetic field to boost the extracted current leads to a higher emittance. However, the radically elevated electron energy (from 80 to 220 eV) seems only to have a marginal influence on the ion temperature and thereby on the emittance.

Surprisingly enough, it was found that the measured emittance varied strongly with the separator magnet settings, see Fig. 6, which is not expected if it assumed the elements are evenly distributed within the plasma with thermalised ion temperatures. No correlation with the ionisation potential, noble versus non-noble gas, or the isotope current was noticed. Neither could the ion-source magnetic field explain the emittance variation [11], as the effect was present also for zero field. Instead the anomaly is most likely due to an emittance increase for light elements in the separator magnet.

As for the surface ioniser, the plasma source emittance varies considerably as a function of the puller distance. The minimum is found for D_{puller}=80 mm, with a brightness optimum between 60 and 80 mm. The emittance increases by a factor 3 for H_2^+ and almost doubles for Ar^+ when the puller is displaced ±30 mm. The phase-space ellipse orientation changed notably with the puller distance, while the emittance value did not vary with the puller voltage (total extraction voltage kept constant) for an optimised puller position. This is exactly as for the surface ioniser. No space-charge effects were observed up to 4 μA.

After optimisation, the $\varepsilon_{95\%}$ for the two plasma sources was found to be 8-10 π·mm·mrad for typical operation conditions (D_{puller}=88 mm, U_{puller}=-30 kV, I_{line}=380-400 A, U_{anode}=180-205 V, I_{anode}=0.03-0.05 A, I_{magnet}=5-6 A, I_{total}=1-3 μA).

3. Discussion

Comparing surface with plasma ionisers, the former has demonstrated somewhat larger emittance values, mainly due to the larger (3 mm compared with 1.6 mm) extraction hole diameter.

Since several of the tests on the plasma ion-sources were carried out for a non-optimum puller distance, at least the cathode current, gas pressure and anode voltage measurements should be redone to confirm the results.

It has to be kept in mind that the phase space was recorded after the separator magnet, implying that beam tails may have been washed out and aberrations introduced. Disregarding this, are the results directly transferable to an on-line situation? The question is motivated by the

lower beam energy (30 keV) at the off-line separator. Because the space-charge effects in the extraction region were shown to be insignificant, as well as the emittance blow-up due to a variation in focussing strength from the plasma meniscus with varying puller voltage, the emittance values are indeed expected to be directly scalable to 60 keV. On the other hand, a variation in orientation of the phase-space ellipse will occur if the obtained optimum puller position is different for the on-line separator. This might preclude the methodology to trace the ellipse backwards to the puller, scale the angular dimension of the ellipse to 60 kV extraction voltage, and thereafter trace it through the separator magnets.

A more detailed emittance investigation will follow, at the off-line separator, and with complementary measurements at the ISOLDE beam lines as these values are significantly higher, possibly due to aberrations in benders etc. The aim is to present a full comparison between the different ion source types operated under various conditions (e.g. gas pressure, line material, extraction hole diameter, etc). Furthermore, a standardised procedure for the emittance documentation of each target/ion source unit produced is to be invoked. A redesign of the extraction system to slit-type geometry may be considered, if the anticipated plasma inhomogeneity along the slit length is tolerable.

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References

1. E. Kugler et al., Hyp. Int. 129 (2001) 23.
2. E. Kugler et al., Nucl. Instr. and Meth. B 70 (1992) 41.
3. T. Giles, these proceedings.
4. D. Habs et al. Internal report ISOLDE, CERN (1994).
5. R. Baartman, Internal report PS/CERN, CERN PS/OP/Note 2002_085.
6. J. Dietrich, J. Häuser, I. Mohos, G. Riehl, F. Wenander, to appear in Proc. of 8th EPAC, Paris, 2002.
7. R. Kirchner and E. Roeckl, Nucl. Instr. and Meth. 133 (1976) 187.
8. T. Bjørnstad, E. Hagebø, P. Hoff, E. Kugler, H. L. Ravn, S. Sundell and B. Vosicki, Phys. Scr. 34 (1986) 578.
9. S. Sundell, H. L. Ravn and the ISOLDE collaboration, Nucl. Instr. and Meth. B 70 (1992) 160.
10. P. Allison, J. D. Sherman, H. V. Smith, Report LA-8808-MS, Los Alamos Nat. Lab., 1981.
11. J. L. Hagedoorn, J. I. M. Botman, Internal report, GSI-90-29, GSI, Germany.

Fig. 1. Measured $\varepsilon_{95\%}$ and $B_{95\%}$ vs. line current for K^+ beams extracted from a surface ioniser (Data: K^+, U_{puller}=-22.5 kV, D_{puller}=125 mm).

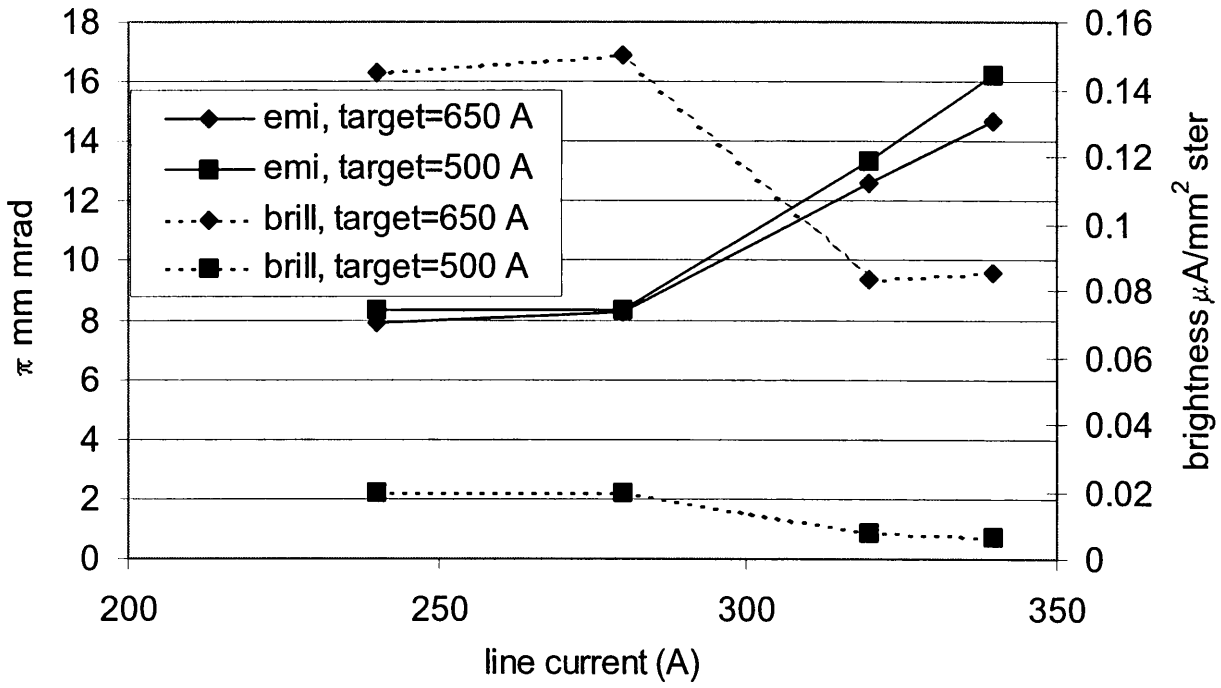
Fig. 2. Measured $\varepsilon_{95\%}$ (a) and $B_{95\%}$ (b) as function of target temperature (Data: Na^+, K^+, U_{puller}=-22.5 kV, D_{puller}=125 mm).

Fig. 3. Measured $\varepsilon_{95\%}$ for three extracted beams for various line and target temperatures.

Fig. 4. $\varepsilon_{95\%}$ and $B_{95\%}$ (a) and current (b) as functions of puller position for a surface ion-source (Data: Na^+, I_{target}=750 A, I_{line}=340 A, U_{puller}=-22.5 kV).

Fig. 5. $\varepsilon_{95\%}$ and isotope current vs. anode voltage (Data: Ar^+, CO^+, I_{anode}=0.03-0.04 A, U_{puller}=-30 kV, D_{puller}=120 mm, $I_{cathode}$=380 A, I_{magnet}=3.5 A).

Fig. 6. $\varepsilon_{95\%}$ and analysed isotope current vs. selected ion mass for a number of ions (Data: U_{anode}=190 V, I_{anode}=0.08 A, U_{puller}=-30 kV, D_{puller}=100 mm, $I_{cathode}$=400 A, I_{magnet}=6.0 A, I_{total}=4.4 μA).



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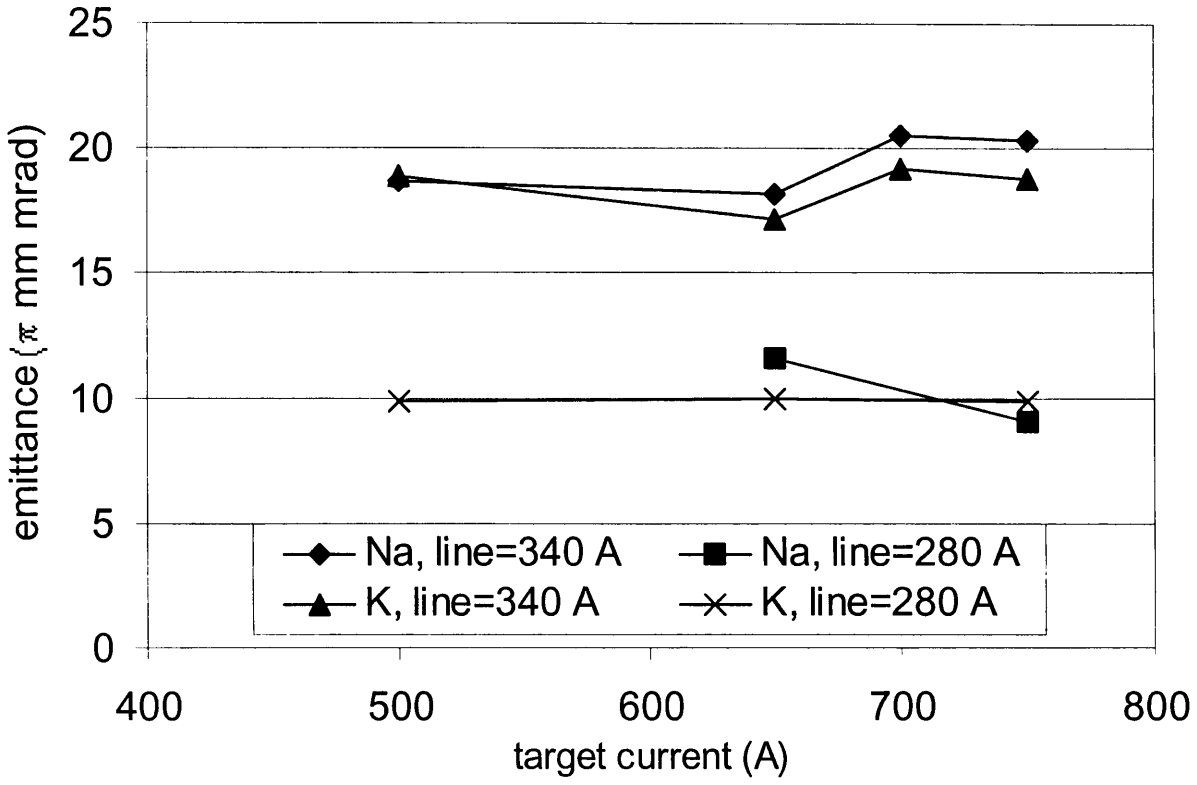

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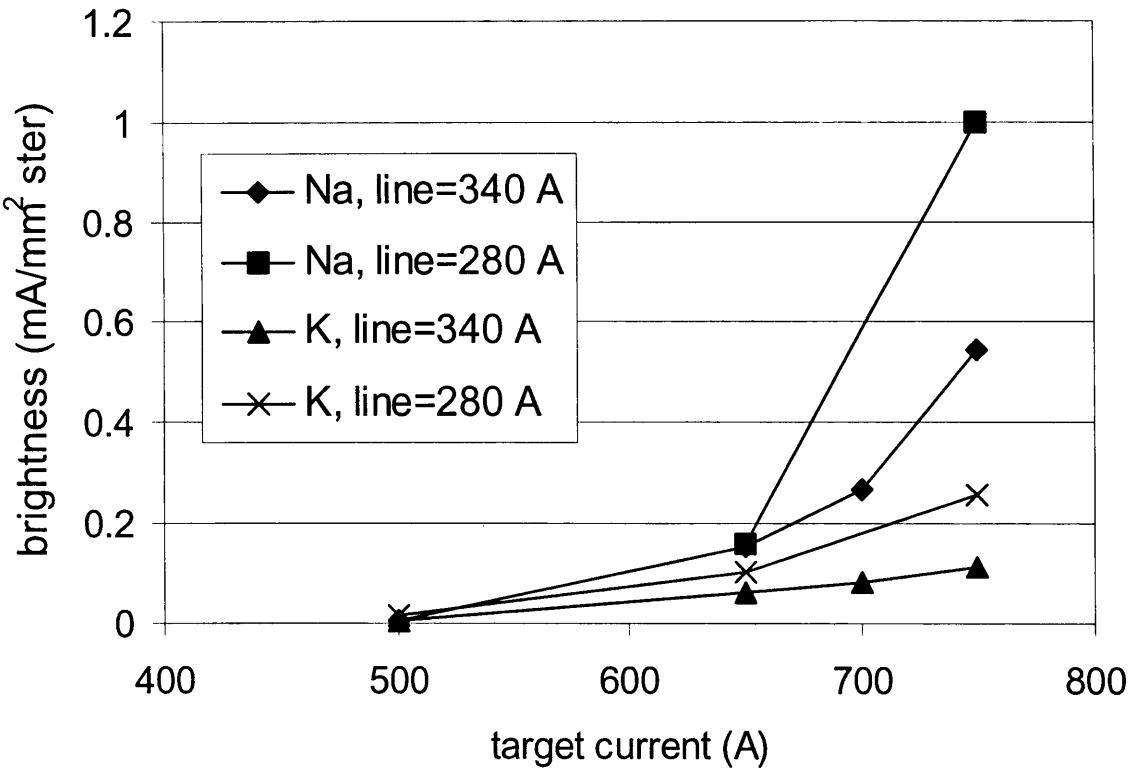
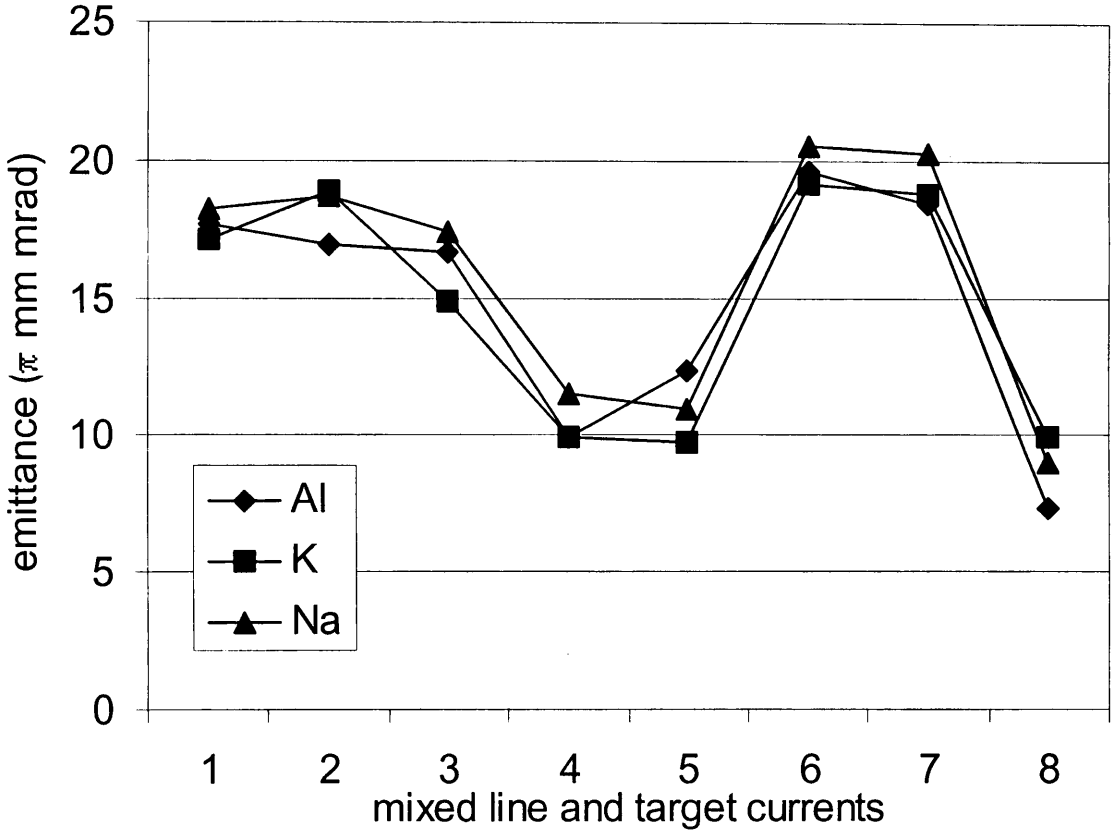


Fig. 2b. Measured $\varepsilon_{95\%}$ (a) and $B_{95\%}$ (b) as function of target temperature (Data: Na^+, K^+, U_{puller}=-22.5 kV, D_{puller}=125 mm).



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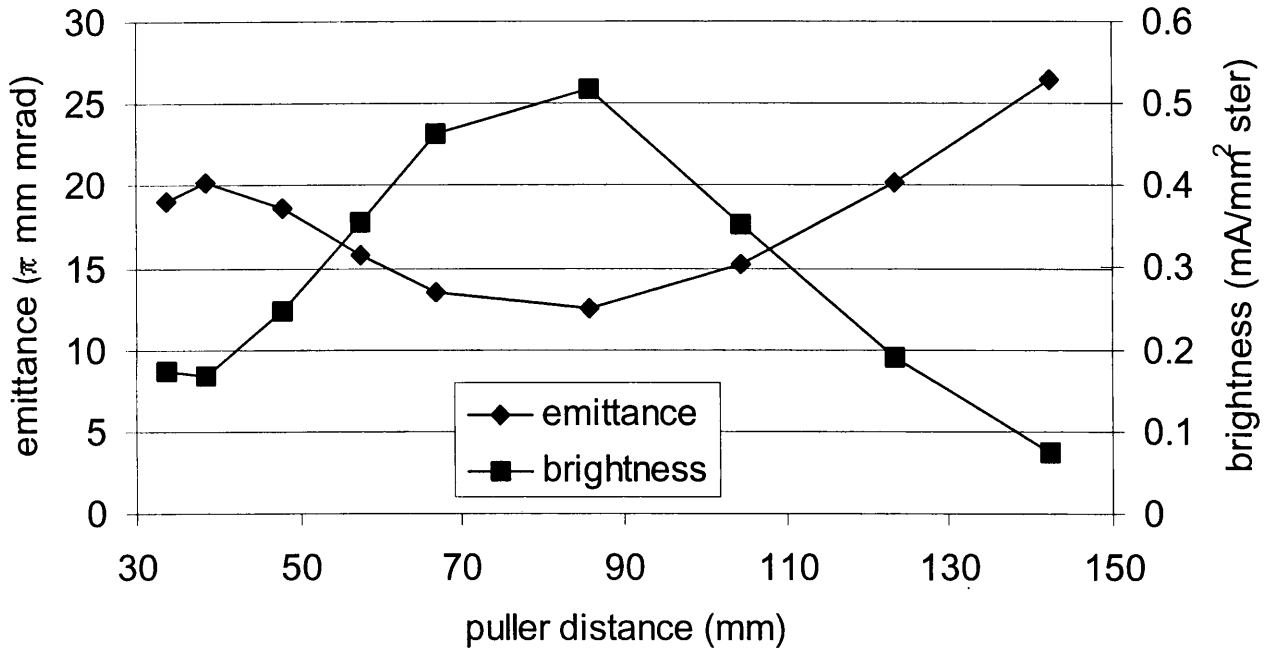

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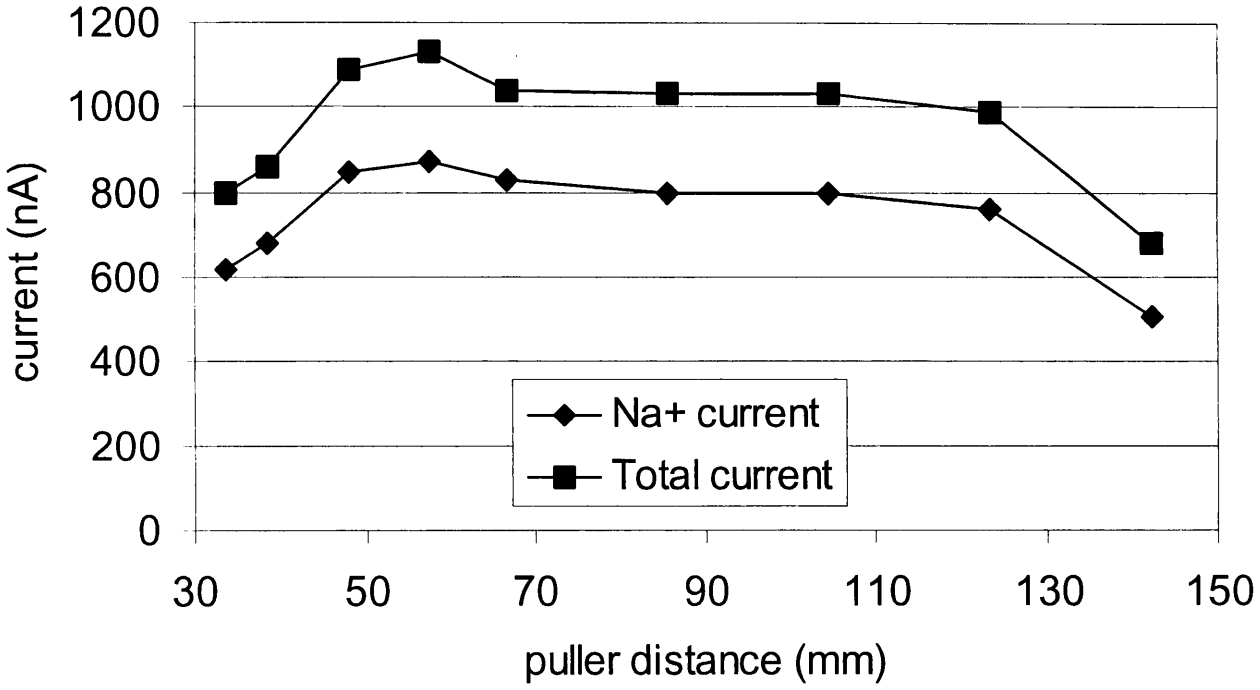

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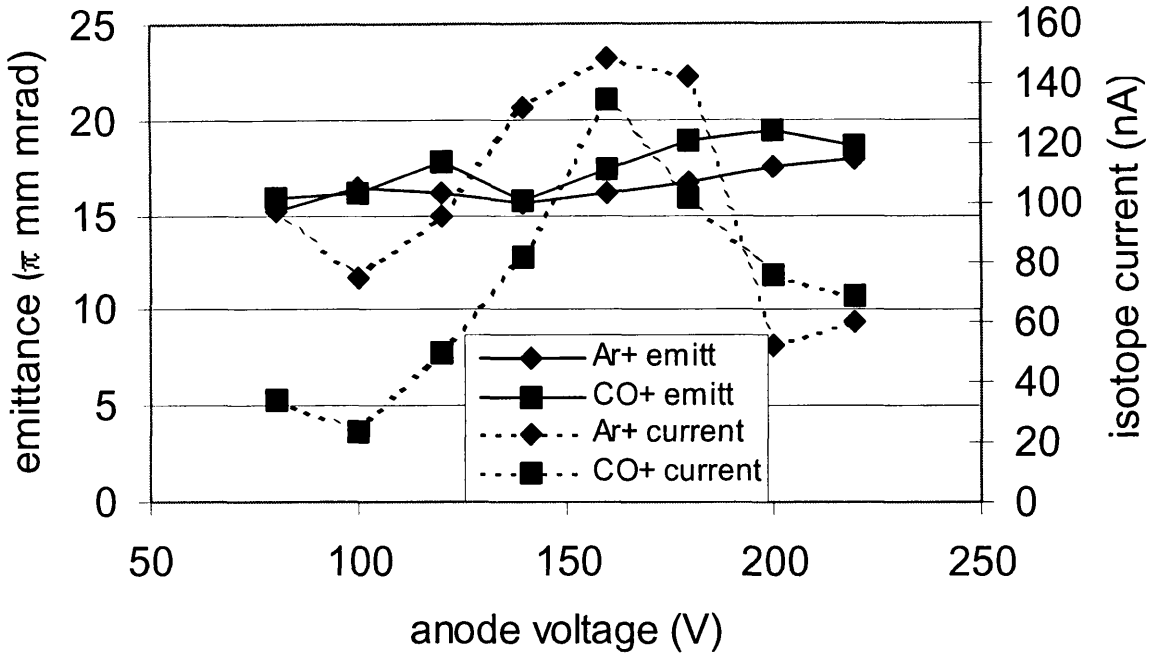

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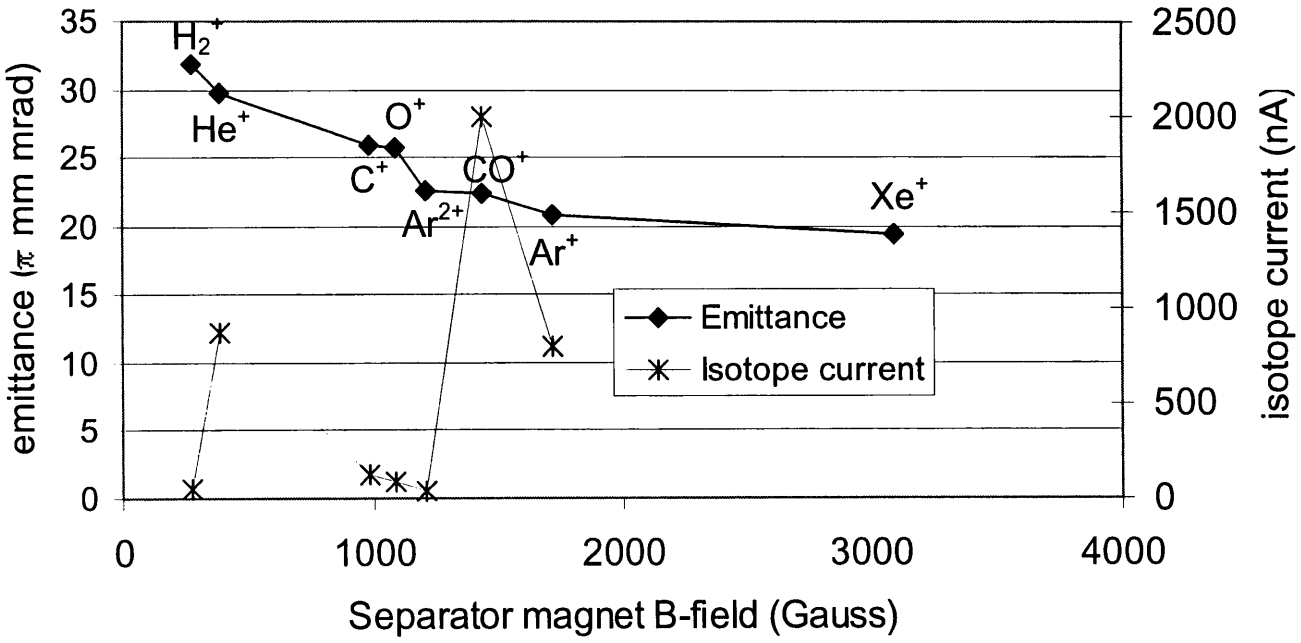

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