Wideband RF Characterization of Micro-Discharge Plasma Parameters

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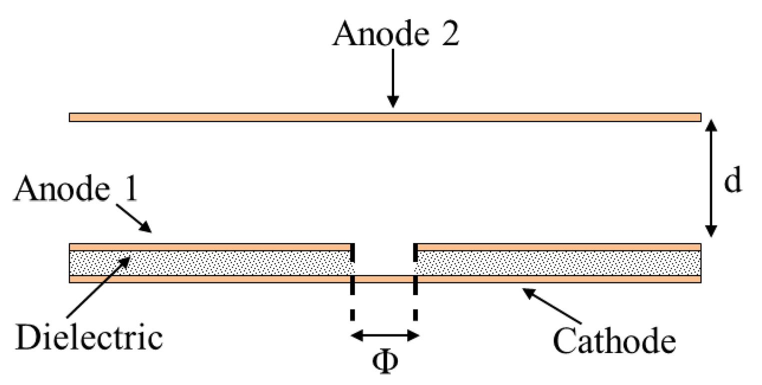
Introduction :

- Plasma discharges interesting from the RF point of view due to their physical characteristics: electromagnetically transparent when not present, low conductivity or low permittivity when present (under several conditions).
- **Purpose of this work:** Explore the possibilities offered by plasma discharges as active RF devices.
- **Potential candidate**: **Micro-Cathode Sustained Discharge (MCSD)**, which is a small size and stable atmospheric discharge suitable for integration in printed technology.
- **Requirement:** RF characterization of MCSD (equivalent permittivity and conductivity).
- **Proposed solution:** Measurement device consisting of a 50 Ω microstrip line with the MCSD placed in its center to perform a wideband evaluation of the scattering parameters (1 GHz to 15 GHz) as a function of several parameters (gas pressure, electric current, applied voltage).

Micro-Cathode Sustained Discharge:

- Three electrode discharge structure.
- Discharge generated between Cathode and Anode 1, inside the hole of diameter Φ.
- Third anode placed on top at a distance *d*, and positively DC biased (hundreds of volts) for pulling up the discharge outside the hole.
- Small size configuration and stable atmospheric pressure discharges.



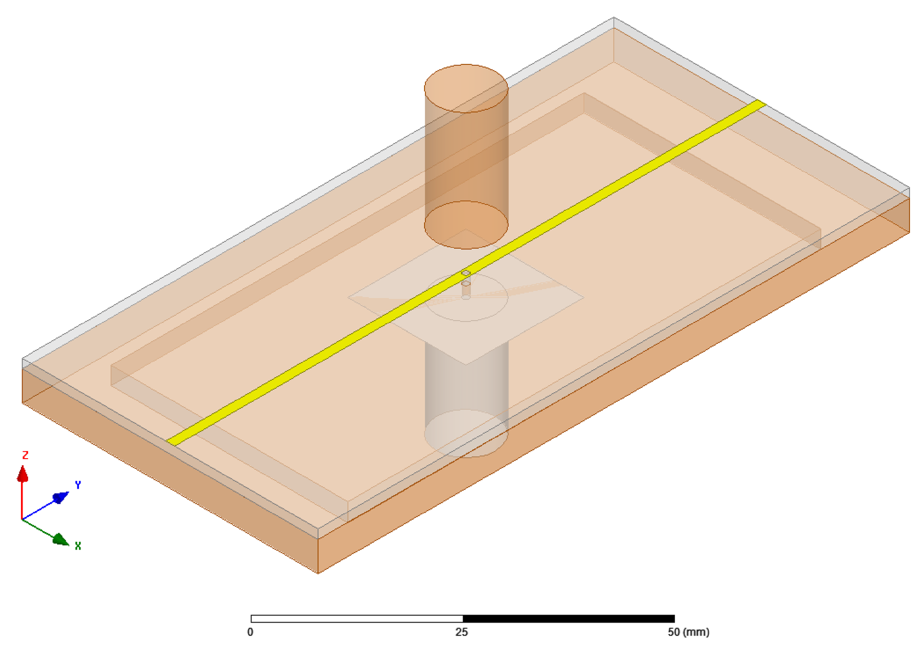
MCSD configuration

Gas	Argon
Temperature	~900 K
Electron density n_e inside the hole	10^{14} cm^{-3} to 10^{15} cm^{-3}
Electron density n_e outside the hole	10^{12} cm^{-3} to 10^{13} cm^{-3}
Plasma collision frequency v_p	~10^{12} s^{-1}

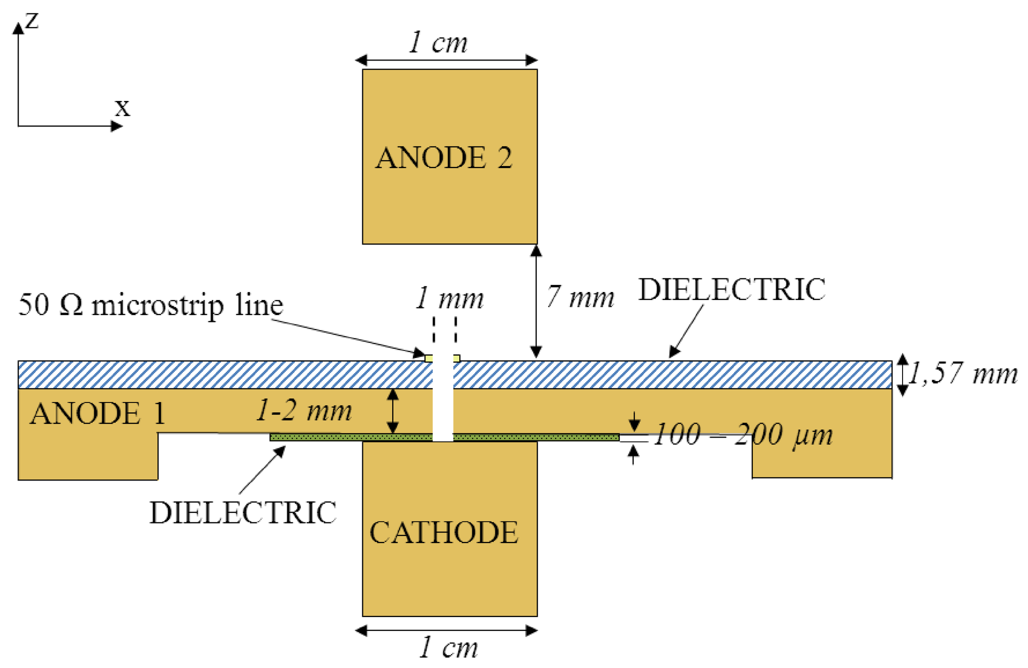
Atmospheric pressure expected parameters

Measurement Device:

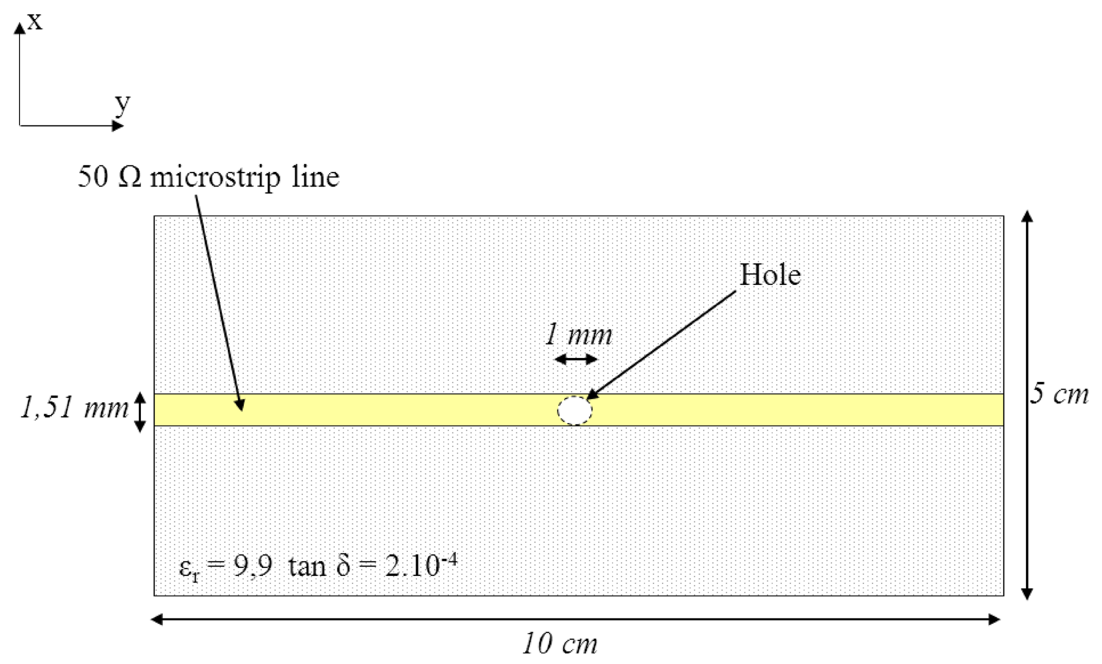
- 50 Ω microstrip line with a MCSD placed in its center:
  - Materials: copper electrodes, alumina dielectrics, gold microstrip line.
  - Decoupling of RF and DC excitations.
  - Device placed in a vacuum chamber.
  - Control over several parameters: gas pressure, voltage, electric current.
- **Goal:** Measure the influence of plasma discharge on the scattering parameters of the transmission line (transmission and reflection coefficients).



3D view



Cut view



Top view (RF section)

Electromagnetic RF Simulation Results:

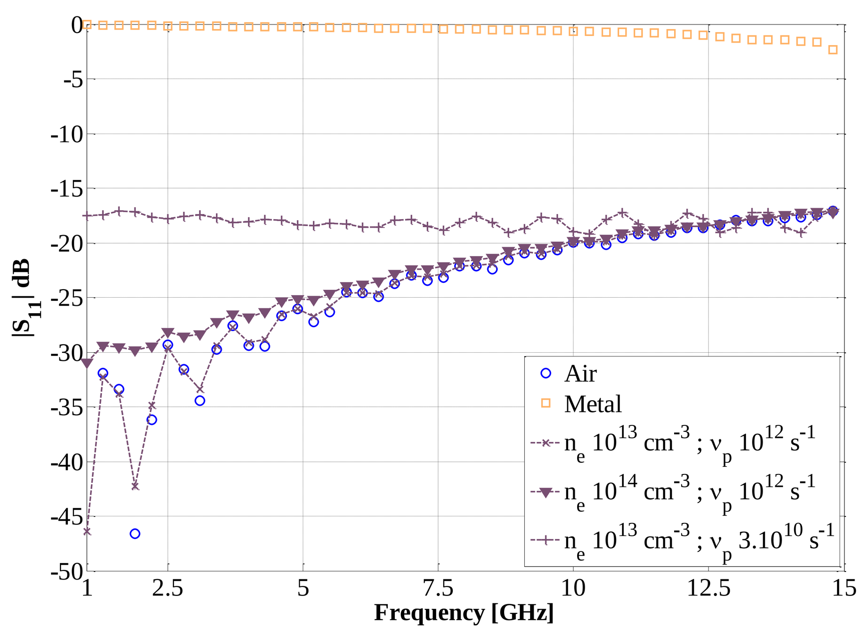
- Drude's equivalent model for a plasma:

$$\epsilon = 1 - \frac{\omega_p^2}{\omega^2 - j v_p \cdot \omega} \quad \text{with the plasma frequency} \quad \omega_p = \sqrt{\frac{n_e \cdot q^2}{\epsilon_0 \cdot m_e}}$$

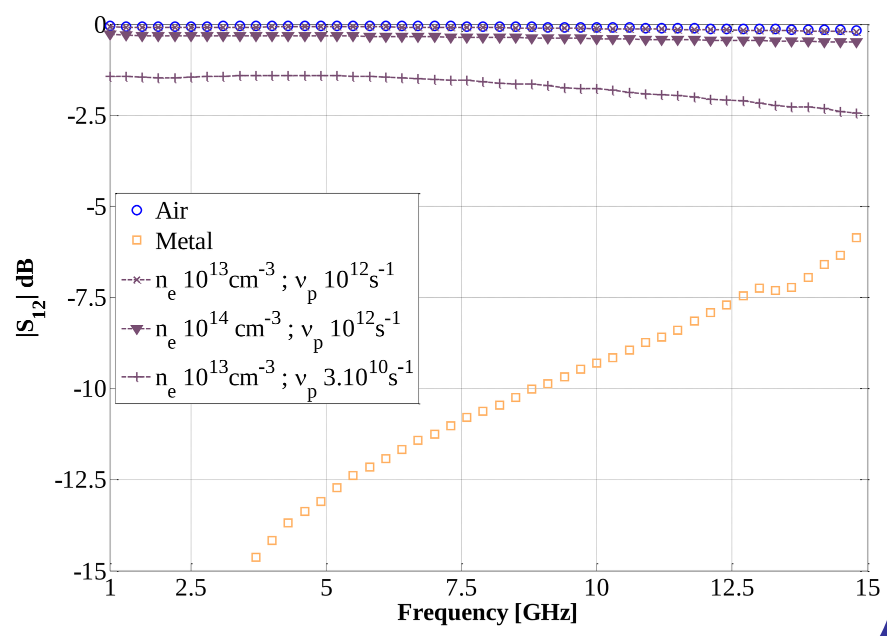
Electron charge (q), *Electron mass* (m_e)

Angular frequency of the electromagnetic wave interacting with the plasma (ω)

- Three different low power discharges compared with air and metal filled holes.
- Discharges simulated with expected values:
  - Two atmospheric pressure discharges ($v_p = 10^{12}$ s^{-1}) with two different electron densities ($n_e = 10^{14}$ cm^{-3} and $n_e = 10^{13}$ cm^{-3}).
  - Very low pressure discharge ($n_e = 10^{13}$ cm^{-3} ; $v_p = 10^{10}$ s^{-1}).
- Higher ω_p / v_p ratio: more influence over RF parameters.



Simulated reflection coefficient



Simulated transmission coefficient

Conclusion:

- Wideband RF measurement device of MCSD parameters (1 GHz to 15 GHz).
- Large possibility of parameter control (power, pressure, type of gas).
- Dependence on ω_p / v_p ratio for significant RF influence: Possible parameter control (gas pressure, voltage, electric current) to obtain a suitable ω_p / v_p ratio for RF applications.

Future Work:

- Measurements varying plasma discharge parameters and comparison with EM simulations.
- Device can be used for characterization of RF generated discharges.