RF potential oscillations in a magnetized capacitive discharge

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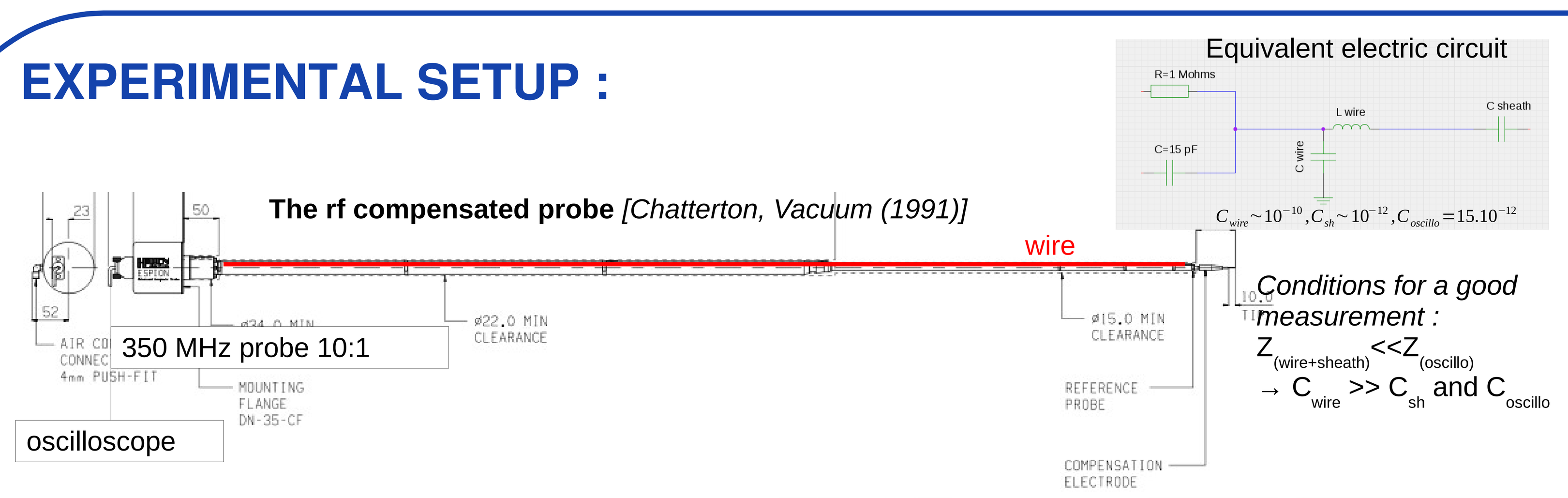
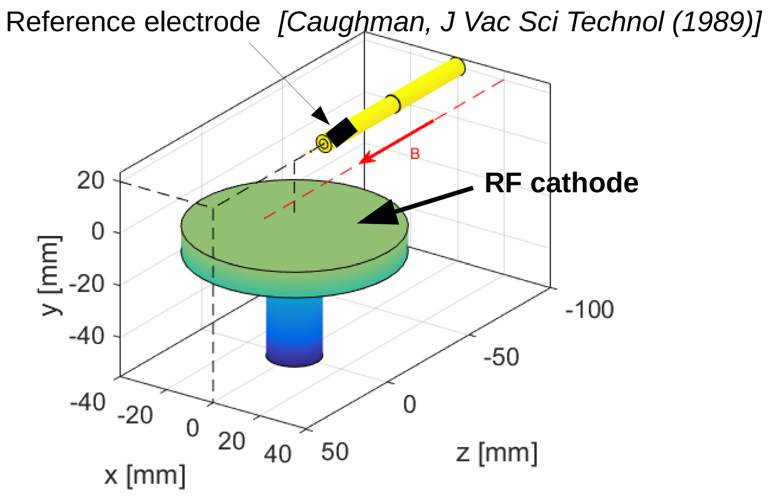
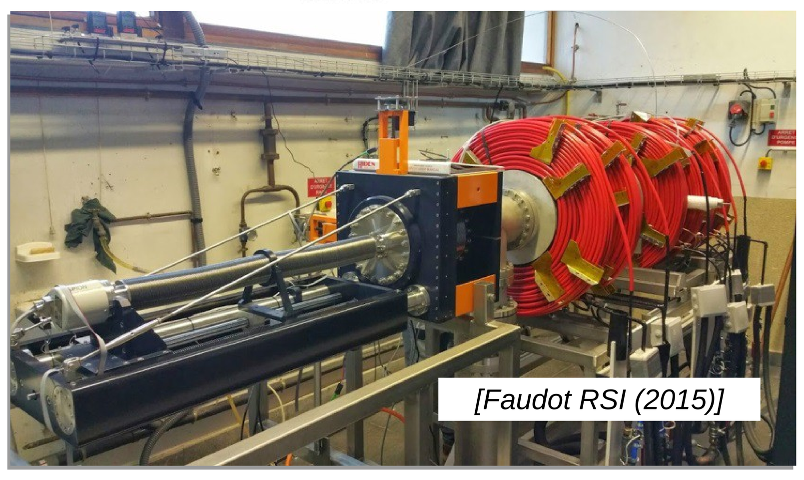
EXPERIMENTAL SETUP :



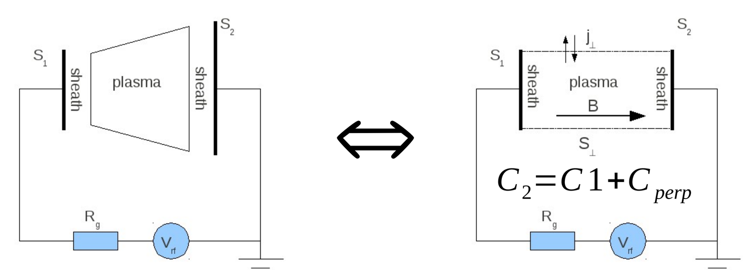
Reference electrode [Caughman, J Vac Sci Technol (1989)]





Aline plasma device : RF capacitive discharge in Argon

Asymmetric double sheath model (no match) DC coupling



$$C_{perp} = \frac{2\pi\epsilon_0\epsilon_{perp}L_{para}}{\log(R_2/R1)}$$

No sheath capa

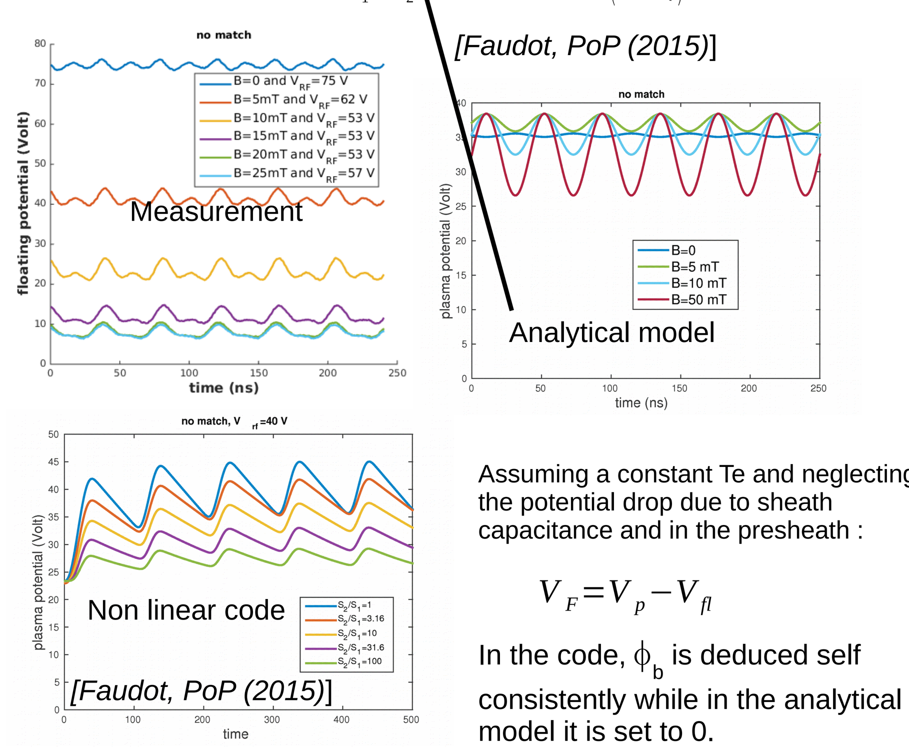
$$\phi = \phi_{fl} + \ln\left(\frac{S_2}{S_1}\right) + \ln\left[1 + \frac{S_1}{S_2}\exp(\phi_{rf})\right]$$

High sheath capa

$$\phi = \phi_{fl} + \gamma_1\phi_{rf} + \ln\left(\frac{S_1 I_0(\gamma_2\overline{\phi_{rf}}) + S_2 I_0(-\gamma_1\overline{\phi_{rf}})}{S_1+S_2}\right)$$

with $\gamma_1 = \frac{C_1}{C_1+C_2}$ $\gamma_2 = \frac{C_2}{C_1+C_2}$ $\phi_{fl} = -k_B\frac{T_e}{2e}\ln\left(2\pi\frac{m_e}{m_i}\right)$

[Faudot, PoP (2015)]

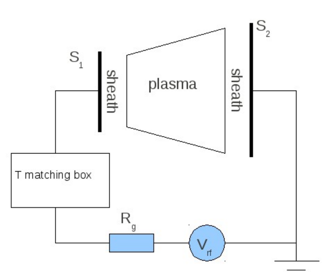


Assuming a constant Te and neglecting the potential drop due to sheath capacitance and in the presheath :

$$V_F = V_p - V_{fl}$$

In the code, ϕ_b is deduced self consistently while in the analytical model it is set to 0.

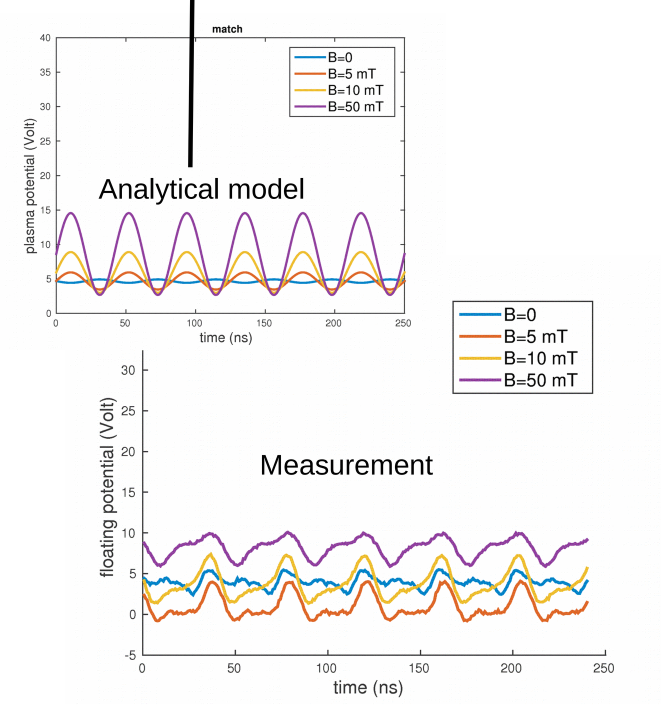
Asymmetric double sheath model (match) Capacitive coupling



$$\phi = \phi_{fl} + \gamma_1\phi_{rf} + \ln\left(\frac{\exp(\phi_b)S_1 I_0(\gamma_2\overline{\phi_{rf}}) + S_2 I_0(-\gamma_1\overline{\phi_{rf}})}{S_1+S_2}\right)$$

$$\phi_b = \frac{C_1 - C_2}{C_1 + C_2}\overline{\phi_{rf}}$$

[Raizer, « radio-frequency capacitive discharges, CRC Press]



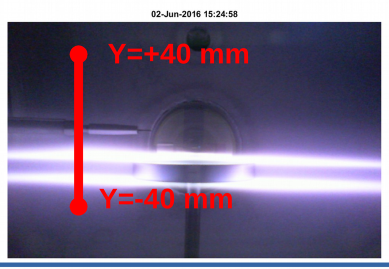
Floating potential profiles as a function of the magnetic field

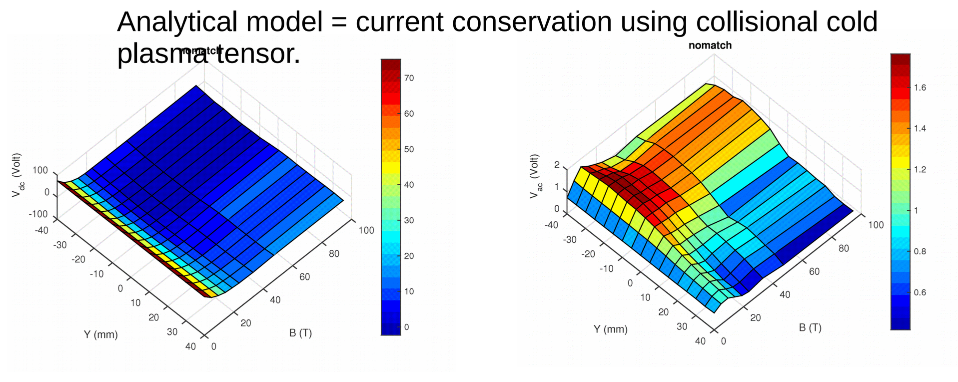
Discharge parameters :

P	1.3e-2 mbar
RF power	37 W
frequency	24 MHz
B	0-5-10-15-20-25-35-50-100 mT

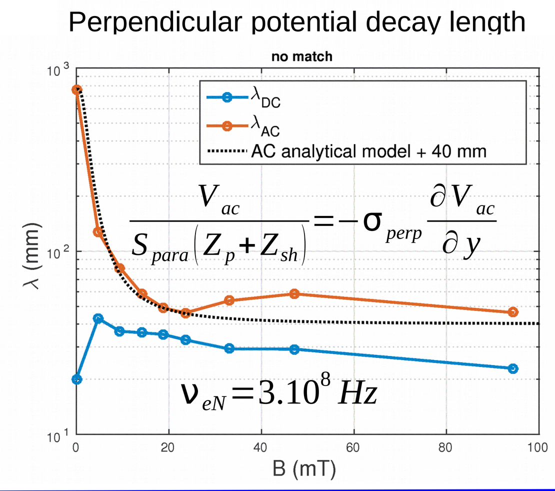
2 cases : without matching (dc coupling) and with matching (capacitive coupling)

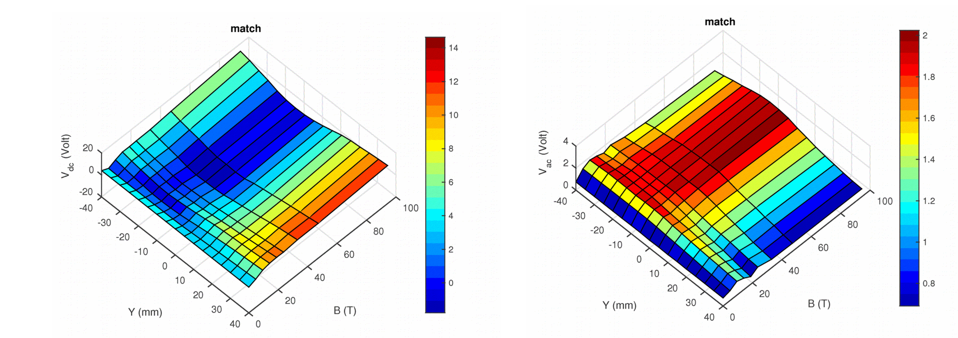
Analytical model = current conservation using collisional cold plasma tensor.

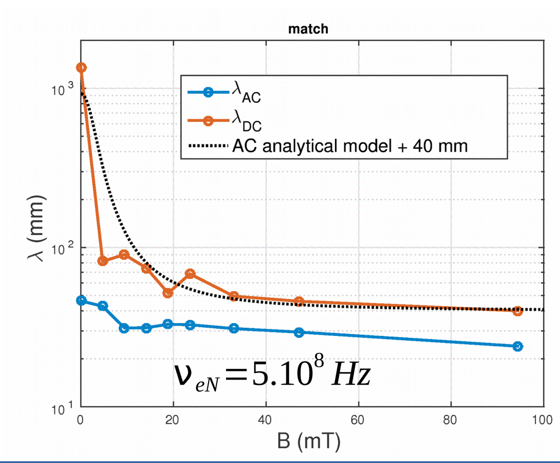




Perpendicular potential decay length





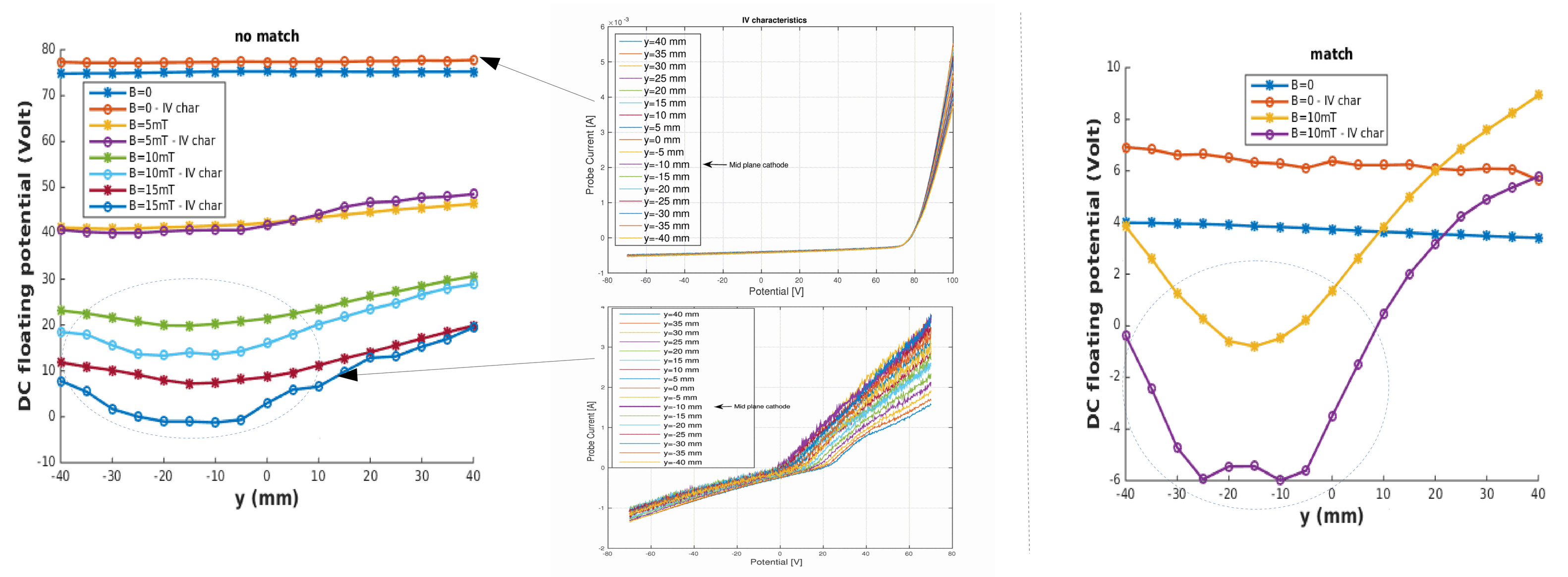


Conclusions : The AC decay length seems to saturate at 40 mm for both matchings. The DC decay length is twice lower than AC decay length. The current conservation analytical model yields the good behavior but needs to be improved to explain the 40 mm limit length.

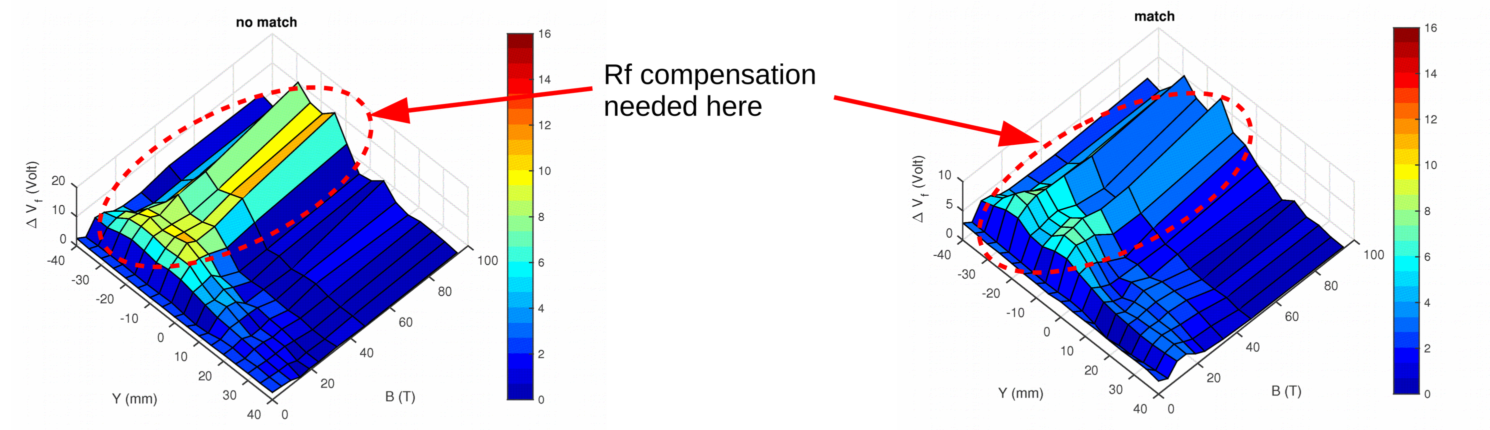
Without matching : The DC floating potential **decreases** as a function of the magnetic field, which means the magnetic field transforms the DC coupling to a capacitive coupling. This explains also why the DC coupling is better with a strong enough magnetic field (above 25 mT here). The AC floating potential connected to the cathode increases with the magnetic field and remains constant above 15 mT.

With matching : The DC floating potential is weakly dependent on the magnetic field but **increases** as a function of the magnetic field. The AC floating potential connected to the cathode increases with the magnetic field and saturates at 15 mT.

Necessity of the RF compensation in the probe



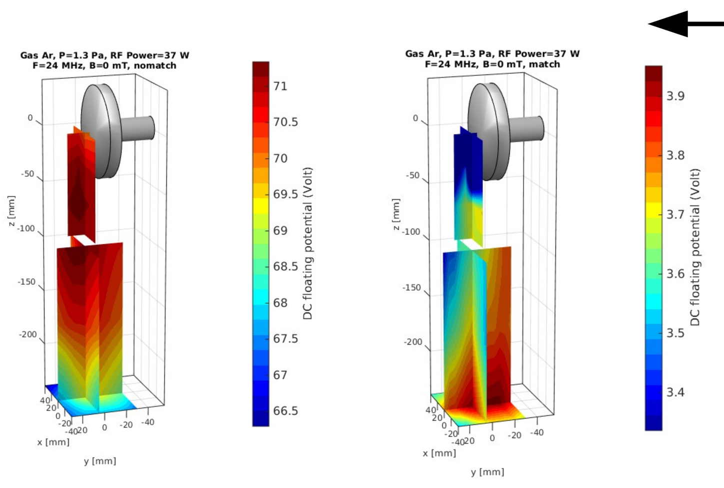
Comparison of the floating potential profiles measured by the reference probe and deduced from the IV characteristic of the uncompensated probe. The main discrepancy occurs in the region connected to the cathode where the oscillating potential is stronger.



Potential gap between the floating potential measured by the reference probe and deduced from the IV characteristic. This gap is stronger in the region connected to the probe.

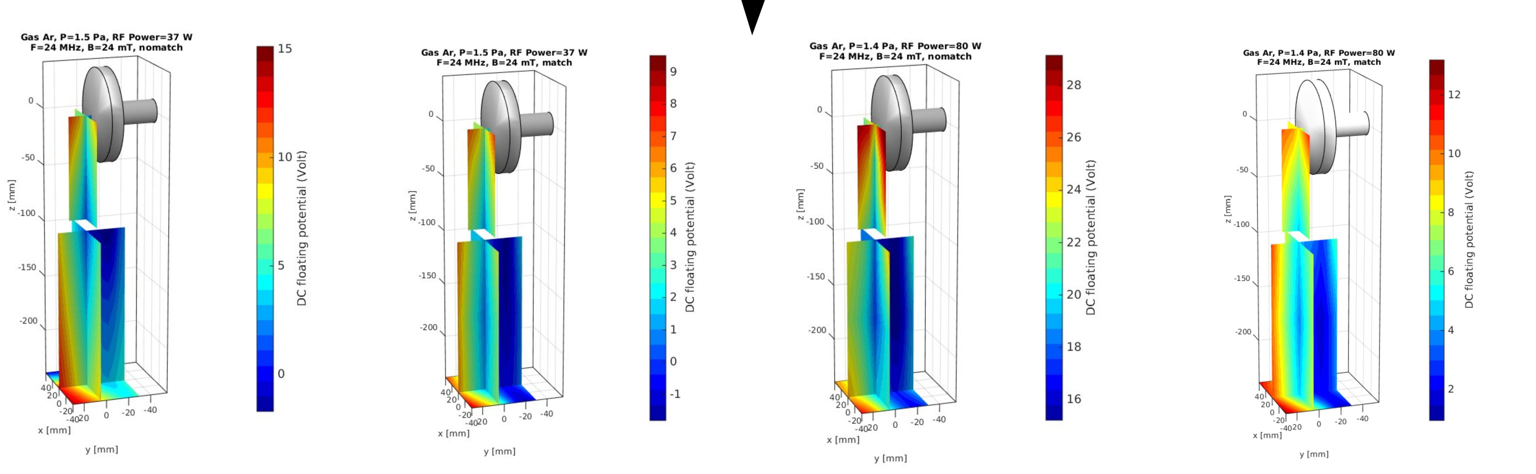
The rf compensation is needed when ΔV > 2V, which means higher than T_e. The rf compensation must be used in the region connected to the cathode to avoid reshaping of the IV characteristics, which shifts the floating potential on the negative side.

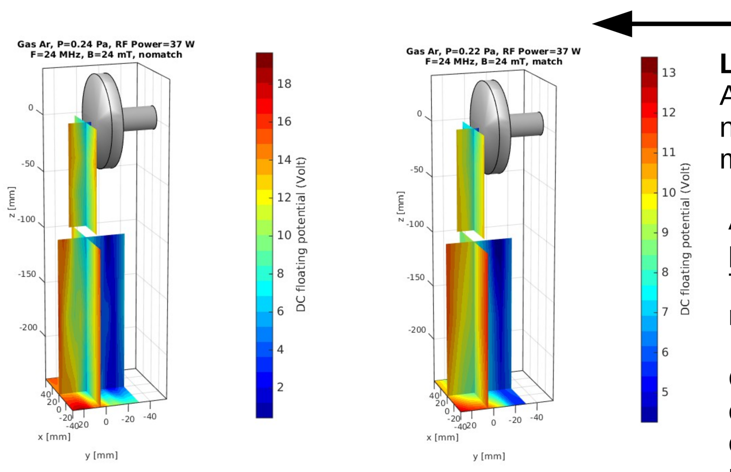
3D DC floating potential maps as a function of the magnetic field, rf power , and gas pressure *(153 points measured per map)*



No magnetic field :
The self biasing is negative on the cathode with matching, and positive in the plasma without matching at the same rf power

With magnetic field :
The self biasing discrepancies (between match and no match) are lower than without B. The magnetic field limits the DC current and plays the same role as the capacitor in the matching box. The higher the rf power, the higher the self biasing potential.





Low pressure :
At lower gas pressure, the collision frequency with neutrals is lower and the parallel potential decay length is much higher.

AC maps are also available, but the magnitude of the AC potential is lowered by the wire and oscilloscope impedances . The design of the reference electrode has to be improved to retrieved the good AC potential in the plasma.

One can see an asymmetry of the potentials around the cathode in the (x,y) plane. This may come from the plasma convection (ExB) around the cathode, which changes the plasma densities and then the amount of current.

Conclusion :

3D AC and DC floating potential maps have been drawn from measurements of a reference electrode mounted on a 3D manipulator moved by step motors. One has good values for the DC potential, but the magnitude of the AC potential is underestimated due to wire and oscilloscope impedances at the working frequency (24 MHz).

The time variation of the potentials permits to retrieve the AC and DC components. These ones can be approached by analytical models in asymptotic cases (no sheath capacitance and high sheath capacitance). A global model is difficult to build because we have to know the typical parallel and perpendicular surfaces collecting the currents, which depends on the magnetic field, but the main tendencies can be described by the model. The higher the magnetic field, the higher the AC potential, and the lower the DC potential.

The plot of perpendicular potential profiles allows to deduce the typical AC and DC decay lengths, which can be approached by a model based on the current conservation law associated to the collisional cold plasma tensor.

The floating potential from the reference electrode and from the IV characteristics are compared, revealing the compensation is needed when the AC potential is higher than 2 V. The region close and connected to the cathode has to be diagnosed with the compensation while it is unnecessary far from the cathode where the potential oscillation is lower than these 2 V.

Here electrons are well magnetized while ions are not because the ion collision frequency is higher than ion cyclotron frequency. Other measurements could be made in Helium, with magnetized ions to study the typical decay lengths.
The model describing the floating potential as a function of time has to be improved to make the self biasing decrease with the increase of the magnetic field in the no matching case as it is predicted by the code.