Armenian Journal of Physics, 2019, vol. 12, issue 4, pp. 283-288

Discharge Quenching by Acoustic Waves

A.H. Mkrtchyan[1], A. R. Aramyan[1*], R. A. Aramyan[1], G. B. Hovhannesyan[2] and G.A. Harutyunyan[1]

[1]*Institute of Applied Problems of Physics NAS RA,*
Nersesyan Str.25, Yerevan, 0014, Armenia
[2]*Université de Bourgogne,*
9 Avenue Alain Savary, 21000 Dijon, France
* E-mail: aramyan.artur@gmail.com

Received 25 June 2019

Abstract. The results of an experimental investigation of the discharge quenching by an acoustic wave are presented. Acoustic discharge quenching occurs as follows: an increase in the intensity of an acoustic wave causes a swirl, which mixes the gas in the radial direction, as a result of which the discharge in the tube shifts. An increase in the diameter of the positive column leads to an increase in the loss of charged particles on the walls of the tube, followed by an increase in the ionization frequency and the electric field. For a certain acoustic intensity, the voltage reaches a value that corresponds to the rated power of the supply unit, and at higher voltages the discharge is quenched.

Keywords: Gas discharge, electrons, acoustic wave, positive column.

1. Introduction

The interaction of acoustic waves with a plasma leads to the appearance of a number of interesting acoustoplasma phenomena, including the appearance of swirl in the plasma by acoustic waves, as a result of which the gas temperature in the discharge decreases [1].

In [2], for plasma with acoustic disturbances, temperature and density changes caused by acoustic disturbances were calculated from experimentally measured values of acoustic pressure. Acoustic modulation of temperature, density and pressure is no more than 0.1% of average values. The vibrational velocity of molecules is hundreds of times less than the root-mean-square velocity, but due to the collective effect of a large number of molecules and the chosen direction of oscillations, it is the vibrational velocity that determines the creation of acoustic superlattices in a plasma. Thus, in acoustoplasma, acoustic superlattices of particle velocities and impulses, are created, rather than pressure and density ones.

In [3], it was shown that acoustic waves cause the stratification of a homogeneous positive column when they are directed along its axis. The electron concentration increases in the rarefied layer and decreases in the condensed layer as the intensity of the acoustic wave increases. The change in the structure of the positive column from uniform to layered should lead to an increase in the resistance of the discharge gap.

It was shown in [4] that the processes of vortex generation in a weakly ionized gas are considered under conditions where a high-velocity flow propagates along the gas discharge, and acoustic waves interact with a positive column. Results are presented on the effect of the longitudinal gas flow on the properties of the positive column. It is shown that under certain conditions the gas flow in the positive columns increases to vortices, which cause the plasma to mix radially, forming a uniformly excited gas at high pressures. The results of the interaction of acoustic waves with a low-temperature plasma are discussed, and the acoustically stimulated formation of vortex motion, leading to uncontracted discharges and elevated pressures, is discussed. Also considered are superluminescence flashes in an argon discharge, caused by an abrupt transition of a positive column containing acoustic vortices from an uncontracted state to a contracted state at elevated pressure: It is believed that this transition occurs due to a turbulent-laminar transition in an acoustic flow. Finally, a gas-discharge acoustically induced laser is described.

In [5], the cathode region and the positive column are considered at the discharge of direct current and the acoustoplasmic mode. The spectrum and intensity of the nitrogen lines and other components of the CO_2-laser working mixture are shown. The dependence of the intensity of individual spectral lines and the integral spectrum in the visible range $(300-800nm)$ on the frequency and on the modulation depth of the discharge current was obtained experimentally. The spectra of the factory mixture of a CO_2 laser and a mixture of $CO_2 : N_2 : He = 1:1:8$ are compared.

This work reports on the results of a study of a new phenomenon of acoustoplasma - the quenching of a gas discharge by an acoustic wave, which has an applied aspect.

2. Experiment and results

The experimental studies were performed on a stand of $100cm$ long quartz discharge tube with a diameter of $60mm$. Electrodes in the form of taps were attached to the lateral wall of the tube. The distance between the electrodes was $85cm$. The plasma was created by applying a high voltage from the d.c. source to electrodes in the tube.

The acoustic wave was generated in the discharge tube either by applying sinusoidal electric oscillations from current modulation unit on the constant discharge current, or by using an electrodynamic radiator of acoustic waves attached to one of the ends of the tube.

The acoustic radiator was supplied from a generator of sinusoidal oscillations through an amplifier and a dividing transformer. A microphone was attached to the opposite end of the tube, which was used to measure the parameters of an acoustic wave that passed through the discharge range.

The gas temperature in the discharge was measured by two thermocouple sensors, one of which was set in the middle of the positive column, and the other on the tube wall at the same distance of $20cm$ from the grounded anode.

Below are the results of experimental studies of the impact (influence) of an acoustic wave generated in the tube by an electrodynamic radiator on the value of stationary current and the voltage difference across the electrodes in an argon discharge.

The acoustic oscillations propagate in the tube as a result of applying voltage to the radiator at a certain gas pressure in the tube and a current of $50mA$ from the generator of sinusoidal oscillations. When the intensity is $J_{cr} = 76dB$, the positive column is stratified. The effect of stratification of the plasma column by acoustic waves occurred only with the formation of a standing wave. i.e. at a frequency of $f = 190Hz$, half of the wavelength of which was equal to the length of the tube. At higher frequencies, the stratification was not observed, since the sound intensity was insufficient due to the fact that the absorption coefficient of an acoustic wave in a gas is inversely proportional to the square of the frequency.

At constant gas pressure in the tube, an increase in the intensity of the acoustic wave above J_{cr}, leads to a decrease in the current and an increase in the voltage across the discharge gap. So, at a pressure of $123\,Torr$ of argon in the tube, an increase in the intensity of the acoustic wave from 76 to $82dB$ leads to a decrease in the discharge current from 50 to $30mA$, while the electric field intensity here increases from 3 to $5kV$.

It is worthwhile to note that the quenching of discharge by the sound wave takes place at pressure of $123\,Torr$ and intensity of $86dB$. This means that the resistance of the discharge gap increases with the sound intensity and at an intensity of $82dB$ it reaches a value at which the voltage at the output of the power supply is insufficient to maintain the discharge at a given ballast resistance in the discharge circuit and the current is broken. When the pressure of argon in the pipe is $84\,Torr$, the discharge is quenched at $86dB$. At the same time, at a pressure of $40\,Torr$, discharge quenching was not achieved. This is due to the fact that when the same voltage is applied to the sound radiator, the sound generated in the tube at a pressure of $40\,Torr$ will have a smaller amplitude, which is insufficient for quenching the discharge (sound intensity in the gas is proportional to the pressure value).

In Fig. 1 shows the dependence of the discharge gap resistance on the sound intensity with a frequency of $190Hz$ at various values of pressure in the tube. The discharge current in the absence of sound was $50mA$. An increase in the intensity of the sound wave to 2 relative units $(76dB)$ did not lead to any change in the discharge current.

When the sound intensity was $J_{cr} = 2$ relative units, the stratification of the positive column took place. An increase in intensity from 2 to 7 relative units (from 76 to $92dB$) at constant pressure causes a decrease in the discharge current and an increase in voltage, and as a result, the resistance of the discharge gap at $P = 123\,Torr$ increases by more than 2.5 times (curve 1).

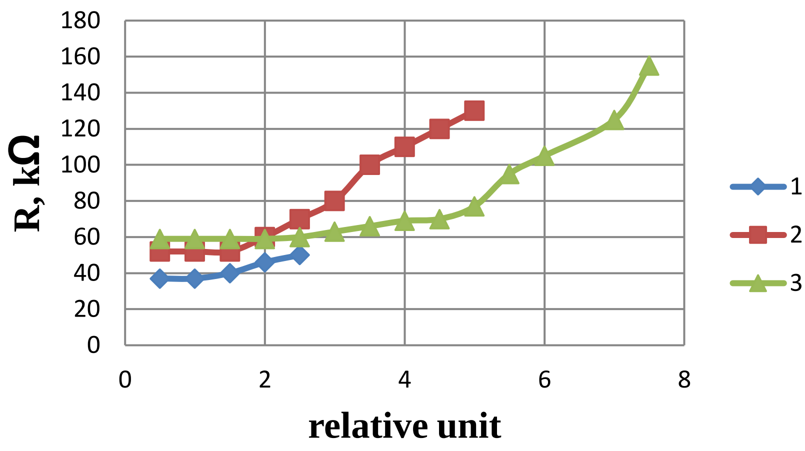

Fig. 1. Plots of discharge gap resistance versus the intensity of sound wave in argon discharge in 100 cm long tube of 6 cm in diameter, 85 cm gap between electrodes, at pressures of 123 Torr (curve 1), 84 Torr (curve 2), 40 Torr (curve 3).

Now consider the gas temperature in the discharge as a function of sound intensity, measured in the middle of the positive column and on the tube walls in the presence of a standing wave with a frequency of $190 Hz$.

With a pressure of $110\,Torr$ in an argon discharge and a current of $50mA$, the gas temperature on the positive column axis with no sound, corresponded to $405K$, and $300K$ on the tube wall. Creating a sound wave and increasing its intensity to $84dB$ reduced the gas temperature on the discharge axis to $363K$ and its increase on the wall by 20^0, i.e. the difference of the radial gas temperature between the axis and the tube wall decreases under the influence of a sound wave from 105 to 43^0. The influence of the sound wave on the gas temperature in the discharge at a higher gas density is more pronounced.

In the absence of a sound wave, a contracted discharge with a positive column, having a visible boundary with a diameter of $2cm$, is established at an argon pressure in a tube of $110\,Torr$ and a current of $50mA$. Creating a sound with an intensity of $84dB$ leads to an increase in the discharge diameter up to $6cm$, which is equal to the internal diameter of the tube, i.e. the impact of a sound wave leads to a complete deconstruction of the positive column.

The most general physical reason for discharge contraction is the temperature heterogeneity of the gas in the plasma across the current [6]. The effect of destruction by the acoustic field is the result of the intensification of transfer processes along the radius of the tube, increasing heat removal from the plasma filament, the decrease in the radial gradient of the gas temperature and the increase in the diffusion losses of electrons on the walls caused by the vortex motion arising in the discharge. Vortex movement in the volume of the tube is observed visually. The vortex flow (pulsation) is clearly manifested in a standing sound wave (the so-called acoustic flow [7, 8]).

3. Discussion

The nature of the occurrence of the acoustic flow in the discharge is as follows. At low sound intensity in the discharge, the distribution of the vibration velocity of atoms and molecules in the region of the sound wave through the tube has the form of a parabola with a maximum on the axis and zero on the tube wall. When the sound intensity increases, the vibration velocity of the gas particles on the discharge axis increases, and the derivative of the velocity along the radius near the tube wall also increases. At a certain value of the intensity of sound, the boundary layer is destroyed, as was the case with a discharge with a longitudinal flow of gas in the tube.

Under these conditions, pseudo-turbulent low-frequency large-scale oscillations occur in the discharge. A further increase in sound intensity leads to the fact that large-scale vortices turn into smaller ones, a range of developed turbulence arises with intense gas mixing in the radial direction, which causes the gas temperature drop in the radius of the tube to equalize due to the vortex movement and an increase in the diameter of the positive column.

Due to the increase in the diameter of the positive column, the frequency of diffusion losses of particles on the tube walls will increase (turbulent diffusion will begin, exceeding the classical ambipolar) with a subsequent increase in the E/N parameter of ionization frequency (to ensure the balance of particles in the discharge) and longitudinal electric field.

For a certain sound intensity, the voltage reaches a value that corresponds to the rated power of the supply unit, and at higher voltages the discharge is quenched.

4. Conclusion

Finally, the following conclusions can be made.

Resonant acoustic waves in the discharge tube give birth to a stationary acoustic flow. Due to these acoustic flows in the discharge tube occur decontraction of contracted discharge. At the same time, the radial temperature gradient of the neutral component of the gas in the discharge tube is equalized.

When the gas pressure in the discharge chamber exceeds $80\,Torr$, as the intensity of the resonant acoustic wave increases, the effect of quenching the discharge in the chamber can be achieved. The effect of quenching the discharge in a chamber with different gas pressures in the tube is achieved at different intensities of the resonant acoustic wave. With increasing gas pressure in the tube, the required intensity of the resonant acoustic wave for quenching the discharge decreases.

Author Contributions

The authors equally contributed to all steps of the paper preparation.

Funding

The paper has been supported from Basic financing of IAPP NAS RA.

Acknowledgments

The authors are grateful to the Vardan Sargisyan for his technical support.

Conflicts of interest

The authors declare no conflict of interest.

References

[1] A. R. Aramyan, G. A. Galechyan andA. R. Mkrtchyan,Soviet physics. Acoustics **37**, No. 2 (1991) 107-111.

[2] A.S. Abrahamyan, R.Yu. Chilingaryan, Q.G. Sahakyan, H.T. Hovhannisyan, M.A. Hakobyan, Armenian Journal of Physics, 2017, **10**, No 2 (2017) 76-80.

[3] A.R. Aramyan and G.A. Galechyan, Physics–Uspekhi, **50**, No. 11 (2007) 1147-1169.

[4] A.R. Mkrtchyan, K. Z. Hatsagortsyan, G. A. Galechyan and E.G. Divanyan, Acustica62, No. 2 (1989) 124-127.

[5] [R15] A.S. Abrahamyan and R.Yu. Chilingaryan, Armenian Journal of Physics, **8**, No 4 (2015) 191-204.

[6] Yuri P. Raiser,Gas Discharge Physics.Berlin, Springer-Verlag, 1991.

[7] L. D. Landau and E. M. Lifshitz, Hydrodynamic.New York, NY, USA: Pergamon, 1971.

[8] A. R.Aramyan, Physical Review Letters**91**, No. 15 (2003) 155002-1-155002-4.