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Microplasma photoionization sensor CES as an advanced portable molecular analyzer

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Abstract

The 21st century is a time that requires new multifunctional technologies for analyzing the state of human health, both at industrial facilities and in conditions far from hazardous industries. Today, a large number of analyzers are known, that principles of operation are based on traditional physical methods usually. The scientific novelty of our study is that our photoionization sensor works due to the innovative collision electron spectroscopy (CES) method and it helps to solve a number of problems related to ensuring the health of workers in hazardous industries.

Keywords: microplasma, plasma, electron collisional spectroscopy, gas-analyzer.

Collision electron spectrography method

Research of plasma methods for analyzing of the molecular and atomic composition of substances are important both in fundamental and in applied terms due to their widespread application in scientific research and in real production conditions. The object of special interest is the development of new and updating existing principles and methods for analyzing substances from various points of view, including miniaturization, low energy consumption and adequate cost of equipment. Developments in this area are very active and have a long history, it means that search and implementation of new basic physical principles in the development of analytical tools and methods of the new generation.

The vast majority of analyzers is based on the ionization of the mixture and the analysis of the trajectory of movement of charged particles (ions and electrons) in specially created electric or magnetic fields to the detector. In this case, either the correlation of mass to charge or kinetic energy is determined, this data allows to identify the analyte, often in combination with additional analytical tools gas chromatography. However, it should be noted that in all such analyzers the impulse vector of the charged particle is determined, that imposes a strict requirement to maintain a high vacuum along the trajectory of movement. Any collision of an analytically charged particle with atoms or molecules of residual gas leads to scattering of this particle and to «dropping out of the game», or to erroneously detect at an unpredictable point of the receiver with a loss of resolution. An additional technical and methodological problem is the introduction of atoms or molecules of a sample, usually under

the atmospheric pressure, into the analyzer's area where it is necessary to maintain a high vacuum.

These circumstances lead to an increase in weight, dimensions, energy consumption and technical complexity of traditional means of determining the composition of gas mixtures, that does not allow to solve a number of important analytical problems facing modern science and technology. An important task is the creation of individual detectors (a size of several cubic centimeters) and distributed networks of gas analyzers, which will be widely in demand in energy conservation, chemical, food and bio-technologies, healthcare, meteorology, environmental management, ecology, security systems and etc. In this case, it is desirable to switch from the principle of measuring the vector of a impulse, which is critically sensitive to scattering by residual gases in the analyzer, to the methods of energy measurements using potential nature of the electric field.

In previous papers, the idea of plasma electron spectroscopy (PES) was proposed using the classical Langmuir probe method and an attempt was made to develop methods for analyzing a gas that do not require high vacuum in their implementation. However, in experimental studies, it was possible to advance to working pressures no higher than 1-3 Torr due to the fundamental limitations of probe theory. As a further advance the importance of the nonlocal nature of the formation of the electron energy distribution function and the concept of the length of the energy relaxation of electrons in a plasma detector has been shown previously. Various approaches to the detection of atoms and molecules in the form of charged particles using resonant plasma radiation were also considered in the previous time, but they also did not allow advancement into the high-pressure area of the analyzed mixture.

For this reason, the development of methods of analysis of substances based on new physical principles that will allow to overcome these difficulties is an urgent problem.

Physical installation for studying electron energy spectra in a CES microplasma detector

The electrophysical installation was developed and created with the aim of building the experimental prototype of the microplasma detector, as well as testing diagnostic methods. The installation includes a vacuum installation, a cuvette with an ionization chamber, as well as traps cooled with liquid nitrogen, cylinders with pure inert gases (helium, xenon) and gas distribution valves for preparing gas mixtures and filling the cuvette.

The chamber for ionization of the CES detector with a variable geometry, schematically is shown in Fig. 1, consists of two cylindrical electrodes 5, 6, made of steel and installed in a cuvette 8 made of molybdenum glass with a diameter of 30 mm and a length of 200 mm, mounted horizontally. The diameter of the cylindrical electrodes in the outer circle is equal to the inner diameter of the cuvette, one of the electrodes 1 is fixed in the cuvette, and the second electrode 2 can freely slide on a little friction on the cuvette so that the required distance between the electrodes can be set using an external magnet. The ends of the cylindrical electrodes,

Fig. 1. Diagram of the ionization chamber of the experimental layout of the CES detector

facing each other, had a flat shape and were perpendicular to the axis of the electrodes, thus forming a planar configuration of the CES microplasma detector. These electrodes were connected to electrical inputs 9, 10 made of molybdenum wire soldered to the ends of the cell,

and the electrode 6 was connected to the input 9 through a flexible nickel tape 11 folded in accordion, which allowed the electrode to move freely along the cell.

The vacuum installation system consisted of the following elements:

- diffusion and forevacuum pumps providing background pressure up to 10^{-7} Torr;
- a gas collector to which cylinders with test gases can be connected;
- a unit for precision gas purification, which includes a system of traps cooled by liquid nitrogen, some of which are filled with silica gel and zeolite;
- thermocouple VIT-1A and ionization VI-1 vacuum gauges;
- discharge cell.

So, the cuvette is filled with pure helium, which has additionally been purified by passing through a cryogenic trap.

The mode of operation of the discharge tube can be varied using both the flow mode (pumping speed $v \sim 1-10$ m/s) - allowing to remove from the discharge zone the products of dissociation of molecules present in the gas mixture and plasma chemistry products formed during the combustion of the discharge - and sealed off mode (without gas flow through the discharge tube).

Thus, this design of the device allows to achieve the highest possible size of current of a characteristic electron on the analyzing electrode, which allows to obtain the maximum sensitivity and well-balanced ratio of signal/noise for the gas analyzing method.

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