Experimental study of inductively coupled plasma in a wide frequency range

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Introduction

There are two main methods of plasma generation: capacitive coupling plasma (CCP) and inductive coupling plasma (ICP) [1]. In ICP method electromagnetic energy is transmitted from plasma source with frequencies between 1 and 50 MHz, and for 10-1000 mTorr optimal frequency is 0.05-13.56 MHz [2]. Cold plasma is used for surface modification of materials [3]. One of the advantages of cold plasma is temperature, so material surface is not heated to critical temperatures [4].
The main problems in a wide frequency range are matching RF generator with inductor and RF generator power. In a wide frequency RF generator power less than 25-40 dBm. Broadband generators have low output impedance. For these reasons, such studies are extremely rare.

Experimental installation

The experimental setup is shown in Figure 1. The main elements are a R&S signal generator, a capacitive coupled plasma generator, a fluorescent tube, an inductor, an optical spectrometer and PC. The R&S generates a signal in the range from 1 MHz to 12.75 GHz. Avantes spectrometer detects radiation from 200 nm to 900 nm. The inductor has a value of 350-700 nH: 5 turns and a length of 2-4 cm. As a standard, fluorescent tubes are filled with argon and mercury, the partial pressures of which are 350 Pa and 1 Pa, respectively.

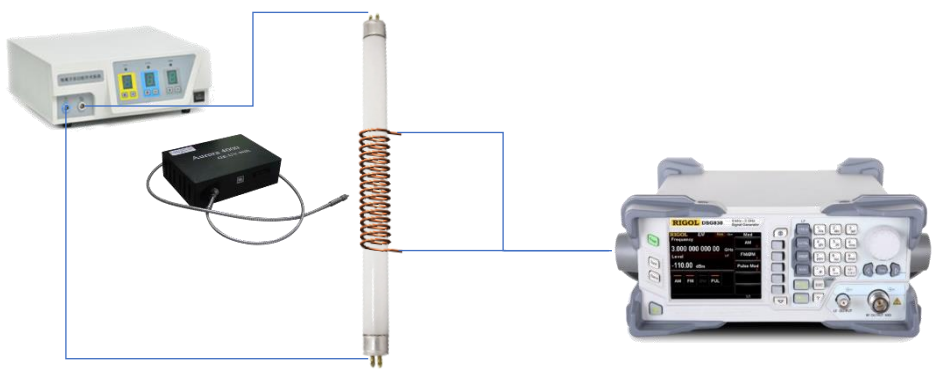

Figure 1. Experimental installation.

A PWM amplifier with a step-up transformer was used as a capacitive generator. The authors of the article [5] found that high-voltage pulses with a frequency of more than 1 kHz can be used to generate a constant concentration of charges in the plasma. In standard chokes for fluorescent lamps, the operating frequency is 50-60 Hz. This implies a constant and complete recombination of free charges in the volume of the tube.

Frequency dependence of luminance intensity

The frequency dependence of the intensity was experimentally observed as follows: a capacitively coupled plasma generator created plasma in the volume of a fluorescent tube for several seconds; immediately after the appearance of plasma, a signal from R&S was applied to the inductor; then the capacitive generator was turned off; the intensity dependence of frequency was measured. The optical emission spectrum of a fluorescent lamp is shown in Figure 2. An example of the glow of a fluorescent tube under the influence of a signal on an inductor is shown in Figure 3.

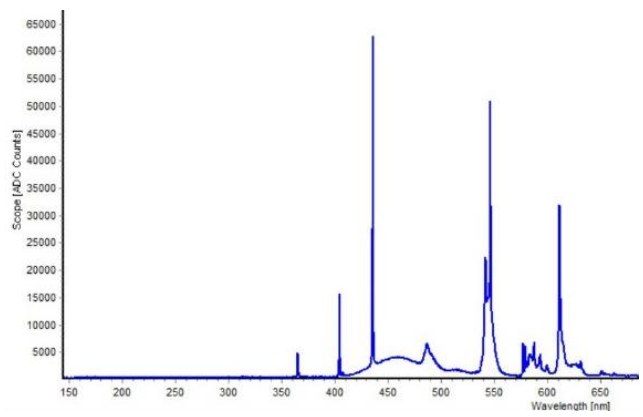

Figure 2. Frequency dependence of luminance intensity.

A fluorescent lamp emits a wide optical frequency range. The plasma itself, made from a mixture of argon and mercury, emits ultraviolet light, which is absorbed by a fluorescent powder on the inner surface of the tube. The most objective examination will be if you use tubes without a fluorescent coating, therefore, bactericidal lamps were also used. They do not have a fluorescent coating on the tube walls. However, inductively coupled plasma effect was not observed. This is most likely due to the lower amount of mercury vapor in these types of tubes. In the spectrum of the fluorescent tube, two main spectral lines were selected: at 435 and 540 nm. These two lines were the most intense of all the others. Measurements were carried out in a dark laboratory.

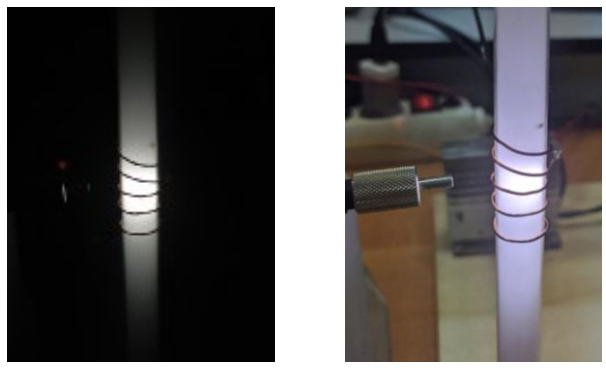

Figure 3. Inductively coupled plasma in coil area.

In the course of the experiments, it was found that the plasma is not extinguished under the action of the applied sinusoidal voltage (current) in the coil region. Was identified frequency dependence of the glow intensity on the parameters of the inductor: length, number of turns, cross-sectional area. The glow was stable.

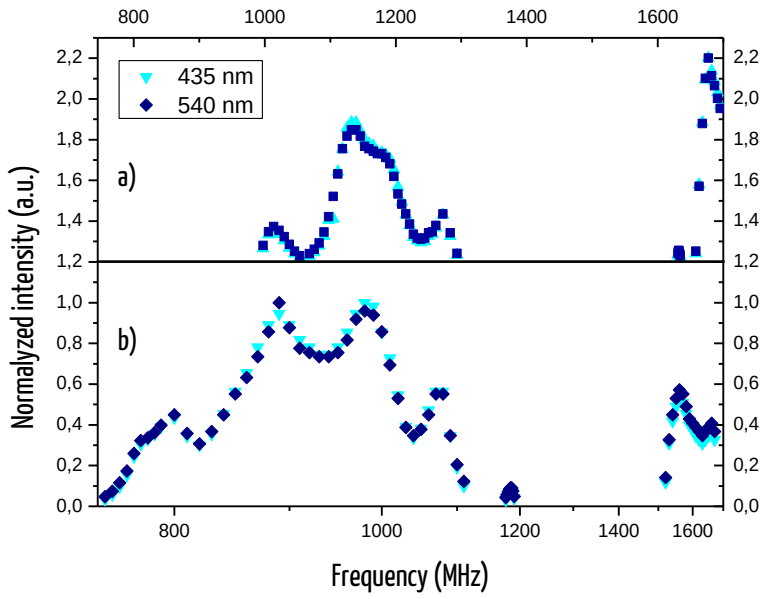

Figure 4. Frequency dependence of luminance intensity for inductors 700 nH (a) and 350 nH (b).

Conclusion

It has been suggested that this effect is a form of resonance series. But such a description has not been found in the literature. Most likely, this effect is a hybrid form of capacitive and inductively coupled plasma. In the introduction it was said that one of the main problems of research in wide frequency ranges is the matching of the generator and the load. At 750 MHz, the coil reactance (350 nH) is 1.65 kΩ, and at 1 GHz it is 2.2 kΩ. Thus, as the frequency increases, the system tends to an open line, which will lead to standing waves. And standing waves will be responsible for the capacitive component. In the future, it is planned to match the generator with the inductor in the frequency range from 900 MHz to 950-1000 MHz.

References

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