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Returning Electron Simulation for a Klystron Collector Using EGS4

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Abstract

The process of electron backscattering in a klystron collector has been calculated using EGS4. A program to simulate the returning electrons from the klystron collector has been developed and its evaluation achieved. The effects of the collector shape, i.e. its diameter and length, are discussed and physical phenomena are clarified. The dependence of the returning electrons on various materials is also discussed in this paper.

1 Introduction

For a klystron collector, various efforts were made to understand power dissipation, cooling method, collector potential depression and so on. Though the roles of secondary electrons and backscattered electrons on the collector surface were suggested regarding abnormal collector heating, less attention had been paid to the returning electrons from a collector. Recently, UHF klystrons at KEK have shown a strong oscillation without any driving power in the input cavity, and it was found that this oscillation was caused by returning electrons. Recently, the EGS4 Monte Carlo method[1,2] has enabled us to simulate electrons interacting with the collector material in the energy range from a few keV to several hundred keV; this energy range corresponds to the applied voltage of a klystron. Thus, a simulation of the returning electrons from the klystron collector has been attempted by designing a program using the EGS4.

In this paper, prior to klystron applications, the EGS4 results are compared with experimental data to check the accuracy in chapter 2. We have successfully performed a simulation on the returning electrons from the klystron collector. Descriptions of the calculation method and the application results to the klystron collector are given in chapter 3.

2 Comparison Between Backscattering Simulations and Experiments

Concerning the klystron collector, we are interested in electrons in the energy range from a few keV to several hundred keV. Many scientists, such as E. J. Sternglass[3] and G. Neubert[4], had measured backscattered electrons in this energy range. The experimental concept for backscattered electrons is shown in Fig.1. Generally, a backscattering coefficient is defined as the ratio of the amount of backscattered electrons to that of incident electrons. The angle dependence of the backscattering coefficient for copper[4] is shown in Fig.2. The energy distribution of backscattered electrons[3] is shown in Fig.3.

For this decade, an electron backscattering process could be simulated using the EGS4 code. Before applying EGS4 to a klystron, it is necessary to confirm the code validity by comparing the calculation with experiments for the fundamental process. This was applied for the case of a copper plate thicker than 1mm.

It is well-known experimentally that the backscattering coefficients are essentially independent of the primary energy[3]; a simulation reproduced this successfully. For normal incidence on copper, the backscattering coefficient is known to be about 0.3, and a simulation gave the same value. Fig.2 gives the simulation results of the backscattering coefficient as a function of the incident angle. The calculated energy distributions of backscattered electrons are shown in Fig.3. The simulation results of backscattered electrons agree well with the experiment results. From these studies, it is concluded that the EGS4 code is sufficiently reliable to be applied to backscattered electrons from a klystron collector.

3 Returning Electrons From a Klystron Collector

3.1 Simulation method

In the klystron the electron beam emitted from a gun is focused by external magnetic fields are transported in the drift tube. The focusing magnetic field decreases rapidly at the entrance of the collector and the beam diverges in the collector due to the space-charge force. After the beam bombards the collector surface, some of electrons are backscattered, and secondary electrons are also created. Since the energy of the secondary electrons is less than 50eV, we could neglect these effects. Some of the backscattered electrons have a chance to go back to the drift tube directly, or undergo a few successive collisions with the collector wall. Some of them are reflected by the rapidly varying magnetic field due to its mirror effect, and electrons which are not reflected can be focused again by the magnetic field in the drift tube and transferred to the gun direction. These are called returning electrons, and are considered to be harmful since they can cause instabilities. Here, we define the returning electron coefficient as the ratio of the number of returning electrons to the number of incident electrons.

The simulation of returning electrons from a klystron collector is divided into three steps:

1. a beam trajectory calculation due to the space-charge force in the collector up to the collector wall,
2. a calculation of backscattered electrons on the collector surface using the EGS4 Monte-Carlo method and associated track calculation in the collector, and
3. a plotting routine of the trajectories after the simulation.

The programs of step (1) and step (3) have been written by FORTRAN 90.

In step (1), the initial conditions of the beam at the entrance of the collector are calculated first. Here, because we assume the case of no driving rf power in an input cavity, the electrons have a constant kinetic energy corresponding to the applied voltage. A uniform-density beam is assumed and beam rotation due to the focusing magnetic field is derived by the Bush theorem, the angular-momentum conservation law in the electromagnetic field. The beam is divided into a large number of rays, each trajectory of which was calculated by solving the equation of motion numerically. In this calculation, space-charge forces, relativistic effects, self-field and external magnetic field effects were included. The final data in this step were saved in memory to be made use of in the next EGS4 application. The second step program was made by constructing a so-called "user code" using MORTRAN. Using the data calculated in the previous step, backscattered processes are calculated for each ray. Some electrons are absorbed in the collector material and some are backscattered after bombarding the surface. The tracks of the backscattered electrons are traced by solving an equation of motion including a magnetic field until they hit the wall again or until they go back to the drift tube. Parts of them might be backscattered or absorbed in the next collision; these are repeated until returning electrons are completed to be calculated. In second step, the space-charge force is neglected.

Usually 1,000,000 electrons are employed for a calculation to obtain good statistics. After carrying out simulations for all of these incident electrons, the information concerning the returning electrons is saved in memory, including their coefficient and energy distribution, and is used to plot trajectories in the final step. This program is executed using a personal computer with a clock of 333MHz; it takes 2 hours for a simulation.

3.2 Simulation results

A typical collector shape used in this simulation is shown in Fig.4; D_t is the diameter of the drift tube: D_c and L_c are the diameter and length of the collector, respectively. Returning electrons have been calculated based on the various shapes of a collector made of a copper material. The results, including the actual klystron dimensions, are given in table 1; the relative error in this table is reduced from the statistical error of the number of the returning electrons. The energy distributions of returning electrons corresponding to the actual collector shapes are shown in Fig.5. In this figure, the energy of the returning electrons is normalized by the incident-beam energy at the collector entrance, and a few of the returning electrons have a higher energy than the incident beam, since some are accelerated by the space-charge force. It has been clarified that the number of returning electrons strongly depends upon the ratio of the drift-tube diameter to the collector diameter. It has also been clarified that the length of the collector has a large effect on the returning electrons. These tendencies are given in Fig.6; (a) shows the returning electron coefficient as a function of the collector length, L_c; (b) shows the returning electron coefficient as a function of the collector diameter, D_c.

In order to analyze the features of returning electrons from the collector, a sketch of three different typical collector shapes is shown in Fig.7, where the shaded line on the collector boundary indicates the collector surface bombarded by the incident beam. From Fig.6 the contributions to the returning coefficient can be divided into two parts: one from the cylindrical surface of the collector and another from the cone shaped surface of the collector. The former contribution seems to come mainly from backscattering of the beam edge parts, since the coefficients remain constant for large Lc. This also means that one collision is predominant for the returning electrons. This may be directly shown by some artificial setting of the boundary of EGS4, which we are planning to do. It is natural that if the cone-shaped part of the collector is located near to the drift tube, a fairly large number of direct backscattering electrons contribute to the returning electrons. For designing a suitable collector with small returning electron coefficients, a suitable ratio of the drift-tube diameter to the collector diameter should be determined for an acceptable backscattering coefficient. If a longer collector shape can be chosen, only this diameter ratio determines the number of returning electrons. When a longer collector size is not allowed for some manufacturing reason, compromising between the two factors mentioned above is necessary by investigating the tendency, like Fig.6. A similar analysis is applicable to a collector of other microwave tube devices, a beam dump of the accelerator, a secondary electron monitor (SEM) and a Farad cup, if unwanted returning electrons are desired to be eliminated.

Interesting features can be obtained by changing the collector material. Figure 8 shows the returning electron coefficient from a collector made of various materials, and Fig.9 gives the energy distribution of returning electrons from a collector made of various materials. Obviously, a smaller number of returning electrons is expected from low atomic-number materials. Using an aluminum or its alloy is possible for the collector material. Another application is, for example, to use SiC as the collector material. Since the range in material for this electron energy region is very small, making a coating on the collector surface using the sputtering technique is also possible. If a manufacturing limitation prevents a suitable size of the collector, the material choice may be important.

4 Conclusion

A simulation code for applying EGS4 to calculate returning electrons from the klystron collector has been developed after an evaluation of the electron backscattering process; returning electrons were successfully calculated. The returning electron coefficient and energy distributions are shown with various collector shapes. It is shown that the ratio of the drift-tube diameter to the collector diameter plays an important role concerning the number of returning electrons. The procedure used to design a collector with small returning electron coefficients is also presented. Interesting features of returning electrons concerning various materials have been investigated, and the possibility to use other materials instead of well-used copper material is also presented. These simulation results had been applied to a study of the oscillation of a UHF klystron caused by returning electrons; the results agreed with the experiment [5].

References

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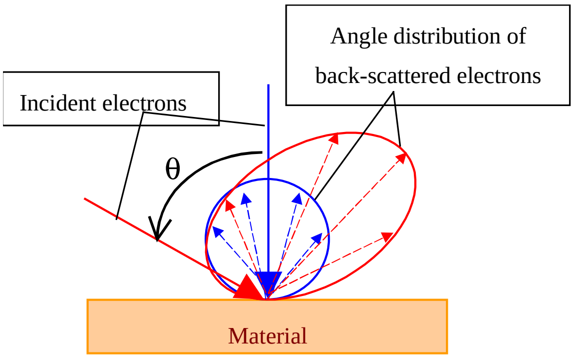


Figure 1: Sketch of electron backscattering on a plate

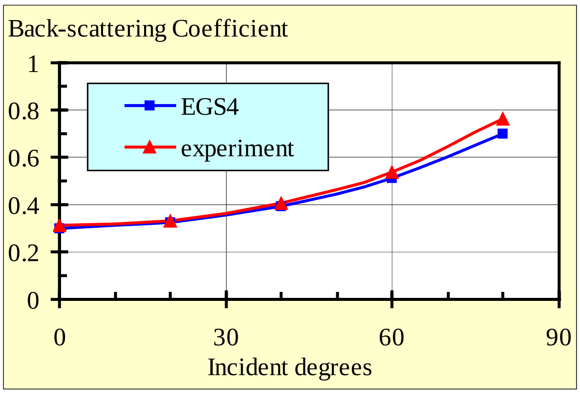


Figure 2: Back-scattering coefficient as function of the incident angle on a copper surface.

(Incident energy of electrons, 60keV; Experiment data, reference 4)

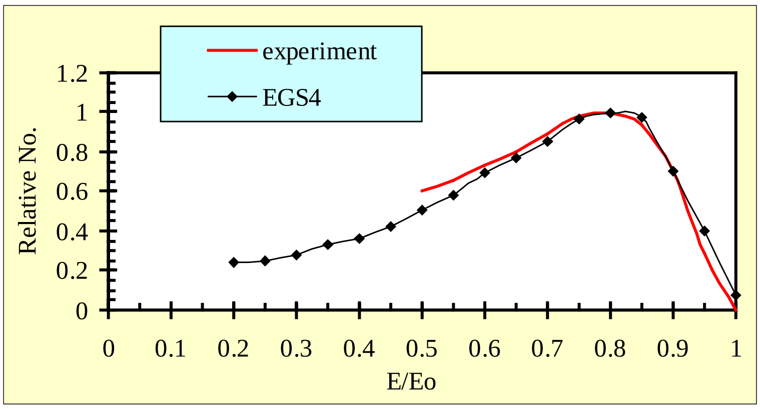


Figure 3: Energy distributions of back-scattered electrons from a copper surface.

(Incident energy of electrons, 32keV; Experiment data, reference 3)

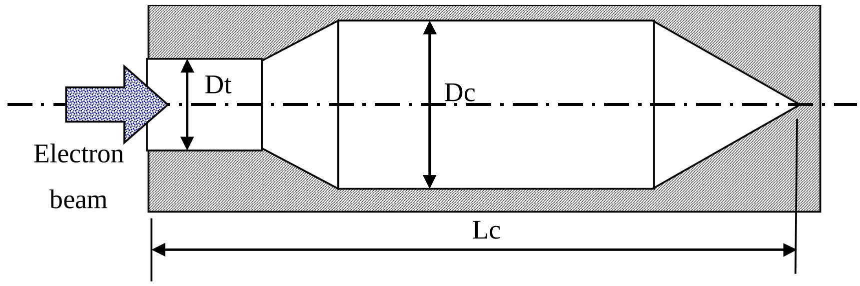


Figure 4: Typical collector shape

Table 1: Returning electron coefficient for different dimensions of a copper collector.

Dt(cm)	Dc(cm)	Lc(cm)	Returning electron coefficient	Relative error
10	13	62.4	0.00665	1.2%
	23	92.4	0.00174	2.4%
	23	122.4	0.00136	2.7%
7	23	122.4	0.00081	3.5%
5			0.00023	6.6%

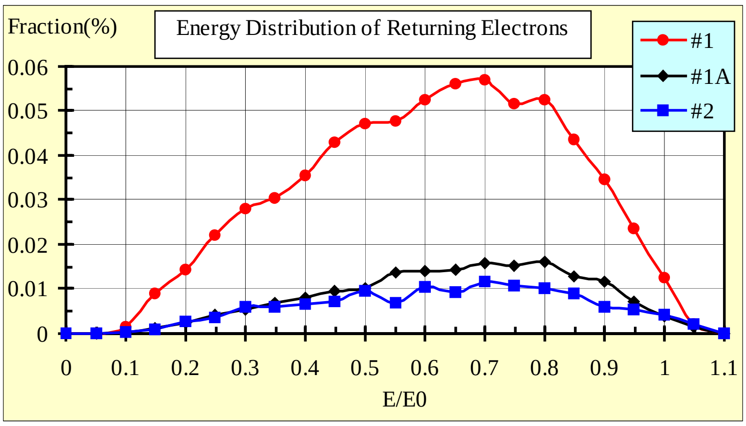
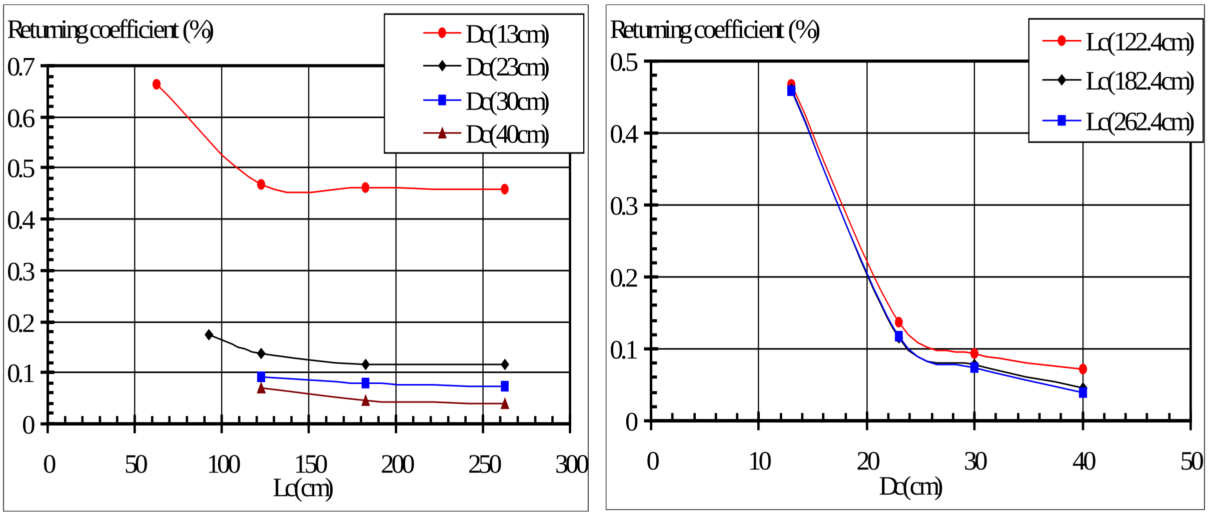


Figure 5: Energy distributions of returning electrons for different dimensions of a copper collector.



(a) (b)

Figure 6: Returning electron coefficient as function of the collector length (Lc) and diameter (Dc).

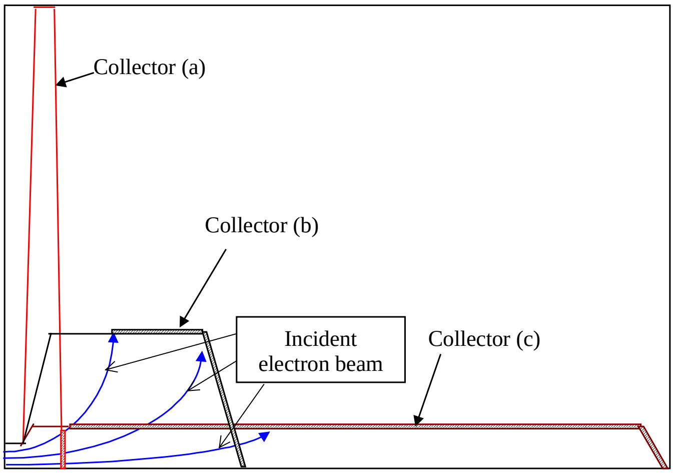


Figure 7: Sketch of three different typical collector shapes.

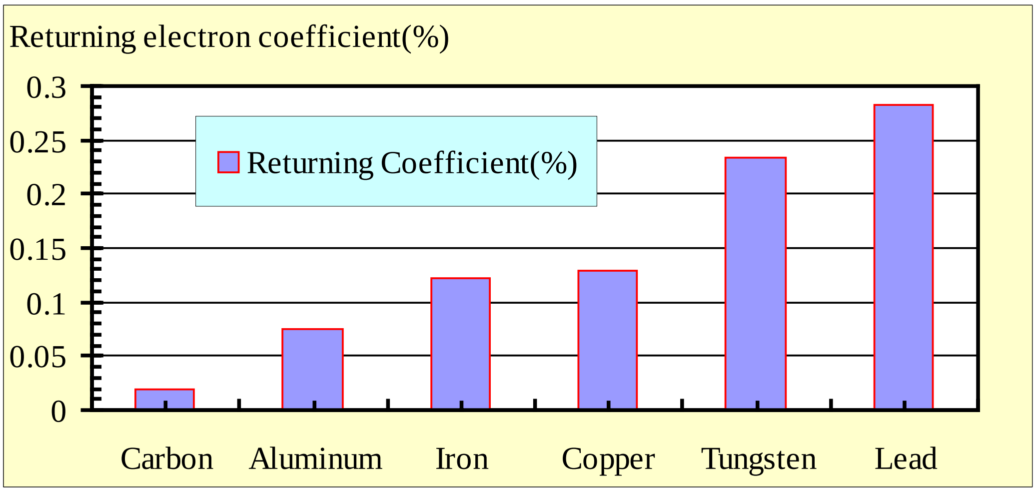


Figure 8: Returning electron coefficient as a function of the collector material.

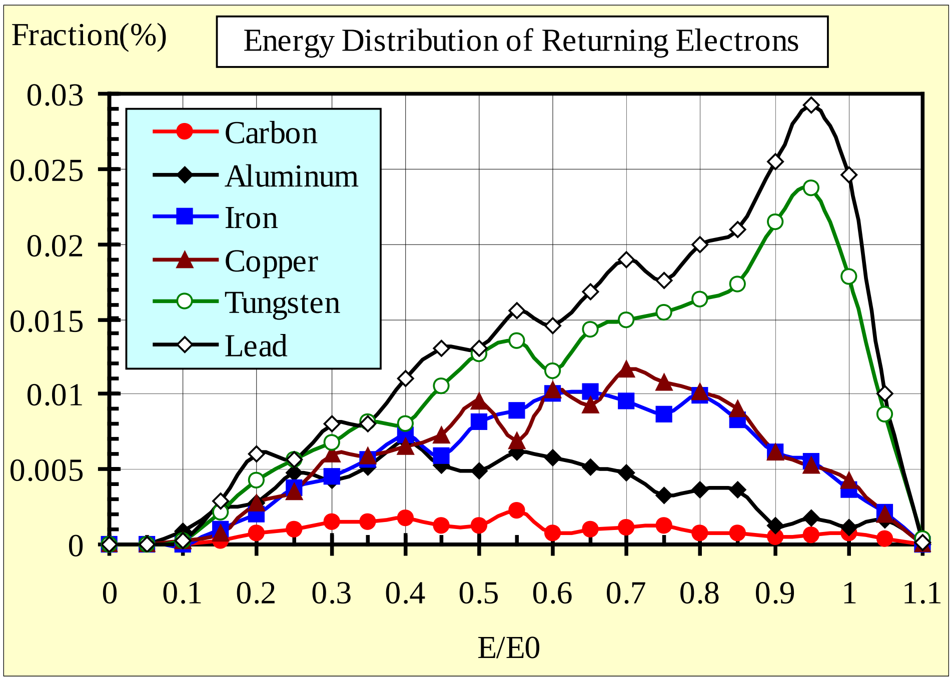


Figure 9: Returning electron energy distribution as function of the collector material.