Leibniz
Ferdinand-Braun-Institut

Microwave Plasma Simulation Applied to a Double ICP Jet Reactor

COMSOL Conference Stuttgart 2011

Horia-Eugen Porteanu and Roland Gesche
Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

…translating ideas into innovation

Outline

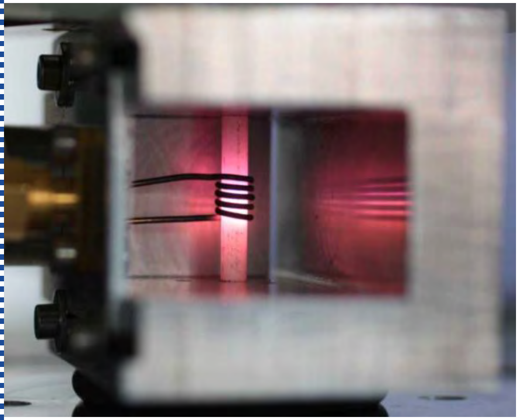
1. ICP sources, development, structure
2. RF Simulation: Q-factor, matching impedance
3. Plasma simulation for p=10 mbar realistic results
4. Plasma simulation for p=0.1 mbar, not realistic results
5. Conclusions

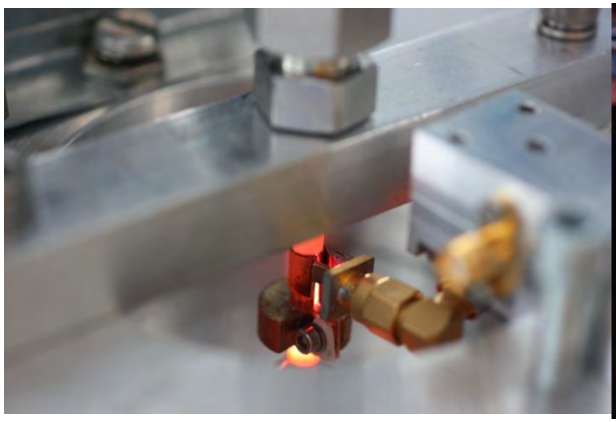
Microwave Sources for Inductively Coupled Plasma (I)

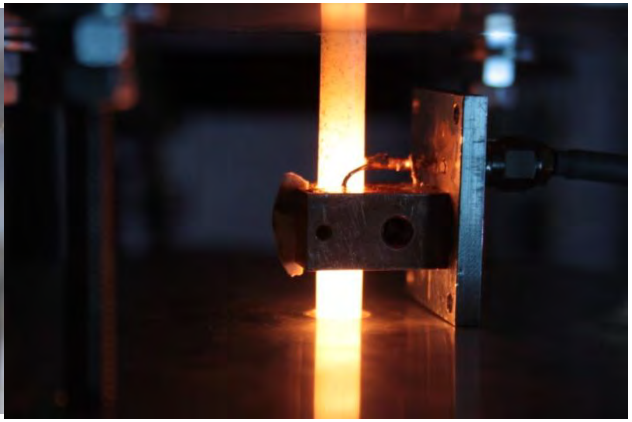
Single ICP

3 mm tube

7 mm tube

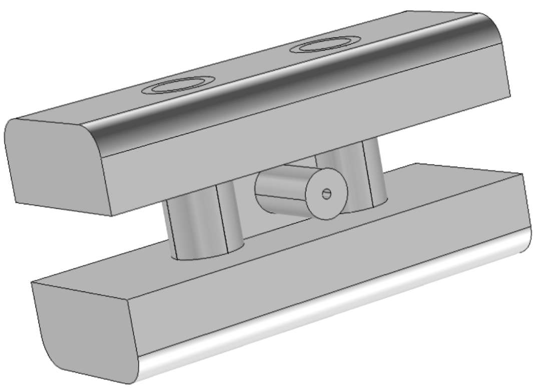


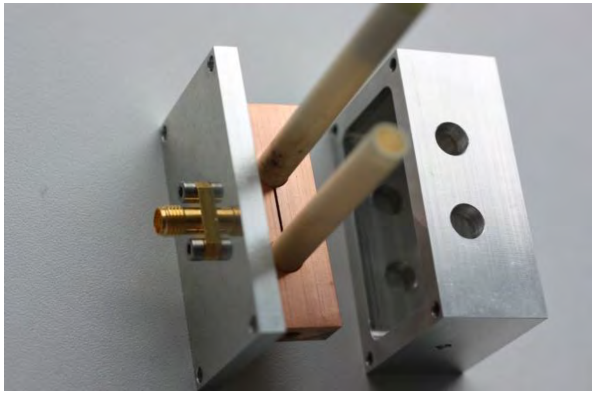


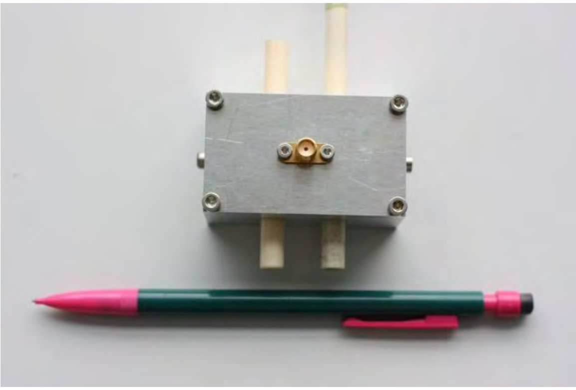


Microwave Sources for Inductively Coupled Plasma (II)

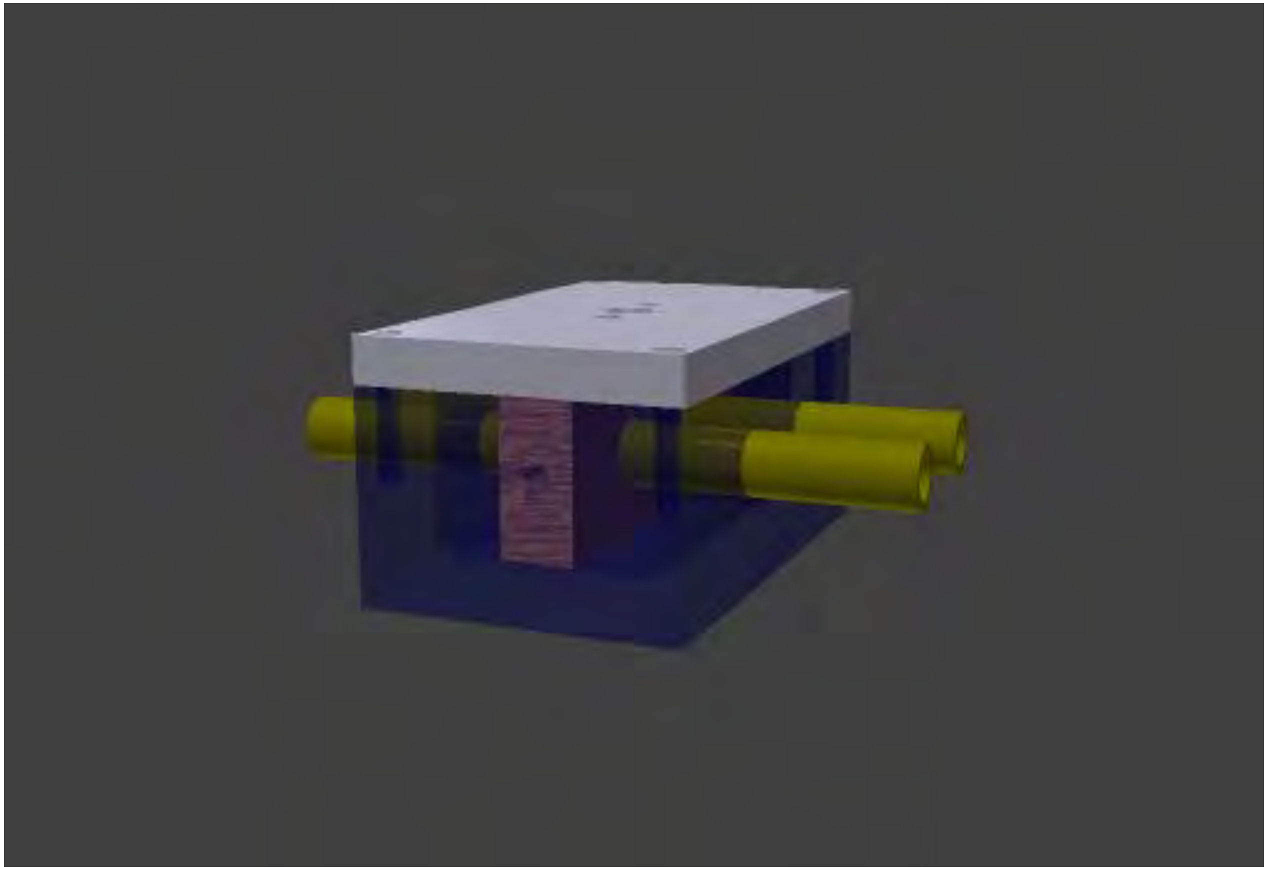
Double ICP





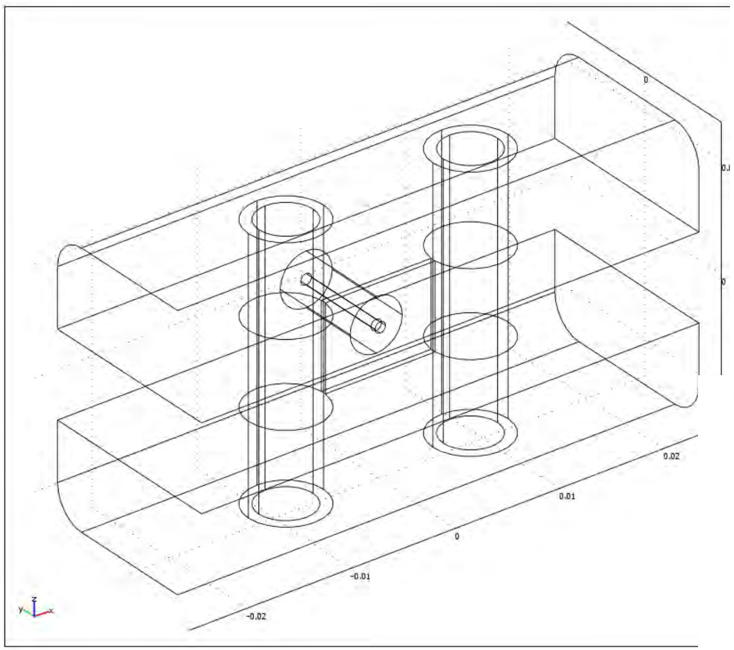


Microwave Sources for Inductively Coupled Plasma (II)

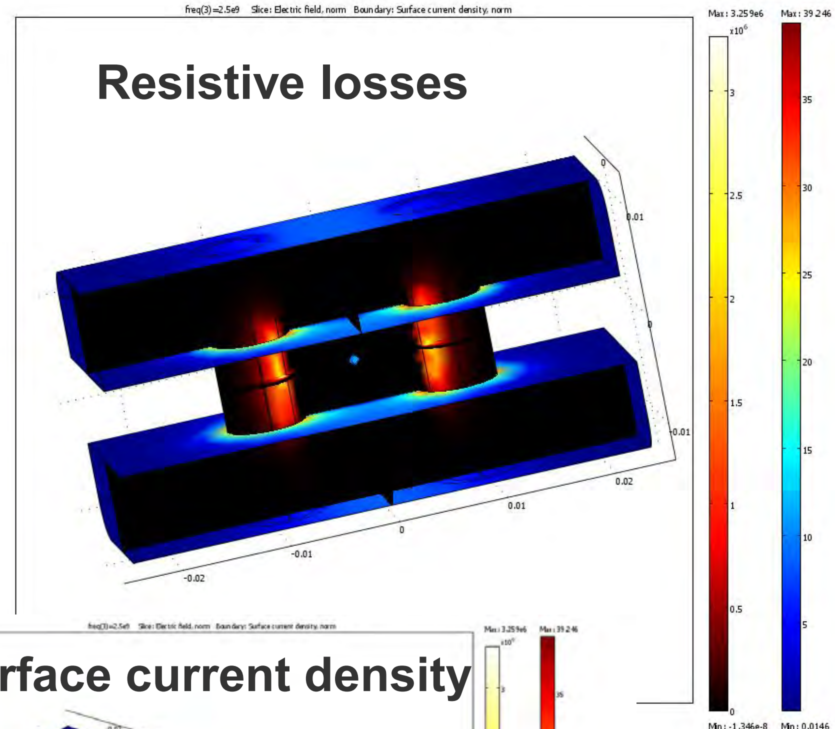


RF Simulation (I)

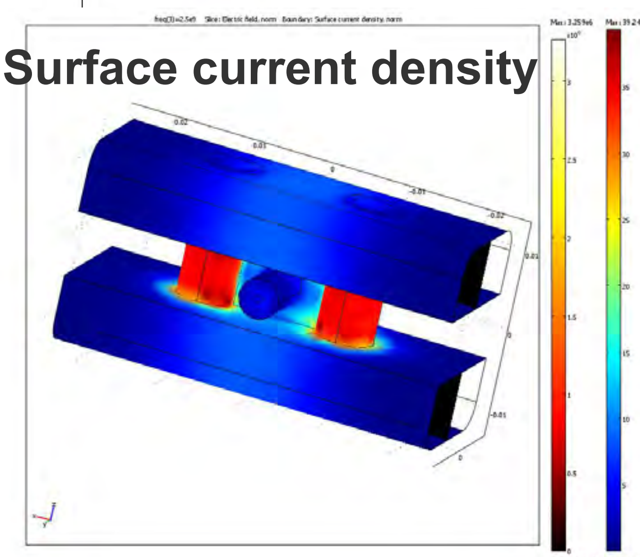
RF coupling



Resistive losses

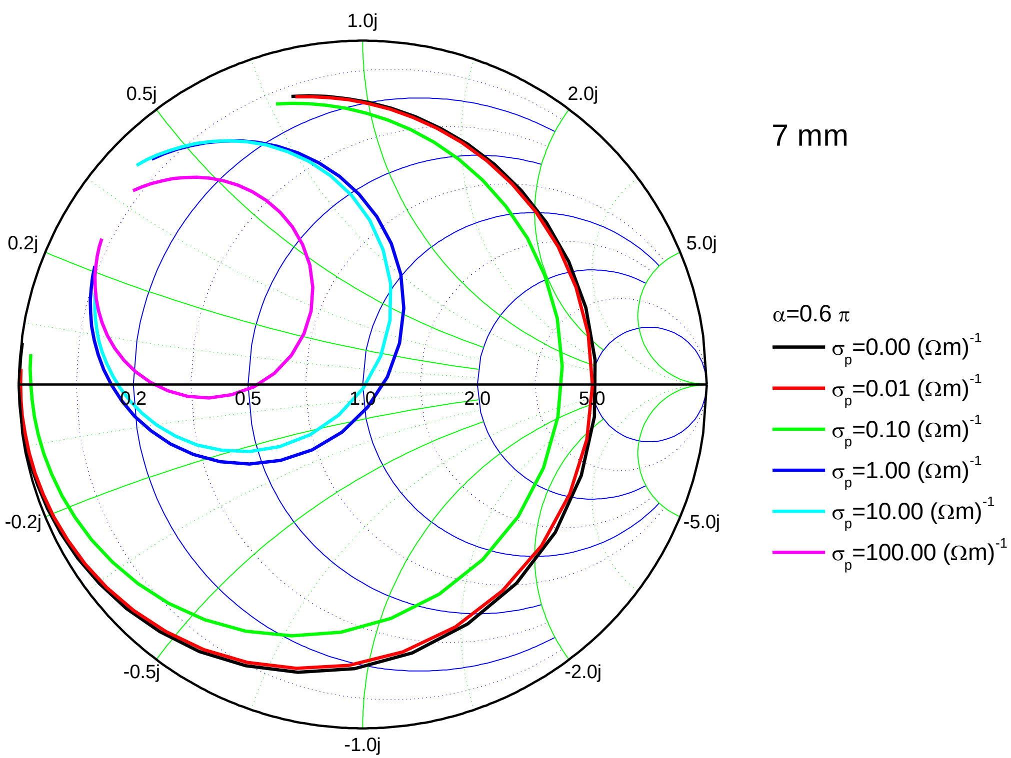


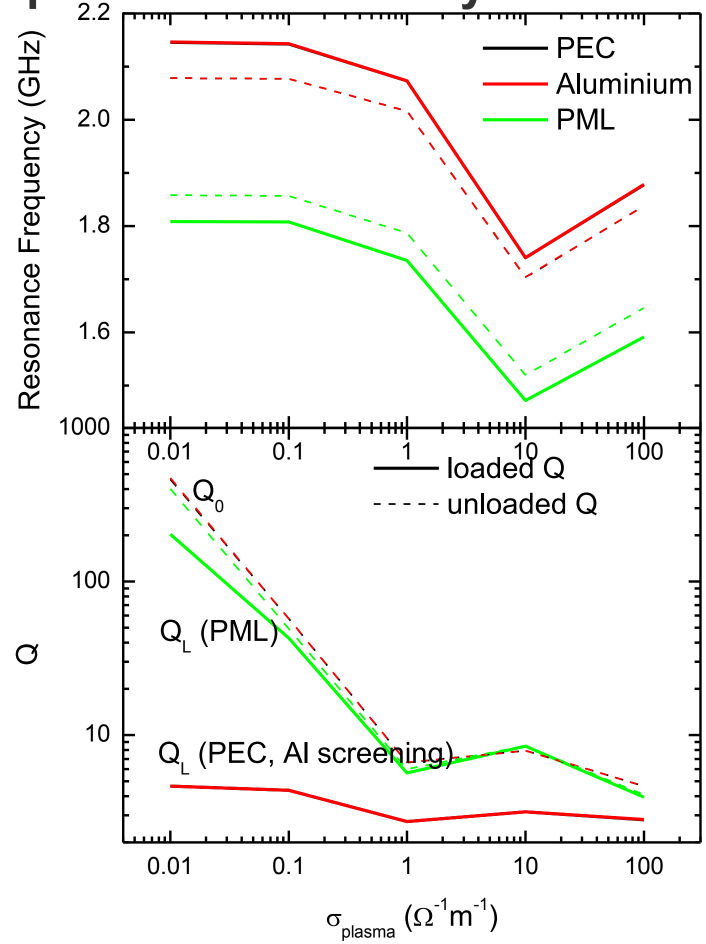
Surface current density



RF Simulation (II)

Behavior of the resonator for homogeneous plasma conductivity

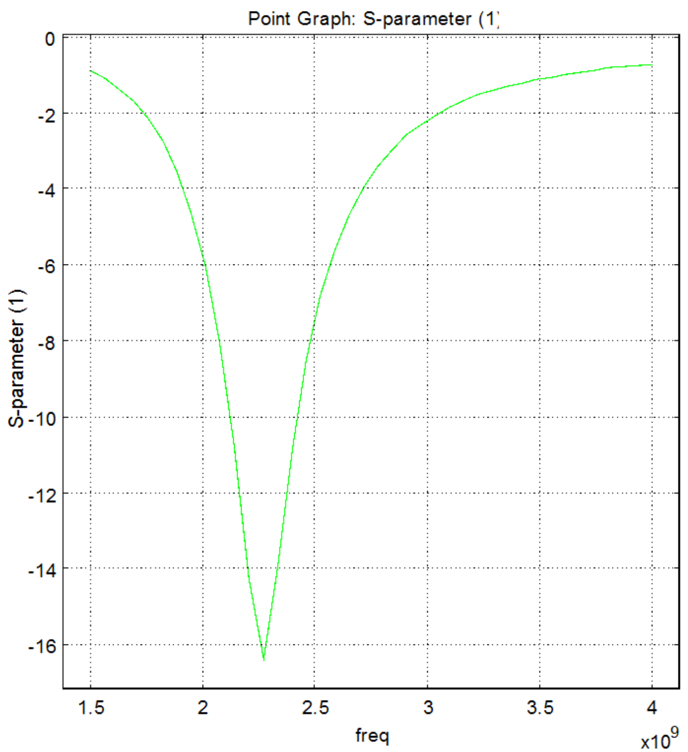


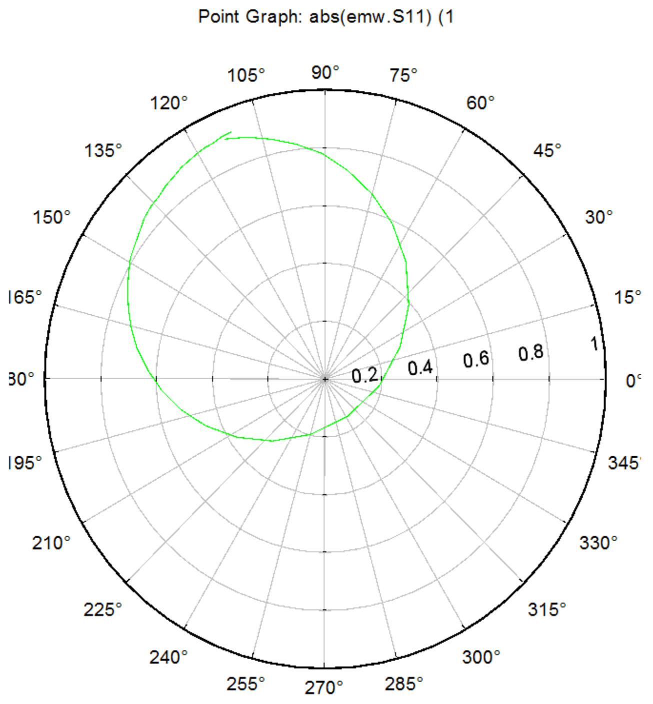


Q_0~2000 (without plasma and influence of the VNA)

RF Simulation (III)

Ideal matching for sigma$_{plasma}$=1 $(\Omega m)^{-1}$

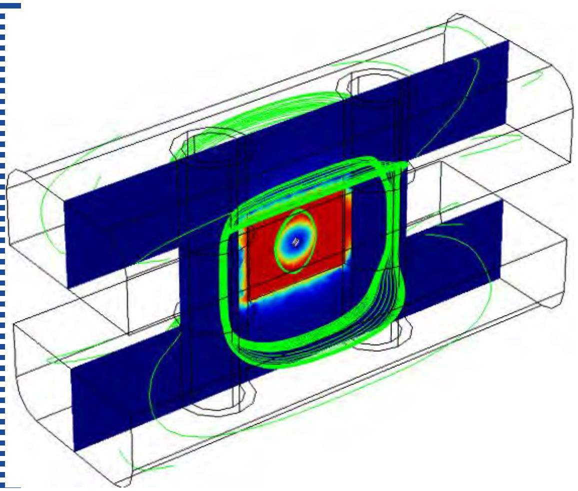




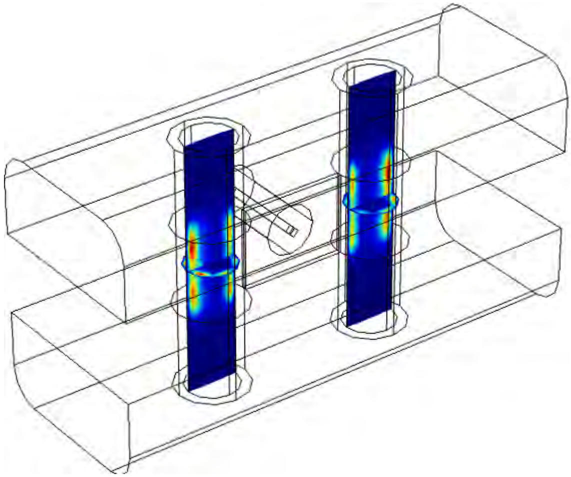
σ_{plasma}=1 $(\Omega m)^{-1}$

Plasma Simulation (I): Plasma Parameters

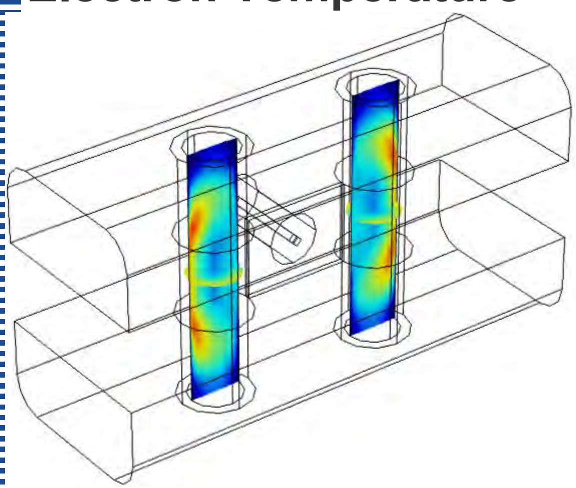
E and H Fields



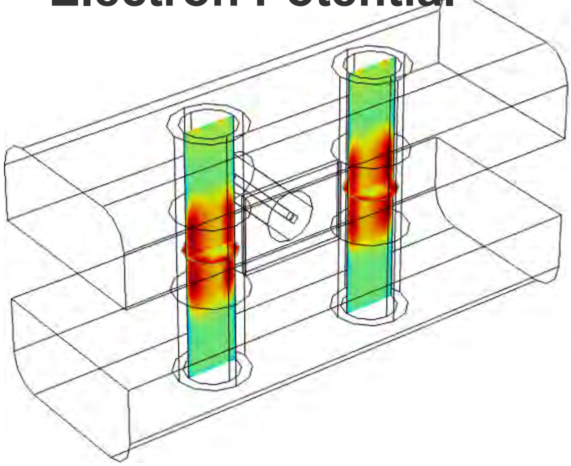
Electron Density



Electron Temperature

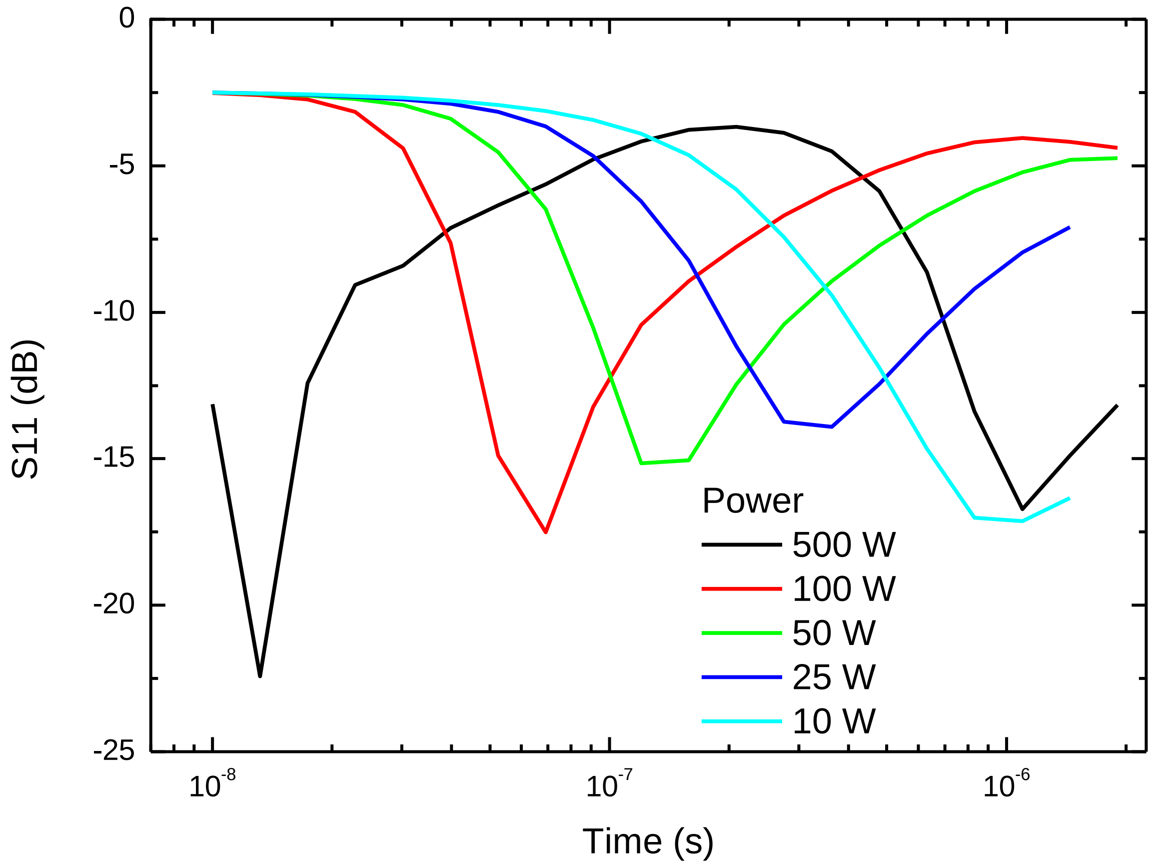


Electron Potential



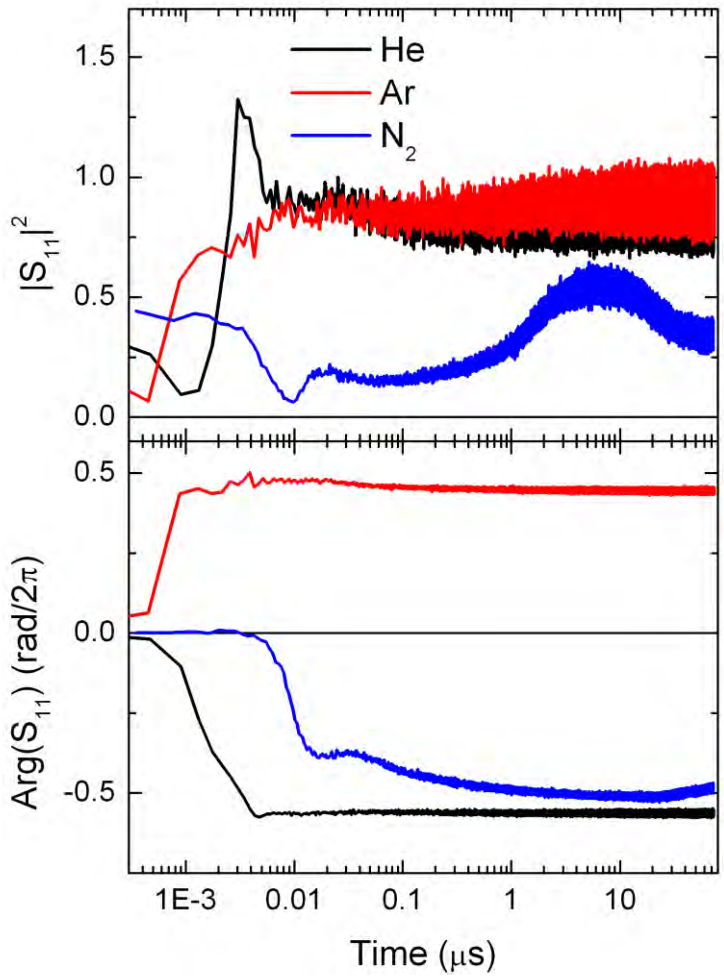
Plasma Simulation (II)

Power Dependence of the plasma ignition
p=10 mbar, $n_{e\ ini}=10^{14} - 10^{15}\ m^{-3}$, gas flow=$10^{-2}\ m^3/s$



Plasma Simulation (II)

Experimental results on transients

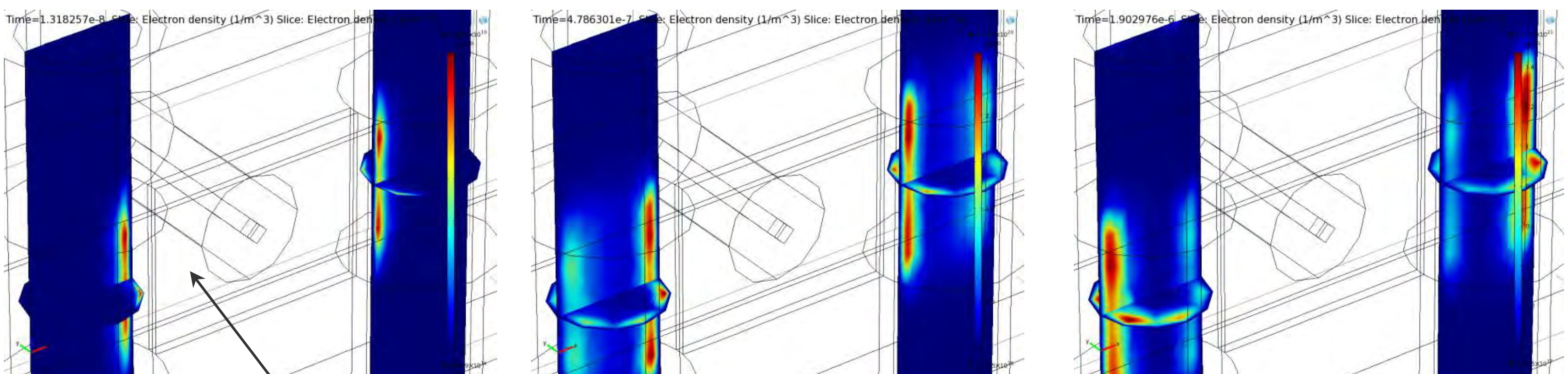


Leibniz
Ferdinand-Braun-Institut

Plasma Simulation (III)

Time dependence of the plasma ignition,
P=500 W, p=10 mbar, $n_{e\ ini}=10^{14} – 10^{15}\ m^{-3}$, gas flow=$10^{-2}\ m^3/s$

$t=10^{-8}$ s, $n_e=4\ 10^{19}\ m^{-3}$ | **$t=5\ 10^{-7}$ s, $n_e=3\ 10^{20}\ m^{-3}$** | **$t=2\ 10^{-6}$ s, $n_e=1.5\ 10^{21}\ m^{-3}$**



CCP | **CCP – ICP** | **ICP**

Capacitor

Time

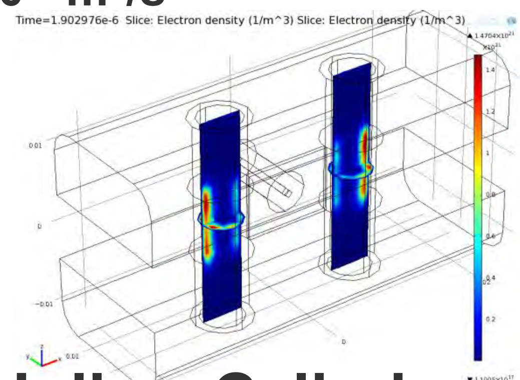
Plasma Simulation (IV)

Gas flow dependence,

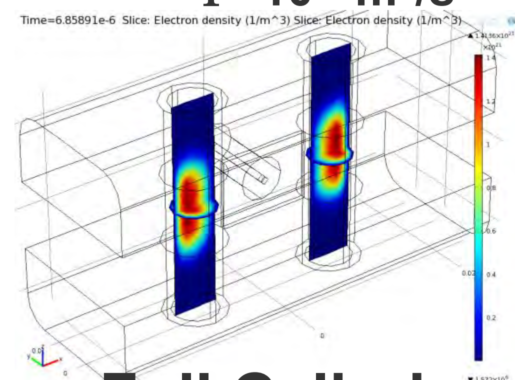
P=500 W, p=10 mbar, $n_{e\ ini}=10^{14}\ m^{-3}$, Gas Flow= 10^{-4} - $10^{-2}\ m^3/s$

t=2 10^{-6} s, n_e=1.5 $10^{21}\ m^{-3}$
$\Gamma=10^{-2}\ m^3/s$

t=7 10^{-6} s, n_e=1.4 $10^{21}\ m^{-3}$
$\Gamma=10^{-4}\ m^3/s$

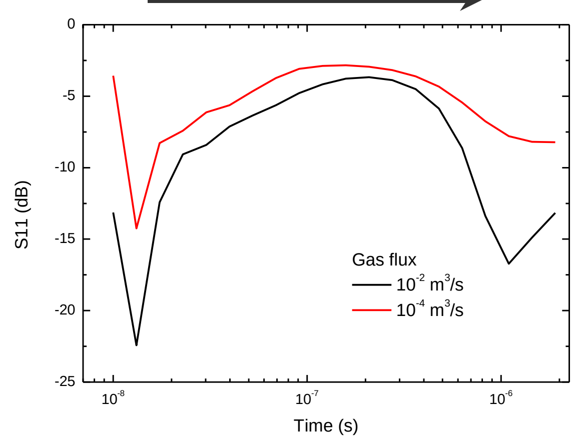


Hollow Cylinder



Full Cylinder

For $\Gamma=10^{-2}\ m^3/s$
No convergence after t=2 10^{-6} s



Simulations qualitatively confirmed by experiment

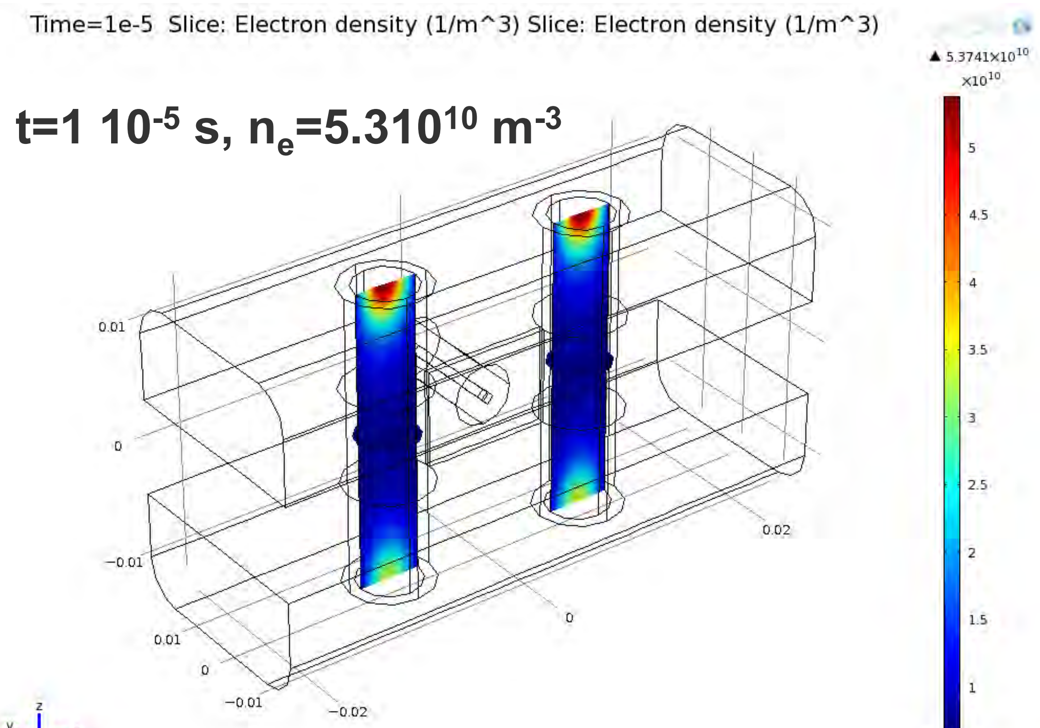
Plasma Simulation (V)

Low pressure behavior, with gas flow

p=0.1 mbar, P=30 - 5000 W, $n_{e\ ini}$=10^{14} m^{-3}, gas flow= 10^{-4} m^3/s

No physical results!

t=1 10^{-5} s, n_e=5.3$10^{10}$ m^{-3}



Even for P=5000 W and $n_{e\ ini}$=10^{18} m^{-3} the electron density decreases.
The electron density is the smallest in the center of the resonator

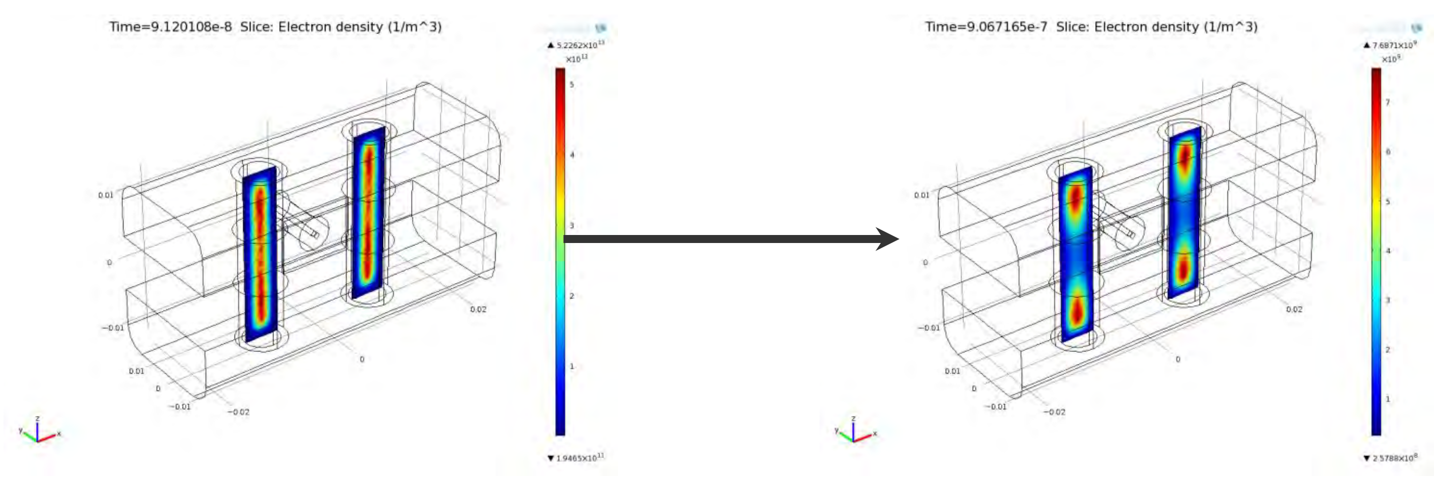
Plasma Simulation (VI)

Low pressure, no gas flow (no gas flow module, only plasma module)

p=0.1 mbar, P=50 W, $n_{e\ ini}=10^{14}\ m^{-3}$,

No physical results!

$t=1\ 10^{-7}$ s, $n_e=5\ 10^{13}\ m^{-3}$ $t=1\ 10^{-6}$ s, $n_e=8\ 10^{9}\ m^{-3}$



Even a finer Mesh (here „extra fine“) does not help neither for better convergence nor for correct physics

Conclusions

1. One can calculate a time evolution of the ignition process for a pressure of 10 mbar
2. According to simulations for Argon it should appear an ICP modus only over 100 W
3. For a pressure of 0.1 mbar it seems to be no interaction between microwaves and plasma. The results are physically not realistic.
4. A finer mesh does not improve neither the convergence nor the physics.