Influence of the auxiliary plasma on the deuterium optical spectrum emitted from the dielectric target being irradiated by the e-beam with energy up to 25 keV

Yu S Akishev¹,², A A Balakirev¹, A V Petryakov¹ and N I Trushkin¹

¹SRC RF TRINITI, 108840, Russia, Moscow, Troitsk, Pushkovykh Str., 12
²National Research Nuclear University MEPhI, 115409, Russia, Moscow, Kashirskoe sh. 32

Abstract. The dielectric or metal targets isolated from the ground and being irradiated by an electron beam accumulate the electric charge on their surfaces. The amount of a charge is determined not only by the parameters of an e-beam and material of the target and sort and pressure of the gas in which the target is placed but also by the existence or absence of plasma around the target. The paper presents the experimental results about influence of the barrier discharge (BD) plasma on a spectrum of the radiation arising at a surface of a quartz plate irradiated by an electron beam with energy up to 25 keV. The high-current e-beam was generated by the pulsed open discharge in strongly overvoltage regime. The BD-plasma did not influence a shape of the Dα line radiated from the near-surface area of a target that proves a weak impact of the BD plasma on the charge of a target and electric field around the target.

1. Introduction

High-current electron beams of average energy (up to 25 keV) are used in various applications. One of the recent and promising application of such e-beams is the ultrahigh charging of dust particles [1, 2]. High electric charge can be accumulated on dielectric or metal targets isolated from the earth and placed in the path of an electron beam. The amount of charge is defined not only by parameters of a beam, material of a target and sort and pressure of gas surrounding the target but also by the existence or lack of plasma around the target. In case of the particles placed in a vacuum, an e-beam doesn't create plasma around them, and the amount of the charge deposited by a beam on a target will be determined only by parameters of a beam and material of a target. In the gaseous ambiance around a target, plasma is being created by the slow secondary electrons which are beaten out from a target and such electrons have the large cross-section for ionization. On the one hand, the arising positive ions will discharge a negatively charged target. However, on the other hand, this process can play also a positive role.

In papers [1, 2] it is offered to use the deuterium positive ions which can be accelerated in the strong E-field of the negatively charged target up to high energy sufficient for generation of neutrons at their striking the target containing deuterium or tritium. In these works, it was shown by numerical calculations that the preset concentration of ions in the surrounding plasma will quickly diminish due to their leaving onto the negatively charged particles if there is no any source generating the plasma. The rate of depletion of ions around a target depends on the initial density of the plasma. This process reduces the efficiency of generation of neutrons even in the case of the high amount of the charge on the particles. It should be noted that in these calculations the ionization of gas around particles by slow
secondary electrons which are beaten out by beam electrons was not considered. The efficiency of formation of slow secondary electrons increases with the potential energy of a beam. In this case, electrons of a beam are being slowed down in the E-field of the charged particle to energy at which the efficiency of knocking-out of secondary electrons approaches unit. In this work the question is raised - whether the plasma generation by a beam in the vicinity of a target is effective in comparison with the barrier discharge creating plasma around the target? As a tester, the radiation of the Dα line of the Balmer series emitted from the near-surface area of a target is used. The shape and intensity of this line react to the electric field and the density of plasma around the target charged by a beam, therefore, comparison of a contour of this line in the presence of the BD plasma and without this plasma will allow us to receive the answer to the question posed.

2. Experimental setup
The scheme of the experimental setup is shown in Fig. 1. The electron beam with the energy of electrons up to 25 keV was generated by the overvoltage open discharge in a deuterium at pressure P= 0.5 - 2 Torr with use of the three-electrode system placed in a quartz tube with an internal diameter of 110 mm and 300 mm in length. The movable electrode system for creation of the auxiliary discharge was also placed in a quartz tube. The dielectric barrier discharge excited by sinusoidal voltage with the frequency of 100 kHz has been used as the auxiliary discharge to generate additional plasma around the target. Two 60x60 mm in size and 1.5 mm thick ceramic (Al2O3) plates served as dielectric barriers. The copper foil of 50 microns thick and the size of 40x40 mm has been pasted on the back side of each plate. Each foil was covered by a thick layer (15 mm) of the dielectric material. The distance between ceramic plates is equal to 36 mm. The transparent quartz plate 36x60 mm in size and 1.5 mm thick has been placed in the gap between two electrodes of BD. The plate has been situated in the middle of an inter-electrode gap and oriented perpendicular to the ceramic plates and to an electron beam as well. The electric power consumed by the BD does not exceed 0.5 W.

Figure 1. The scheme of experimental setup with the auxiliary dielectric barrier discharge and a quartz target. 1 is the electron gun; 2 are the dielectric plates; 3 are the ceramic plates with metallization (BD electrodes); 4 is the target (thin quartz plate), 5 is the spectrometer.

Dynamic spectral measurements were performed with use of the double monochromator MDR-6 (spectral resolution 0.7 Å), at the exit of which there was a photomultiplier tube. The radiation emitted from the area where the quartz plate interacts with an electron beam was registered by fiber-optical spectrometer AvaSpec-2048L (spectral range λ = 200-1100 nm, spectral resolution Δλ =1.2 nm). The recorded spectrum was integrated over the time of the recording. The currents and voltages of the open discharge and BD were registered by low-inductive current shunts R = 0.024 Ohm and R = 50 Ohm and by the compensated voltage dividers PINTEK HVP-39 (1000:1, 40 kV, 200 MHz), respectively. The electrical signals from the current shunts, voltage dividers and PMT were transferred to digital oscilloscope Tektronix DPO 2024. The images of luminescence formed by the BD, e-beam and plasma in the area of interaction of a quartz plate with an e-beam were taken by Canon EOS 550 and CASIO-EX-F1 digital cameras with a frequency of 1200 shot/s. To maintain high purity of the working gas (99.99% of D2), all experiments were performed at weak pumping of the gas through the gas-discharge camera.
3. **Experimental results and discussion.**

The overall view of the e-beam propagating from the right to the left and the target irradiated by e-beam is shown in Fig.2. The distance between the e-gun exit and the target is 18 cm. One may see that the visible cross-section of the gas luminescence produced by the e-beam shrinks with a distance from the e-gun exit. However, the visible diameter of light spot on the target exceeds the visible diameter of the gas luminescence at the target.

![Image](image1.png)

**Figure 2.** a) The image of a luminescence emitted by both the deuterium along the e-beam trajectory and the target (on the left) area irradiated by e-beam generated by open discharge in the pulsed-periodical mode with a frequency of 150 Hz. The barrier discharge is switched off. The exposure time is 0.6 s. b) The voltage and current waveforms of the overvoltage open discharge generating e-beam. The discharge voltage is 25 kV, gas pressure P = 2 Torr.

The deuterium review spectrum of the light emitted from the target area irradiated by the pulsed-periodical e-beam in the course of 40 pulses is presented in Fig.3a. The spectrum in Fig.3b represents the joint action of the pulsed-periodical e-beam and the BD continuously operating during 40 short pulses of the open discharge pulsing with a frequency of 1 Hz. It means that real exposure time for the BD plasma exceeds the exposure time for the e-beam plasma by factor of $10^6$. This is the main reason why the intensity of spectrum in Fig.3b exceeds the intensity of spectrum in Fig.3a. Follows from the presented results that spectrum of the radiation collected from the area of interaction of an e-beam with a target includes both molecular bands and atomic lines. Close examination of these spectra reveals that the BD influences mainly the intensity of molecular bands but the intensity of spectral lines of Balmer series is determined predominantly by the e-beam.

![Image](image2.png)

**Figure 3.** The review spectrum of the deuterium emitted from the target area irradiated by the pulsed-periodical e-beam in the course of 40 pulses (a); the spectrum of the joint action of the e-beam and the BD continuously operating during 40 pulses of the open discharge pulsing with a frequency of 1 Hz. The discharge voltage is 25 kV, gas pressure P = 2 Torr.

It has turned out that in the absence of the BD plasma in the vicinity of the target the radiation of the Dα line arises later about 100 ns after the beginning of charging of a target by an e-beam (see Fig. 4a). The creation of the BD plasma around the target does not change the magnitude of this delay and
does not provide the appearance of the $\text{D}_\alpha$ line emission before these 100 ns. It means that the plasma quickly created by the e-beam exceeds the influence of the plasma supported stationary by the BD. We suppose that the revealed delay can be attributed to the time that is necessary to charge the target to the potential which is equal practically to kinetic energy of the e-beam. After that, the charged target will strongly decelerate the e-beam. Due to that, the great number of the retarded electrons of the e-beam and the low-energy secondary electrons taken out of the target appear around the target. In contrast to high-energy electrons of the e-beam, the low-energy electrons have ability effectively dissociate a deuterium, excite his atomic and molecular states and also provide intensive ionization. After the termination of the beam, the luminescence of the $\text{D}_\alpha$ line continues the increasing that is succeeded by a long decay which is attributed to the discharging of the target by positive ions.

![Figure 4](image)

**Figure 4.** a) Temporal behavior of the emission intensity of the $\text{D}_\alpha$ line for different parts of its contour; the figures at the curves show the wavelength on the contour. The emission happens due to irradiation of the target by the e-beam. This picture shows also the voltage waveform of the discharge generating the e-beam. b) and c) the shape of the $\text{D}_\alpha$ line recorded at the moment $t=136$ ns after applying the voltage; the central part of this line is described by Gaussian approximation with half-width about 1.9 Å (b) and 1.97 Å (c); b) the BD is switched off, c) the BD is switched on.

4. Conclusion.
Approximation of the line form by a Gaussian contour has shown that half-width of lines without and with the BD plasma are almost identical and equal to 1.9 Å and 1.97 Å. It proves high intensity and efficiency of plasma production around the highly-charged target by primary and secondary electrons which are formed due to deceleration of an e-beam by the target. Thus, the formation of the barrier plasma in the area of interaction of an e-beam with a charged target practically changes neither dynamics of $\text{D}_\alpha$ line radiation from this area or shape of this line (see Fig.4b, c). The obtained results allow us to hope for the realization of neutron generation due to the ultrahigh charging of targets by an e-beam without the use of any auxiliary discharges.

5. References
[1] Akishev Yu, Karal’nik V, Petryakov A, Starostin A, Trushkin N and Filippov A 2017 *Plasma Physics Reports* **43** 472–479

[2] Akishev Yu, Karal’nik V, Petryakov A, Starostin A, Trushkin N and Filippov A 2017 *Journal of Experimental and Theoretical Physics* **124** 231–243

Acknowledgments
This work has been carried out thanks to full financial support by the Russian Science Foundation (Grant № 16-12-10458).