Equivalent Circuit and Electrodynamic Characteristics of Waveguide-Based Coaxial-Type Microwave Plasma Source

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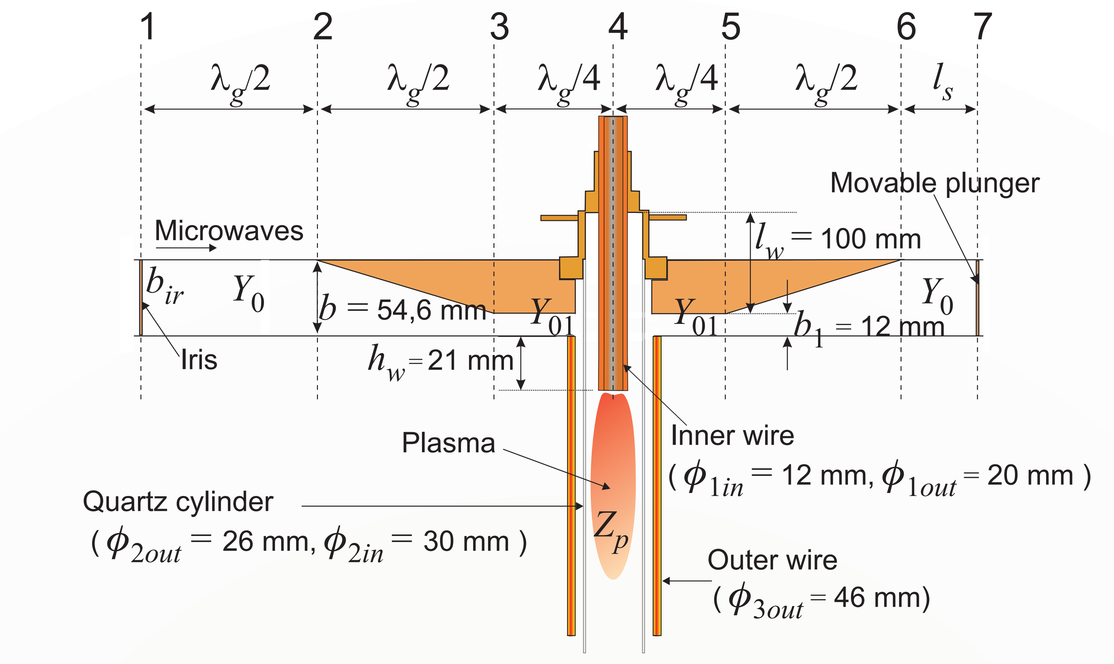
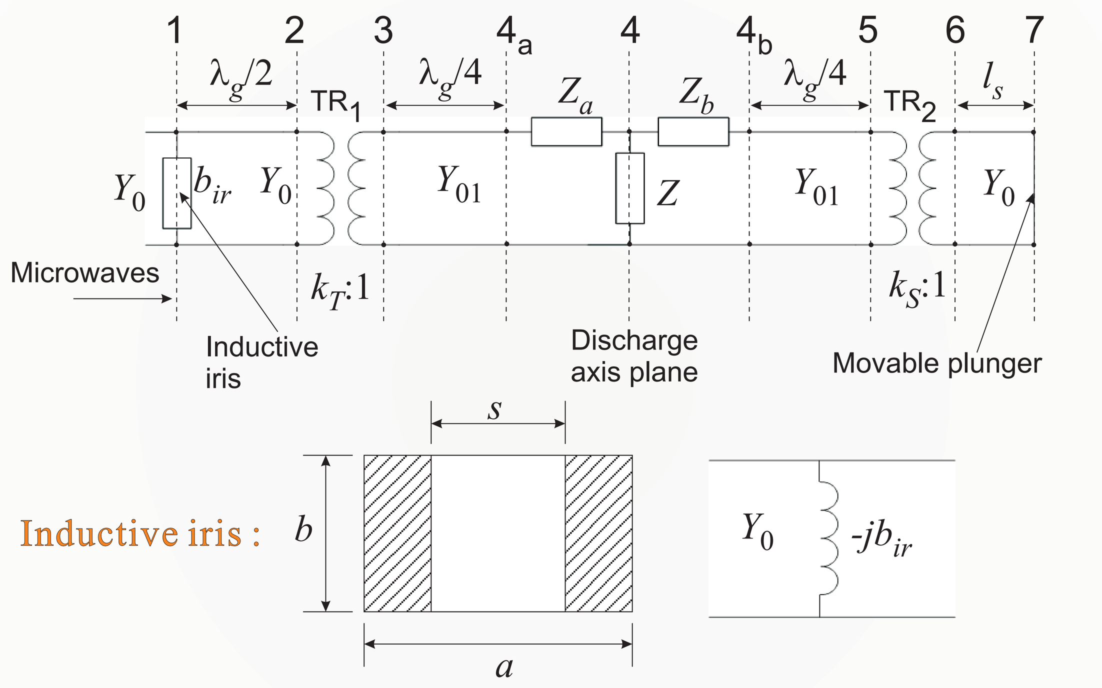
INTRODUCTION

We present equivalent circuit of existing waveguide-based coaxial-type microwave plasma source (MPS) which was used to hydrogen production via methane reforming. This MPS is operating at frequency of 2.45 GHz, in different gases at atmospheric pressure. The equivalent circuit cannot describe all electrical properties of the real MPS accurately due to some structural elements, which electrical lumped equivalents are difficult to find or are unknown. We used Comsol Multiphysics software to numerical investigate the unknown lumped impedance of some structural elements. The equivalent circuit includes formula which allows to calculate tuning characteristics which are one of essential indicator of power transfer from the feeding line to the MPS. The MPS is terminated with movable plunger which plays the role of the tuning element. Despite of the fact that the equivalent circuit describes specific MPS, it can be helpful to examine theoretically any similar waveguide-based coaxial-type MPSs.

MICROWAVE PLASMA SOURCE



Sketch of the MPS



Equivalent Circuit of the MPS

Quantity	Description
λ_g	Wave length in standard WR 430 waveguide
l_S	Movable plunger position
$Y_0 = 1/Z_0$	Characteristic admittance of standard WR 430 waveguide
Z_0	Characteristic impedance of standard WR 430 waveguide
$Y_{01} = Y_{02}$	Characteristic admittance of reduced height b_1 section
l_W	Length of short section of coaxial line
h_W	Length of coaxial line section with plasma
ϕ_{3IN}, ϕ_{1OUT}	Diameters of coaxial line wires
Z_p	Plasma impedance
b_{ir}	Normalized susceptance of inductive iris
s	Width of the inductive iris
Z_a, Z_b	Impedances representing discontinuity (holes) in reduced height waveguide
k_T, k_S	Transformation factors of the input and output transformer respectively
a, b	Standard WR 430 waveguide width and height respectively
Z	Impedance in discharge axis

FORMULAS

Normalized susceptance of iris:

$$b_{ir} = \frac{B_{ir}}{Y_0} = -\frac{\lambda_g}{a} ctg^2\left(\frac{\pi s}{2a}\right)$$

Transformation factors:

$$k_T = \frac{Y_0}{Y_{01}} \qquad k_S = \frac{Y_{01}}{Y_0} = k_T^{-1}$$

Normalized movable plunger susceptance in output plane:

$$b_S = \frac{B_S}{Y_0} = ctg\left(\frac{2\pi}{\lambda_g} \cdot l_S\right) = t_S^{-1}$$

Admittance in discharge axis:

$$Y = (jX_W + Z_p^t + jX)^{-1}$$

Reactance of short coaxial line section:

$$X_W = Z_{0W} \cdot tg\left(\frac{2\pi}{\lambda} l_W\right)$$

Characteristic impedance of coaxial line:

$$Z_{0W} = 60 \ln\left(\frac{\phi_{3IN}}{\phi_{1OUT}}\right)$$

Plasma impedance transformed via coaxial line of h_w lenght:

$$Z_p^t(h_W) = Z_{0W} \frac{Z_p + jZ_{0W} tg\left(\frac{2\pi}{\lambda} h_W\right)}{Z_{0W} + jZ_p tg\left(\frac{2\pi}{\lambda} h_W\right)}$$

Normalized input admittance:

$$y_{in} = \frac{Y_1}{Y_0} = k_S \frac{Z^{-1} \cdot (Z_b Y_{01} - jt_S^{-1}) + Y_{01}}{Z_a[Y(Z_b Y_{01}^2 - jk_S Y_0 t_S^{-1}) + Y_{01}^2] - jk_S Y_0 t_S^{-1}} + jb_{ir}$$

Tuning characteristic:

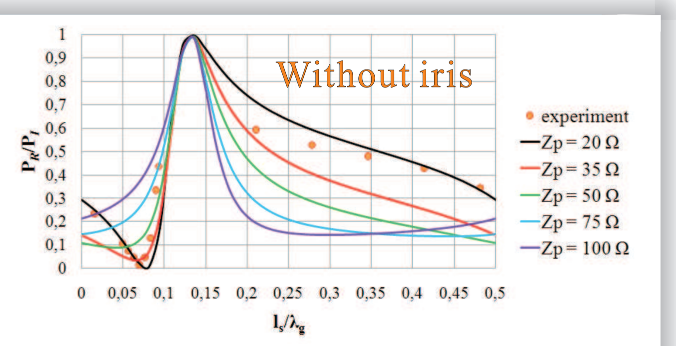
$$\frac{P_R}{P_I}\left(\frac{l_S}{\lambda_g}\right) = \left|\frac{y_{in} - 1}{y_{in} + 1}\right|^2$$

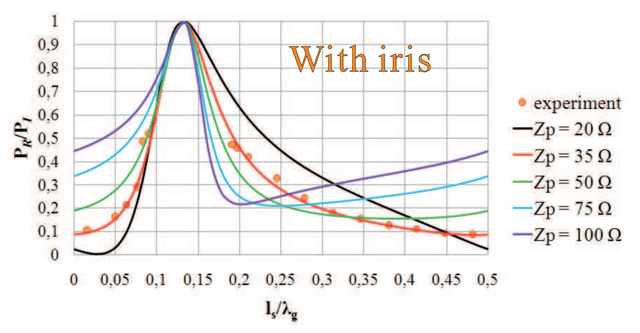
where P_I and P_R are the power of incident and reflected waves respectively, X is the reactance of inner wire of coaxial line introduced in waveguide, λ is the wave length in free space

TUNING CHARACTERISTICS

Quantity	Value
λ	122.45 mm
λ_g	147.7 mm
Z_0	357.5 Ω
$Y_{01} = Y_{02}$	12.7 mS
Z_{0W}	50 Ω
b_{ir}	-1.11
s	58 mm
Z_a, Z_b	j33.5 Ω, j72.22 Ω
a, b	109.2 mm, 54.6 mm
X	112 Ω
X_W	-112 Ω

Experimental data for:
- *Nitrogen flow rate 100 l/min*
- *Input power 2kW*





CONCLUSIONS

- The calculated results and results achieved in experiment are very similar for assumed plasma impedance Z_p = 35 Ω , and reactance X = $-X_W$
- The power reflection coefficient P_R/P_I of the MPS with iris is small for wide range of normalized movable plunger position
- The presented equivalent circuit of the MPS can be helpful to improve any similar MPSs.

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