OPTIMIZATION OF A LOW-ENERGY ELECTRON GUN BY ELECTRON RAY-TRACING SIMULATIONS

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Abstract. We have performed electron ray-tracing simulations, in order to optimize a commercial low-energy electron gun used for controlled irradiation of biological samples deposited on a surface. The simulations have been performed by using SIMION program packet, for electron energies from 1 to 20 eV. The results suggest possibilities to improve the performance of the electron gun considering the stability of the focal position over the used energy domain.

1. INTRODUCTION

A novel method that allowed for the first time to visualize the electron-induced dissociation of single chemical bonds within well-defined self-assembled DNA nanostructures has been recently developed [1]. It is based on AFM imaging and quantification of low-energy-electron-induced bond dissociations within specifically designed oligonucleotide targets that are attached to DNA origami templates.

The previous electron-irradiation experiments [1] investigated the strands breaks as a function of electron fluence at fixed electron energy of 18 eV, and it was found that at the fluence of 1–5x10^{12} cm^{-2} the number of DNA strand breaks increased linearly with the fluence. Further experiments are presently in progress, in order to investigate the electron energy dependence of the strand breaks over a domain from 1-20 eV. In order to perform such experiment properly, the incident electron beam should be controlled to preserve an optimal electron current density at the sample. We present herein the electron ray-tracing simulations that should help obtaining the best conditions of the electron gun used in the experiment. Although the present study does not take into account all possible parameters (for example, the Earth and other stray fields), the results suggest possibilities to improve the performance of the electron gun.

2.RESULTS AND DISCUSSION

2.1 Simion

The simulation of the electron gun in the present study was conducted by using the commercial program SIMION8[1]. Briefly, a desired geometry of the electrodes of the gun is loaded into SIMION through a geometric file, written in SIMION’s specific programing language. Each electrode, specified in the geometry file has itsown electric potential value, which should be defined by the user. SIMION program solves the Laplace equation for a given electric potential and stores data in a potential array (*.pa#) file. By solving Laplace equation, SIMION calculates the electric field defined by gradient of electrode potential, using a method of finite differences. Additional changes of electrode potentials and starting conditions of the projectiles (electrons) have been done through “LUA” programing code, written in a separate file which controls the entire simulation. In the final step, charged particle trajectories are being displayed.

2.2 Modeling and simulation

The present electron gun consists out of five cylindrical electrodes, with the cathode being one of them. Geometry of the electrodes and a 3D model of the electron gun are displayed in Figure1.

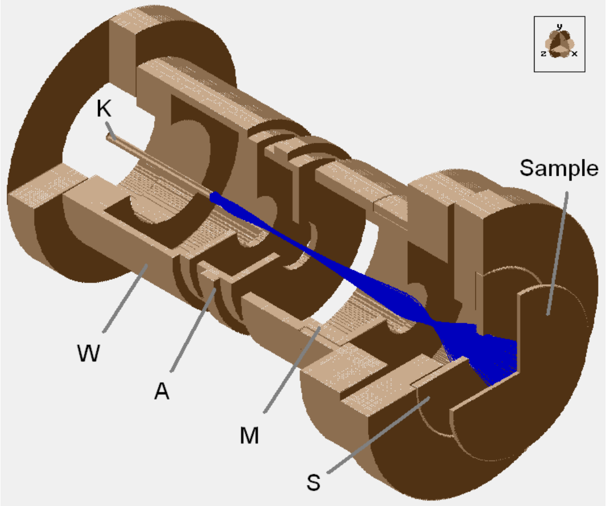

Figure1. 3D model image from SIMION8 of the electron gun. Denotations: K-cathode, W-wehnelt, A-anode, M-metal rings (gnd), S-shutter and Sample holder disk.

In the present simulations, in order to preserve a cylindrical symmetry of the whole electrode assembly, the cathode is made as a simple bar, although it is hairpin in real. This should not affect the present preliminary simulation, because the electrons are generated just in front of the cathode with 0.1eV energy,without simulating a thermo-electronic emission, where a shape of the cathode is very important.

The present experimental setup has W, M and S (see Figure 1) set on the ground voltage, with the anode biased to a high positive voltage (500V in the simulation). The sample disk is grounded through a picoamperemeter and placed at a distance of d=5 mm apart from the last electrode (shutter), while cathode is set to a negative voltage which defines the electron energy. To control the irradiation time, a deceleration of all electrons is achieved by applying a small negative voltage (around 110% of the electron's energy) on the shutter electrode (S). In the simulation, 501 electrons were generated uniformly from a disk with a radius of r=0.5 mm, with E_0=0.1 eV initial energy and α_0=45° cone divergence angle, just near the surface of the cathode. The radius of the electron beam as a function of the electron energy was recorded, with fixed anode voltage (Figure 2).

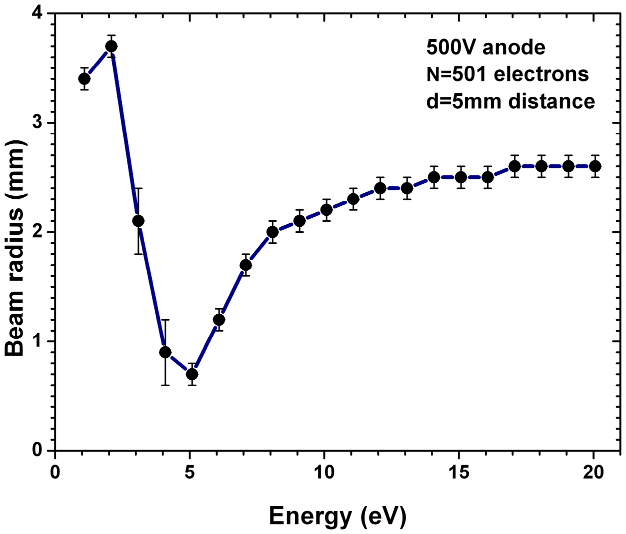

Figure2. The radius of the electron beam for different electron energies, at 5mm distance from the exit, with fixed anode voltage of 500V.

Low energy electrons (up to 5 eV) are highly scattered, with the Wehnelt electrode being grounded, because no primary extraction zone was formed. In that energy range, the transmission of electrons through the electron gun was below 50%, while the electron beam had unstable geometry. For the electron energies above 5eV, the electron beam is well defined and approaches desired 2.5 mm radius (5 mm diameter) even with the fixed anode voltage. Optimization of the anode voltage up to 5eV energy range, had no influence on the stabilization of electron beam. Experimentally obtained electron beam diameter at 10 eV is in a good agreement with the calculated value.

In order to further improve the electron transmission and better control the beam geometry, formation of the primary extraction zone as well as it's tuning of gun’s potentials as a function of the energy is needed. This was done by setting floating voltages on the wehnelt and the anode (W and A in Figure1, respectively) relative to the cathode. W was set to -4V, while A was set to 500V, both relative to K. With additional programming in “LUA” the voltage on A was adjusted in order to obtain the beam radius of r=5 mm at a distance of d=5 mm, from the shutter, for different applied electron energies. The results of this optimization are given in Figure3. Clearly, beam radius is dependent of the energy, therefore at least one (anode) voltage must be set accordingly.

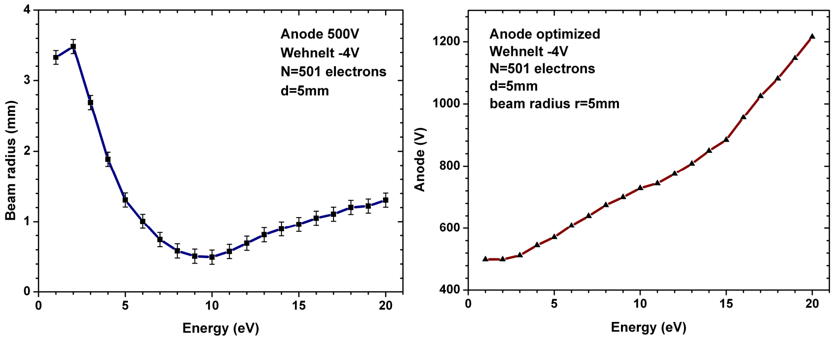

Figure3. Left: Electron beam radius at d=5mm distance for fixed anode (500V) and wehnelt (-4V) voltages, relative to kathode; Right: Optimized anode voltage, to keep electron beam radius near r=5mm at a distance of d=5mm.

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