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DEVELOPMENT OF THE PSEUDOSPARK-SOURCE ELECTRON GUN AND A SLOW-WAVE STRUCTURE FOR A MILLIMETER-BAND BACKWARD-WAVE OSCILLATOR

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Introduction

Millimeter- and sub millimeter-band sources have attracted significant attention in recent years because of their promising application such as security and counter-terrorism (remote non-destructive monitoring), ultra-high-speed information and communication systems, radio astronomy, spectroscopy, medicine and etc. Nowadays vacuum electron devices still remain the main sources of high power broadband millimeter-wave radiation. Among electron beam sources the pseudospark discharge can be distinguished as a promising pulsed plasma electron beam source with the beam current density up to 10^6 Am^{-2} [1], [2]. The reason is that the pseudospark discharge sourced electron beam has the ability to self-focus due to the unique discharge structure and the formation of ion channel generated by the beam front. Ion channel enables the electron beam to propagate and eliminates the need for a guiding magnetic field [3], [4]. Therefore the development of a compact and high-power vacuum and plasma sources utilizing a pseudospark discharge based hollow cathode electron gun is one of the promising trends.

[1] J. Christiansen and C. Schultheiss, "Production of high current particle beams by low pressure spark discharges," *Zeitschrift fur Phys. A Atoms Nucl.*, vol. 290, no. 1, pp. 35–41, Mar. 1979, doi: 10.1007/BF01408477.
[2] H. Yin *et al.*, "Millimeter wave generation from a pseudospark-sourced electron beam," *Phys. Plasmas*, vol. 16, no. 6, 2009, doi: 10.1063/1.3155444.
[3] H. Yin, A. W. Cross, A. D. R. Phelps, D. Zhu, W. He, and K. Ronald, "Propagation and post-acceleration of a pseudospark-sourced electron beam," *J. Appl. Phys.*, vol. 91, no. 8, pp. 5419–5422, 2002, doi: 10.1063/1.1459757.
[4] N. Kumar, R. P. Lamba, A. M. Hossain, U. N. Pal, A. D. R. Phelps, and R. Prakash, "A tapered multi-gap multi-aperture pseudospark-sourced electron gun based X-band slow wave oscillator," *Appl. Phys. Lett.*, vol. 111, no. 21, pp. 1–5, 2017, doi: 10.1063/1.5004227.

Purpose of this work

Current work is devoted to the design and development of the pseudospark discharge based electron gun and the slow-wave structure for a V-band backward-wave oscillator (BWO)

Development of the pseudospark discharge based electron gun for a V-band backward-wave oscillator

A 3-gap sheet beam plasma cathode electron gun design has been developed and optimized. The optimization study of design parameters has been performed using COMSOL Multiphysics. The optimized design parameters are presented in Table 1.

Hollow cathode diameter to length ratio	1
Hollow Cathode Cavity Diameter	30 mm
Hollow Cathode Cavity Length	30 mm
Hollow Cathode aperture size	3 mm dia
Anode Sheet Aperture Aspect Ratio	5:1
Anode Sheet aperture size	1.25 X 0.25

Table 1: Optimized design parameters of 3-gap sheet beam plasma cathode electron gun

The schematic of the developed sheet beam plasma cathode electron gun based on the optimized design parameters is presented in the Figure 1. The sheet beam plasma cathode electron gun consists of hollow cathode cavity with circular aperture, 3 insulators disc and 2 floating anodes disc with circular aperture and planar anode disc with sheet aperture.

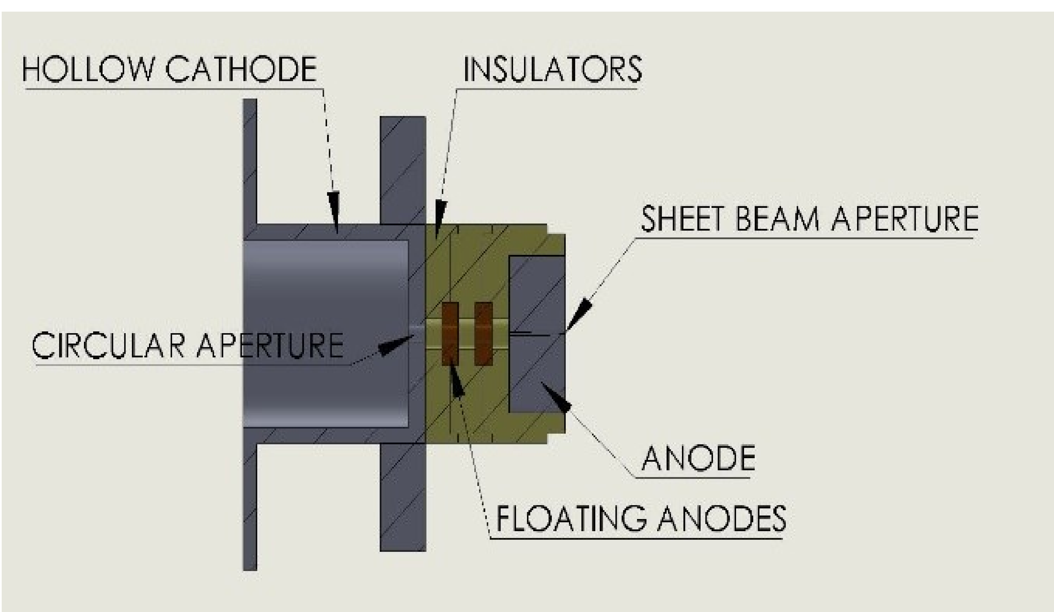

Figure 1: Schematic of Sheet beam Plasma Cathode Electron Gun

The developed sheet electron beam source has been operated at different applied cathode-anode gap voltage ranging between 20 kV-30 kV. The developed sheet electron beam source has been operated in self-breakdown condition. The maximum obtained beam current was 30 A and current density was 26 A/cm^2. The electron beam has been generated from the sheet aperture 1.25 mm X 0.25 mm. The electron beam has been propagated for more than 5 cm inside the drift space.

Development of the slow-wave structure for a V-band backward-wave oscillator

We have proposed a truncated type of folded waveguide as a slow-wave structure for the V-band backward-wave oscillator with the pseudospark discharge based sheet beam electron gun. The schematic view of the proposed slow-wave structure is shown on Figure 2.

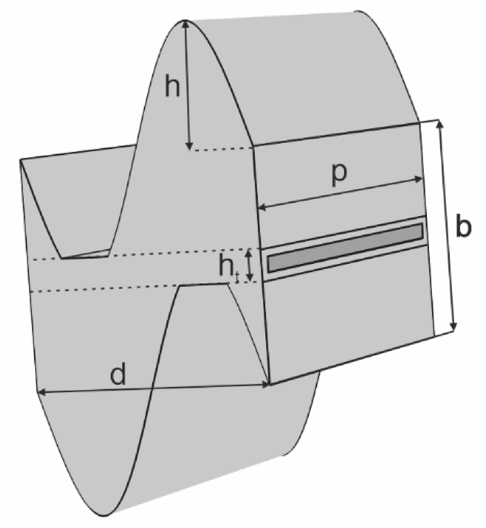

Figure 2: Schematic drawing of the proposed SWS

Waveguide height, b (mm)	1.8
SWS oscillation amplitude, h (mm)	0.81
Period, d (mm)	1.4
Waveguide width, p (mm)	3.6
Beam tunnel height, h_t (mm)	0.35
Beam dimensions, h_b×w_b (mm)	0.25×1.25

Table 2: Dimensions of the proposed SWS

Electromagnetic parameters of the SWS were simulated using COMSOL Multiphysics. The plasma was simulated as a dielectric with effective permittivity ε_{eff}:

$$\varepsilon_{eff} = 1 - \left(\frac{\omega_p}{\omega}\right)^2 \qquad \omega_p = \sqrt{\frac{e^2 n_i}{\varepsilon_0 M_i}}$$

Argon was assumed with the charge density n_i=10^{18} m^{-3} and ion mass M_i=6.63*10^{-23} g for plasma frequency computation

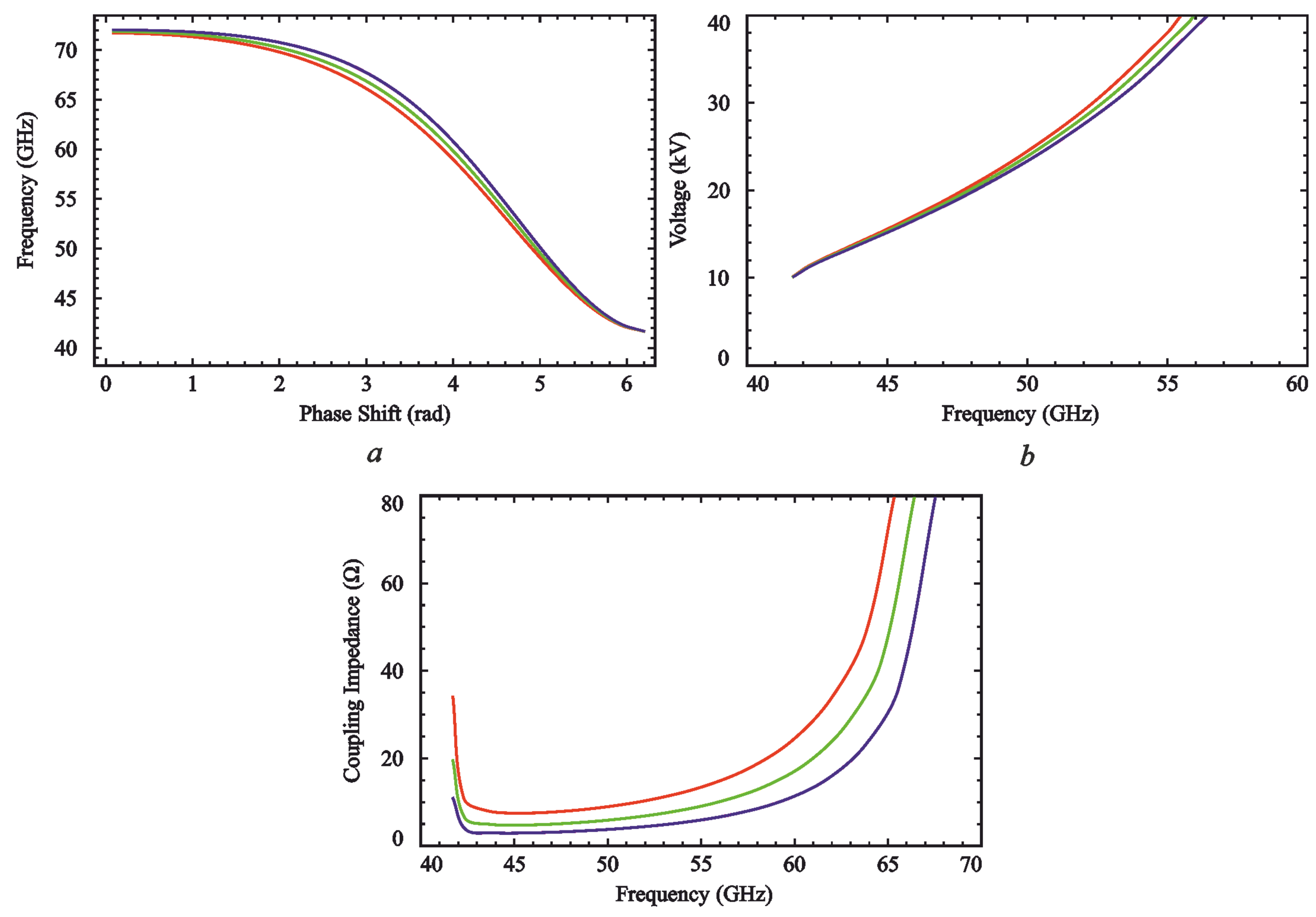

Figure 3: Electromagnetic parameters for the plasma-filled SWS with different beam tunnel height h_t: 0.35 mm (red), 0.45 mm (green) and 0.55 mm (magenta)

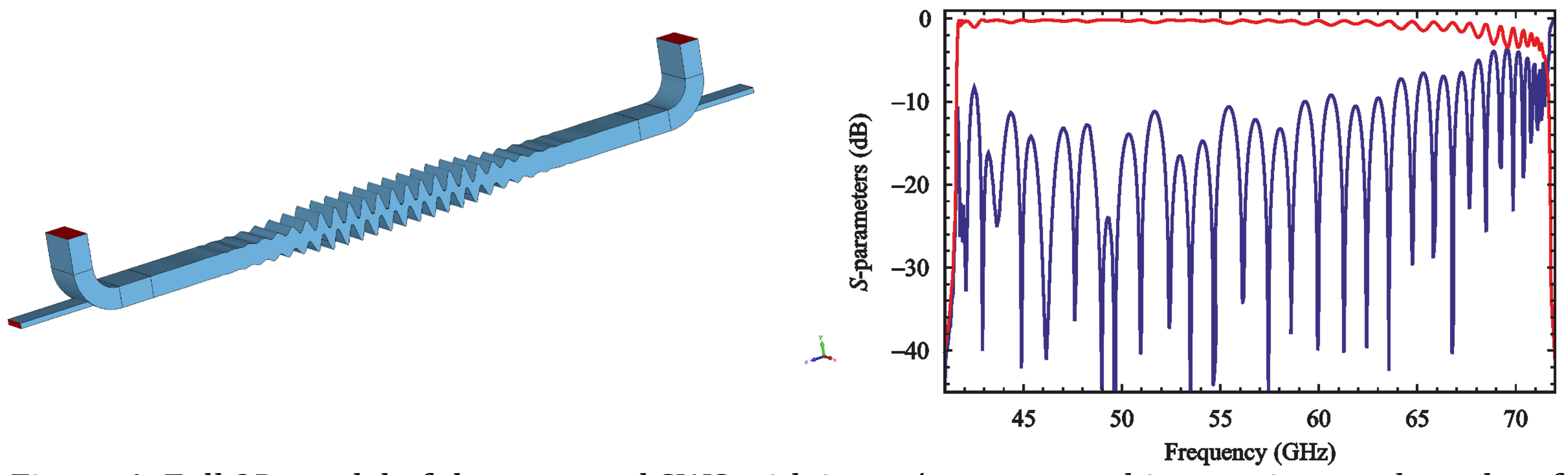

Figure 4: Full 3D-model of the proposed SWS with input/output matching sections and results of its 3D PIC numerical study of cold S-parameters by CST MWS (h_t=0.55 mm).

Conclusion

We have considered the results of the pseudospark discharge based electron gun and the slow-wave structure developments for the V-band BWO. The microfabrication of the proposed SWS by CNC micro-milling is in progress now. Also, we are going to carry out the experimental study of the cold S-parameters. We are going to utilize the SEM and optical microscopy methods for verification of the dimensions of the microfabricated sample of the SWS. To study the cold S-parameters of the microfabricated sample of the proposed SWS we are going to use a PNA 5227A Keysight Technologies vector network analyzer. Experimental and calculated data will be compared and analyzed.

Acknowledgment

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