Operation and stability of an emissive cathode in a high density plasma

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OBJECTIVE

A tungsten emissive cathode is used to control plasma properties such as Φ_p. Its thermionic emission must be known to model the potential drop at the plasma core. Yet the emitted current depends unexpectedly on its bias. The goal is to **understand the emission properties of this cathode in a pre-existing plasma.**

1. Experimental setup

Plasma setup:
- RF source (13.56 MHz), magnetized [1].
- DC heated tungsten cathode

Video of a plasma shot with a strong emitted beam

Quantity	Pressure	Mag field	RF Power	Density	Electron temperature
Value	1 mTorr	170 G	1 kW	$2\cdot10^{18}$ m^{-3}	3 – 4 eV

2. I_h and V_b coupling

Naive prediction:
- I_b is controlled by I_h independently of V_b.

$$I_b = I_{em} + \cancel{I_i} - \cancel{I_e}$$

$I_i, I_e \ll I_{em}$

$$I_{em} = A_G S T_W^2 \exp\left(-\frac{eW}{k_B T_W}\right)$$

Temperature-driven emission

Experimental results:
- Dependence on V_b.
- Runaway behaviour.

T_W investigation with an optical pyrometer

3. Spatially and temporally resolved temperature measurements

Pyrometer experiment:
1. Light intensity measurement at 650 nm.
2. Conversion to temperature along curvilinear abscissa and time.
3. Computation of thermionic emission.

$$I_{em} = \int_0^s A_G T_W^2 \exp\left(-\frac{eW}{k_B T_W}\right) 2\pi r \, dx$$

Experimental results:
- Heterogeneous T_W profile.
- Good agreement with experimental I_b.

4. Numerical thermal model

- Thermal inertia $\dot{H} = C_p \rho V \frac{\partial T_W}{\partial t}$
- Conduction $\dot{Q}_c = \lambda \pi r^2 \frac{\partial^2 T_W}{\partial s^2}$
- Ohmic heating $\dot{Q}_\Omega = R\left(I_h + \int_s^{L_W} i_b \, du\right)^2$
- Outward dissipative radiation $\dot{Q}_{\sigma,out} = \sigma S \epsilon T_W^4$
- Inward dissipative radiation $\dot{Q}_{\sigma,in} = \alpha\epsilon\left(\dot{Q}^{N-1}_{\sigma,out} + \dot{Q}^{N+1}_{\sigma,out}\right)$
- Thermionic cooling $\dot{Q}_e = \frac{I_{em}}{e}(eW + 2k_B T_W)$
- Ion bombardment $\dot{Q}_i = I_i\left[E_i - W + \beta(\phi_p - V_b)\right]$

- **Integro-differential equation**

$$\dot{H} = \dot{Q}_c + \dot{Q}_\Omega + \dot{Q}_i + \dot{Q}_{\sigma,in} - \dot{Q}_{\sigma,out} - \dot{Q}_e$$

5. Application to I_b prediction and measurement

I_b prediction and runaway behaviour:
- Anticipate I_b for different parameters.
- Understand V_b and I_h dependencies.
- Avoid damaging strong emission.

Versatile T_W measurement method:
- Get the global cathode resistance.
- Deduce $\overline{T_W}$ value through resistivity.

$$\rho_W = a T_W^{1.22} + b$$

- Correct homogeneous $\overline{T_W}$ assumption using numerical results.

CONCLUSION

A complex plasma-cathode dynamic system has been investigated experimentally and numerically with an excellent agreement.
It provides a fine understandig of the physical phenomena at play as well as new methods to operate this simple cathode.
Such emissive cathode could be commonly use to achieve plasma control.

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