Development of metal ion beams and beam transmission at JYFL

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Content:

- MIVOC method for the production of metal ion beams

- oven development at JYFL

- sputter development at JYFL

- beam transmission efficiency

- beam structure

- beam neutralization (space charge compensation)

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JYFL 14 GHz ECRIS

Main source for the K-130 cyclotron

JYFL 6.4 GHz ECRIS

Back up for cyclotron

Ion beam related R&D

Solid ion beams at JYFL

Ovens, MIVOC, sputter technique

Element	Method	Intensity [μA] (q/mÅ02)	Note
B	MIVOC	235	$(C_2H_{12}B_{10})$
C	CO_2	195	
F	SF_6	19	6.4 GHz
Mg	MIVOC	12	6.4 GHz
Al	Oven	9.5	6.4 GHz
Si	SiH_4	124	
S	SF_6	22	6.4 GHz
Cl	$TiCl_4$	23	6.4 GHz
Ca	Oven	75	CaO + Zr
Ti	MIVOC	45	$CH_3)_5C_5Ti(CH_3)_3$
V	MIVOC	10	$V(C_5H_5)_2$
Cr	Ind. oven	20	
Mn	Oven	22.5	
Fe	MIVOC	115	$Fe(C_5H_5)_2$
Co	MIVOC	12	$Co(C_5H_5)_2$
Ni	MIVOC	55	$Ni(C_5H_5)_2$
Cu	Oven	7.5	
Zn	Sputter	5.5	6.4 GHz
Sr	Oven	30	ZrO + Zr
Y	Foil oven	5	
Zr	Sputter	12	
Ru	MIVOC	9.1	$Ru(C_5H_5)_2$
Ag	Oven	5.8	
Au	Oven	15	

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MIVOC method: Metal Ions from VOlatile Compounds

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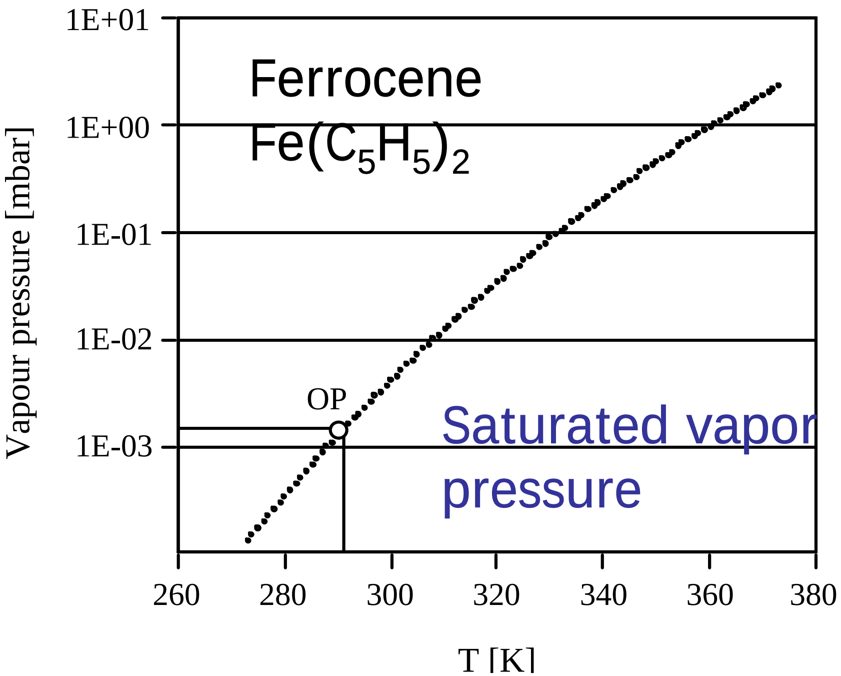
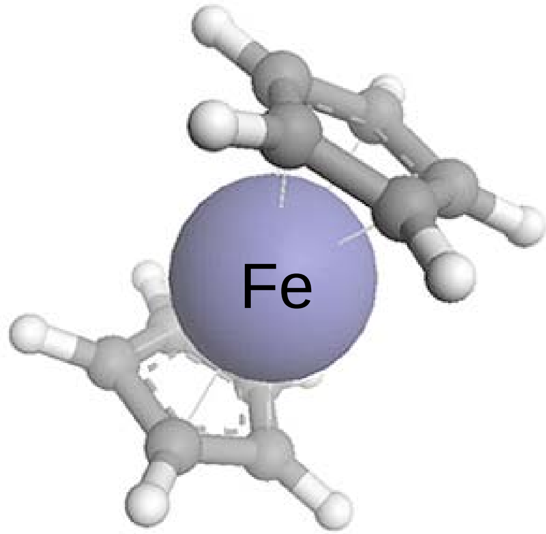
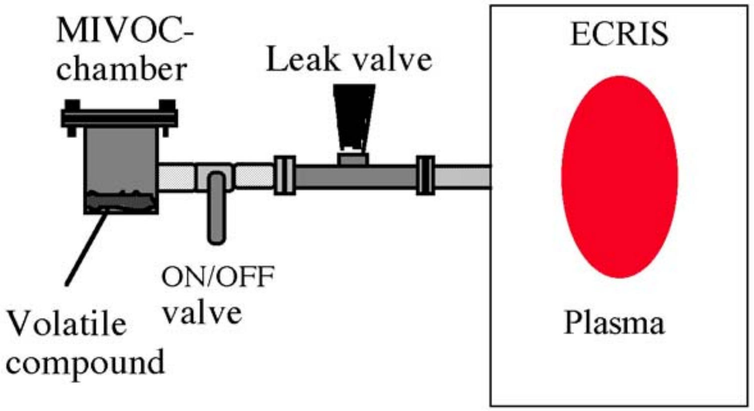
Compound including element of interest and having adequate vapor pressure has to be found!



1E+01
1E+00
1E-01
1E-02
1E-03
Vapour pressure [mbar]
Ferrocene
Fe(C5H5)2
OP
Saturated vapor pressure
260
280
300
320
340
360
380
T [K]



Fe



MIVOC-chamber
Leak valve
ECRIS
ON/OFF valve
Volatile compound
Plasma

MIVOC is very effective for some metal ion beams like iron

$X(C_5H_5)_2$ X = Fe, Ni, Ru, Os

Rev. Sci. Instrum., Vol. 69, No. 2, February 1998

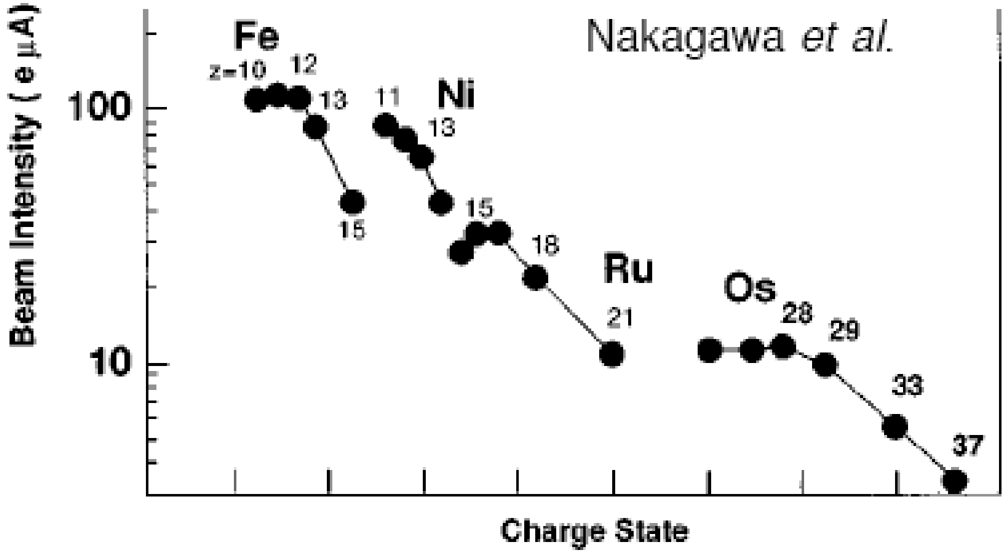


FIG. 1. Beam intensity of Fe, Ni, Ru, and Os ions as a function of charge state.

- used at RIKEN for studies of super-heavy elements

Drawbacks:
- lack of suitable compounds
- carbon contamination

JYFL evaporation ovens

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a) Miniature oven, b) foil oven, c) induction oven

Main problem concerning the oven technique:

Surface to surface stability!

TABLE V. Maximum temperatures (°C) for surface-to-surface stability for some ceramics and refractory metals.[a]

	C	W	Mo	Ta	ThO_2	ZrO_2	MgO	BeO
BeO	2300	2000	1900	1600	2100	1900	1800	
MgO	1800	2000	1600	1600	2200	2000		1800
ZrO_2	1600	1600	2200	1700	2200		2000	1900
ThO_2	2000	2200	1900			2200	2200	2100
Al_2O_3	1300[b]	1700[c]	1800[c,d]	1700[c]				
BN	1900[e]			1500[e]				
C		1400[c]	1200[c]	1000[c]				

Ross & Sonntag **Rev. Sci. Instrum., Vol. 66, No. 9, September 1995**

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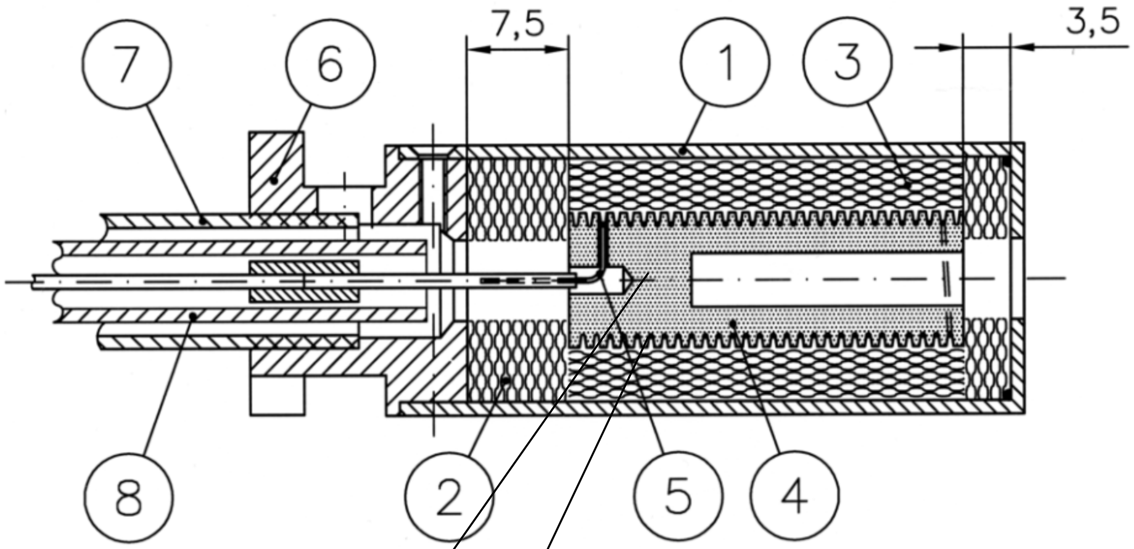
JYFL miniature oven

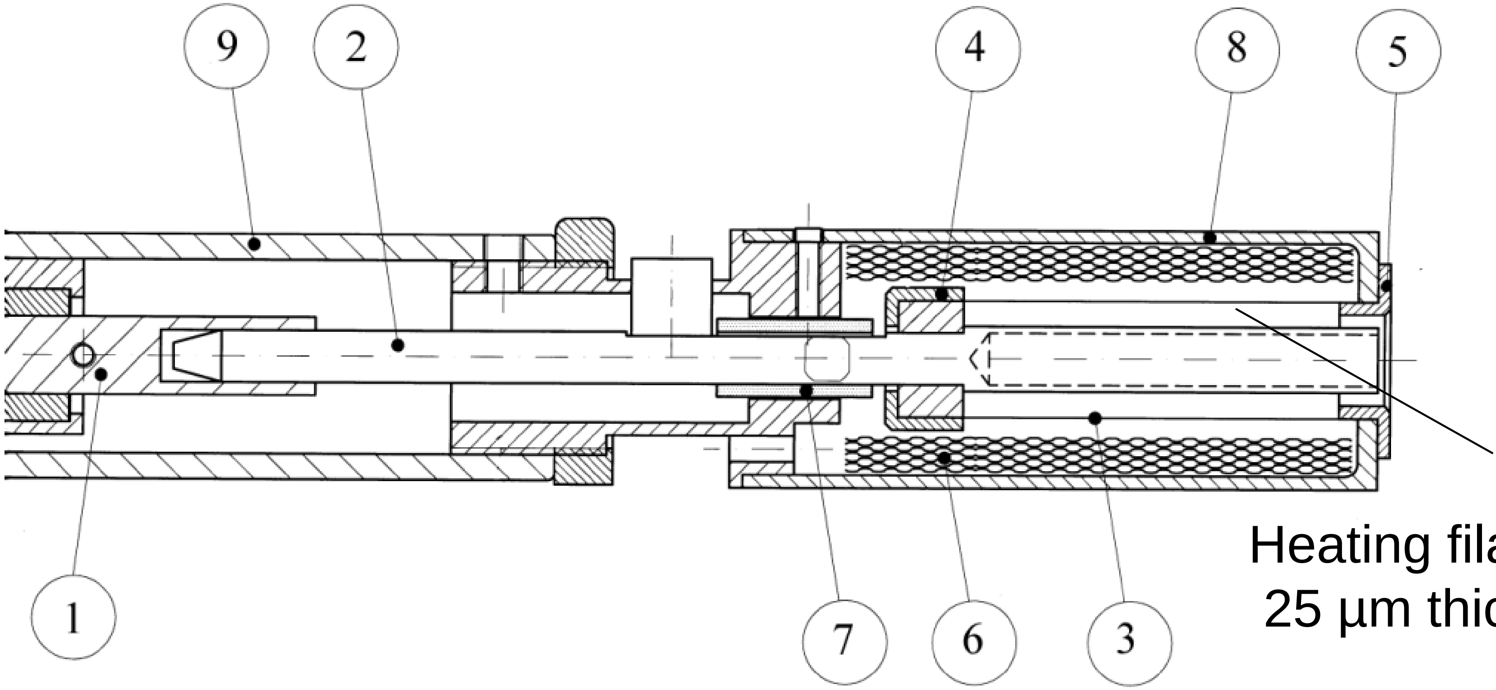


Ta heating wire

Al_2O_3 insulator

⇒ surface-to-surface stability < 1700°C (practical max. operation T ≈ 1500°C)

JYFL foil oven (up to 2000°C)



Heating filament:
25 µm thick Ta foil

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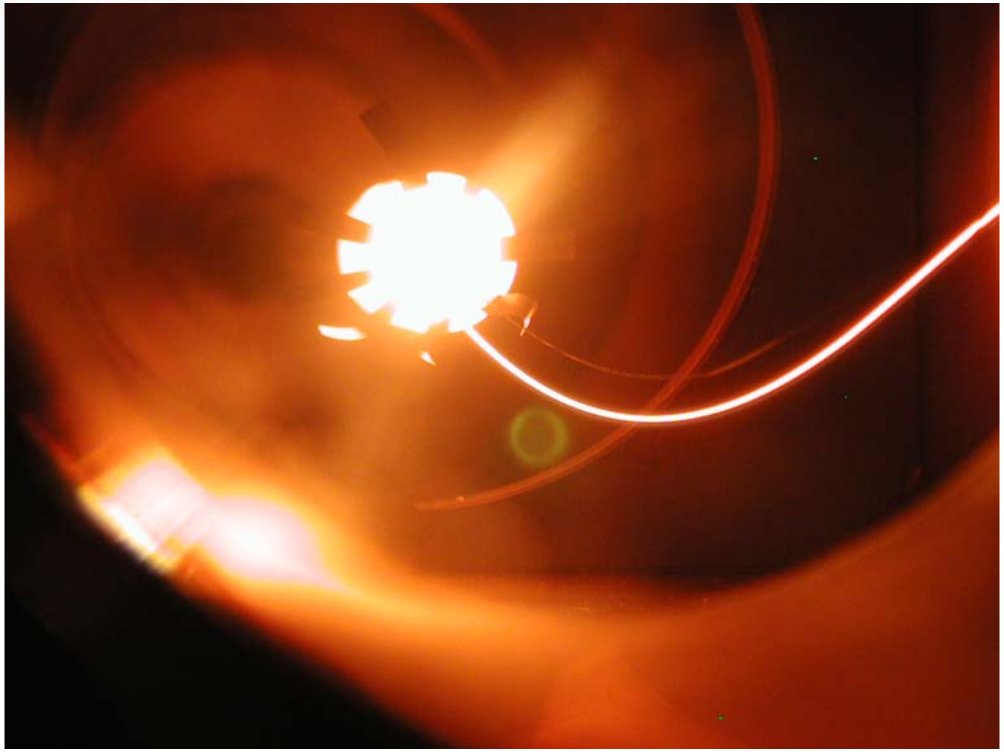
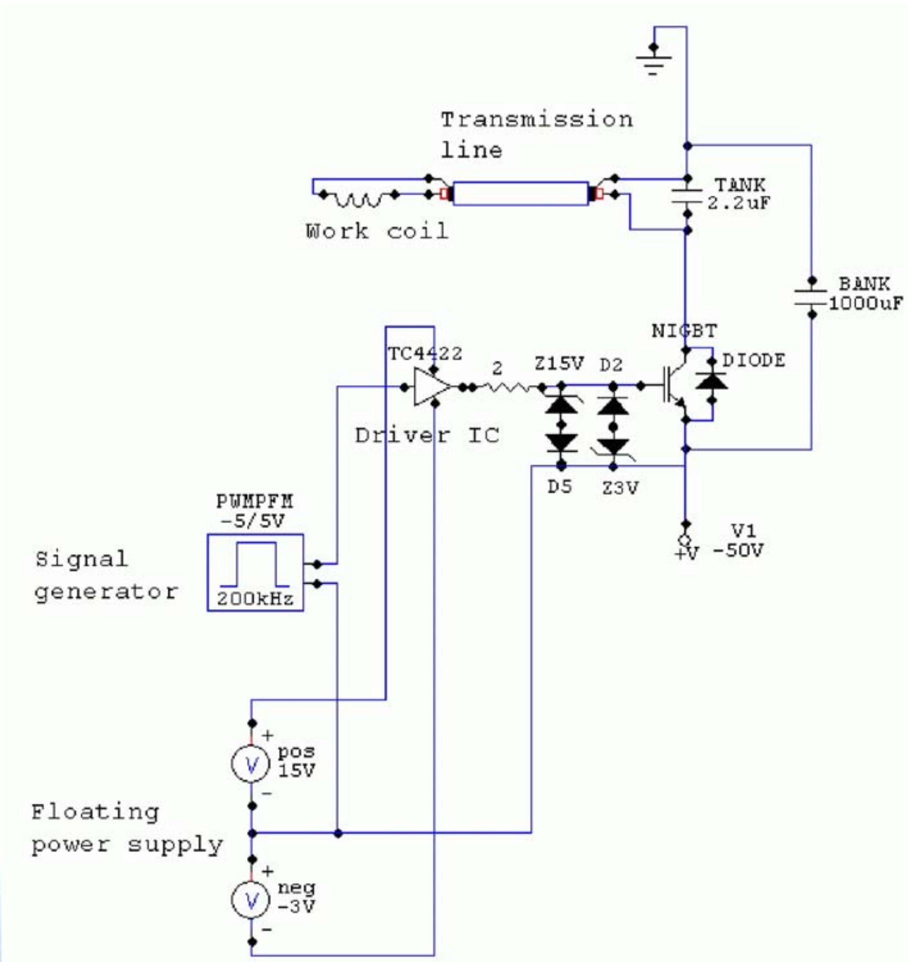


JYFL inductively heated oven

- home-made control unit



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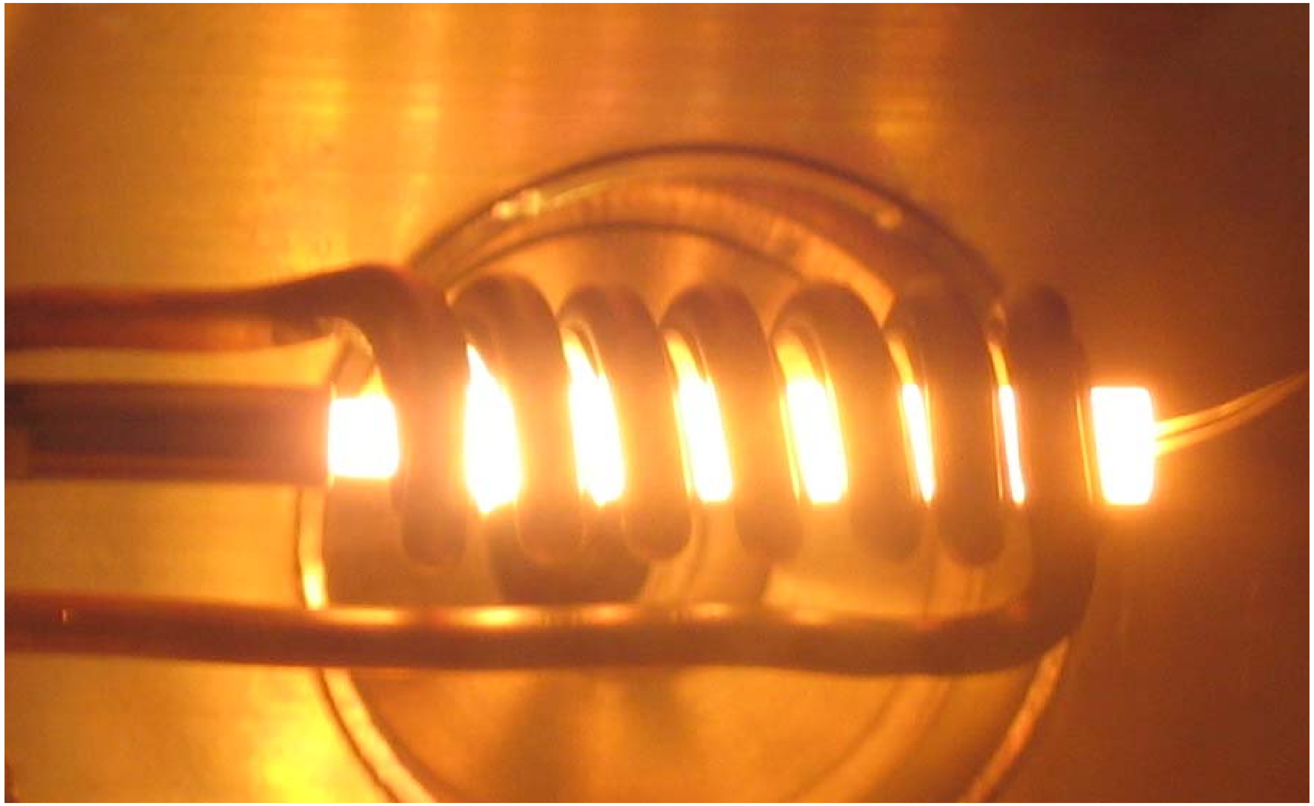
Induction oven at 2000°C



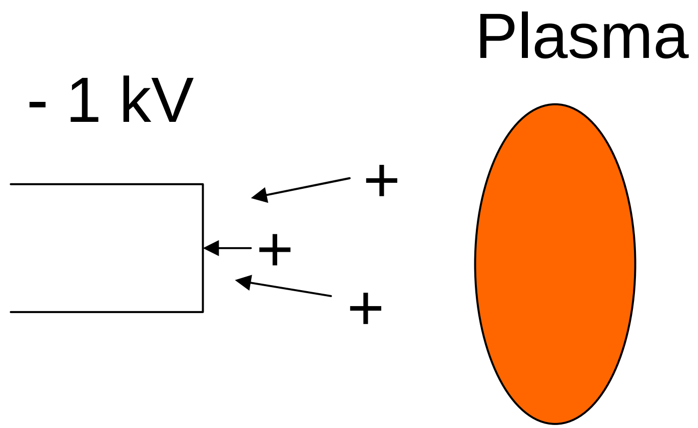
Reliable tests have been carried out at 1800 - 1900°C at least for a week

Main problem: surface-to-surface reactions between crucible material and material to be evaporated!

Sputter technique

For ECRIS the method has been developed at ANL

- plasma particles are accelerated by negative voltage (≈ 1 kV)



Ions have enough energy to remove atoms from bulk material

Sputter yield

Efficiency of the method depends on the sputter yield of material

Yield = number of removed atoms/number of incident particles

INPUT:

Target: Zr

Projectile: He

Energy E= 1000 eV

OUTPUT:

Energy Threshold= 53.37 eV

Sputter Yield Y= 0.049

http://eaps4.iap.tuwien.ac.at/www/surface/script/sputteryield.html

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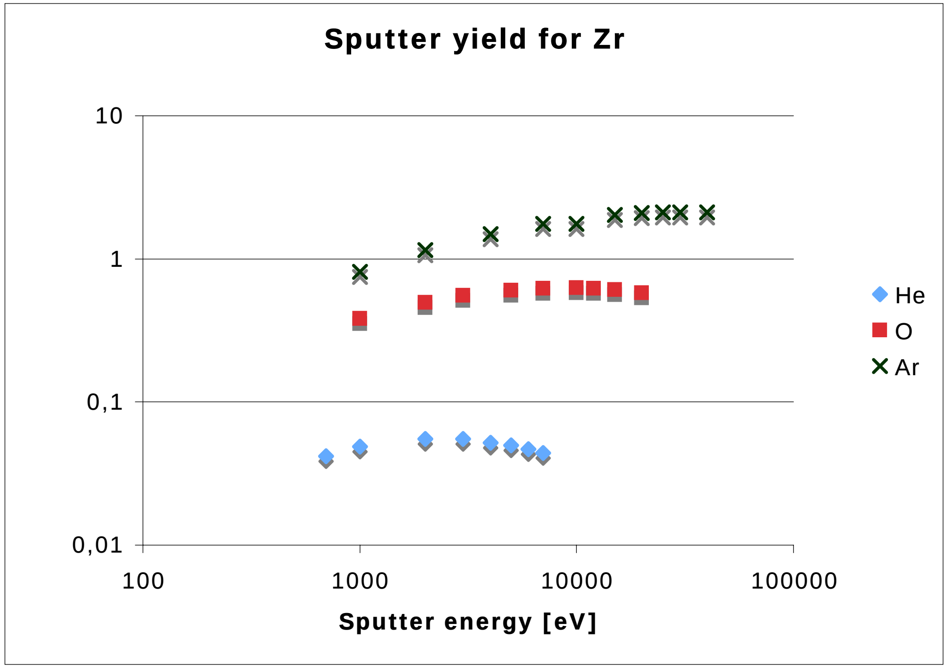
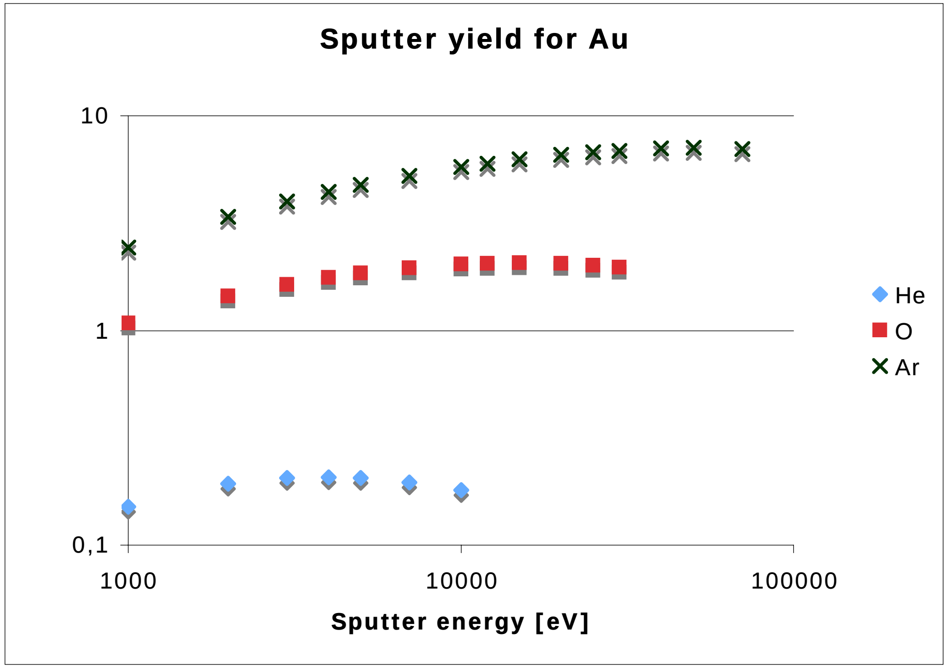
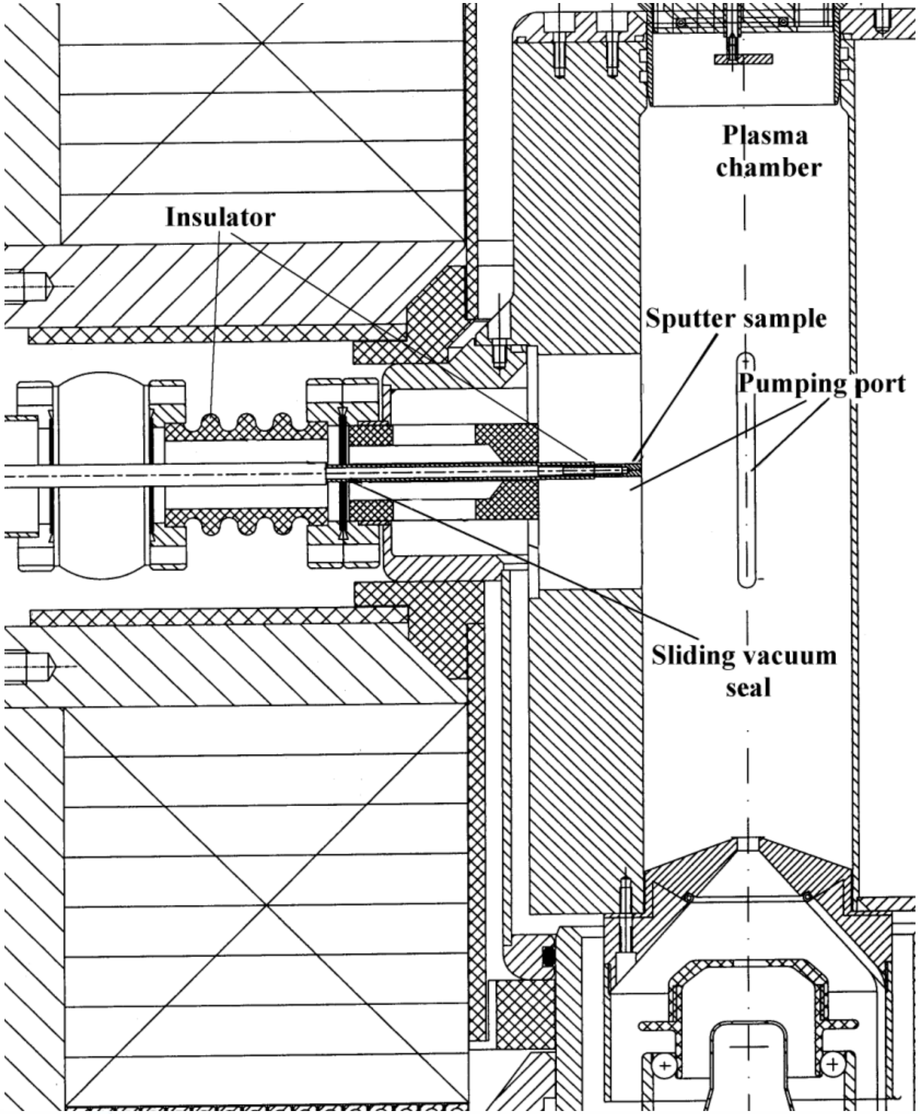






- Operation very sensitive on sample position!

- radiation from plasma destroyed the sliding o-ring!

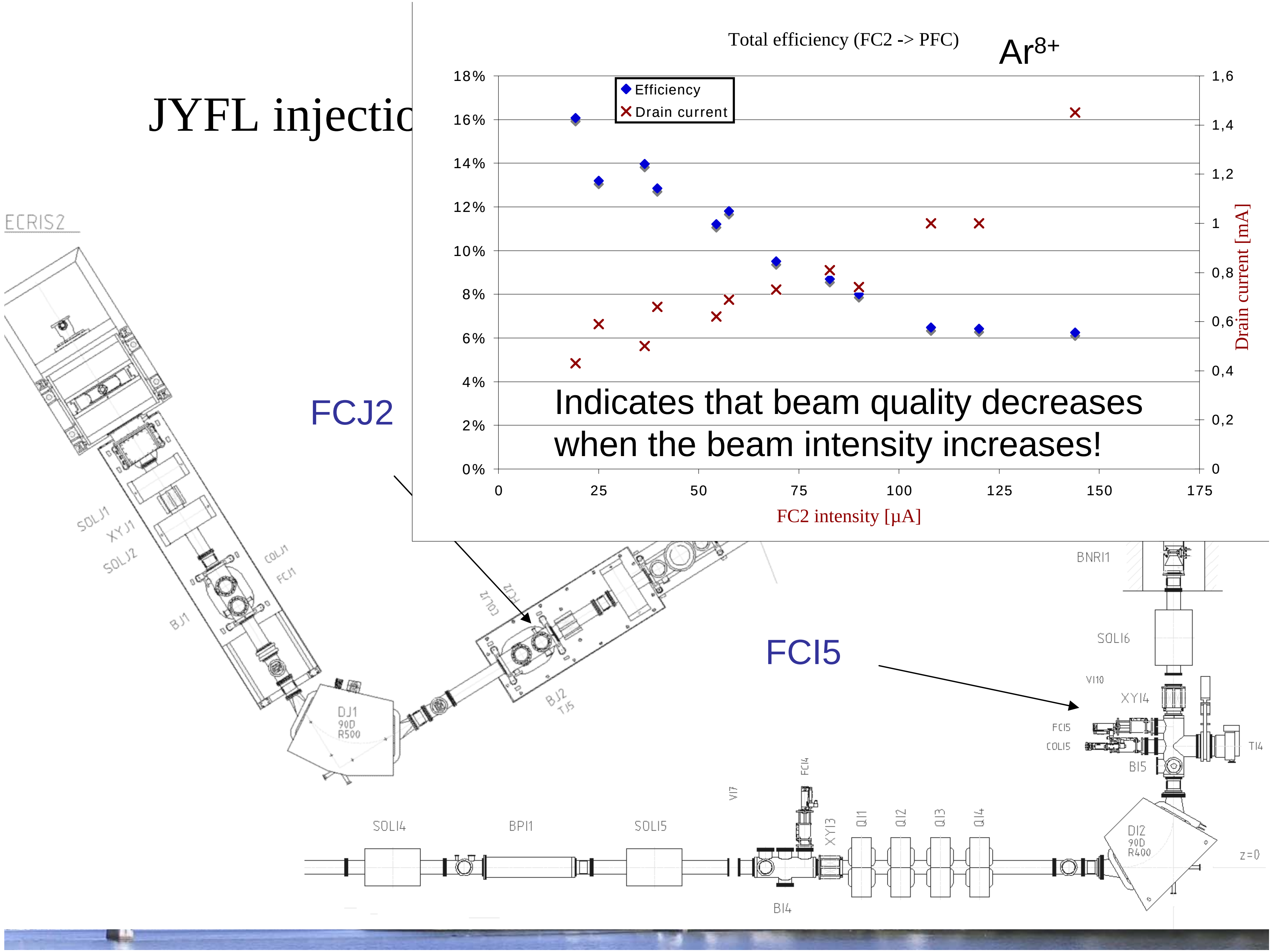
- intensity level of 10 µA with oxygen plasma at 10 kV

Table 2: Sputter yields for different elements

Element	Yield	Element	Yield
Ag	3.4	Ni	1.5
Al	1.2	Os	0.9
Au	2.8	Pd	2.4
Be	0.8	Pt	1.6
C	0.2	Re	0.9
Co	1.4	Rh	1.5
Cr	1.3	Ru	1.3
Cu	2.3	Si	0.5
Fe	1.3	Ta	0.6
Ge	1.2	Th	0.7
Hf	0.8	Ti	0.6
Ir	1.2	U	1
Mg	1.4	V	0.7
Mn	1.3	W	0.6
Mo	0.9	Y	0.6
Nb	0.6	Zr	0.7

- similar results can be anticipated with some other refractory elements using sputter technique!

JYFL injectio



Problem: Asymmetric beam profiles

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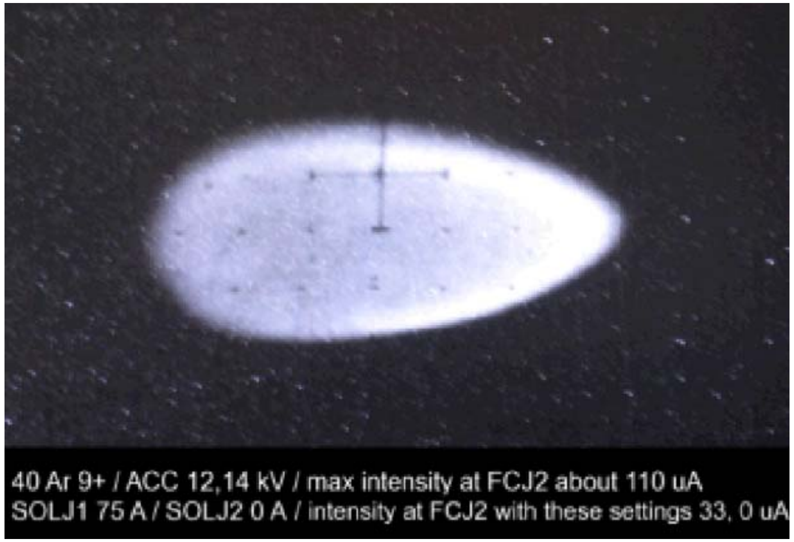
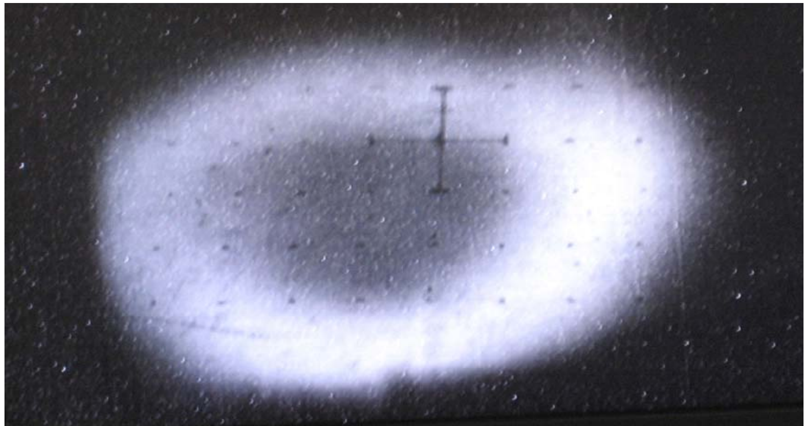
Beam profiles have been studied by KBr-viewers



- In 2007 it was found that the beam profile is asymmetric
- Can be due to the wrong entrance/exit angle of DJ1, which would cause different focusing properties in different planes
- will increase 2D-emittance later if solenoid focusing is used

Hollow beam structure



40 Ar 9+ / ACC 12,14 kV / max intensity at FCJ2 about 110 uA SOLJ1 98 A / SOLJ2 0 A / This is the beam shape with maximum intensity

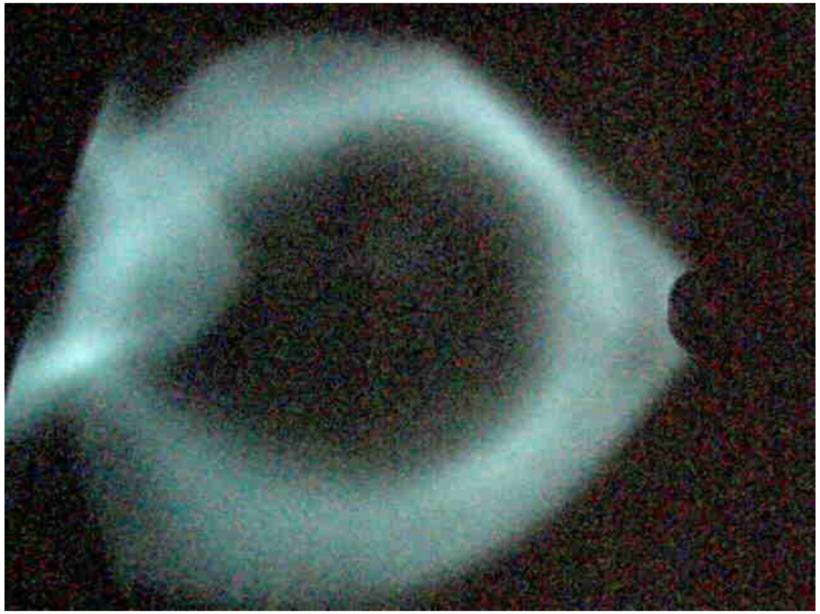
More pronounced:

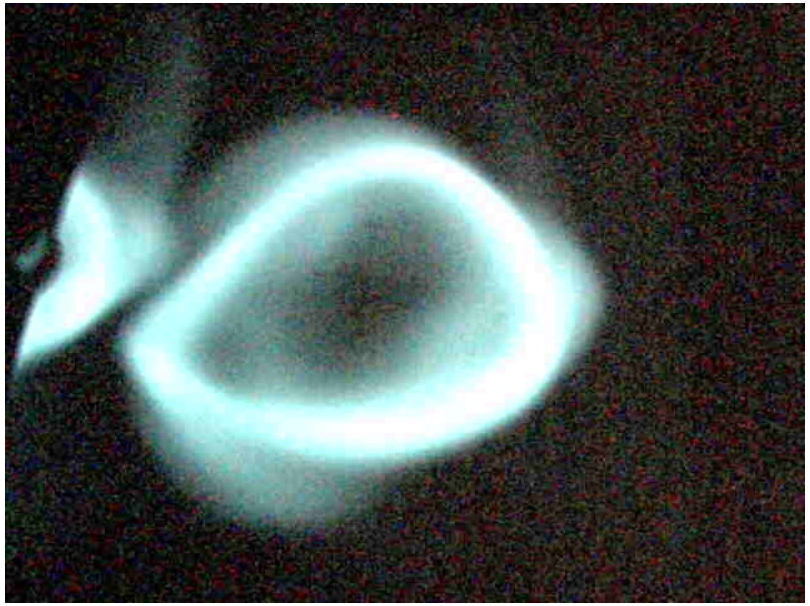
- with low acceleration voltage
- with high intensities
- with high focusing power
- for low charge states

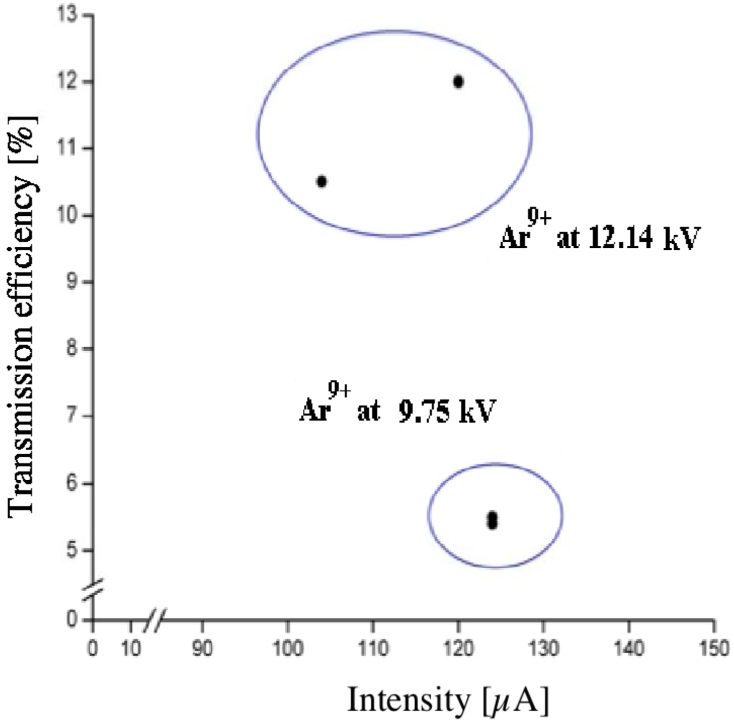
Effect of acceleration voltage

Ar^{8+}, 10 kV, 143 µA, 277 π mmmrad Ar^{8+}, 14 kV, 195 µA, 186 π mmmrad

Effect on emittance and intensity bigger than can be explained by the voltage scaling!







Effect much bigger than can be anticipated from voltage scaling!

Reason: Less hollow beam?

Charge state dependence

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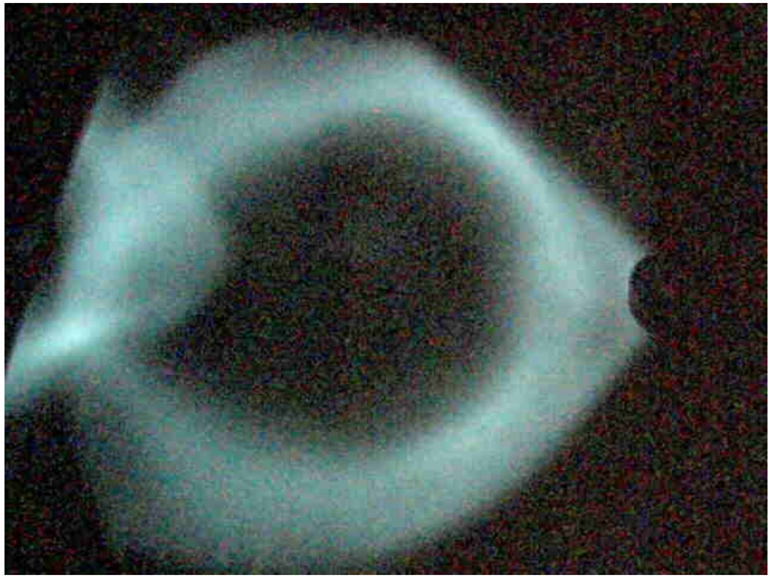
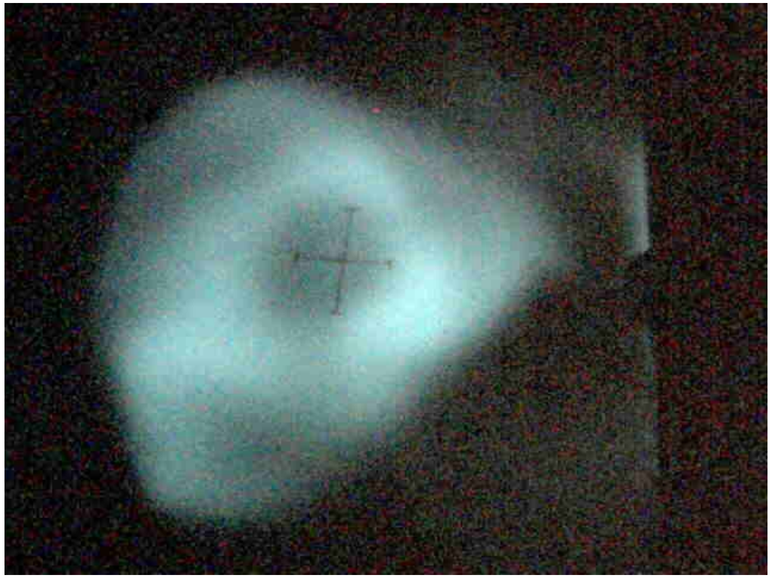
Ar^{8+}, 10 kV, erms 277 π mmmrad



Ar^{9+}, 10 kV, erms 162 π mmmrad



Location of focal point depends on the charge state: higher charge state can "explode" lower charge state if intensity high enough

Indicates (possibly) that hollow beam structure is formed inside the beam line

Space charge compensation effect: preliminary unpublished results!

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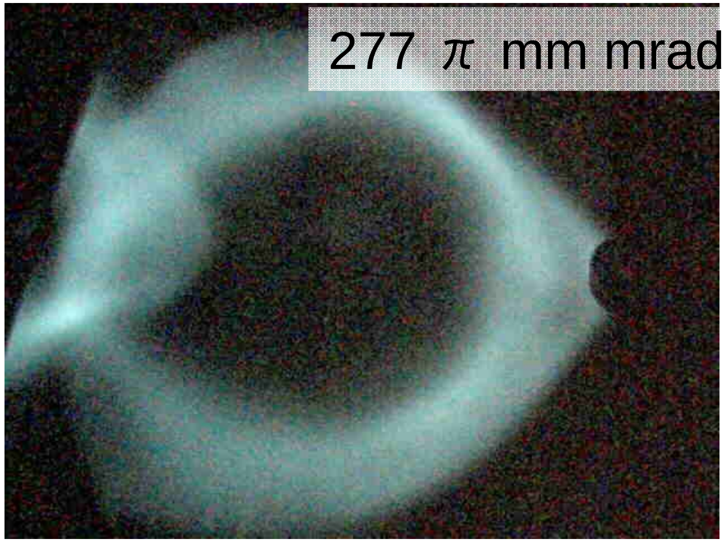
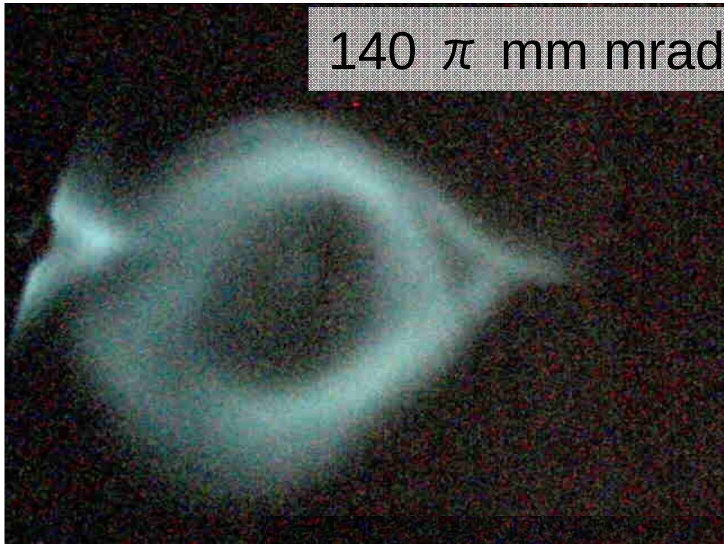
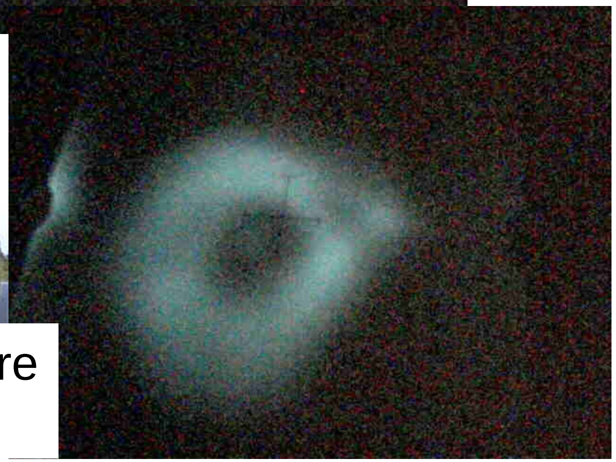
Gas was fed into the beam line close to the focal points (N_2, Ar)

Ar^{8+}, 10 kV, 143 µA, 1.8E-7 mbar

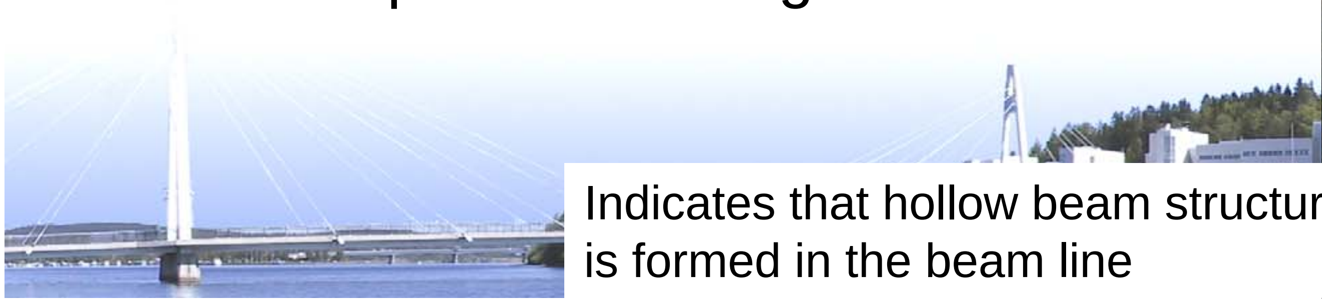


Ar^{8+}, 10 kV, 120 µA, 6.2E-6 mbar





Clear optimum for brightness is found!



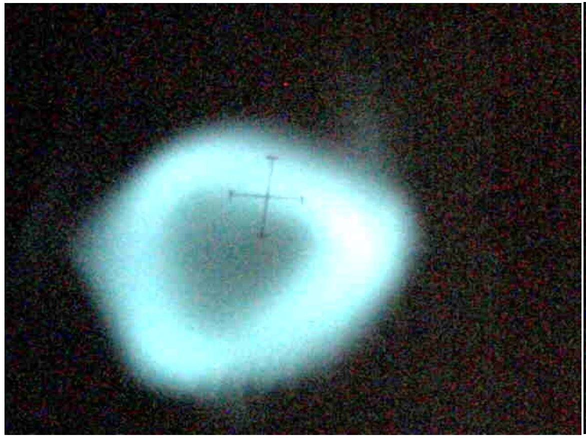
Indicates that hollow beam structure is formed in the beam line

Frequency tuning

In the experiment the µw-frequency was changed.

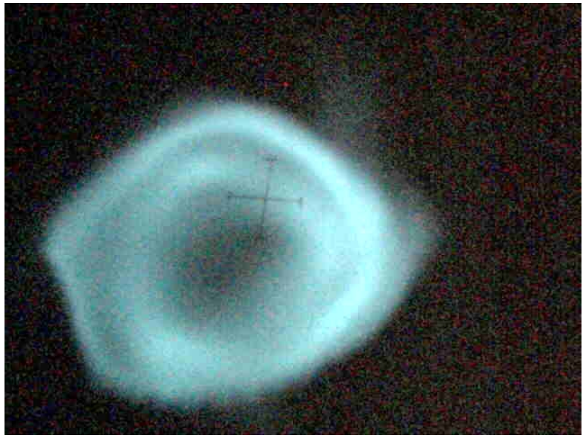
Collaboration with LNS ion source group (idea by L. Celona)

Ar^{8+}, 14.100 GHz, 91 µA



Ar^{8+}, 14.125 GHz, 94 µA

Klystron + TWTA



- frequency affects the hollowness of the beam.

- with two frequency heating two rings can be seen in some cases (this cannot be produced by optics)

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Summary and future plans

- MIVOC method, inductively heated oven and use of sputter technique makes possible the wide variety of metal ion beams
- the beam transport plays an important role concerning the heavy ion facilities
- the hollow beam structure decreases remarkably the transport efficiency
    - experiments have shown that it can be formed:
        1) Inside the plasma (frequency tuning)
        2) Inside the beam line (voltage and charge state effect, compensation)
    - further studies are needed for better understanding
- ion beam quality can be improved (even in the case of highly charged ion beams) with residual gas related compensation
- filament will be tested for beam compensation