Development of a device for monitoring gas discharge parameters in a system with boiling liquid in a channel

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Abstract. Experimental prototypes of the high-voltage power sources for initialization of a gas discharge in the channel with boiling liquid are designed. The development principle of the device for control of the discharge system parameters is presented. The emission characteristics of a gas discharge at different frequencies are given.

1. Introduction

Today there is an intensive development of devices for water composition analysis [1]. Designed devices vary in the studied parameters, dimensions and price. Special attention is paid to a compact device capable of analyzing an aqueous solution sample in the field conditions. The gas discharge at atmospheric pressure is often used for this purpose [2, 3]. This type of discharge has high temperature and pressure plasma, which serves as a high brightness light source. If liquid is placed between the electrodes and the discharge is initiated, the spectral lines of chemical elements which salts are dissolved in the liquid will arise in the spectrogram, saying about the qualitative composition of the analyte under study [4, 5].

In this regard, when creating devices for gas discharge initialization in the field conditions, a number of problems should be solved, related not only to the choice of the discharge cell, but also to the development of an electrical circuit for excitation and control of discharge parameters. Currently there are a number of systems that are intensively used to maintain the gas discharge at atmospheric pressure that do not require high voltages and frequencies of the power source. There are three types of these devices of frequent occurrence: a system with a liquid electrode, a system with a liquid supply and a system with boiling liquid in a channel. Each of them has a number of advantages and disadvantages. The system with liquid supply is used in industrial enterprises, has a complex structure and is inefficient in the analysis for small samples. The system with a liquid electrode has simple structure, but it is quite difficult to ensure the safety of the spectral lines registration in this case, because the optical fiber should be placed quite close to the discharge arc. The most safe and easy to use is a system with boiling in the channel which is shown in figure 1. The electrodes 2 are located in the vessels 1, interconnected by a quartz glass capillary 3.

To excite and maintain the gas discharge in this system the high-voltage pulse power sources capable of providing the output voltage up to 5 kV and pulse repetition rate in the range from 15 to 50 kHz should be used. These settings should be maintained in the specified ranges to ensure optimal initialization conditions in a portable device. In order to simplify the actions of the intended user, the
system should be automated. In this regard, it is necessary not only to develop a high-voltage power source, but also a device for monitoring its parameters.

![Figure 1. Gas discharge system with boiling liquid in a channel.](image1)

2. Development of a high-voltage power source

During the development of a high-voltage pulse power source, two electrical circuits were created: one based on a half-bridge self-clocked driver IR2153, the second was based on the commonly used self-clocked driver NE555N.

The circuit of the power source based on the IR2153 driver is shown in figure 2. The circuit is powered by a battery to ensure portability of the device. The driver controls the transistors Q1 and Q2 in the booster mode, which leads to the formation of rectangular pulses of a given amplitude and frequency. To obtain high output voltage, the step-up transformer and a voltage multiplier consisting of four amplifying stages is used.

![Figure 2. Power source circuit based on the IR2153 driver.](image2)

In order to ensure the efficiency of the developed circuit for use in portable applications, its experimental prototype was created. The three-dimensional (3D) printed circuit board (PCB) model of this prototype is shown in figure 3. Changes were made to adjust the value of the output pulse frequency: instead of a fixed value resistor R3 a potentiometer was used. The waveform of the circuit output signal is demonstrated in figure 4. The presence of a rectangular pulse source at the output indicates the suitability of this circuit for use in the discharge parameters control device.

The electrical circuit diagram based on the NE555N timer is shown in figure 5. Due to further use in portable applications, power was also provided by a battery. By pressing the S1 button, the optocoupler sensor U1 is activated, which has an output resistance of about 50 Ohms. Then the transistor Q1 is opened, and the supply voltage is feeding the timer. Transistor Q2 is used to amplify the output pulses from the current timer. Pulse duty cycle is regulated by a potentiometer R4. The pulses are fed from the circuit output to the primary winding of the step-up transformer. The voltage
formed by the secondary winding is increased by several times and supplied to the high voltage multiplier. Figure 6 shows the topology of the developed power source based on the NE555N timer. Figure 7 shows the output waveform at frequency of 22 kHz. The presence of emissions on the waveform is due to the parasitic inductance of the resistors used.

Both developed circuits are applicable to the device for gas discharge parameters monitoring, but it is preferable to use a power source based on the IR2153 driver, since the output waveforms have virtually no parasitic pulses, providing the device performance stability.
3. Glow discharge control device

The developed control device must have high functionality to minimize the work of the intended user, so the device must be able to independently control the discharge parameters. It is possible to implement this using a variety of peripherals operated by microcontroller. The device must have the following components: stepper motor driver, which will be used to monitor the position of the tip-shaped electrode, ultrasonic sensor to determine the water level in the discharge cell, display indicating the current status of the system, matrix keyboard for the data input. It is also necessary to add programming connectors to be able to make adjustments to the program code of the device not only by connecting a special programmer, but also by connecting to a laptop computer with specialized software.

The 3D PCB model of the developed control device is shown in figure 8. All terminals are located relative to the convenience of connecting the battery, and the terminals for connecting the stepper motor, ultrasonic sensor and step-up transformer are at a distance from the microcontroller and connectors for programming and output information. Matrix keyboard and display aren’t located on the PCB and connected as input-output peripherals.

The electronic components used in the circuit were selected under the condition of minimum power consumption to increase the system operation time. Some circuit elements, such as DC-DC converters and drivers, are heated during long-term tests. To improve the stability of the circuit, the necessary calculations were made to determine those chips that need an additional heat sink. Based on the thermal calculations the heat dissipating pads for voltage regulators were increased and the heat sinks for transistors cooling were added.

4. Application of the glow discharge control device in the experiment

The spectrograms of discharge plasma radiation were obtained under various operating modes of the device in the course of further research. In this case, the influence of pulse frequency on the spectrum curves, as well as the presence of obvious impurities (potassium permanganate in particular) was considered. The spectrometer ISM3600 [6, 7] with 2 s accumulation time setting was used. The software processing of the obtained spectra was carried out with the ASpect2010 software [8].

Figure 9 shows a gas discharge spectrogram of the system with boiling liquid in the channel at different frequencies. Tap water was used as the analyte under study.

The spectral curves are arranged as the intensity increases, which corresponds to an increase in the pulse repetition rate: 20, 25 and 30 kHz. In the range 200–300 nm low-intensity spectral lines of nitrogen and hydroxyl group are observed. The lines with the highest intensity are located in the wave
range from 300 to 400 nm and correspond to the hydroxyl group $\text{OH}^-$, single-charge nitrogen $\text{N}^+$ and oxygen $\text{O}^+$ ions, molecular nitrogen and oxygen. The wave range from 600 to 800 nm is of greatest interest, because it contains various impurities containing in the sample e. g. potassium, sodium, aluminum, calcium.

![Graph](image-url)

**Figure 9.** Gas discharge emission characteristic for different pulse frequencies

The presented results suggest the possibility of using small-sized circuits and PCBs in the creation of a portable device for environmental monitoring of water resources using glow discharge spectra. For further minimization, the spectrometric equipment should be significantly simplified, leaving the accuracy of the analyte composition determination unchanged.

**5. Conclusion**

The actual research proves the implementation possibility of the gas discharge parameters monitoring device in the setup with analyte boiling in the narrow channel. The circuit based on a half-bridge self-clocked driver IR2153 as a high-voltage pulse power source will be used in the future, since it has no output voltage surges, compared to the similar circuit utilizing the NE555N timer.

The developed gas discharge parameters control device will be further used in a portable setup for water resources quality monitoring due to its high functionality. The device obtains high-accuracy spectra, allowing the determination of the analyte qualitative composition.

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