Determination of the electrical circuit equivalent to a pulsed discharge in water: assessment of the temporal evolution of electron density and temperature

Thomas Merciris[1,2], Flavien Valensi[2], and Ahmad Hamdan[1]

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[2] Université de Toulouse, LAPLACE (Laboratoire Plasma et Conversion d'Energie), 118 route de Narbonne, F-31062 Toulouse Cedex 9, France

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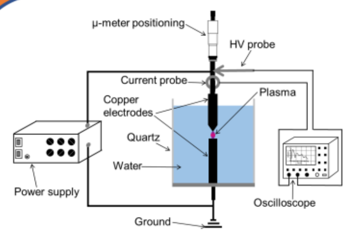
Abstract : Pulsed electrical discharges in dielectric liquids are intensively studied due to the wide range of applications in which they are implicated. Despite the simplicity of the experimental manipulation of these discharges, the underlying fundamental physics is relatively complex. In this study, we use the electrical characteristics, voltage and current, of pulsed discharges in water (various applied voltage and pulse width conditions) to determine the equivalent electrical circuit of the plasma. Based on a Mayr-type model, the plasma resistance is time dependent, but the inductance is not. Considering that plasma resistivity also depends on electron density and temperature (Spitzer formula), the temporal evolution of these two parameters were also determined.

Experimental system

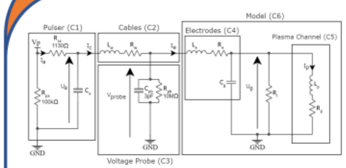


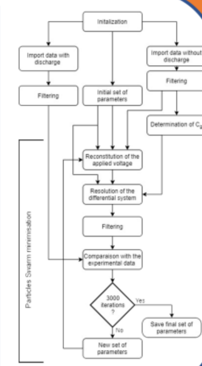
Probes :
- Current : Pearson 6585
- Voltage : Tektronix P6015A

Spectroscopy :
- Gate width : 25ns
- Repetitions : 250

Data processing :
- Numeric filtering, 75MHz 3rd order Butterworth
- Delay correction between probes (~ 15ns)
- Lorentzian fit on Hα : 656nm

Equivalent Circuit

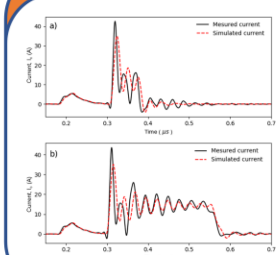




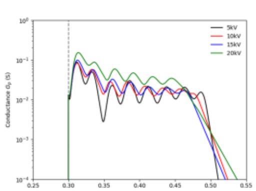
Steps
- Theoretical / Experimental estimation of parameters (wire/probe/electrodes)
- Global minimisation of the error between experimental and simulated current after filtering

Plasma model :
- Time fixed inductance (fixed radius approximation)
- Mayr model (arc conductance):
- $d_t G_p(t) = \frac{G_p(t)}{\tau}\left(\frac{I_p(t)^2}{G_p(t) P_w} - 1\right)$

Simulation results



15kV_200/400ns discharges

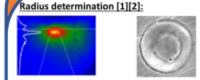


Plasma inductance:

Applied voltage (kV)	5	10	15	20
Plasma inductance (μH)	1.66	1.36	1.27	1.27

Plasma parameters

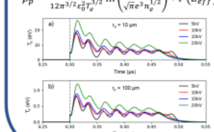
Radius determination [1][2]:



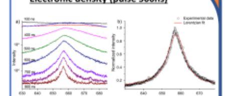
Discharge imaging (ICCD) Impact (plane electrode)

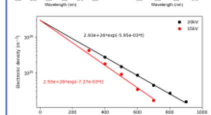
Spitzer formula (electrons-ions collisions) :

- $\rho_p = \frac{\sqrt{2m_e}e^2 * Z_{eff}}{12\pi^{3/2}\varepsilon_0^2 T_e^{3/2}} \ln\left(\frac{T_e^{3/2}}{\sqrt{\pi}e^3 n_e^{1/2}}\right) * F(Z_{eff})$



Electronic density (pulse 500ns)





- <300ns → continuum spectrum → Lorentzian fit impossible.
- Exponential extrapolation (temporal evolution)

Conclusion : The electrical characteristics of this discharge (current and voltage) were experimentally determined under various conditions of applied voltage and pulse width and used to theoretically calculate plasma properties such as inductance and resistance.

The inductance of the cylindrical plasma channel was assumed to be time independent, and its average value was used to study the temporal evolution of plasma resistivity, according to a Mayr-type model. Considering that resistivity depends on electron temperature and density (Spitzer formula), the evolution of these parameters as a function of time was also assessed. However, the influence of electron density (measured experimentally) on plasma resistivity was taken to be insignificant, and so, only the temporal variation in electron temperature was analyzed. The obtained results demonstrate that electron temperature is highly dependent on plasma radius, with the impact radius (10 μm) yielding a value of approximately ~25 eV. The plasma emission radius (~100 μm), on the other hand, results in an electron temperature of ~1.2 eV.

Our approach in determining some plasma properties based on an equivalent electrical circuit is approximative, at best. Nevertheless, the results reported herein demonstrate that the temporal evolution of electrical characteristics, mainly the current, can be directly related to variations in electron temperature and/or plasma radius.

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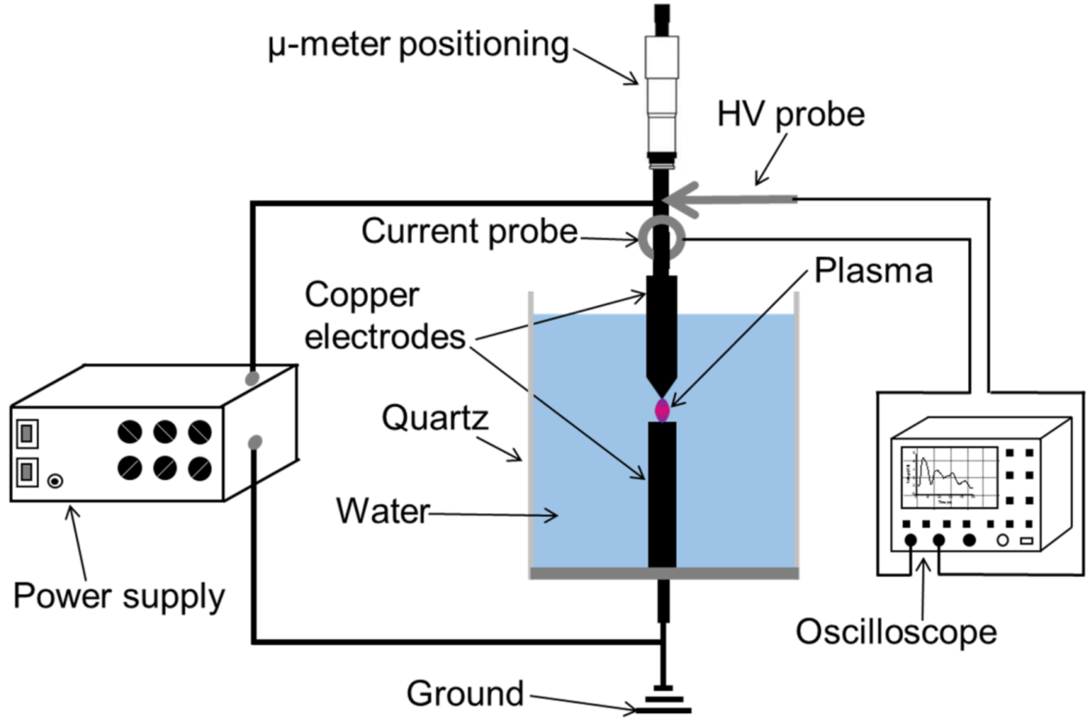

Probes :

- Current : Pearson 6585 (<200MHz)
- Voltage : Tektronix P6015A (<75MHz)

Spectroscopy :

- Gate width : 25ns
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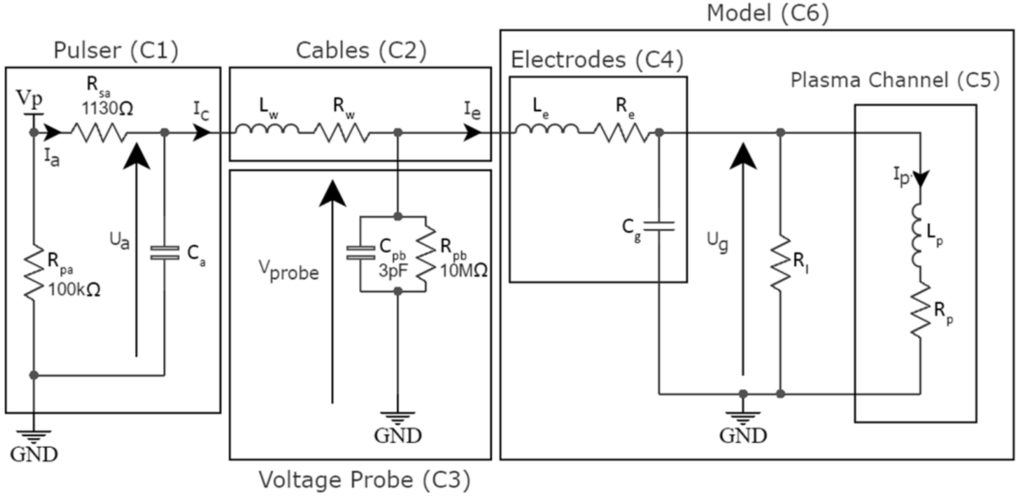

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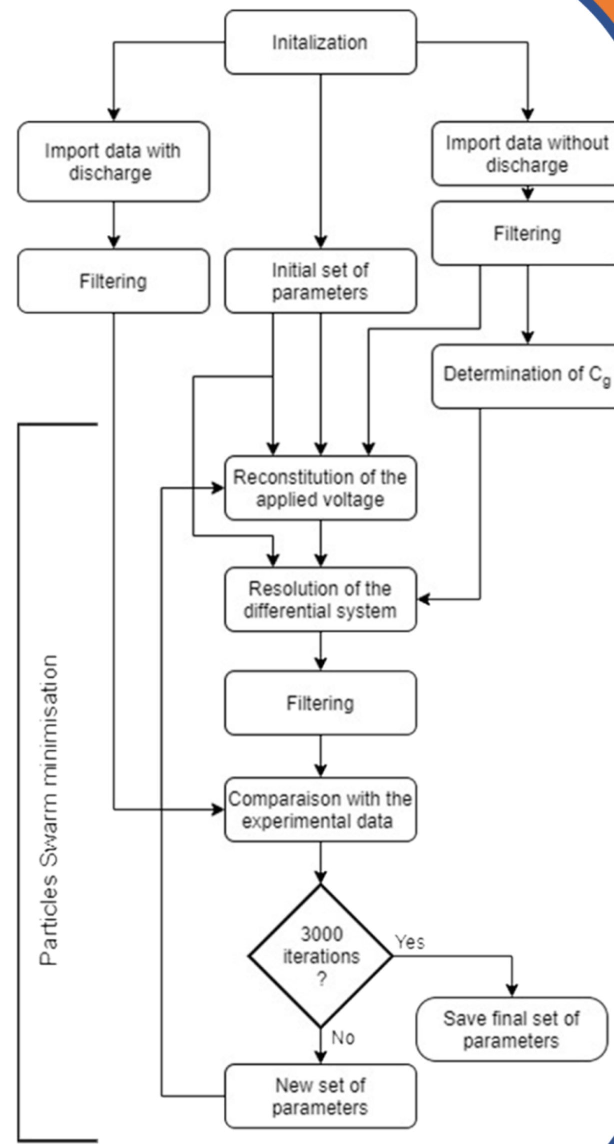

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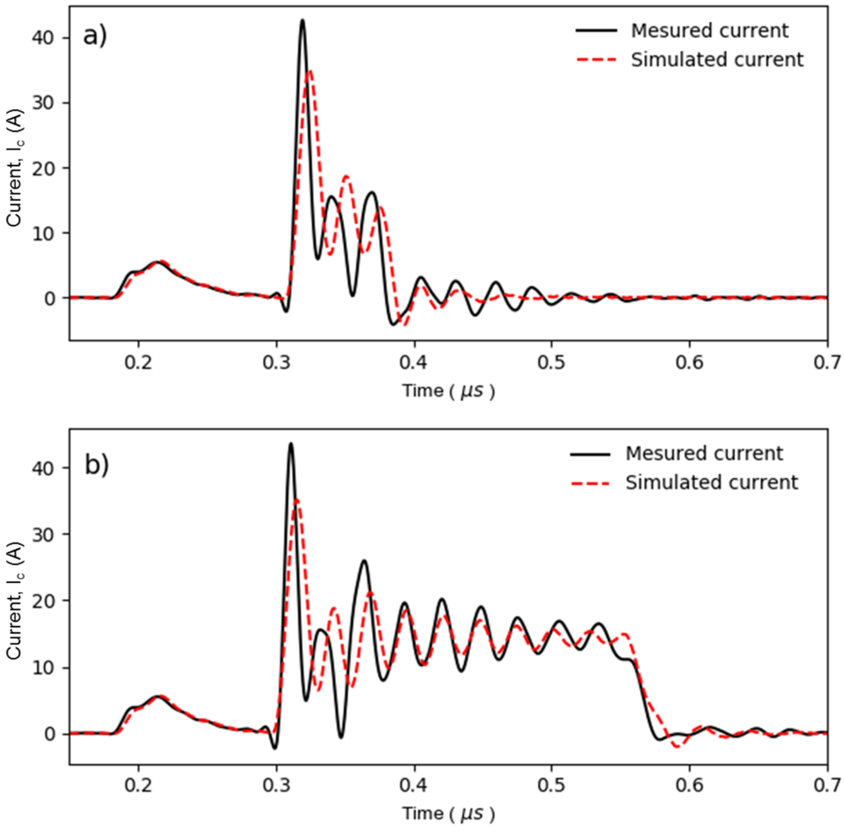

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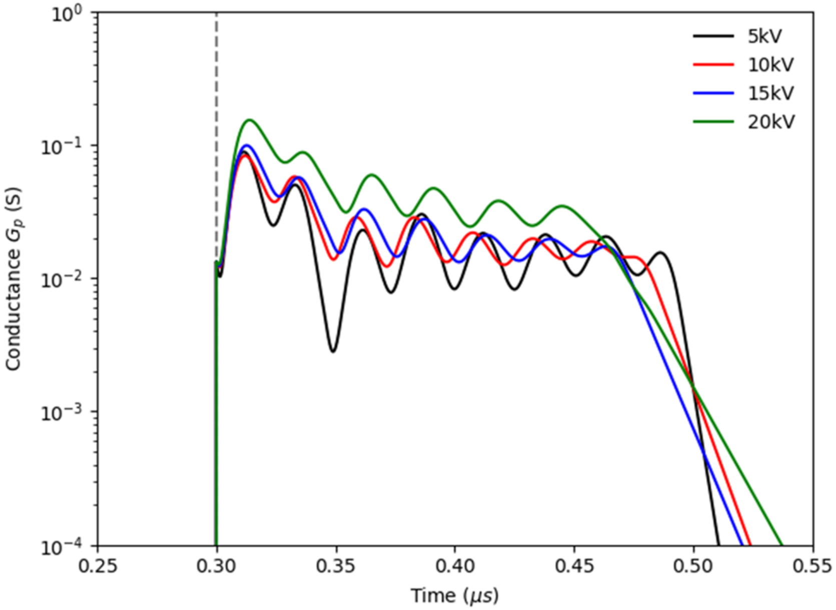

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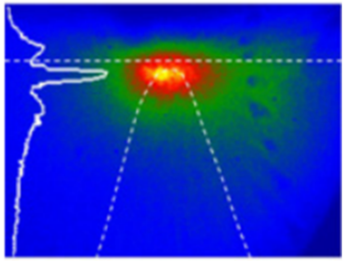

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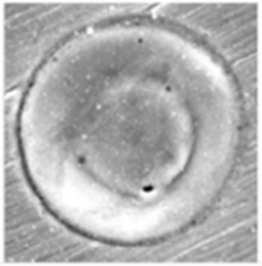

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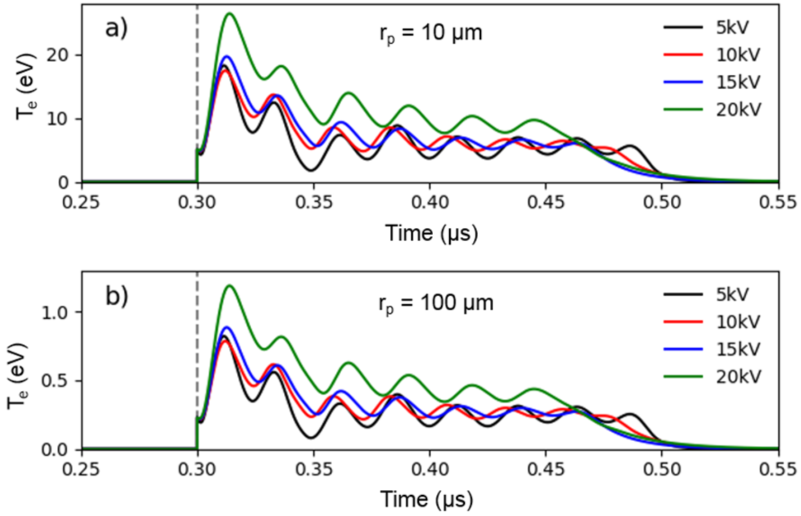

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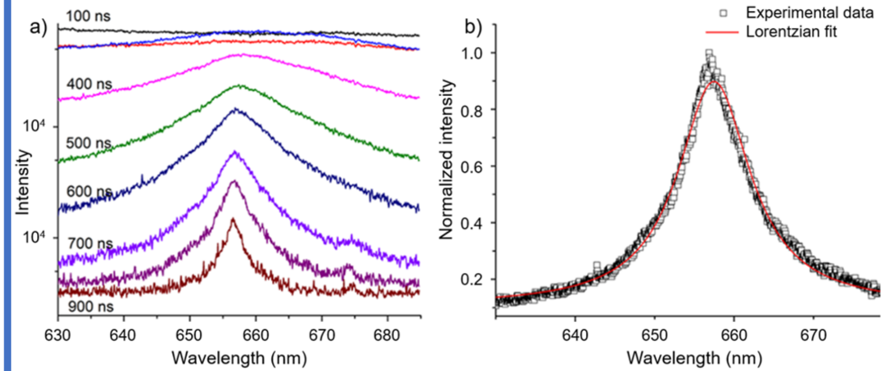

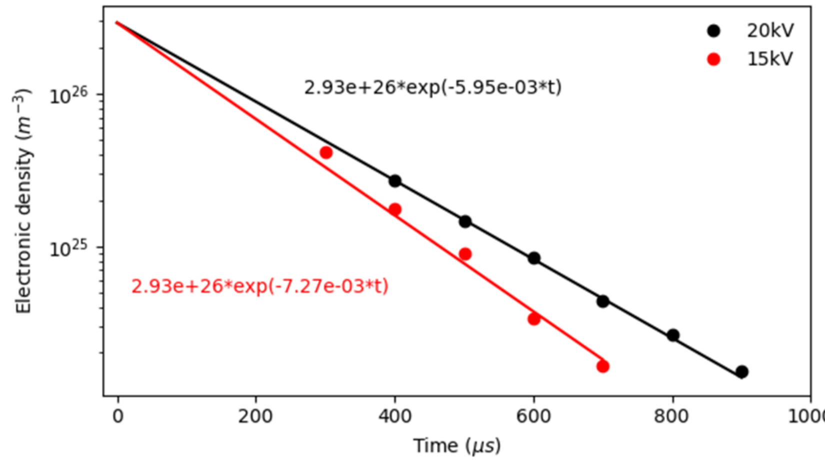

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