Carbon Film in RF SPS with Cesiation

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ABSTRACT

It is assumed that a long time persisted cesiation in SNS RF SPS is connected with deposition of carbon film on the collar converter. The work function dependence for graphite with alkali deposition has no minimum typical for metals and semiconductors and a final work function is higher. By this reason the probability of H- secondary emission from cesiated metal and semiconductors can be higher than from cesiated carbon films but latter can better keep the cesiation and can operate with low cesium consumption.

For efficient negative ion generation it is necessary to keep the minimal surface WF contacting with gas discharge plasma. Normally, H− ion beams from cesiated SPS decay unless there is a continuous feed of Cs (from 0.5 mg/day in DESY magnetron SPS to 1 g/day in Los Alamos converter SPS; more common ~1mg/hour in SPS for accelerators).

Fortunately, in RF SPS developed for SNS were found conditions for long time operation with adding a small amount of cesium during beginning operation.

Long time question: why this cesiation is persistent without the continuous feed Cs?

One possibility: apparently, the plasma conditioning scrubs the metal surface atomically clean, replacing the covalent bonds with surface sorbates with ionic bonds with the metal surface. The persistence of the SNS beam suggests that most Cs sticks well to the converter and therefore is not sputtered by the ultra high purity hydrogen plasma. However, earlier experience suggests that the Cs does not stick well on surface contaminants and is lost within a few hours.

M. P. Stockli, B. X. Han, T. W. Hardek, Y. W. Kang, et al., "Producing persistent, high-current, high-duty-factor H- beams for routine 1 MW operation of Spallation Neutron Source", Review of Scientific Instruments 83, 02A732 (2012).

M. P. Stockli, "Plasma-Wall Interactions in the Cesiated SNS H- Ion Source", Journal of Physics: Conference Series 399, 012001(2012).

Stockli, M. P.; Han, B.; Murray, S. N., et al., "Ramping up the Spallation Neutron Source beam power with the H- source using 0 mg Cs/day", REVIEW OF SCIENTIFIC INSTRUMENTS, 81, 02A729 (2010)

Other possibility:

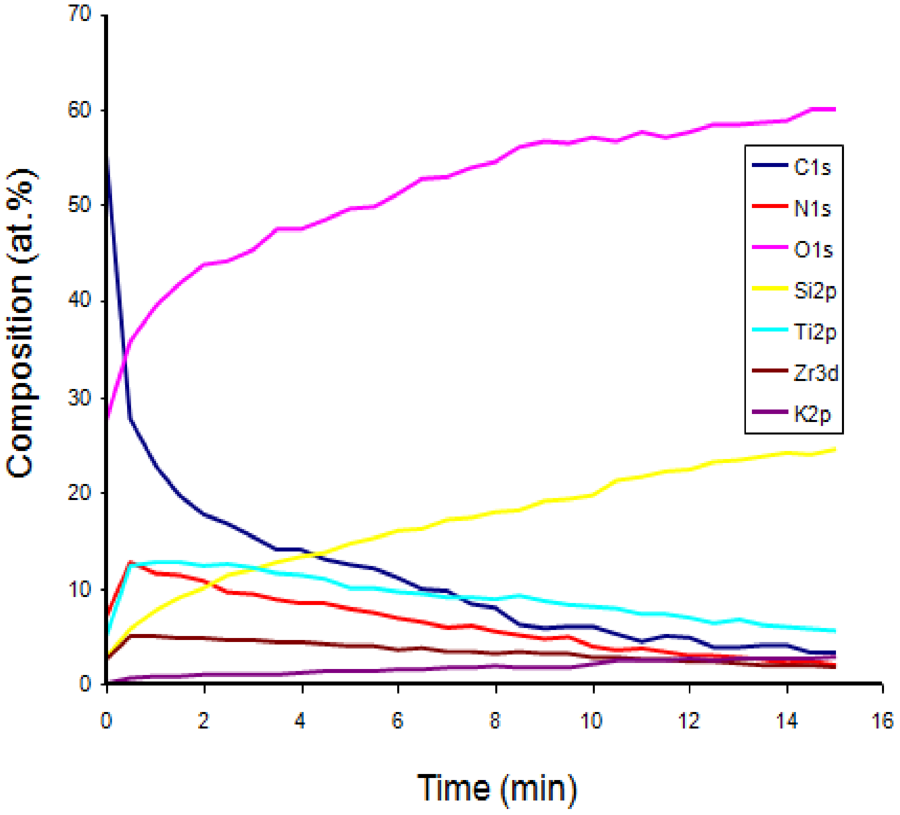
It is very probably that a long lifetime of cesiation in SNS RF surface plasma sources (SPS) can be connected with deposition into the emitter/converter cone and to the discharge chamber some specific carbon films.

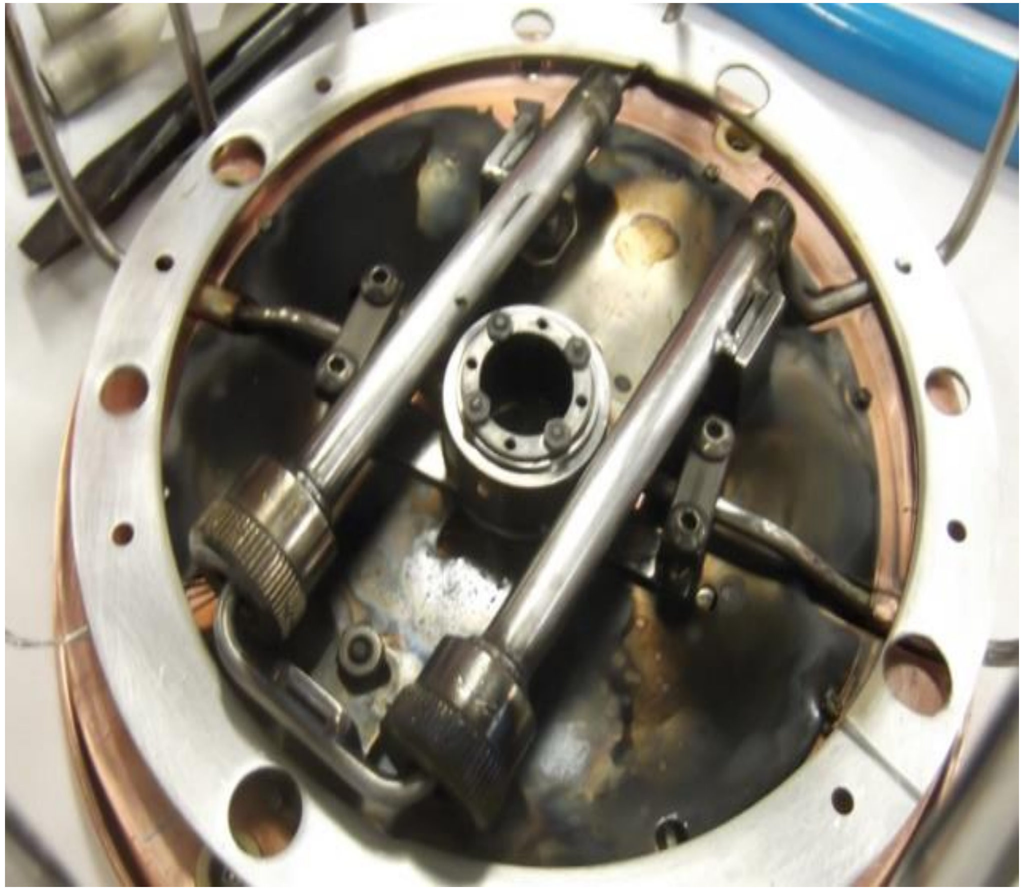
The work function dependence for graphite with alkali deposition has no minimum typical for metals and semiconductors and a final work function is higher. By this reason the probability of H- secondary emission from cesiated metal and semiconductors can be higher than from cesiated carbon films but latter can better keep the cesiation and can operate with low cesium consumption.

It is known that a two-dimensional graphite films and films of pyrolitic graphite can adsorb and trap alkali atoms with very high probability (sticking coefficient ~1) up to very high temperature and can be desorbed by heating up to high temperature, much higher than for evaporation from a metal surface up to 2000 K.

Internal antenna of baseline SNS RF SPS after long time operation is coated by black film.

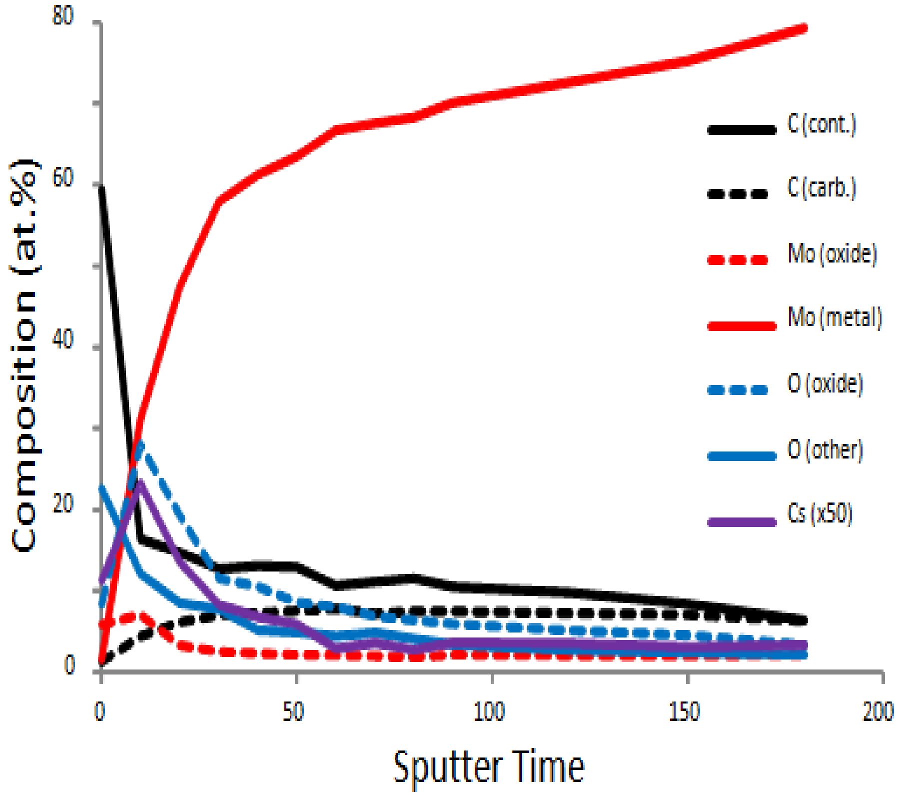
Concentration profiles of elements at the antenna insulation surface (the profile from a dark area on the porcelain). 1 minute of ion sputtering is relating to removing ~20 nm of material.





Dark film deposition on the converter cone.

Dark film deposition on the plasma plate components (surfaces bombarded by intense fluxes of plasma are clean).

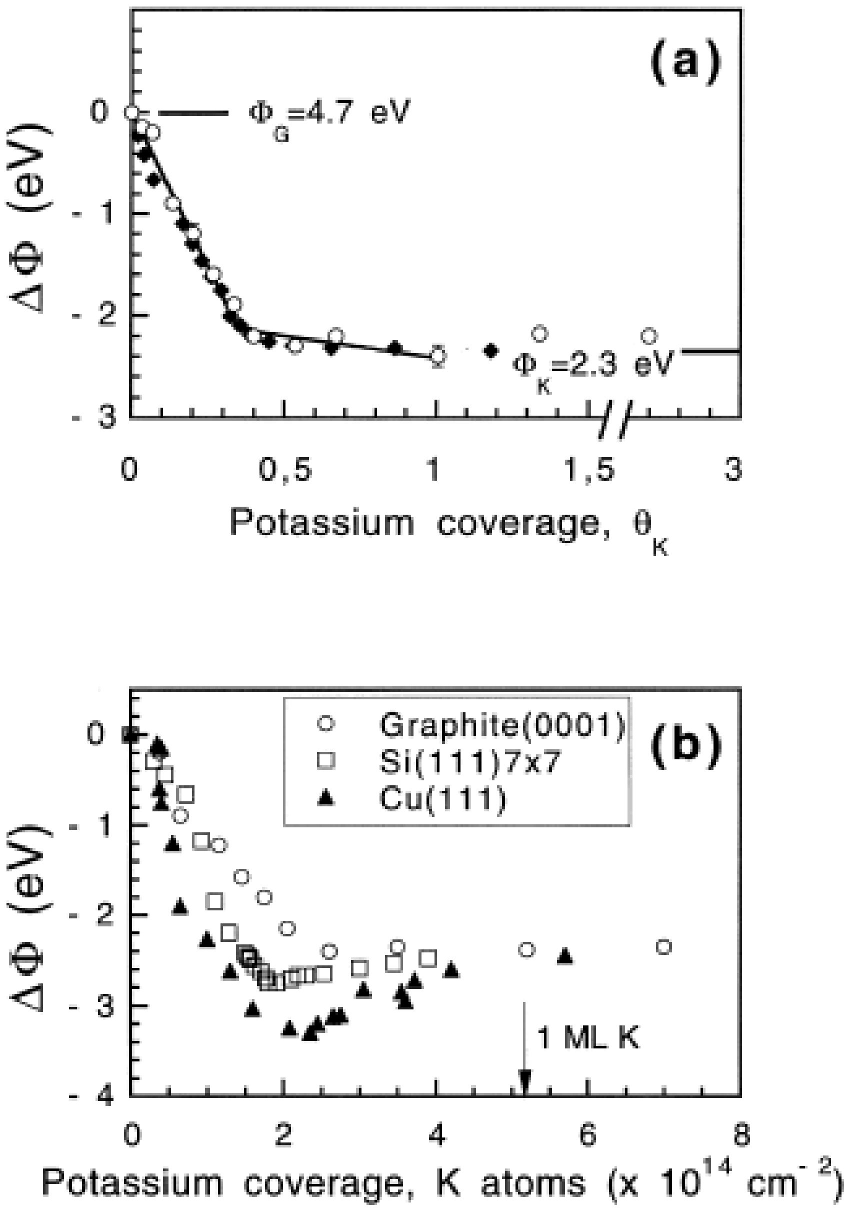


Surface Composition (at.%)

	Mo	O	C	Cs	Na	Cl
As Rec.	7.6	32.8	58.6	0.3	0.5	0.3
Sputter Etched	71.2	12.1	16.7	0.0	0.0	0.0

Distributions of elements on the converter cone surface. Sputter time in minutes. 20 min of sputtering is ~20 nanometers.

Further investigation of surface film deposition is necessary for understanding and reliable reproduce efficient negative ions generation with a low cesium catalyst consumption.



(a) The work function as a function of potassium coverage measured at *T*=83 K by the RP method (o), and at *T*= 160 K by UPS (diamond) .
(b) A comparison of the work function change as a function of number of K adatoms for graphite, Cu(111), and Si(111) 7×7. The K coverages were obtained by exposures from the same alkali metal source as in estimate the induced dipole moment associated (a), and with surface temperatures of 90 K.

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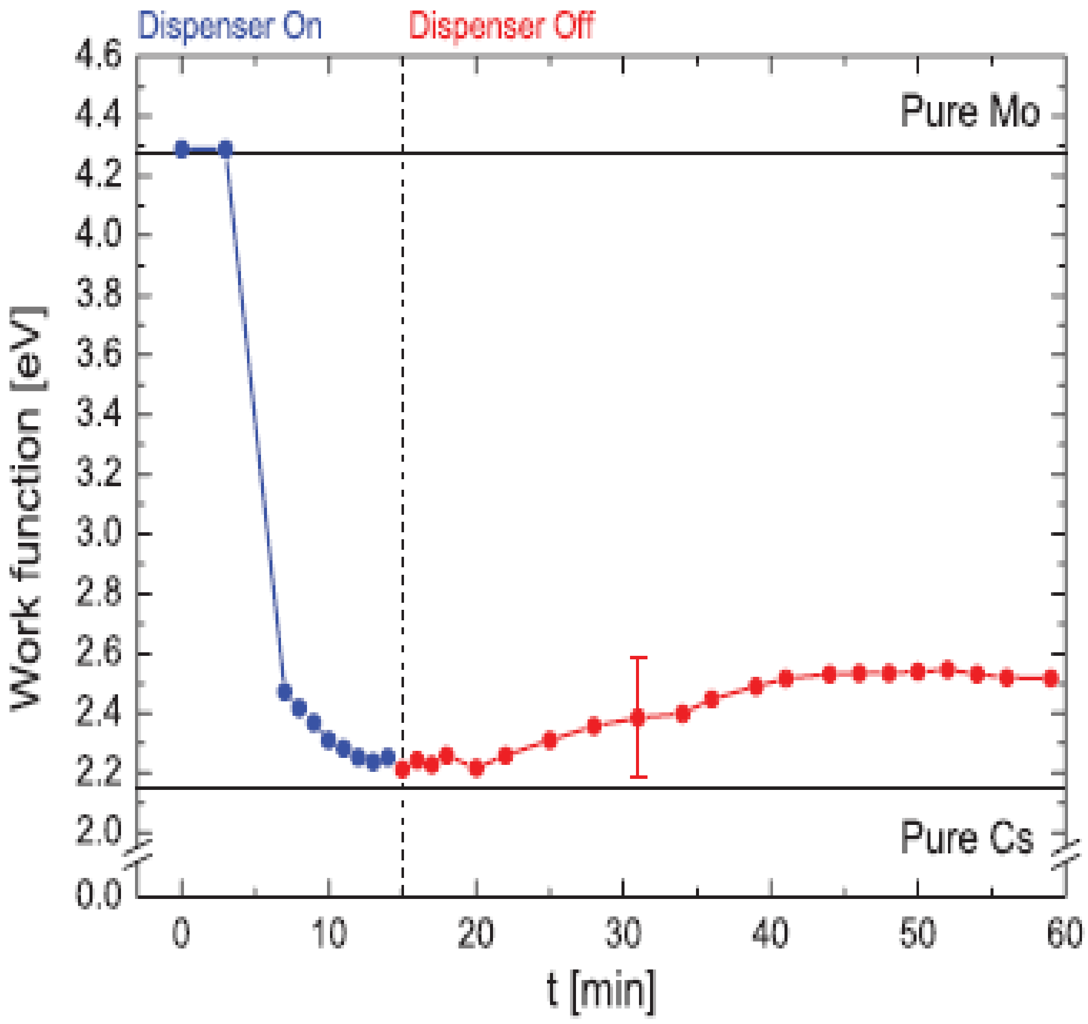
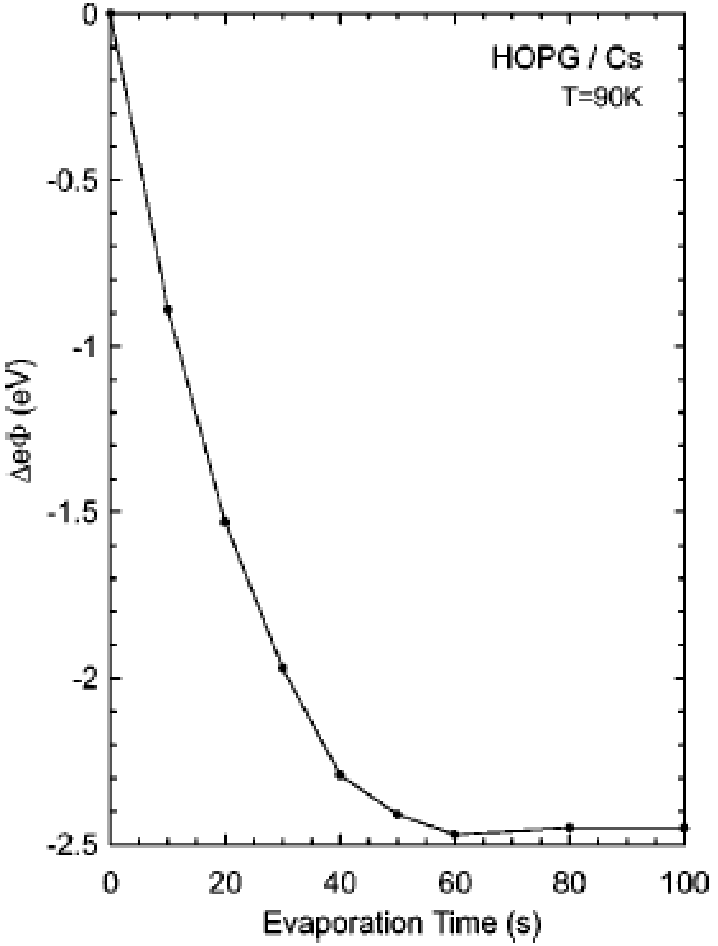
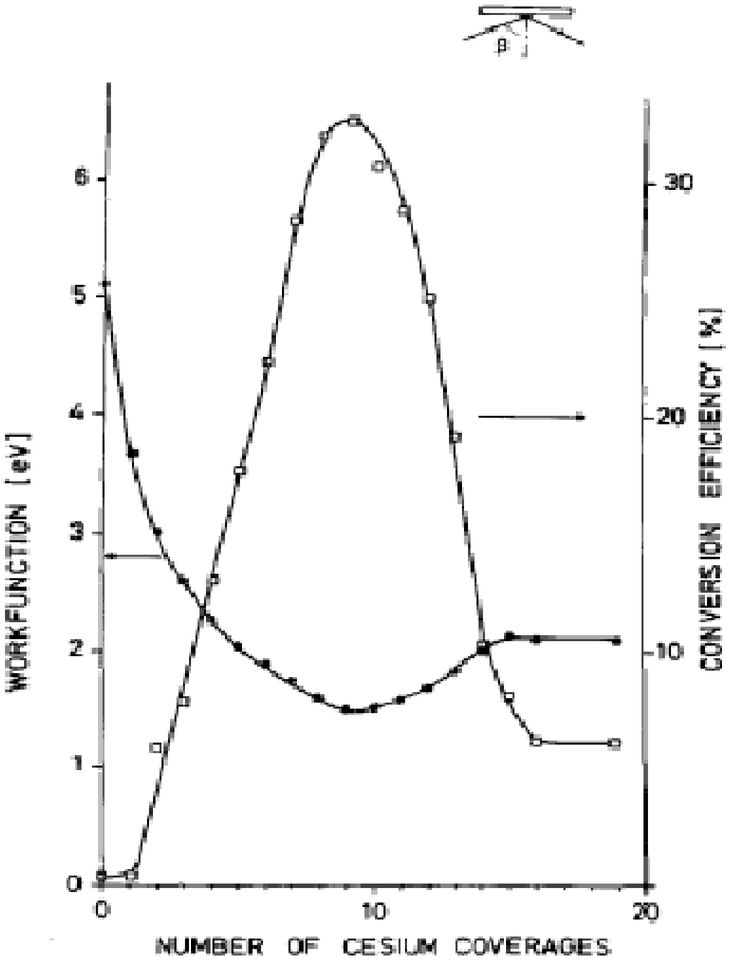
L. Osterlund, D.V. Chakarov, B. Kasemo, Potassium adsorption on graphite (0001), Surface Science, 420, 174, (1999).



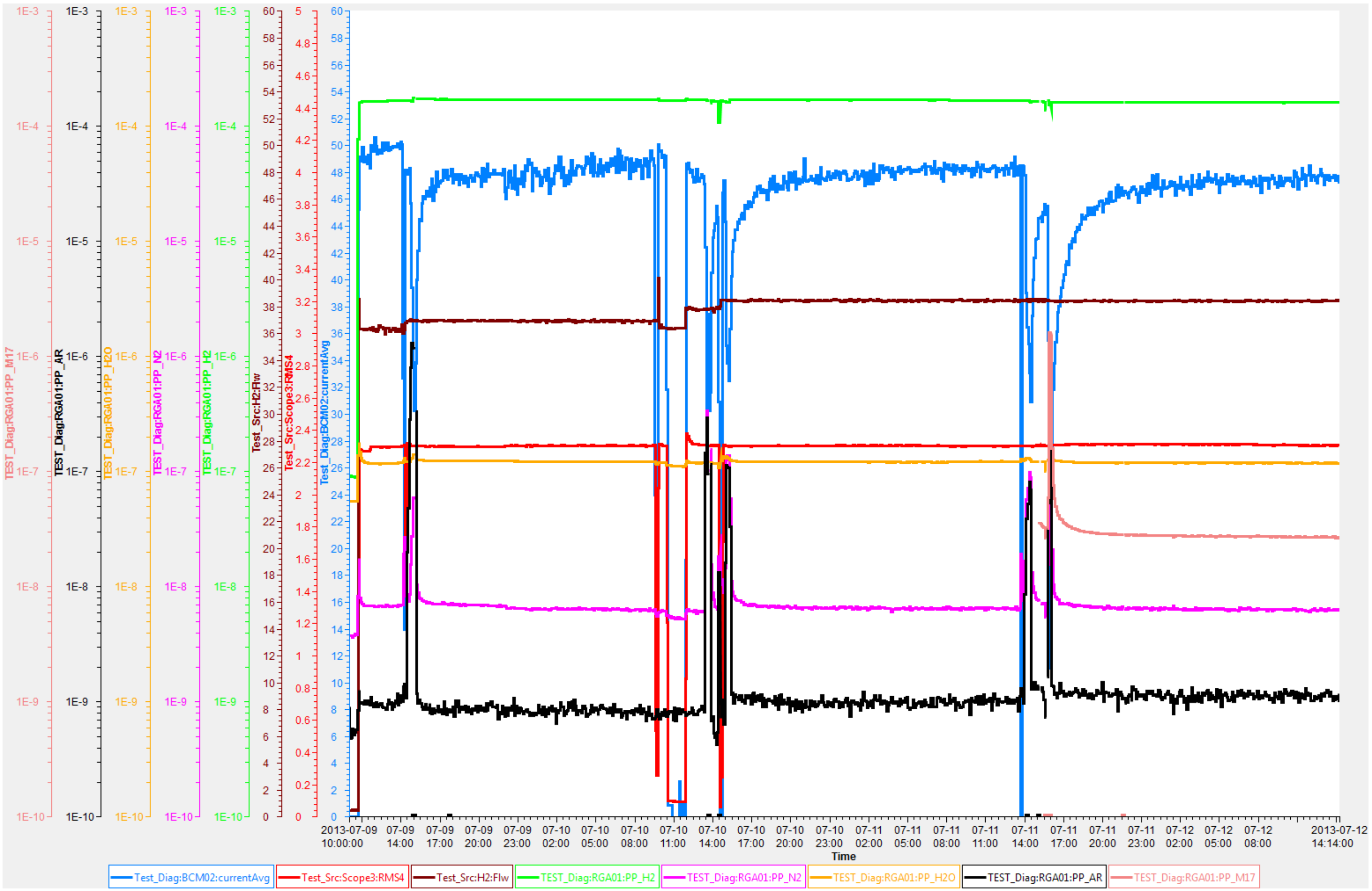
Work function time trace of a cesium exposed molybdenum
After plasma processing



Work function change for graphite upon Cs deposition (1 ML of Cs corresponds to an evaporation time of 350 s).

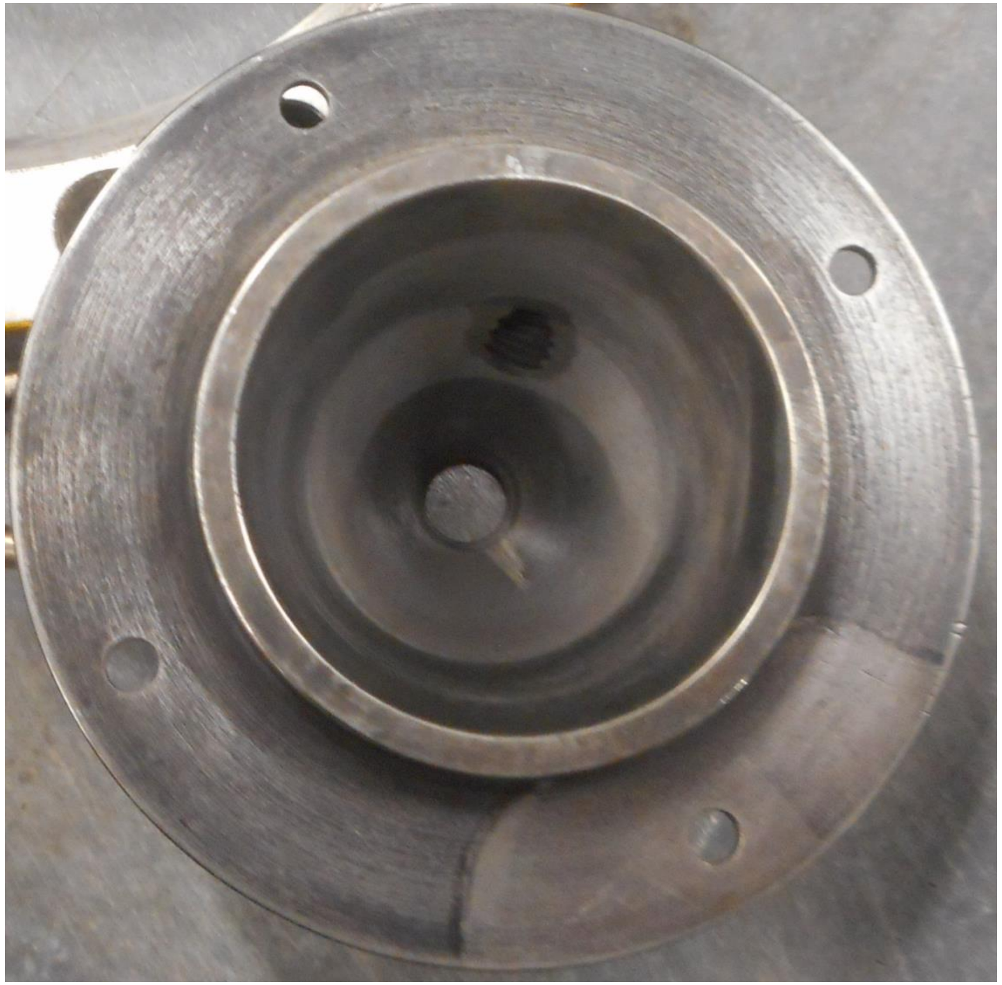


Work function change for Molybdenum upon Cs deposition and efficiency of H particles reflection as H-

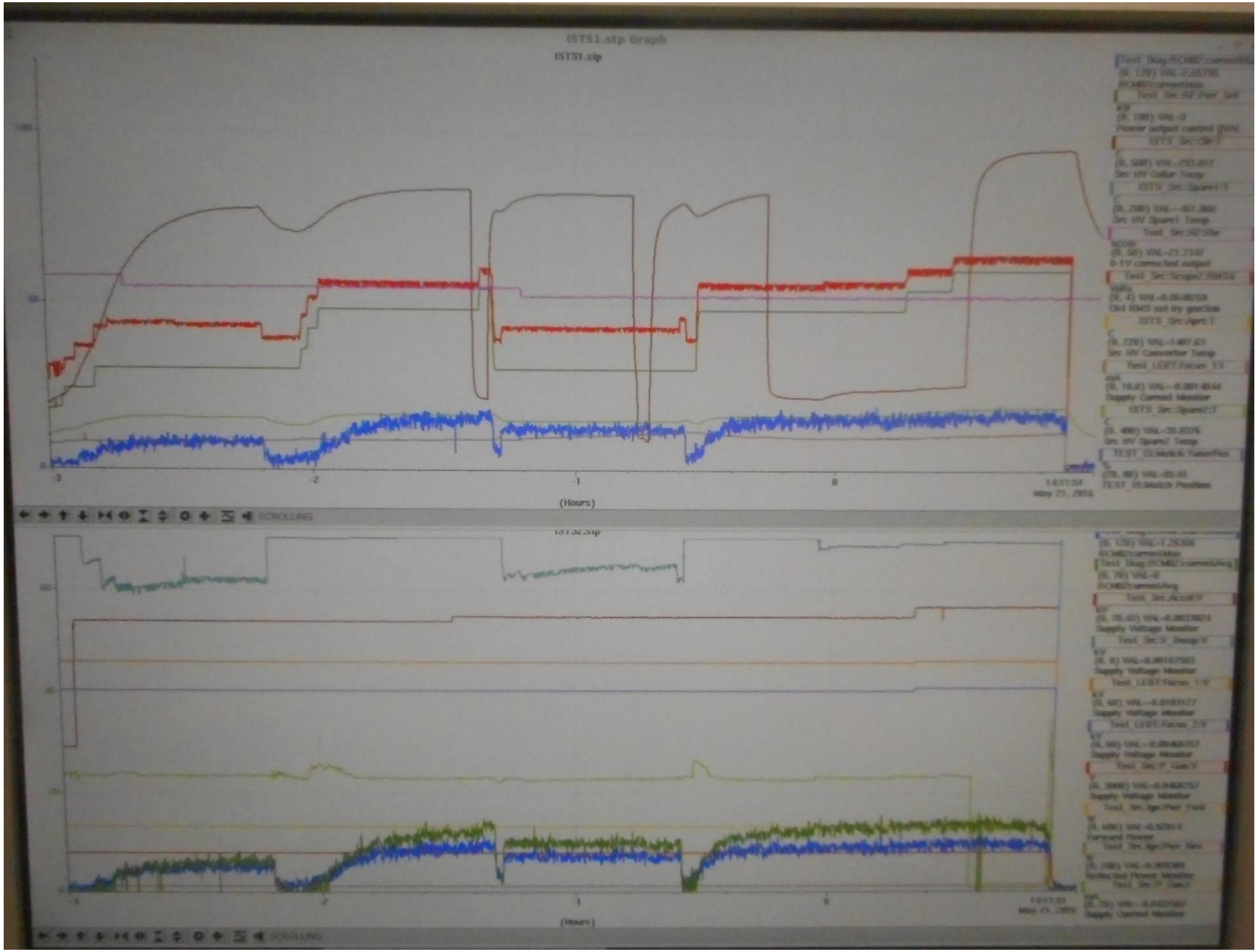


Variation of H- beam intensity (blue line) during a periodical injection of nitrogen: after long time stable operation was observed fast decrease of H- beam current with injection of N_2, slow decrease during stationary phase of injection; fast recovery phase and slow ~2 hours recovery up to previous level. During N_2 injection was observed very strong increase of mass 17(NH3) signal from RGA (ammonia NH3)

Efficiency of plasma generation in a Radio Frequency (RF) ion source can be increased by application of a solenoidal magnetic field. The specific efficiency of positive ion generation was improved by the solenoidal magnetic field, from 5 mA/cm^2 kW to 200 mA/cm^2 kW. Chen presented an explanation for the concentration of plasma density near the axis by a magnetic field through a short circuit in the plasma plate [*D. Curreli and F. Chen, Equilibrium theory of cylindrical discharges with special application to helicons, PHYSICS OF PLASMAS, 18, 113501 (2011).*]. Additional concentration factor can be a secondary ion-electron emission initiated by high positive potential of plasma relative the plasma plate. Secondary negative ion emission can be increased by cesiation-injection of cesium, increasing a secondary electron and photo emission.



Conical collar with a dark deposition around the emission aperture



Change of collar temperature from 60C to 400C do not change efficiency of H- generation.

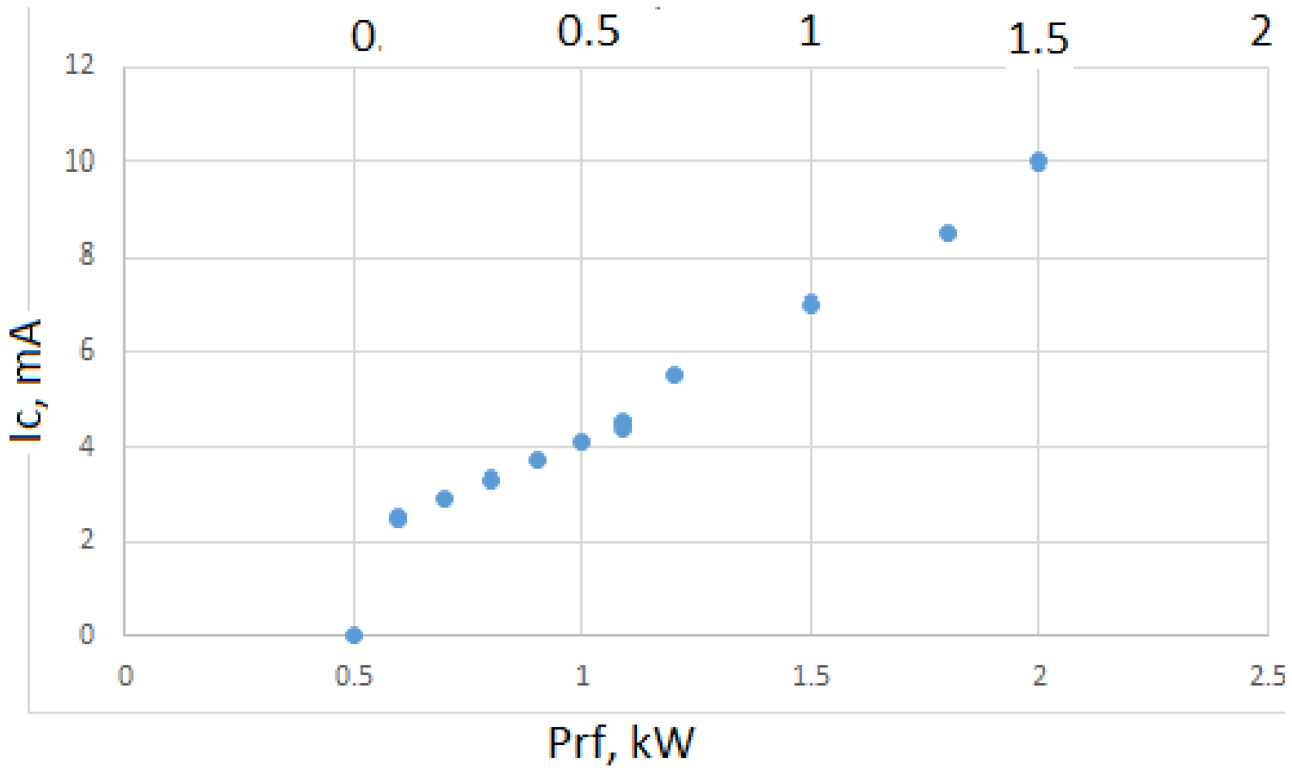
CW operation of the SA SPS with negative ion extraction was tested with RF power up to ~2 kW from the generator (~ 1.5 kW in the plasma) with production up to Ic=10 mA. Long term operation was tested with 1.8 kW from the RF generator (~1.3 kW in the plasma and 0.5 kW is dissipated in the antenna and matching network) with production of Ic=9 mA, Iex ~15 mA (Uex=8 kV, Uc=15 kV). This mode of operation was tested during : 50 days. After this test SA SPS was capable to work.

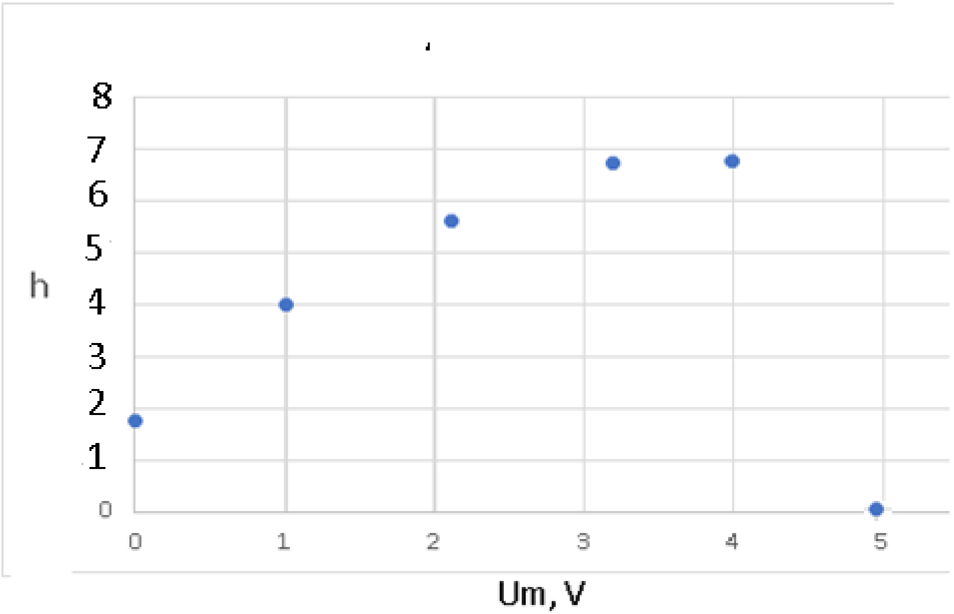
The collector current is increase with increase of a magnetic field up to Um ~4 V, and decrease with further increase of magnetic field because a plasma flux is compressed to the emission aperture and interaction of plasma flux with a collar surface is decreases.

The specific power efficiency of negative ion beam production in CW mode is up to Spe = 20 mA/cm^2 kW. (In the existing RF SPS the Spe ~ 4-6 mA/cm^2 kW; in the TRUIMF filament arc discharge negative ion source the best Spe is about 2 mA/cm^2 kW; in a compact Penning discharge SPS the Spe is 150 mA/cm^2 kW).

CW RF discharge can be triggered with CW discharge in the Triggering Plasma Gun (TPG) at gas flow Q~8 sccm and can be supported up to Q~3 sccm. The main CW discharge in SA RF SPS can be triggered without discharge in the TPG at Q~ 10 sccm and supported up to Q~4 sccm.

CW operation. Dependence of collector current I_{fc} on RF power from RF generator and from discharge power in plasma (upper scale).





Efficiency of H- generation on solenoid voltage