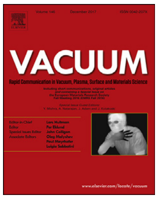
Vacuum 146 (2017) 79–86

Contents lists available at ScienceDirect

Vacuum

journal homepage: www.elsevier.com/locate/vacuum



Investigation of cold cathode for nanosecond electron accelerators

S.Yu. Sokovnin [a, b, *], M.E. Balezin [a, b]

[a] *Institute of Electrophysics UB RAS, 106 Amundsen Street, Yekaterinburg, Russia*
[b] *Urals State Agrarian University, 42 Karl Liebknecht Street, Yekaterinburg, Russia*

ARTICLE INFO

Article history:
Received 16 June 2017
Received in revised form
1 September 2017
Accepted 2 September 2017
Available online 12 September 2017

Keywords:
Accelerators
Radiation technology
Cold cathodes
Pulsed cathode luminescence
Food irradiation

ABSTRACT

In many technological applications, electron beams of large size are required on one of the coordinates. The cold cathode used for this purpose has to possess high stability of characteristics, durability and be able to generate a uniform distribution of the electron beam current density. Comprehensive research into the properties of the metal dielectric (MD) cathode on the URT-1M accelerator was conducted. The influence of quantity and the relative positioning of the emission elements on the beam parameters and distribution of the electron beam current density were established. The influence of the shape of the cathode case on stability of operation at a high repetition rate was also investigated. A measurement technique using pulsed cathode luminescence (PCL) of phosphorus to estimate the distribution of the electron beam current density was developed. This PCL technique was tested by a dosimetry technique using plastic detectors. The qualitative compliance of the results from both techniques was established. By selecting the number and arrangement of MD plates, it was possible to obtain a more or less uniform (15%) electron beam current density distribution on the output foil.

It was set so that falling of emission MD cathode by operation at high repetition rates (>100 pps) occurs rather slowly, thus ensuring continuous functioning for 40 h.

1. Introduction

Frequency nanosecond electron accelerators of the URT series, based on the thyratron -pulse-transformer- semiconductor opening switch scheme [1], are successfully used for the industrial modification of film polymers [2], radiation sterilization [3], production of nanopowders [4], development of new sorbents [5] and dosimeters [6], i.e. in the radiation technologies at the surface, in gases and layers of liquid, loose or solid materials with layer thickness up to 0.3 g/cm^2.

In many technological applications, electron beams of large length are only required for one of the coordinates. The cold cathode used for these purposes should have a high stability of characteristics, durability, and provide a uniform distribution of the current density over the width.

The cathode is one of the critical elements of nanosecond electron accelerators (NEA). Historically, it is the first type of the cathode which was used in the NEA explosive emission cathode. However, it can work only in case of high intensity of an electric field (>50 kV/cm), has significant (tens of nanoseconds) time delay of current appearance in the event of intensity submission, and rather fast loss of the emission properties [7,8] that created the development of new types of cathodes, especially for repetitive accelerators.

Our approach to a solution consisted in the creation of cathodes based on use of electron emission from plasma (arc discharge, discharge with hollow cathode, etc.) [9]. In these types of cathode, plasma appears before the acceleration voltage that allows its parameters to be controlled completely. However, use of these cathodes requires additional power sources, and trigger and synchronization systems that significantly complicate designs, and also the use of these types of cathode in industrial NEA.

The existing cold MD (metal-dielectric) cathodes have satisfactory characteristics. The principle of their action is based on use of electron emission from the plasma of the pulse discharge on a dielectric in vacuum [10]. With use of a large number of such discharge emission elements in vacuum on the dielectric surface, a large size MD cathode [11] is created, allowing uniform distribution of discharge on all the dielectric surfaces of quite large squares to be achieved. Structurally the MD cathode is a dielectric plate with high inductivity (barium titanate) on which the metal gauze densely rests.

---

* Corresponding author. Institute of Electrophysics UB RAS, 106 Amundsen Street, Yekaterinburg, Russia.
E-mail address: sokovnin@iep.uran.ru (S.Yu. Sokovnin).

https://doi.org/10.1016/j.vacuum.2017.09.014
0042-207X/© 2017 Elsevier Ltd. All rights reserved.

Research into the creep on the surface barium titanate in vacuum [12] made it possible to establish that the discharge on the dielectric starts from a threshold value of intensity, the size of which grows with reduction of inductivity, increase in thickness of dielectric and shortening of the pulse. The mechanism of starting the discharge is connected with micro-gaps on the surface of the metal and dielectric in the field of contact. This leads to a considerable strengthening of electric field intensity in these micro-gaps, and as a result, to explosive emission of electrons from the metal. Thus, on the surface of the dielectric there is a dense plasma which in some way increases the area of the electrode and significantly (many times) reduces the work function. The discharge begins to develop from the edges of where the plasma is created. It leads to heating of the dielectric as the result of electron bombardment, to evaporation of the dielectric material and the subsequent ionization of these vapors. Spectrographic investigation has shown that in the range of luminescence of the discharge, there are registered lines of barium and other components of the dielectric, and also material of the metal edge. Further research of explosive emission from the MD cathode [13] made it possible to establish that the pulse rise rate of the electron beam depends on the area of the emitting plasma surface.

The MD cathode provides fast formation of the plasma surface, not only of explosive emission from the metal, but also formation of plasma on the dielectric surface as a result of electronic bombardment from the formed plasma. In the case of extension on the dielectric surface at the front of the plasma, there is a tangential electric field in relation to the surface which draws out electrons from the plasma, directing them to the surface. It leads to additional creation of plasma on the dielectric surface, to increase in growth rate of the plasma surface, and to rise of current.

On the basis of the data obtained by the authors [14], a design of the MD cathode consisting of a packet of dielectric plates set vertically in the metal base was developed. The metal combs in elastic contact with the dielectric and electrical contact with the base (an emissive element) rest on the dielectric plates. Similar cathodes work perfectly in NEA and make it possible to create emitting surfaces of large size. However, to start operation, the MD cathode requires rather high intensity of the electric field, and the cathode's effect is restricted to an erosion of the dielectric surface.

For lowering of electric field intensity, one of the versions of the MD cathode [15] contains an additional outer electrode. In the event of the application of a start pulse which moves before the arrival of the main pulse between the cathode holder and the outer electrode, executed in the form of a band, there is an incomplete breakthrough, which is initiated at triple points, i.e. where the metal is in contact with the dielectric in vacuum [16]. It makes it possible to control the parameters of a created electron beam of average electric field intensity (<20 kV/cm) and acceleration intensity with a density of electric current up to 25 A/cm^2, without formation of explosive emission plasma. The shortcomings of the cathode include rapid lowering of the emissive properties of such cathodes [17,18] at the density of the electric current >100 A/cm^2, and also the fact that it requires the use of an additional power source, and trigger and synchronization systems.

By the start of our work, there were some data about the work of the vacuum diode with explosive emission [19] and MD [20] cathodes. In the event of low vacuum, they did not make it possible to determine cathode parameters, their influence on the impedance of the vacuum diode, or the current distribution of the electron beam on the anode.

Therefore it was expedient to continue this research to determine the nature of change of the vacuum diode impedance with the MD cathode, and also the size and structure of the forming electron beam that is essential e.g. in the case of an output electron beam in the atmosphere, and in many practical applications.

The purpose of the work was the creation of an MD cathode for the generation of an electron beam up to 400 mm wide with non-uniformity of current density distribution of electron beam on an output foil ~15% capable of operating continuously at high repetition rate (>50 pps) for at least 40 h (working week).

In this work, a comprehensive study of the properties of MD cathodes on the accelerator URT-1M was carried out [21]. In particular, the influence of the number and mutual arrangement of the emitting elements (EE) of the cathode on the beam parameters and the uniformity of the current density distribution was investigated. In addition, the effect of the shape of the cathode body in which the EE was installed on the stability of operation high repetition rates (more than 50 pps) was studied for use in URT-1M-300 [22] and URT-0.2 [1] accelerators, for food irradiation, in particular, for eggs in the flow [23].

2. Description and results of experiments

The drawing and photo of MD cathodes for producing electron beams are shown in Fig. 1. The EEs were placed along (Fig. 1a and b) and across (Fig. 1c) the cathode casing. In this case, emitting elements containing 19 (EE19) and 5 (EE5) triple points (TP) metal-dialectic-vacuum were used (Fig. 1). Two types of cathodes were created to produce a beam of 200 and 400 mm width, the first for the URT-02 accelerator series, the second for URT-1 accelerators.

Originally, a design of cathodes having a rectangular casing with rounded corners was used (Fig. 2) [21]. This resulted in emission from the corners of the shells, the heating of these places and the appearance of carbon deposits during prolonged operation at high frequencies. This effect was eliminated by changing the design of the cathode casing, as well as the EE holders. Under these conditions, the deposit is distributed evenly throughout the cathode during prolonged operation at high repetition rates (Fig. 1d).

A film detector [24] was then successfully used to measure the electron beam current density distribution (EBCD). For all its advantages, this method possesses essential shortcomings — labor inputs and brief duration. Of course, dosimetric technology is not direct measurement of EBCD distribution as an application of a collimated Faraday cup; however, the application of such a cup is possible only in a vacuum and is difficult in application. Apart from this, measurements with use of a Faraday cup have poor space resolution. It is important that the absorbed dose is directly proportional to the EBCD distribution.

The first shortcoming is connected to the large number of manual operations required to measure the optical density of blackening of the dosimeter in a set of points, the number of which determines the space resolution of the EBCD distribution. Modern scanners allow labor input to be reduced sharply, but increase absolute measurement errors, since scanning is done in all visible wavebands, but not in the waveband selected for the detector. It is not essentially possible to eliminate the second defect, but at the same time, the irradiated detector is a document. Furthermore, film detectors are rather expensive.

The specified shortcomings stimulated development of new methods of EBCD distribution measurement; note in particular the thermal imager [25] and radiation and acoustic [26] methods.

For on-line diagnostics of the pulse electron beam energy distribution on the section, use was made of the thermal image of a foamed polystyrene target surface after irradiation by the pulse electron beam produced by means of the thermal imager Fluke TiR10 (spectral range 7÷14 μm). The analysis of the thermal imager signal permits space distribution of EBCD within the permissible error (~1÷2 mm); however, the method demands application of high current electron beam with rather high energy for essential