Optimization of Waveguide-Supplied Coaxial-Line-Based Microwave Plasma Source

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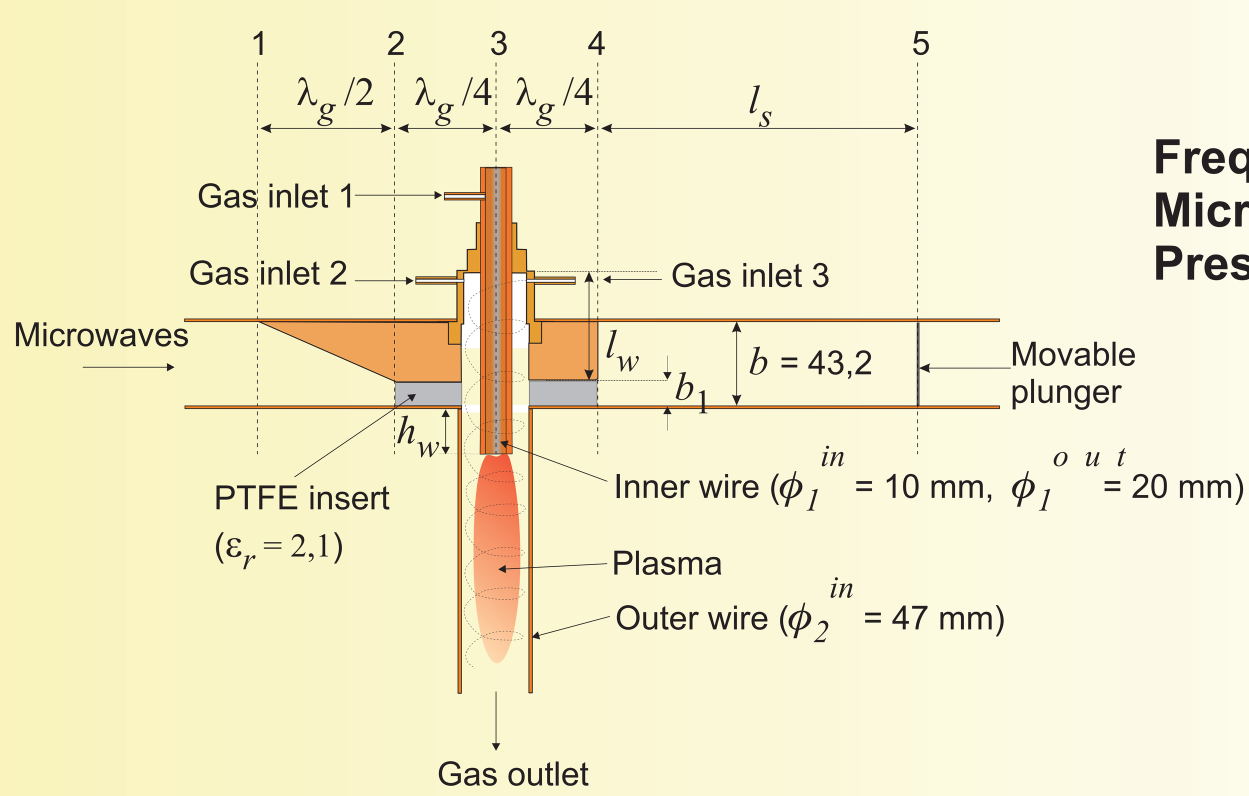
INTRODUCTION

Microwave plasma sources (MPSs) operating at atmospheric pressure are used in spectroscopy, surface treatment, carbon nanotubes synthesis and sterilization. Moreover, MPSs are applied for different kind of gas processing, such as purification of gases, abatement of fluorinated compounds gases, decontamination of chemical warfare agents and hydrogen production via hydrocarbons reforming. Presented microwave plasma source supplied by WR 340 waveguide is modified version of existing coaxial-line-based MPS supplied by WR 430 waveguide. Originally new MPS presented in this paper did not work correctly, because there was no ability to initiate and maintain microwave discharge. One of essential characteristics of any MPS is power transfer from the feeding line to the plasma. It can be expressed as ratio P_R/P_I, where P_I and P_R are the power of the incident and reflected waves, respectively. Tuning characteristic of the MPS is a dependence of P_R/P_I on the position of the movable short normalized to the wavelength. We present optimization process of energy transfer in coaxial-line-based MPS. Comsol Multiphysics software was used to numerical investigate the problem.

MICROWAVE PLASMA SOURCE



Frequency: 2.45 GHz
Microwave power: 2 kW
Pressure: atmospheric

Parameter	Description
λ_g = 173,4 mm	Wavelength in standard WR 340 waveguide
l_S	Movable plunger position (tuning element)
a = 86.4 mm , b = 43.2 mm	Standard WR 340 waveguide width and height respectively
h_w = 80 mm	Length of coaxial line section with plasma
l_w = 27 mm	Length of short section of coaxial line (variable)
b_1 = 9.6 mm	Height of the reduced section (variable)

PURPOSE OF OPTIMIZATION

To improve efficiency of energy transfer

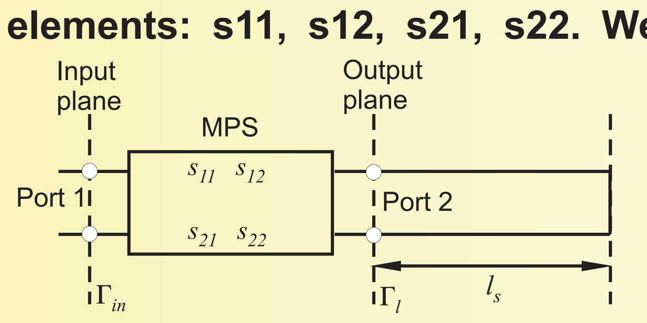
The purpose of the optimization process of presented waveguide-supplied MPS is to achieve possible the lowest value of tuning characteristic in a wide range of normalized to wavelength movable plunger position. Owing to equivalent circuit of similar coaxial-line-based MPS we know that, the most significant construction parameters which influence on a shape of the tunning characteristic are lengths: h_w, l_w, and height of reduced section b_1.

To ensure stability of MPS

We must emphasize, that the shape of tuning characteristic strongly depends on plasma parameters which depends on gas type, gas flow rate, and microwave power incident. It is desired that the tuning characteristic near minimum is independent of plasma parameters.

METHOD OF ANALYSIS

MPS is treated as a two-port network terminated with a short-circuited transmission line of the length l_s. The two-port can be represented by its scattering matrix, which contains four elements: s11, s12, s21, s22. We can obtain the formulations below according to [1].



Reflection coefficient in the output plane of the two-port:

$$\Gamma_l = \frac{jtg\left(\frac{2\pi l_s}{\lambda_g}\right) - 1}{jtg\left(\frac{2\pi l_s}{\lambda_g}\right) + 1}$$

Tuning characteristic:

$$\frac{P_R}{P_I}\left(\frac{l_s}{\lambda_g}\right) = \left|\Gamma_{in}\right|^2 = \left|s_{11} + \frac{s_{12}s_{21}\Gamma_l}{1 - s_{22}\Gamma_l}\right|^2$$

[1]Nowakowska H., Jasiński M., Mizeraczyk J., Optymalizacja transferu energii w mikrofalowym generatorze plazmy zasilanym falowodowo, 6th International Conference: New Electrical and Electronic Technologies and their Industrial Implementation "NEET 2009", Zakopane, Poland, June 23-26, 2009

ASSUMPTION DATA

General data:

All metal boundaries are perfect electric conductors. Microwave power 2 kW is delivered in input plane 1-1 by λ_g long WR 340 waveguide.

Plasma model:

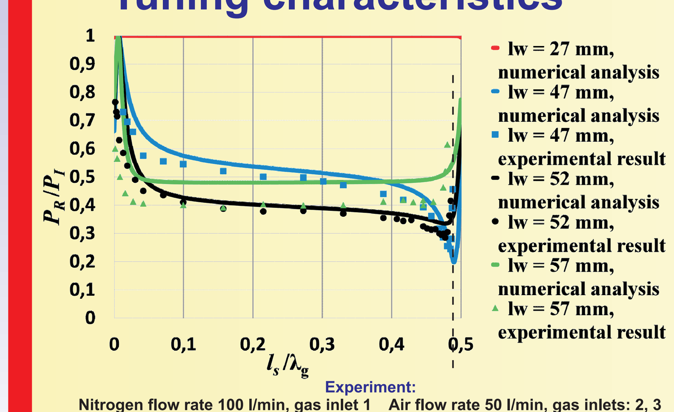
We assumed that plasma region is a cylinder of diameter 20 mm and height 80 mm. Plasma is homogeneous medium and its relative permittivity ε_p can be written:

$$\varepsilon_p = 1 - \frac{n}{1 - js}$$

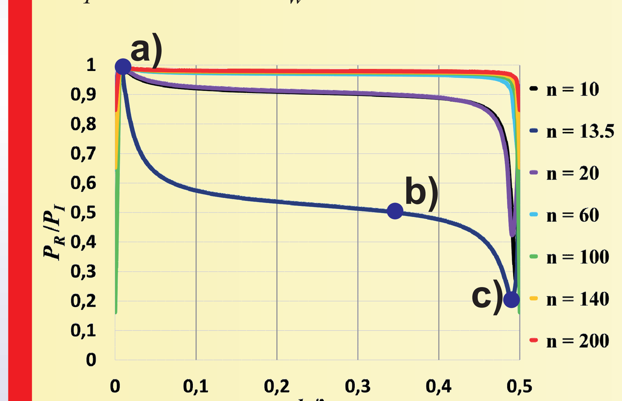
Where n is the electron density normalized to the critical electron density, s is the collision frequency normalized to angular frequency of electric field. We assumed: s = 0.1, n = 10÷200

RESULTS OF NUMERICAL ANALYSIS

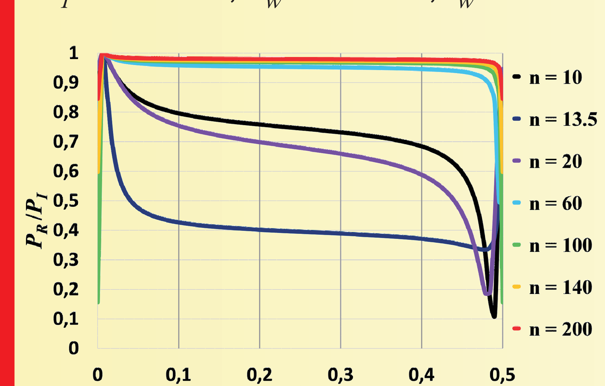
Tuning characteristics



b_1 = 9.6 mm, h_w = 80 mm, n = 13.5

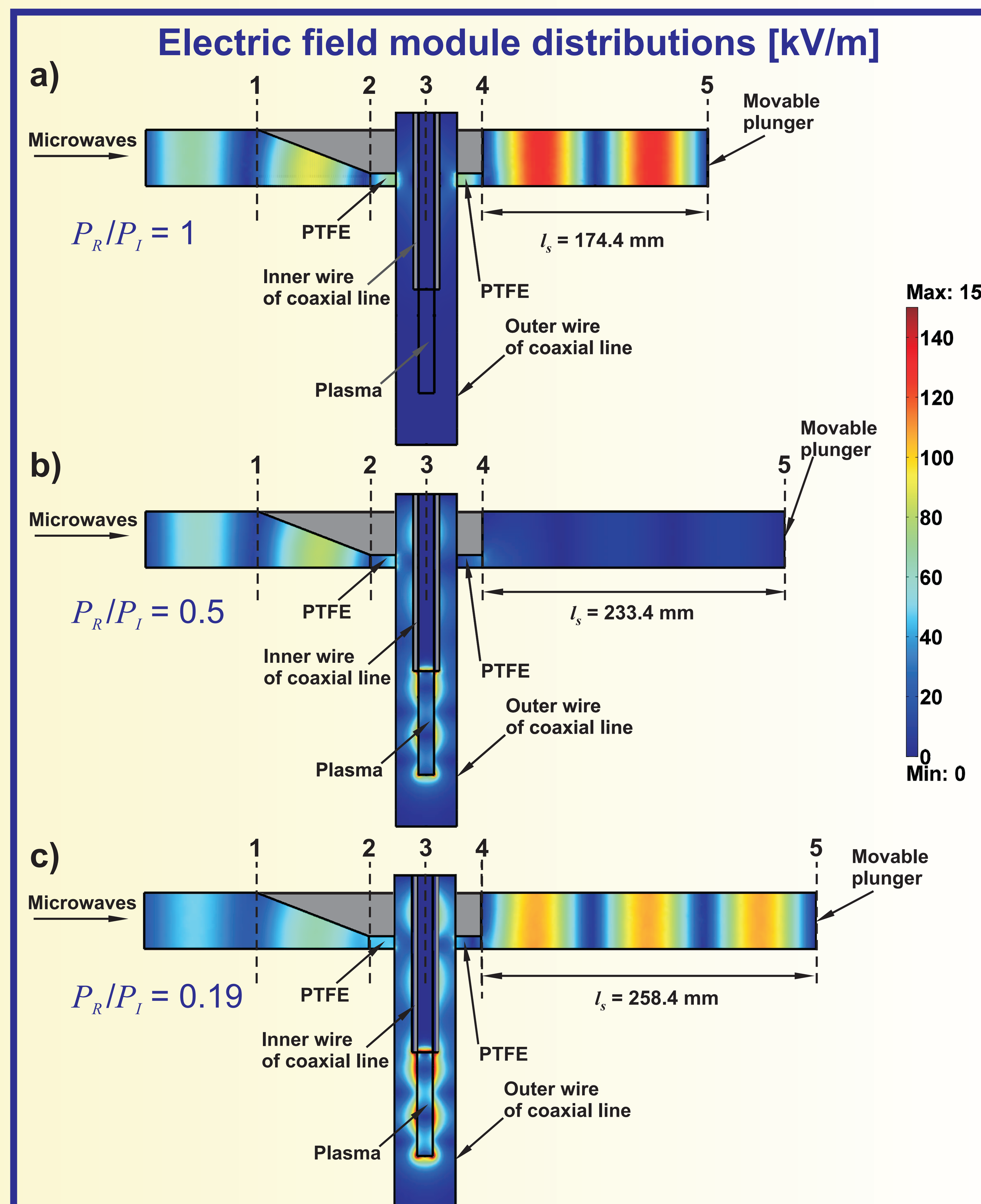


b_1 = 9.6 mm, h_w = 80 mm, l_w = 47 mm

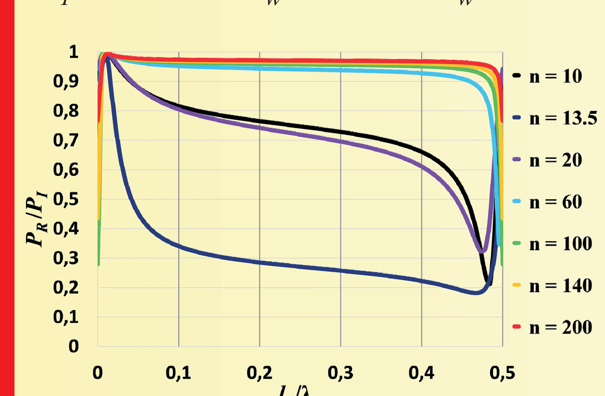


b_1 = 9.6 mm, h_w = 80 mm, l_w = 52 mm

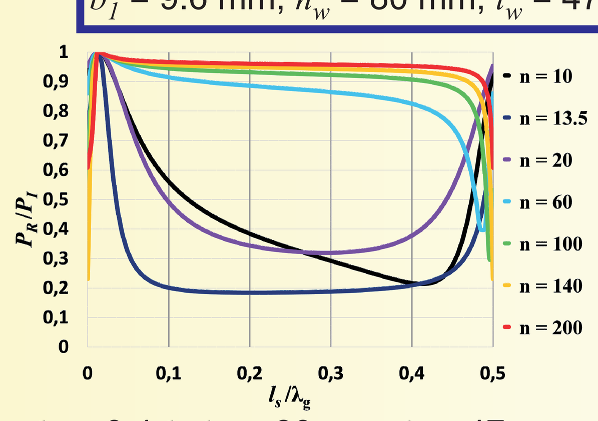
Electric field module distributions [kV/m]



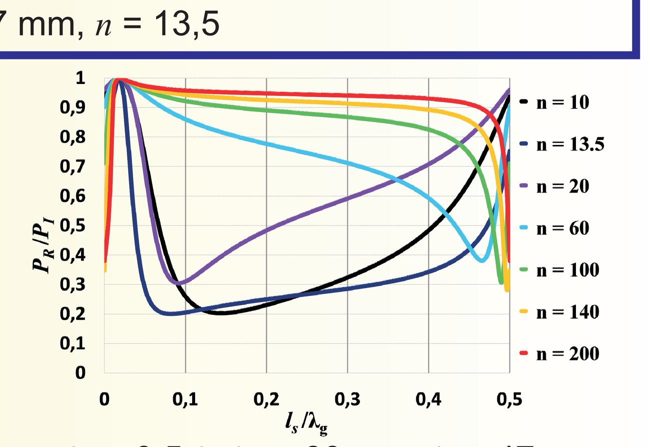
b_1 = 9.6 mm, h_w = 80 mm, l_w = 47 mm, n = 13,5



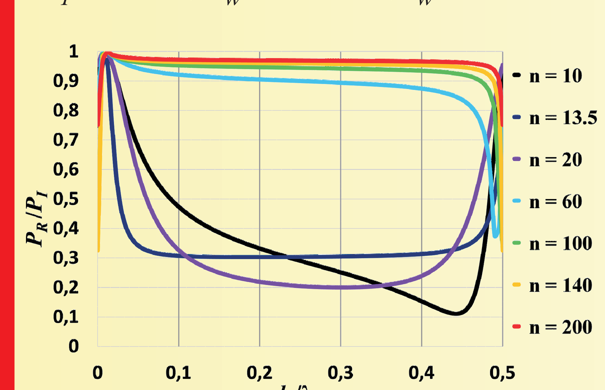
b_1 = 0.3 b, h_w = 80 mm, l_w = 47 mm



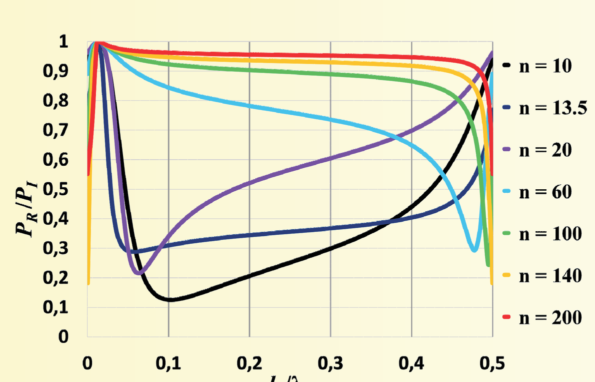
b_1 = 0.4 b, h_w = 80 mm, l_w = 47 mm



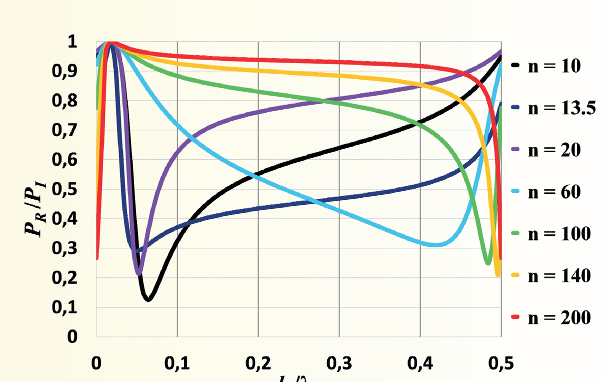
b_1 = 0.5 b, h_w = 80 mm, l_w = 47 mm



b_1 = 0.3 b, h_w = 80 mm, l_w = 52 mm



b_1 = 0.4 b, h_w = 80 mm, l_w = 52 mm



b_1 = 0.5 b, h_w = 80 mm, l_w = 52 mm

CONCLUSIONS

For assumed plasma parameters: n = 13.5, s = 0.1 the tuning characteristics obtained from numerical analysis are similar to experimental results. For original height of b_1 equal to 9.6 mm and new length of l_w equal to 47 mm, there was a possibility to initiate discharge and to maintain discharge. Experimentally measured minimum of P_R / P_I was equal to 0.25 but in wide range of l_s / λ_g the P_R / P_I was about 0.5. However, for l_w = 52 mm, measured P_R / P_I was about 0.4 in wide range of l_s / λ_g but minimum of P_R / P_I was equal to 0.29. For l_w = 47 and b_1 = 0.4b, P_R / P_I was about 0.2 in wide range of l_s / λ_g for n = 13.5. For l_w = 52 and b_1 = 0.5b, minimum of P_R / P_I was equal to 0.12 for n = 10, however incresing length of b_1 made worse the stability of MPS.

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