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PROPERTIES OF A GAS DISCHARGE IN THE FIELD OF AN INTENSE SOUND WAVE

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The influence of a sound wave on the parameters of a gas discharge is investigated. The behavior of the electric field, the gas temperature in the discharge, and the electron temperature and density in the field of a sound wave is clarified. Modulation of the discharge current and electron density and temperature by a sound wave and the phase shift between oscillations of different plasma components are investigated, as well as modulation of the discharge current by a sound wave in a nitrogen discharge. The influence of sound on the contraction of a nitrogen discharge is also revealed.

In the propagation of acoustic waves in a plasma, changes can occur both in the plasma parameters and in the acoustic waves themselves. Two papers were published in 1965 that defined the beginning of the development of these two fields of research. The possibility of sound amplification in a plasma, associated with nonuniform volume heat release in the interaction of electrons with heavy particles in a stratified nonequilibrium plasma, was shown in [1]. In [2] it was established experimentally that stratification of the positive column occurs under the influence of an acoustic wave set up along a discharge.

The first experimental studies of sound amplification in a plasma were described in [3]. A traveling wave was excited in a discharge tube 4 cm in diameter in helium, neon, and argon at a pressure 4 torr and a sound frequency 7.1 kHz. It was found that the amplification ratio increases with increasing current. In [4] sound amplification ratios were measured on similar equipment in an argon discharge with the same parameters but in a somewhat different frequency range (1-2.3 kHz) and at pressures from 1 to 100 torr. The amplification ratios in the two series of measurements [3, 4] coincided, but there was one difference. In [3] a difference was observed between the sound amplification ratio α measured with sound propagating with and against the direction of electron drift. Measurements were made in the current range 10-100 mA. A difference in a developed at a current higher than 60 mA; α increased with increasing current, and at 100 mA the amplification ratio was 50% higher for sound propagation in the direction of electron drift than for the opposite direction. In [4] those graphic dependences coincided

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to within the measurement error (10%). The anisotropy of the sound amplification ratio in a discharge was analyzed in [5], in which it was found that the sound amplification ratio in a plasma depends on the direction of sound propagation, since the growth rate is higher when the direction of flow coincides with the direction of the sound wave because of the longer time of interaction of the wave with electrons. That difference decreases with decreasing sound frequency, and becomes almost imperceptible at 2 kHz. In [4] it was found that the amplification ratio does not depend on pressure in the range from 1 to 100 torr.

A nonlinear theory of sound amplification in a vibrationally nonequilibrium molecular gas was developed in [6-8]. The mechanism of such amplification is the possibility of the conversion of vibrational energy into the energy of the sound wave. Nonlinear amplification of sound waves in a nonequilibrium molecular gas, associated with the strong dependence of the amplification ratio on the intensity of the sound wave, was considered in [9, 10].

The processes occurring in the stratification of a discharge by acoustic waves directed along a positive column were analyzed in [11]. The stratification mechanism is related to the fact that the ratio of the electric field to the gas density (E/N) is higher in rarefied layers than in dense ones. Because the gas ionization frequency in the plasma is related exponentially to the parameter E/N, the electron density is higher in rarefied than in dense layers. An acoustic wave in the discharge modulates the electric current. Experimental results on modulation of a discharge current by sound in argon were described in [12]. The current modulation frequency was found to equal the sound frequency, and the depth of modulation increases with increasing gas pressure, wave intensity, and discharge current and is $\sim 1\%$. Modulation of a discharge current by sound in molecular nitrogen was investigated in [13]. It was found that the depth of modulation increases with increasing gas pressure and sound wave intensity, while the depth of modulation decreases with increasing average current, in contrast to the case in argon. The depth of modulation was 26% for a nitrogen pressure 40 torr in a discharge tube 9.8 cm in diameter, a current 40 mA, and a sound intensity 98 dB. The addition of argon or helium to the nitrogen decreases the depth of modulation of the current, and a depth of modulation 2-3% is established for an 80% argon abundance in the argon–nitrogen mixture. The addition of oxygen (up to 40%) to a nitrogen discharge considerably increases the depth of current modulation. The pronounced increase in the depth of current modulation in a nitrogen discharge in comparison with an argon discharge is associated with processes of VT relaxation of vibrationally excited levels of nitrogen molecules. The further increase in the depth of current modulation upon the introduction of oxygen into a nitrogen discharge is due to the fact that the constant for VT relaxation of vibrationally excited nitrogen molecules by oxygen is higher than by nitrogen. Pumping of gas along a discharge in the field of a sound wave decreases the depth of current modulation. This can be explained by the removal of vibrationally excited nitrogen molecules from the discharge zone by the gas stream. As a result of that removal, the frequency of VT relaxation and the intensity of heat release caused by that process decrease. Moreover, the relaxation time increases due to the decrease in gas temperature, which leads to a decrease in the depth of modulation.

The phase shifts between oscillations of the electron and ion components of the plasma and a sound wave in a nitrogen discharge has been investigated experimentally. The measurements were carried out at pressures 10-60 torr and currents 40-90 mA in a tube with a diameter 9.8 cm. The intensity of the sound wave was varied from 60 to 90 dB. It was found that at a gas pressure 40 torr, a current 40 mA, and an intensity 60 dB, the phase shift between the electrons and the sound wave was 45°, while that between the ion component and the sound wave was 5°. The phase shift decreases with increasing intensity of the sound wave, while it increases with increasing nitrogen pressure.

At a constant gas pressure and current, the longitudinal electric field in the discharge increases with increasing intensity of the sound wave, which is directed along the positive column. In an argon discharge at a gas pressure 100 torr, a current 50 mA, and a tube diameter 6 cm, for example, an increase in the sound intensity to 83 dB at the resonance frequency 190 Hz results in doubling of the electric field in the discharge. In the process, the gas temperature in the plasma at the axis of the positive column, measured with a thermocouple, decreases from 124 to 92°C, while the temperature at the wall of the tube increases by 20°C, i.e., the drop in gas temperature between the axis and the wall decreases from 105 to 43°C under the influence of sound waves. The decrease in the gas temperature gradient over the radius of the discharge leads to unpinching of the positive column. The diameter of the visible boundary of the discharge, equal to 3 cm in the absence of a sound wave, expands to 6 cm when sound with an intensity 83 dB is turned on. The effect of unpinching of a discharge by sound is displayed better at lower currents [14].

The effect of sound waves on the electron temperature and density was clarified by probe measurements in a nitrogen discharge. It was shown that an increase in sound intensity at a constant current and gas pressure leads to an increase in electron temperature and a decrease in electron density. It was also established that sound waves modulate the electron temperature and density. The depth of modulation increases with increasing gas pressure and sound intensity.

Contraction of a discharge in nitrogen and the influence of sound waves on the current–voltage characteristic (CVC) of a pinched discharge were investigated experimentally. The conditions under which sound eliminates the region of hysteresis on the CVC of the discharge and completely eliminates its contraction were determined. In an investigation of modulation of the discharge current by sound waves, it was shown that the depth of modulation increases abruptly when the discharge changes to the contraction mode.

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FREELY LOCALIZED SHF DISCHARGE IN A FOCUSED BEAM

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This paper reports the results of research into the spatial and temporal characteristics of an electrodeless shf discharge in air in a focused beam under different discharge generation conditions and in a wide range of variation of gas pressure, inserted energy flux density, and shf pulse duration. An analysis of the mechanisms responsible for rapid heating of the molecular gas is given. A stationary burning discharge is experimentally produced in free space in a focused beam with energy conducted vertically to the discharge from below.

Progress in the development of shf electronics has lead to the possibility of producing a new form of discharge, namely, an electrodeless shf discharge in a focused beam of electromagnetic energy in free space. Intensive research into this form of discharge has been conducted in different institutions since the start of the 1970's [1-3]. Study of the plasma of a freely localized shf discharge, isolated both from the walls of the discharge chamber and from the radiation source, is a pressing problem from

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