Plasma Column Parameters of Non-self-sustained Atmospheric Pressure Glow Discharges in a Three-electrode Configuration

V.I. Arkhipenko[1], Th. Callegari[2], A.A. Kirillov[1], J. Lo[2],Ya.A. Safronau[1], L.V. Simonchik[1], J. Sokoloff[2]

[1]*Stepanov Institute of Physics NASB, Minsk, Belarus*

[2]*LAPLACE CNRS, Toulouse, France*

Introduction

The possibilities to use a DC non-self-sustained glow discharge maintained by micro hollow cathode glow discharge (MHCD) at middle pressure in an electromagnetic band gap structure has been demonstrated recently in [1,2]. The main requirement to plasma column parameter for this application is the significant electronic density under critical concentration $n_e >> n_c$ (i.e., $2\pi f_0 = \omega_p = (2\pi n_c e^2/m_e)^{1/2}$) for the incident microwave radiation at frequency f_0. If this relation does not strongly fulfill the control of electromagnetic wave is not effective. The aim of this work is to determine the best candidate between two kinds of atmospheric pressure DC discharges to fulfill these requirements. The two systems consist of a three electrode configuration where a self sustained discharge (Micro Hollow Cathode Discharge or Atmospheric Pressure Glow Discharge (APGD)) serves as a plasma cathode for a non self sustained discharge. We present a comparison of discharge parameters between different gases (noble: Ar, He and Ne; molecular: N2, CO2; and air at atmospheric pressure).

Experimental demonstration of an electromagnetic band gap (EBG) structure control

In [3], for example, the propagation of microwaves in several types of two-dimensional (2D) periodic array of microplasma columns has been examined experimentally in a frequency range 33–35 GHz. Electron density in each plasma columns formed by dielectric barrier discharge was estimated at the value of about 10^{13} cm^{-3}. The critical concentration for frequency f_0 = 33 GHz is about 1.35 10^{13} cm^{-3}. As a result, the transmittance of this two-dimensional periodic structure changes only less than 3 dB.

In our experiment, a 2D periodical structure is integrated inside a 90 x 10 mm^2 waveguide, and acts as an EBG structure. This structure consists of conductive rods (5 mm in diameter) distributed in a rectangular lattice (Fig. 1(a)), where spaces between rods are a_x = 44 mm (longitudinal direction) and a_y = 24 mm (transverse direction). Three central rods are replaced by commercial 3 mm diameter neon discharge lamps (ГШ-5, produced in Russia) as shown in figure 1(b). Typical discharge current of 70 mA is obtained with a voltage of 180 V. The electronic density is estimated through the determination of the current density (by measuring the discharge current and the plasma column diameter), and the electron mobility (by using BOLSIG+ [4]). Electron density in these lamps varies from 0.3 10^{13} cm^{-3} up to 2 10^{13} cm^{-3} when the current increases from 30 mA up to 130 mA. These estimations are much higher than the critical electronic density in our frequency range (8 10^{10} cm^{-3} for f_0 = 2.55 GHz). In fig. 1 *(c)*, the transmittance of waveguide band filter at its different state is shown. As it can be seen, the waveguide transmittance changes when current is varying. At discharge currents of 100 mA in each lamp, the microwave attenuation of about -25 dB can be achieved at several frequencies.

When all the conductive rods are present, the dispositive could be considered as a guided EBG structure. In our working frequency range, the guided EBG structure operates in a forbidden band gap regime, thus, the quasi totality of the incident wave is reflected. Removing three of the rods creates defect modes within the guided EBG structure, hence, the increase observed in the transmittance. The plasma tubes here are used in order to reproduce the EBG behavior when all the conductive rods are present.

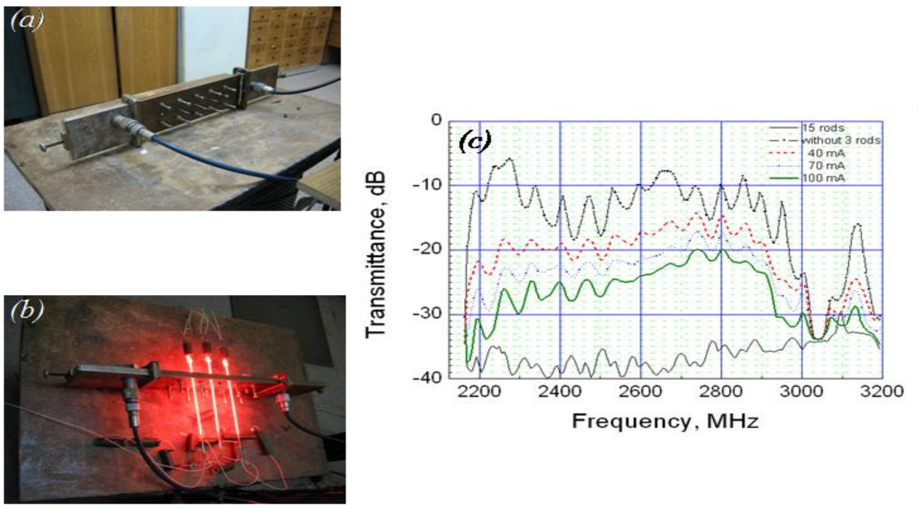

Fig.1: Images of waveguide band filter with metallic rods (a) and with discharge lamps (b), and transmittance at different conditions (c)

This experiment demonstrates good possibilities to control microwave propagation using plasma columns. A few localized plasma columns are enough to switch in between two operational modes (forbidden mode and propagating mode). However, we could not reach the microwave attenuation achieved with metallic roads. Increasing even higher the plasma electronic density may probably allow us to reach the same attenuation as with metallic rods. Our previous work [5,6] has shown that higher electron densities can be obtained using positive columns of non-self-sustained atmospheric pressure glow discharges.

Non-self-sustained glow discharges sustained by the APGD.

Detailed description of our system can be found in [4]. It consists of one discharge chamber separated in two parts (Fig. 2 *(a)*). A DC self-sustained APGD in one of rare gases (He, Ne or

Ar) at atmospheric pressure (photo-inset in fig. 2 *(a)* is for helium discharge) is initiated in the first chamber section **A** between two electrodes separated by a distance of 1-2 mm. A working gas at a flow of about 1 litre/min at atmospheric pressure is provided through this section and the gas exhaust takes place in the neighboring second section **B** through the anode hole. In addition, another gas flow of about 1 litre/min is simultaneously realized through the section **B**. A non-self-sustained APGD is created by applying a voltage between the anode plate and the third electrode located in second section at a distance up to 5 cm from anode plate.

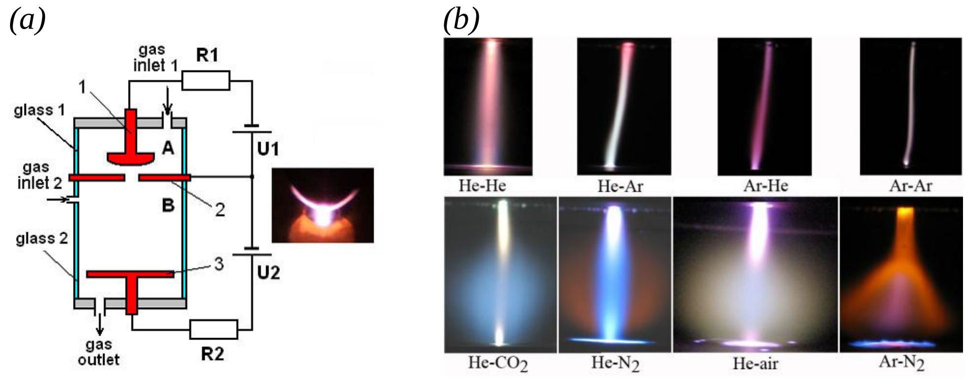

Fig. 2. Schematic of experimental setup. Inset at the right is the image of the self-sustained helium discharge in the chamber **A.**

Depending on combinations of gas kinds and their flows through sections A and B, it is possible to obtain long-scale (up to 5 cm in our experiment) plasma columns in different gases and wide range of discharge currents (Fig. 2 *(b)*). They can be strongly constricted in argon (Ar-Ar image in fig 2 *(b)*) or have two parts: diffuse and constricted (it is typical for molecular gases).

These discharges burn without any limiting walls. For this reason, current density, reduced electric field and diameter of positive column will be different against discharge current. The positive column electronic density in function of the discharge current is shown in fig.3 for different gases, and will be presented in details in [6]. These results were obtained with BOLSIG+ calculation taking into account the measured current density and reduced electric field. In fig. 3, the spectroscopic results using H_β line profiles are presented as well.

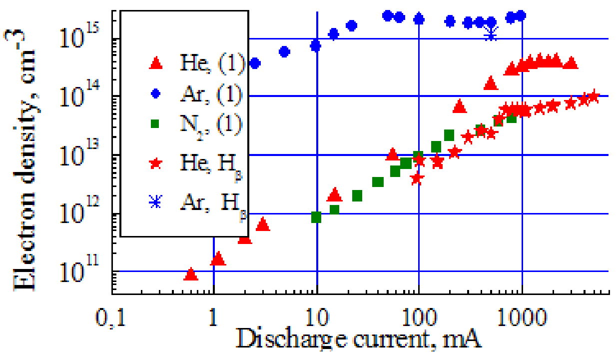

Fig. 3. Measured and calculated electron densities in the middle of 1 cm gap for helium, argon and nitrogen APGDs vs discharge current.

Glow discharges sustained by the MCSD

The second system consists of a micro-cathode sustained discharge (MCSD) created in a 3-electrode configuration in one chamber filled with the gases (Ar, He and Ne) at atmospheric pressure. The first two electrodes forms a cathode boundary layer system (CBL), with a planar cathode (copper) and an anode (silver) separated by a dielectric layer (alumina 0.7 mm thick). A hole (0.9 mm diameter) is drilled through the anode and the dielectric. The CBL will act as a plasma cathode for the 3rd electrode (stainless steel), separated from anode by 15

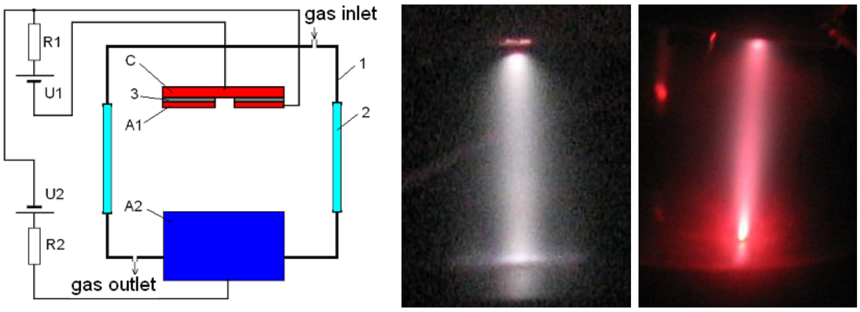

Fig. 4. Schematic of experimental setup for MCSD (a) and discharge images (b) in helium (left) and neon (right).

mm. The MCSD is created between the CBL and the 3rd electrode.

The CBL discharge parameters are as following: voltage 200 V, current 8 mA. The MSCD parameters: gap A1-A2 is 15 mm, voltage is 400 V, and discharge current is 30 mA. Electron density determined by Stark H_β line spectroscopy in neon positive column is about 9×10^{13} cm^{-3}. It decreases up to 10^{13} cm^{-3} at discharge current of about 20 mA.

Conclusions

Possibilities of the electromagnetic wave propagation control by plasma column were demonstrated. It was shown, that long-scale atmospheric pressure glow discharges maintained by glow discharges in three-electrode system can be used for the fabrication of controlled electromagnetic band gap structures. Discharges in argon are more preferable for this purpose.

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