### Caesium and Tungsten behaviour in filamented arc driven Kamaboko-III beam source

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It was found that in long pulse operation the negative ion yield from the filamented Kamaboko III ion source degrades in comparison with short pulse operation <5 s.

This could be linked to the behaviour of caesium (Cs), which is added to the source to increase its negative ion yield, and tungsten (W) evaporated from filaments. Tungsten filaments have a limited lifetime in the ion source and changing filaments and refilling of Cs oven are the only scheduled maintenance events for the ITER injectors.

These are complicated operations as the ITER injectors will be highly activated and all maintenance has to be carried out remotely. Therefore, increasing the filament lifetime and decreasing the Cs consumption is highly desirable "Cs - effect" and "Plasma Grid Temperature effect" in long pulse operation on MANTIS Kamaboko **are not well pronounced** 

The Cs effect is assumed to arise due to the reduction of the work function value of the clean metal surface (4÷5 eV) to  $\phi_{Cs}$ =2.15 eV with Cs coverage, allowing conditions for the production of surface created negative ions.

The PG temperature effect could be explained due to evaporation of the excessive Cs ( $\theta_{Cs}$ >1, where  $\theta_{Cs}$ =1 corresponds to one layer) with increased temperature of the PG, leading to sub-monolayer coverage, i.e. with a work function in the range

 $\phi(\theta_{Cs} \ge 1) = 2.15 \text{ eV} \ge \phi(\theta_{Cs}) > \phi_{min}(\theta_{Cs} \approx 0.6) = 1.45 \text{ eV}.$ 

This relation shows "ideal" case of Cs sub-monolayer coverage on (110) W crystal surface.

The value of the PG temperature effect, obtained in negative beam sources, indicates that  $\phi$  hardly decreases well below the work function value 2.15 eV of pure Cs surface.



View of Kamaboko III arc chamber just after opening to the atmosphere (Cs plasma operation in the campaign  $\approx 10^4$  s).

### Typical Fluxes Values in the beam source

Gas flux $\approx 4.6^{*}10^{17}$  nucleon/(s cm²) (MAMuG, D₂ operation) and<br/>2.4\*1017 nucleon/(s cm²) (SINGAP, H₂ operation)<br/>or 74 and 38 eqv.mA/cm2 (for 0.3 Pa operation)Negative ion flux20-28 mA/cm² (D⁻ and H⁻)

Tungsten flux $\approx 5.3^{*}10^{17}$  atom W/s (Total, MANTIS).Caesium flux $\approx 1.9^{*}10^{17}$  atom Cs/s (Total, MANTIS).Electron flux  $\approx 800$  A (MANTIS)

## Spectroscopic results backstreaming ions (?)



Spectroscopic data in two consequent shots. Cs852 (LOS||) and Cs+460 (LOS\_|\_)line intensity is increased at the time 10 seconds when beam extraction (VG2  $\approx$  7kV) was switched on. Hy lines for the both shots is very similar, indicating the same arc conditions.

# Spectroscopic results backstreaming ions (?)



Spectroscopic data in five consequent shots. Cs+460 (LOS\_|\_) Correletaion Cs+460 line with beam extraction

## Situation in gaps



## Spectroscopic results: No pronaunsed plasma grid temperature effect



Comment to previous page

Cs evaporation from Plasma Grid.

Intensity of Cs 852 nm line in consequent shots (a and b) with increasing PG temperature (c) are shown. At shot #13354 water cooling of PG was switched off. I<sub>drain</sub> current in these shots shown in (d).

No clear evidence of Plasma Grid temperature effect

## Analysis of the surface coverage

Mass, mg

	Cs	W	Cu	Ca	Мо	Fe	Al
PG extraction	150	58.5	1.2	6.3	2.7		
	2.84	76.9	12	3.06	0.189	0.473	3.42
PG perifery	2400	310	3	21	8		
	7.58	15.6	32.5	1.86	0.031	0.162	1.47
Arc chamber	6000	1250	8	7	30		
	13.8	46.6	18.2	2.82	0.123	0.159	0.246
Total, g	8.6	1.8	0.07	0.04	0.04	0.001	0.005

Surface density, atoms/sm<sup>2</sup>

	Cs	W	Cu	Ca	Мо	Fe	Al
PG extraction	2.5E+18	1.6E+18	4.5E+17	5.1E+17	6.6E+16	1.8E+16	2.8E+17
PG periphery	1.3E+19	1.3E+18	4.0E+17	4.1E+17	5.9E+16	2.1E+15	3.9E+16
Arc chamber	4.9E+18	7.5E+17	4.4E+16	2.6E+16	3.3E+16	3.0E+17	9.6E+14

\* Tracks of Cr, Na, Mg and Si were also found

## Analysis of the surface coverage

#### **Comments to these results.**

- Almost total amount of injected Cs was found in arc chamber
- All surfaces including PG extraction area were covered by a thousands layers of **Cs** and **W** (one monolayer is  $\approx 5.10^{14}$  at/cm2) in comparable values. Other components were found in a range of 8-10%.
- The amount of **Cu** and especially **Ca** found was unexpectedly large. A possible reason for the presence of Cu in samples may be physical removal of it from the Cu surfaces of arc chamber and PG during washing with brush and water or/and the sputtering during arc operation. In this case the role of Cu co-adsorption can be similar to that of **W** co-adsorption which restricts Cs re-evaporation from walls.
- Mo was found in amounts proportional to that which exists in the admixture founding the **W** filament wire.
- Fe and **AI** could be sputtered from, say thermocouples tubes and from filament insulators, that are somewhat exposed to the volume, see. Fig. 1.
- Deposition on the extraction area was calculated without accounting for the surface of the apertures, that adds 22% of atoms gone downstream from plasma grid.

### Analysis of the surface coverage

#### The main conclusions from this analysis are:

- Plasma grid coverage is a poly-layer composition of **Cs**, **W** and other metals. This composition is far from the ideal situation, that being a Cs coverage of sub-monolayer on the clean crystal surface of metallic substrate
- The bulk of **Cs** did not leave arc chamber but do not take part in effective negative ion generation due to coverage made by **W**.
- The bulk of **Cs** remains on the arc chamber walls in mixture with **W** and other co-deposited metals but is rendered useless in the surface production of negative ions.

**Physical Values along W-Filament** 





— Temperature

# W evaporation from filaments

## AC heated MANTIS filament during operation.

Main contributors to the power equilibrium are shown in the legend. As positive are shown heating contributors, as negative cooling ones. Local diameter and temperature are also shown

### W evaporation and electron emission from filaments





Relative change of Evaporation/Electron emission ratio with filament temperature (taken as 1 at 2800 K).
Operation with lower temperature (more filaments or larger diameter of filaments) reduces filament evaporation and extends filament's life time (at

the expense of higher filament current supply).

## W evaporation from filaments



The MANTIS Kamaboko III tungsten filaments (1.50 mm diameter, 170 mm long): the new above, and the used after 9800 s of plasma operation.0.13 g of initial 6.26 g was lost during operation. Change (decrease) of emissivity and presence of craters are seen on the used filament.

To all appearance evaporation is not the most limiting factor of filament lifetime.

## Conclusions

- Long pulsed operation of Kamaboko III beam source shows that considerable amount of Cs have to be continuously replenished to keep high negative ion current density.
- Inspection of arc chamber surfaces after campaigns and following chemical analysis have shown: practically all injected **Cs** is still inside of arc chamber in mixture with evaporated tungsten and few other metals.
- Amount of **Cs** chemically found is in agreement with decrease of the Cs oven mass.
- Decrease of total mass of 12 filaments is also in agreement with calculations. Note that Cs and W found in comparable amounts (≈ 3 g Cs and 1.5 g W).
- Operation of Kamaboko III beam source with less evaporating filaments, that is foreseen in next campaign, possibly will help to reduce Cs consumption.