Features of the atmospheric pressure CW discharge, sustained by the 263 GHz gyrotron radiation

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Abstract: The discharge of atmospheric pressure, supported by continuous focused radiation of the gyrotron with a frequency of 263 GHz, was studied. Using a collision-radiative model, the electron temperature was estimated from the emission spectra of the discharge. The electron density of the plasma torch was measured by the Stark broadening of the Balmer series of hydrogen lines. The spatial structure of the microwave torch was investigated using a high-speed camera. The demonstration of a CW non-equilibrium microwave discharge with high powerload at atmospheric pressure is important for various plasmachemical applications

Keywords: sub-terahertz gyrotron, microwave discharge, plasma torch, Stark effect.

The discharge was sustained by the gyrotron radiation at the frequency of 263 GHz. Maximum radiation power was of 1100 W [1]. The sub-terahertz radiation was focused by two quasi-optical mirrors. The focusing system provided a beam focal waist diameter of 2.5 mm (see Fig. 1). This corresponds to a power density of about 20 kW/cm^2.

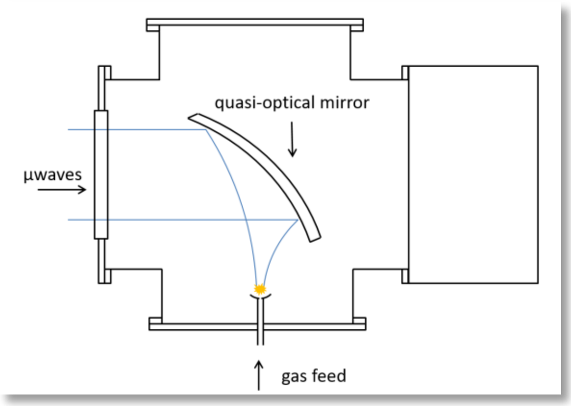

Fig.1. Focusing scheme of the gyrotron radiation at a frequency of 263 GHz.

The discharge was arranged in a stream of argon from a tube with an internal diameter of 4 mm in ambient air at atmospheric pressure. The argon flow rate was from 5 to 30 l/min. A high-voltage spark was used to ignite a discharge. Further, the torch was sustained only by sub-terahertz radiation. A discharge shape was a small torch with a transverse size of about 6 mm and a length of about 18 mm (see Fig. 2). The electron temperature was estimated by plasma emission spectra recorded by the spectrograph-monochromator SOL series MS350 in the range of 300-1000 nm.

Fig. 2. Photo of the torch sustained by the focused beam of 263 GHz waves.

A simple collisional-radiative discharge model was used for the estimation of the electron temperature from the obtained values of the argon emission lines relative intensities [2,3]. The torch emission spectra were recorded at different heating powers and plasma-forming gas flow rates. The values of the electron temperature were in the range from 1 eV to 3 eV. In this case, the electron temperature within the error does not change with the power increase. The heating power and the gas flow rate affect mainly the size of the plasma. The gas temperature does not exceed 2000 K. It indicates a significant disequilibrium of the discharge.

The plasma density was measured by the Stark broadening of the Balmer series of hydrogen (see Figs. 3,4). For these purposes, hydrogen was mixed with argon in an amount of 3 volume percent. The appearance of the discharge and its parameters were not affected by the addition of hydrogen in this case. The technique for determining the plasma density for discharges supported by terahertz radiation is described in [4].

The broadening of the H_a and H_b lines agree with one another and correspond to values of the plasma density close to 2×10^{15} cm^{-3}. This exceeds the cut-off value for the frequency of the heating radiation. The experimental results show a weak dependence of the plasma density on the heating power and gas flow rate.

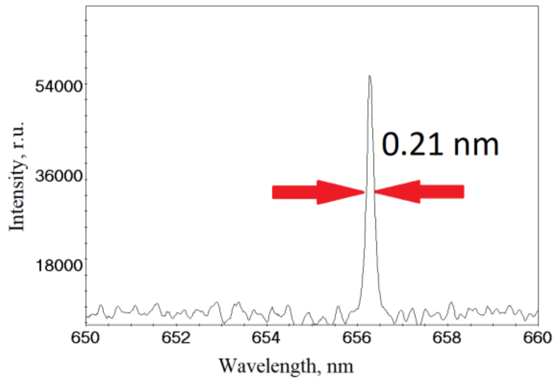

Fig. 3. An example of a measured fragment of the spectrum with H_a.

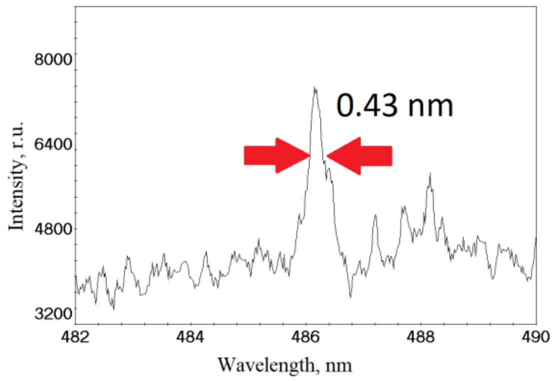

Fig. 4. An example of a measured fragment of the spectrum with H_b. The half-width is 0.43 nm.

Photographing of the torch with a high-speed camera was conducted to study the spatial structure of the discharge and its temporal dynamics. Pictures of various discharge modes were taken at different exposure times from 20 ns to 1 s (see Fig. 5). The plasma has complex dynamics. At exposure from 20 ns to 1 µs, the discharge has spatial periodic inhomogeneities of 1-2 mm in size. The life-time of these "islands" is less than 10 µs.

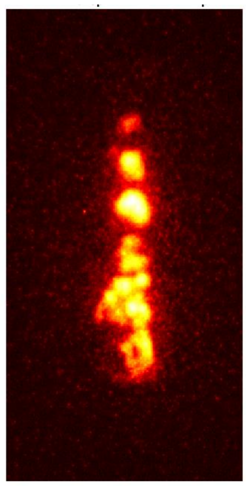

Fig. 5. Photo of the plasma torch in the artificial color scheme at logarithmic intensity scale. Exposure time 20 ns.

Also, we obtained photos of the torch using different optical filters. A set of used optical filters were covered visible range. It turned out that the emission spectrum of the torch is spatially uniform.

The demonstration of a CW non-equilibrium microwave discharge at atmospheric pressure is important for various plasmachemical applications. The use of powerful microwave radiation of the gyrotron to sustain a non-equilibrium plasma at atmospheric pressure will allow the decomposition of highly stable molecules, for example, volatile fluorides and halides. Using higher microwave frequency makes it possible to increase electron concentration and thus concentration of active spices. It becomes possible to realize a wide range of plasma-chemical reactions due to the high electron temperature. The increased pressure in the discharge provides a high production rate, which makes this type of plasma torch attractive for applications.

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