THE EXPERIMENTAL SETUP FOR HIGH VOLTAGE BREAKDOWN STUDIES IN THE HIGH VACUUM

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An experimental setup for studying the processes occurring during breakdown in the high vacuum are described. The equipment is designed for comparative studies of pre-breakdown processes and the breakdown voltage of the different materials used for accelerator technology. Some first experimental results at this setup are shown in this paper.

PACS: 52.80.Mg; 52.80.Vp

INTRODUCTION

The interest to electrical breakdown is explained by the development in different fields of sciences and technology. In many cases, where the breakdown probability is high, it is necessary to use vacuum as insulator. There are many papers are described the disrupt electrical insulating of vacuum, pre-breakdown phenomena and breakdown event [1 - 5]. Nowadays the problem of breakdown is actual at the accelerator technology.

The modern accelerators have are large size and, therefore, require the significant financial expenses for construction and operation. The electrical gradient increasing will reduce the linear size of future accelerators and significantly reduce their costs. Then the electrical breakdowns are limit the maximum of accelerating fields. The studying of breakdown phenomena can help for high-energy particle accelerators design.

It is likely that the high voltage breakdowns in the high vacuum occur due to field emission at the construction materials for accelerating structures. The field emission is a source of electrons and it is determined the small conduction currents and further breakdown initiation [6]. Therefore, the creating of materials with higher work function of the surface layers for construction materials is actual.

Therefore, it is actual the creating and studying the properties of construction materials, which could have the characteristics needed for accelerating structures at the higher work function. One of the way to decrease the breakdown rate in vacuum devices can be work function increasing and, consequently, the breakdown field increasing. The surface modification can be one of the way for this aim.

According to this, it is actual to study the pre-breakdown and breakdown processes to improve the understanding of phenomena and to select the optimal material for electrodes used in vacuum devices and particle accelerators. During recent years, the Institute of Applied Physics National Academy of Sciences of Ukraine (IAP NASU) is a member of CLIC (Compact Linear Collider) collaboration at CERN (European Organization for Nuclear Research). The main direction of join research is to determinate the influence of various factors to breakdown probability in the high gradient electrical fields.

For these aims, the experimental setup for comprehensive study of the high-voltage breakdown phenomenon in the high vacuum was built at the IAP NASU and describes in this paper. The results of the first experiments are given.

1. EXPERIMENTAL SETUP

The DC-spark system is used at CERN for studying breakdown phenomena [7] was taken as a prototype for design this setup. The scheme of the experimental system for study of the high-voltage breakdown phenomenon in the high vacuum is shown in Fig. 1.

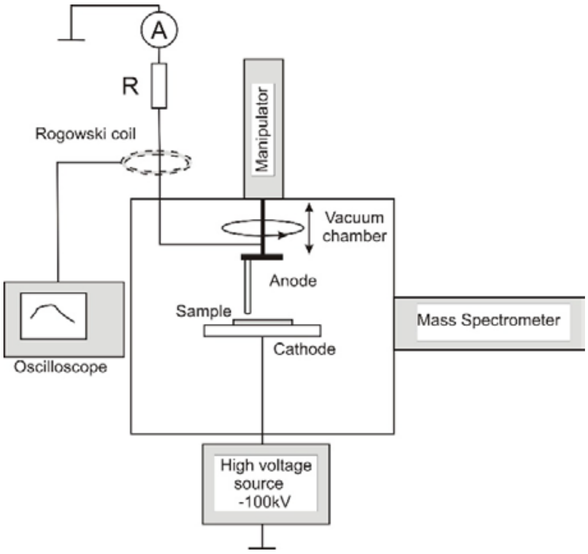

Fig. 1. Schematic drawing of the experimental setup

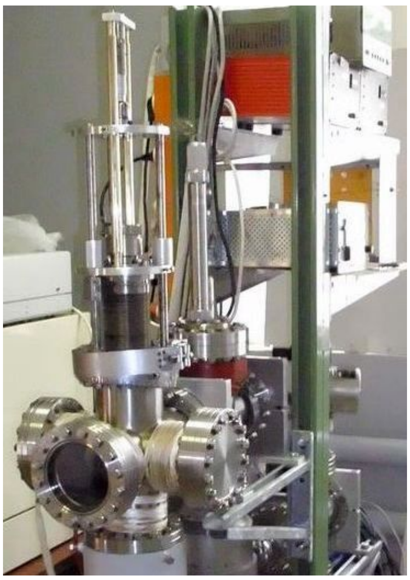

Fig. 2. General view of the experimental setup

The experimental setup includes the following elements: vacuum chamber with samples and monopole mass-spectrometer for as RGA (Residual Gas Analyzer) in the vacuum chamber; the system for pre-breakdown current and breakdown registration; the system for vacuum chamber and sample heating; the power supplies; the vacuum pumping system and the equipment for system operation.

More information about the main elements and devices are given below. The general view of the experimental setup is given in Fig. 2.

1.1. THE VACUUM SYSTEM

The vacuum system design provides the necessary pressure in the different parts of the setup at the preparation step and during experiment process. To minimize the influence of vacuum conditions to breakdown process, the pressure is reached not less than 10^{-7} Pa in the vacuum chamber. The higher pressure in the vacuum chamber can lead to initiation and development of gas discharge. Two turbo molecular pumps LEYBOLD TURBOVAC 361 (the pumping speed is 360 l/s) are used for pumping. If for nitrogen the compression ration is 10^9, the compression ratio for hydrogen is 3×10^3 for each pump. Therefore, the circuit with serial connection of two turbo molecular pumps was used for better hydrogen pumping from the vacuum chamber. High vacuum system's elements have metal sealing and heating system for their outgassing during pumping. The pressure is measured by cold cathode gauges.

The test samples are placed in the high-vacuum chamber. It has the reciprocating mechanical feedthrough. It is located at the upper flange and allows to change the distance between the electrodes. The bottom flange includes a high-vacuum inlet for a high voltage apply to the cathode. The side flanges are used as windows for visual observation of internal volume of the vacuum chamber and measuring current leads. The sample is fixed at the electrode and can be heating up to 400°C for outgassing. The additional chamber with the monopole mass spectrometer connected to the working chamber.

1.2. MASS SPECTROMETRIC ANALYSIS

The monopole mass spectrometer MH7304A is used as RGA in the vacuum chamber. Its advantages are compatibility, relatively cheapness and linear mass scale [8].

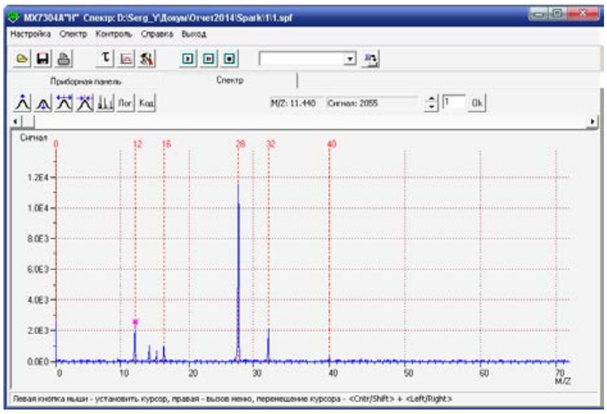

Fig. 3. The interface of software for mass spectrometer with spectrum of residual gases

The mass scale range of mass spectrometer is from 1 to 400. The software for automation control of mass spectrometer was developed by IAP NAS of Ukraine [9]. Fig. 3 shows the interface of the software with spectrum of residual gases.

1.3. MEASUREMENT AND BREAKDOWNS REGISTRATION

The electrodes of the discharge gap have tip-plane configuration, and are located in the vacuum chamber. The sample is mounted on the special holder used as cathode. The size of the sample is 11 mm diameter and 2 mm thickness. The sample holder located on the stem isolated from the walls of vacuum chamber. Though high-voltage input (a metal-ceramic insulator) the high-voltage with negative polarity is applied to the cathode. The power supply allows for reached of electrical field strength up to 500 MV/m. The anode has 2.5 mm diameter and rounded end.

The experiment process is require the possibility of anode motion in two dimensions: set the distance between the electrodes for reaching required value of electrical field strength, and the anode positioning relatively to cathode (test sample) for using sample surface area more useful.

These two goals are achieved by using the mechanism for anode motion. It is located at the top flange of the vacuum chamber. This mechanism allows to change gap distance in the wide range with precision 5 µm and move anode above the cathode by circle with radius 4 mm with accuracy 7 degrees. The Fig. 4 shows the electrodes configuration inside the vacuum chamber.

Fig. 4. The cathode-holder with the sample and anode in the vacuum chamber

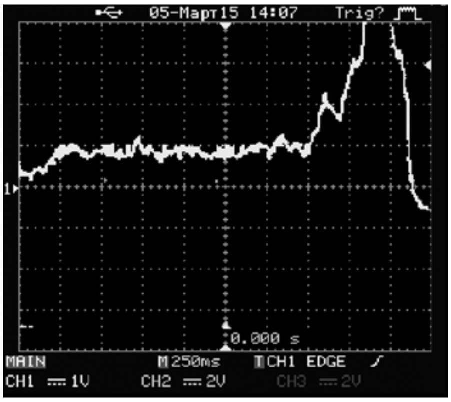

Fig. 5. The image of pre-breakdown and breakdown currents from the oscilloscope

For pre-breakdown current and breakdown events registration the signal output from the through insolated input at the side flange. The digital voltmeter B7-21A is used for pre-breakdown current measurement of small magnitude. The digital oscilloscope GDS-2064 records the current dependence of the time during breakdown process (Fig. 5).

1.4. OPERATING SYSTEM

Automation of the high voltage breakdown registration is required for precise definition of breakdown event, breakdown voltage and pre-breakdown current evolution control of the gap at the voltage changing. The automation provides the computer control of high voltage (100 kV) applied by high voltage power supply and current registration in the gap using B7-21A voltmeter connected to the computer. The software is writing using Delphi environment. The program records data monitors the changes in current and saves data to a file.

2. SAMPLES AND PRIMARY TESTS

The copper and iron samples with low content impurities were used as cathode material at the primary experiments. There are two types of copper samples were used: copper from CERN made by KUGLER GmbH (101 OFE Copper) and made by IAP NASU (grade M1). The samples preparation procedure at IAP NASU is include mechanical grinding, polishing and clearing. As anodes copper C10100, stainless steel 12X18H10T and tungsten rods were used. The distance between electrodes is set typically to 100 µm in the most experiments because the positioning accuracy is around 5 µm. Since gap distance decreasing supposed to use low voltage applied to the cathode for reaching the breakdown field, however, the erosion of the electrodes surface can reach the values comparable with gap distance. According the data from [10], where the gap distance was set 20 µm, the value of erosion reached 50% of the gap distance after few tens of breakdowns during experiments with Ti samples.

To minimize the effect of vacuum conditions to experimental results, the vacuum chamber is heated for outgassing and pumped down to pressure above $(1\ldots5)\cdot10^{-7}$ Pa. The high voltage with negative polarity is applied to sample holder (the cathode). The voltage is increased smoothly and produced the electrical field strength started from 50 MV/m up to value of field when breakdown is happen. The breakdown voltages were determined at the several sites of the sample. To except the effect of the sample surface geometry, the anode position is changed relatively to the tested site at the cathode, where the breakdown occurred during previous tests. The signal taken from the anode is determinate the current at the gap and the breakdown event as described above.

The results from the first experiments are shown in the Figs. 6, 7. The Fig. 6 shows the gap distance effect to breakdown field for tungsten anode and copper cathode from CERN.

The minimum electrical breakdown field strength corresponds to the high voltage applied to the cathode, when first single sparks are happened and further voltage increase is possible.

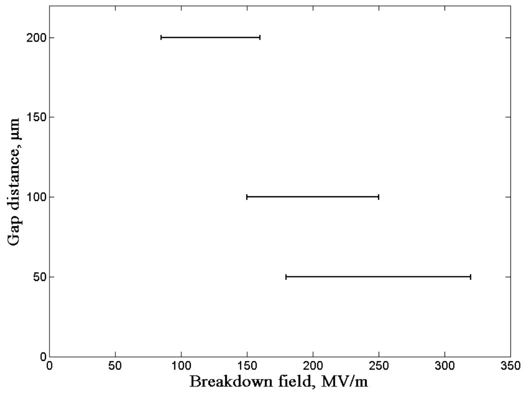

Fig. 6. The electrical breakdown field dependence on the distance between the electrodes (W anode and Cu cathode are used)

There is so-called “training” of the electrodes surface. The maximum of the field strength range (see Fig. 6) corresponds to the applied voltages, when the surface structure changes of the sample are critical and it makes impossible of further field strength increase at this site. According to the data at the Fig. 6, the gap distance increase allows to decreasing of electrical breakdown fields range, this is consistent with data presented in [11, 12].

Fig. 7 shows the average values of electrical breakdown field reached between Cu (from IAP NASU) and Fe cathodes and anodes from different materials.

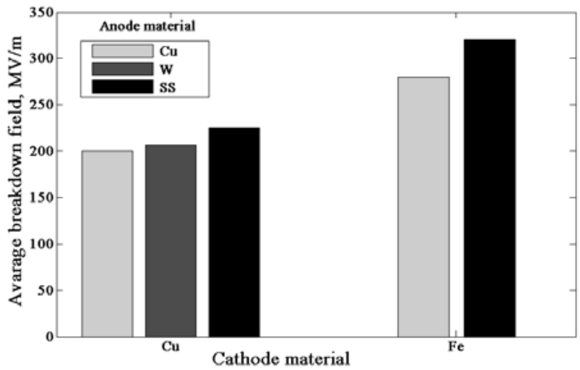

Fig. 7. The average breakdowns field reached between electrodes from different materials for 100 µm gap distance

According to these data, during experiments with different anode metals and the same material of cathode the electrical breakdown fields have the same order of value, but slightly different depending on anode material. The similar experiments are describes in [10] at the gap 20 µm between titanium and tungsten materials as materials of anode and cathode and alternatively. In this case any different in electrical breakdown fields was notice. The authors explained this by the low energy deposited in the anode. At equal electric field, a smaller gap needs a lower voltage. The heating effect at the emission site on the cathode, driven by field emission, is dominated, while the field emitted electrons deposit only a moderate amount of energy on the anode.

It should be noted, the electrical breakdown fields increasing for different anodes (and the same cathodes) has the same tendency in changing as at the experiments with the two electrodes made from same materials [10].

CONCLUSIONS

The system for studying the high-voltage breakdown processes at the material for accelerating technology was design and tested. The setup measures the pre-breakdown currents and the breakdown voltage in the gap between two electrodes. The tested sample is mounted at the cathode holder. The special mechanism is provide the possibility of anode motion relatively to the cathode. The operating system allows to smoothly controlling the voltage at the cathode and records the current in the gap between electrodes. The mass-spectrometry control of gas environment in the vacuum chamber is available. The capabilities of our system are illustrated through the test of the electrodes made from different materials. The influence of gap distance and electrodes material to the conditions of breakdown events were studied. The experiments for surface modification influence to the breakdown field of different materials are planed to be done in future at this setup.

ACKNOWLEDGEMENTS

Publication is based on the research provided by the grant support of the State Fund For Fundamental Research (project N Ф58/174-2014) as well as by the National Academy of Sciences of Ukraine (NASU) under the program of cooperation between NASU, CERN and JINR Prospective Research into High-Energy and Nuclear Physics under Contract No ЦО-5-1/2014).

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Article received 05.05.2015

ЭКСПЕРИМЕНТАЛЬНАЯ УСТАНОВКА ДЛЯ ИЗУЧЕНИЯ ВЫСОКОВОЛЬТНЫХ ПРОБОЕВ В УСЛОВИЯХ ВЫСОКОГО ВАКУУМА

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Описана экспериментальная установка для изучения процессов, происходящих при пробое в условиях высокого вакуума. Установка предназначена для сравнительных исследований предпробойных процессов и напряжения пробоя для различных материалов, используемых в ускорительной технике. Приведены первые экспериментальные результаты.

ЕКСПЕРИМЕНТАЛЬНА УСТАНОВКА ДЛЯ ВИВЧЕННЯ ВИСОКОВОЛЬТНИХ ПРОБОЇВ В УМОВАХ ВИСОКОГО ВАКУУМУ

В.А. Батурін, О.Ю. Карпенко, Я.В. Профатілова, С.О. Пустовойтов, В.І. Мирошніченко

Описано експериментальне обладнання для вивчення процесів, які відбуваються при пробоях в умовах високого вакууму. Установка призначена для порівняльних досліджень передпробійних процесів та напруги пробою для різних матеріалів, що використовуються в прискорювальній техніці. Наведені перші експериментальні результати.