Non-Destructive Method of Electron Concentration De-Terminationin Discharge Tubes

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Abstract: The method of electron concentration determination in discharge tubes is considered. It is based on the measuring of an auxiliary high-frequency discharge conductivity flowing between two external electrodes, located diametrically opposite to a discharge tube surface. The measurements are carried out at a frequency corresponding to the maximum active conductivity of a plasma column. The current of an auxiliary high-frequency discharge is measured with a thermal converter. The direct current is fed from a thermocouple to the input of the direct current amplifier which increases the accuracy of measurements in contrast to the known methods. The numerical value of the thermocouple current is measured by a microammeter connected to the output of a direct current amplifier. The error of the electron concentration determination method does not exceed 8%. The scheme and the technique of electron concentration determination in discharge tubes are provided.

Key words: Discharge, discharge tube, plasma column, external electrodes, measurement, electron concentration

INTRODUCTION

The base element of gas-discharge light sources, laser and ion sources design is the Discharge Tube (DT). The research, development and quality control of gas discharge devices require the creation of affordable methods for discharge characteristics determination. The known probe, spectrometric, microwave methods for plasma discharge column characteristics determination require the change in a device design and are very laborious. With respect to DT, among non-destructive methods of a discharge plasma column characteristics diagnosing, the most promising methods are those based on the use of external electrodes. Their application ensures the universality of measurements and high efficiency. Besides, external electrodes almost do not change the picture of the processes taking place in a gas-discharge channel. The opportunity appears to determine the characteristics of a discharge on alternating current in the conditions close to the real operational ones. An improved method is proposed in this study to determine the electron density in DT. The method is based on conductivity measurement of an auxiliary High-Frequency (HF) discharge.

MATERIALS AND METHODS

Method theory: The method of electron density determination n_e is based on the conductivity measurement σ of an auxiliary high-frequency discharge between two external electrodes (Fig. 1). According to Tahmassebpour (2016) and Kunchur et al. (2013, 2015) the active conductivity σ of an auxiliary discharge is related to n_e of the discharge under study by the following relation:

$$\sigma = \frac{\theta^2 n_e v}{m\left(v^2 + \omega^2\right)} \tag{1}$$

Where:
e and m = The charge and an electron mass, respectively
v = The frequency of an electron elastic collisions with gas atoms
ω = The cyclic frequency of the alternating voltage supplying an auxiliary discharge
n_e = The electron concentration

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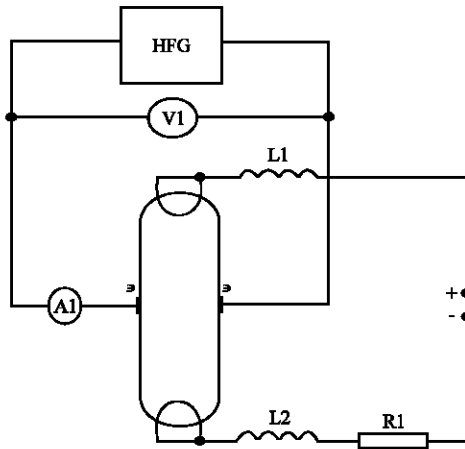M.E. Evseyev, Studencheskaya Str. 11a, 430007 Saransk, Russia

Fig. 1: High-frequency method of electron concentration
determination; HFG: High-Frequency Generator; э:
external electrodes; L1, L2: inductive filters

The measurements of electron concentration are
carried out at the frequency of f_m which corresponds to
the maximum value of the plasma column active
conductivity. The value f_m is obtained according to the
maximum value of the discharge current of an auxiliary
discharge with a fixed voltage on electrodes. Expressing
the conductivity σ through the current I and the voltage
U of the auxiliary discharge, we obtain the following:

$$n_e = \frac{2mdI}{e^2\,SU} \qquad (2)$$

Where:
d = The inner diameter of a tube
S = The area of an auxiliary electrode

The voltage U_C on a capacitor developed by an
auxiliary electrode and an inner surface of a tube which is
a dielectric (glass, ceramic) with the thickness of h and
permittivity ε, makes:

$$U_c = \frac{4\pi hI}{1,11.10^{-10}\,\varepsilon S\omega} \qquad (3)$$

Then, taking into account U_C the average value of
the electron concentration over the cross section of an
auxiliary discharge bounded by an electrode makes:

$$n_e = \frac{2md\omega I}{e^2 S\sqrt{U_э^2 - \left(\dfrac{3,64.10^{10}hI}{\varepsilon S\omega}\right)^2}} \qquad (4)$$

Where:
m and e = The electron mass and charge, respectively
d = Internal diameter of a bulb
ω = The circular frequency of the alternating
voltage supplying a discharge
I = Auxiliary discharge current
S = The area of an auxiliary electrode
$U_э$ = Electrode voltage
h and ε = The thickness and the permittivity of a bulb
glass, respectively

Let us set the relationship between the electron
density n_e over an auxiliary discharge cross section and
the electron concentration $\bar{n}_e$ in the cross section of a
discharge tube. Using the equation describing the
distribution of the electron density over the discharge
column (Seyedhosseini *et al.*, 2016) we determine the
concentration of electrons n_0 on the discharge axis, taking
into account that the linear dimensions of an auxiliary
electrode are small in comparison with the DT diameter,
we obtain the following:

$$n_0 = \frac{n_e}{\displaystyle\int_0^R J_0\left(2.4\cdot\frac{r}{R}\right)dr} \qquad (5)$$

Where:
$J_0(2.4{\cdot}r/R)$ = The Bessel function of zero order
r = The current radius

The average electron concentration $\bar{n}_e$ over the DT
cross-section can be determined from the relation
(Seyedhosseini *et al.*, 2016) derived under the
assumptions that the electron concentration makes zero
on the DT walls and makes the maximum on the axis:

$$\bar{n}_e = 0.43\,n_0 = 0.56\,n_e \qquad (6)$$

Thus, the electron concentration $\bar{n}_e$ in the plasma
column of a discharge tube can be determined from the
measured values of the discharge current I, the voltage
drop $U_э$ and the frequency $f = \omega/2\pi$ of an auxiliary
high-frequency discharge excited between the external
electrodes.

**The installation scheme and the procedure of electron
concentration determination in a discharge tube:** The
determination of the electron concentration in a discharge
was performed by us on the device shown on Fig. 2. In
contrast to Berezin (1975), Sveshnikov (1987) and
Bidabadi *et al.* (2012) the power supply of DT was
performed by an alternating low-frequency voltage.

The removed voltage from the low-frequency
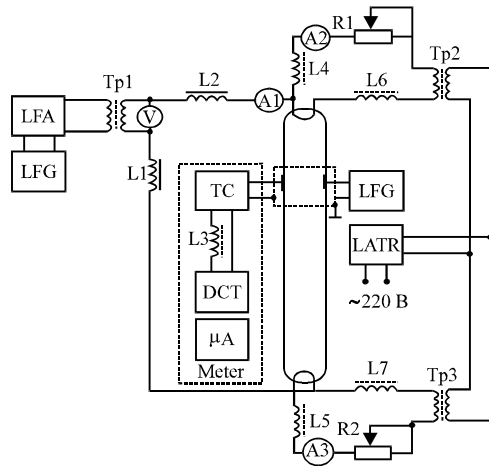oscillator is amplified by LFA amplifier and through the

Fig. 2: Block diagram of the device for electron concentration determination; LFG: Low Frequency Generator; LFA: Low Frequency Amplifier; TC: Thermal Converter; DCT: Direct Current Amplifier; µA-microammeter; HFG: High Frequency Generator; LATR: Laboratory Autotransformer
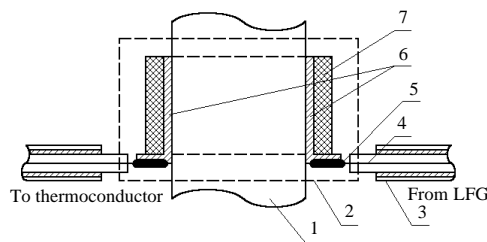

Fig. 3: Sensor design; 1: discharge tube; 2: sensor screen; 3: HF cable; 4: the central core of HF cable; 5: soldered contact; 6: external electrodes; 7: rubber cuff

step-up transformer Tp1 is applied to the electrodes of a discharge tube. The provision of DT electrode uniform heating is carried out by the rheostats R1 and R2.

The high-frequency voltage is applied to external electrodes from a high frequency generator. The limitation of high frequency current leakage to the power supply circuit of DT is achieved by the use of inductive filters L1, L3, L4, L5, L6 and L7.

The current of an auxiliary high-frequency discharge is measured by the thermal converter TC. The direct current is supplied from a thermal converter to the input of the direct current amplifier DCA, due to which the accuracy of measurements is increased in contrast to (Berezin, 1975; Sveshnikov, 1987). The numerical value of the thermal converter is taken from the microammeter µA, connected to the output of DCA.

The procedure of electron concentration determination is the following one. A sensor is placed on DT surface (Fig. 3). The nickel electrodes of the sensor are mounted diametrically opposite to each other on the DT. They are tightly fixed on the DT by a rubber cuff. We used a standard signal generator G4-78 as a high-frequency generator. The thermal converter M5-78 is used as the current sensor. The direct current is supplied from the thermocouple to the direct current amplifier. The power supply of DT is carried out from the generator G4-117 together with the amplifier 100U-101.

The concentration of electrons $\bar{n}_e$ in the plasma discharge column excited in DT is calculated by Eq. 4 and 6 according to the measured values of the current I and the voltage drop U_3 between the external electrodes for a given discharge tube design.

RESULTS AND DISCUSSION

Experiment results: An experimental verification of the determination method $\bar{n}_e$ was carried out on discharge tubes dosed with argon and mercury. DT shells were made of SL-97-1 glass. Oxide cathodes were used from 16 watt fluorescent lamps were used as the electrodes. The measurements were carried out on the DT with the diameter of 12 mm and a wall thickness of 1 mm. The pressure of argon ranged from 6-9 mm of mercury column. The amount of dosed mercury was 15 mg. The discharge current flowing through the DT at the frequency of 50-100 Hz, varied from 20-250 mA. A high-frequency discharge on external electrodes of 3×3 mm was excited at the frequency of 194 MHz. The experimental data were processed by the math CAD program using the moving average method.

Figure 4 shows the dependence graphs of the electron concentration in DT plasma column on the discharge current. The maximum discrepancy between measured values $\bar{n}_e$ and known data (Bashlov, 1998) is <2%.

Figure 5 shows the dependence $\bar{n}_e$ on argon pressure in DT. The graph shows that the increase of the argon pressure in the range from 6-9 mm of mercury column provides the monotonous increase of electrons concentration in the argon-mercury discharge which agrees with the results provided by Bashlov (1996, 1998). The use of a direct current amplifier made it possible to reduce the value of the confidence interval by 35% in comparison with Berezin (1975). Thus the error of the method decreased to 8% due to a more accurate measurement of HF current.

Summary: An improved method to determine the electron concentration in discharge tubes is proposed. It is based on active conductivity measurement of an auxiliary high-frequency discharge flowing between electrodes
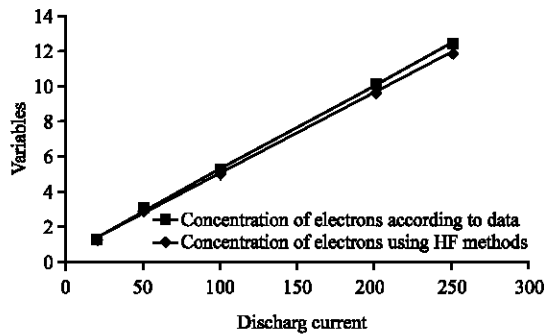
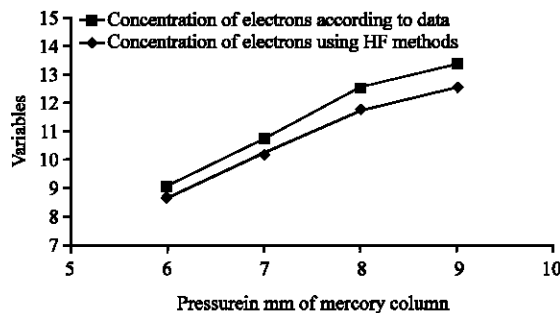Fig. 4: Dependence of n_e on discharge current at d = 12 mm, p = 8 mm of mercury column

Fig. 5: Dependence of ne on pressure at d = 12 mm, I = 250 mA

located on the surface of a discharge tube. The electron concentration is determined by the device in which the discharge tube is powered by a variable frequency voltage which is important for research. High-frequency voltage is applied from a standard signal generator to external electrodes. An auxiliary discharge current is measured by a thermal converter connected to a direct current amplifier which increases the accuracy of measurements. The error of the method is <8%.

The proposed method does not require the change in DT design and the use of expensive equipment. The method can be recommended for the development and the improvement of radiation discharge sources as well as for the creation of a comprehensive methodology of their quality control.

CONCLUSION

An improved method of electron concentration determination in the plasma column of a discharge tube was considered by the means of a high-frequency discharge excited between external electrodes. A device scheme and a sensor design was proposed to determining the electron concentration in a discharge. The device allows to perform the measurements of $\bar{n}_e$ in the low frequency range of a discharge tube supply. The error of electron concentration measurement in a DT with the diameter of 12 mm, at the discharge current of 250 mA and the argon pressure change in the range from 6-9 mm of mercury column does not exceed 8%.

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