Spatial Resolution of YAG:Ce Single Crystal CL Screens

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Introduction

Cerium activated single crystals of yttrium aluminum garnet (YAG:Ce^{3+}) are more and more sought for materials for cathodoluminescent (CL) imaging screens in TEM. Owing to their well defined optical properties including the homogeneity and precise shaping, YAG:Ce single crystal screens can be used as very small elements for forming a small image intended for further processing[1]. In addition to the CL efficiency, spatial resolution of CL screens is the most important characteristic in such an application. The aim of this paper is to find the resolution of YAG:Ce single crystal screens at primary electron excitation energies in the range from 10 to 100 keV.

Methods and Materials

Both theoretical and experimental methods were used for the examination of spatial resolution. Calculations were accomplished by a Monte Carlo (MC) method and corrected for electron diffusion. The MC model used for simulation was based on the single scattering utilizing the screened Rutherford cross-section and Bethe slowing down approximation[2]. The MC model simulated 3-dimensional trajectories of primary electrons in the bulk of the investigated solid. Only primary processes were included in the model. In this paper, attention was concentrated on the perpendicular impact of primary electrons but it is no problem to simulate an inclined impact. Besides trajectories, the MC program was creating both longitudinal (in the direction of the primary electron beam) and transversal (projected into the surface plane) distribution of the absorbed energy. The MC program was written for and executed on the 486DX2/66 personal computer.

Experiments were realized in the Philips CM 12 TEM using the sharp edge projection on to the examined screen. As a projection object (placed in the specimen chamber), the silicon single crystal plate with an orientation-etched hole was used. As the screen (placed near the column bottom), the YAG:Ce single crystal plate with both sides polished was used. The YAG:Ce^{3+} single crystal was pulled in cooperation with the firm Preciosa (Division Monokrystaly, Czech Republic) by the Czochralski method[3]. The edge image from the screen was recorded by the optical equipment constructed in our laboratory. The recording optics consisting of an eyepiece-objective system with two prisms enabled us to take a photograph of the screen image with the magnification 40x. The measuring system was calibrated by using the Agar 300 grid as a projection object.

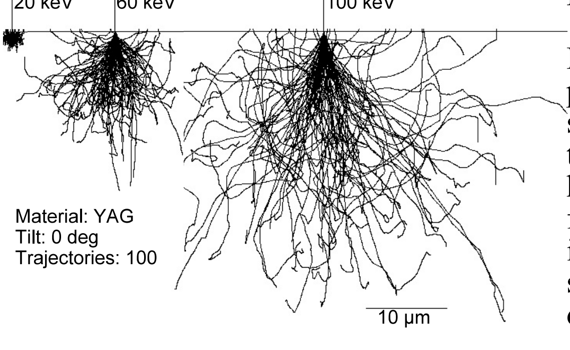

Figure 1 MC simulation of electron trajectories in YAG single crystal.

Results and Discussion

The MC output of a 2-D projection of 3-D electron trajectories in the YAG single crystal at primary electron energies of 20, 60 and 100 keV is shown in Fig. 1. The surface boundary and trajectories of primary beams are indicated by horizontal and vertical lines, respectively. This figure of trajectories provides good visual information about interaction volumes, but it supplies only poor data for an analysis of energy deposition.

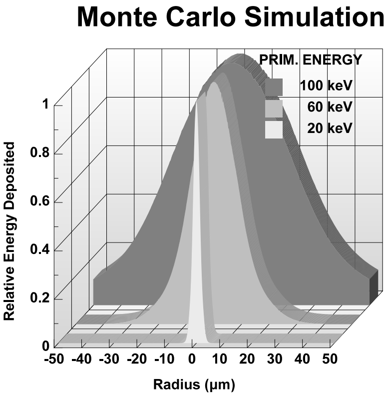

Figure 2 Computed results of transversal energy distributions of diffused electrons in the YAG:Ce screen.

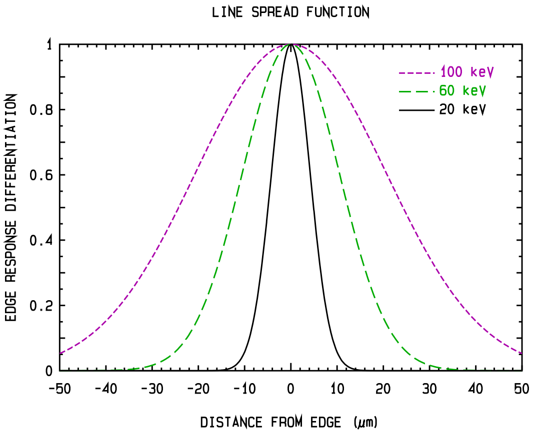

Figure 3 Experimental results of line spread functions of the edge projections on to the YAG:Ce screen.

Therefore, the outputs of the deposited energy distributions, projected into the surface plane of the YAG:Ce screen, were taken from the MC simulation. To reduce the statistical errors for these outputs, the total number of primary electrons simulated has to be 10^3 at least. Furthermore, to determine the spatial resolution, it was necessary to correct the transversal distribution of energy for the diffusion of electrons by using empirical relations. As a result of such a computation the distributions of energy deposited by diffused electrons are shown in Fig. 2. With regard to only primary processes involved in the MC model, the results of simulation should be understood as a rough estimation, and the resulting resolutions can be considered as maximum.

Experimental data from photographs of the edge images were converted to intensities of arbitrary units. After the correction to the film emulsion response, the magnitude of the intensity along the direction perpendicular to the edge (edge spread function) was obtained for each energy of the primary electron beam. By a differentiation of edge spread functions the line spread functions of measured edge responses in the YAG:Ce screen (shown in Fig. 3) were obtained.

The experiment gives results comparable and nearly comparable with the simulation for the energies 100 and 60 keV, respectively. But the measured resolution at 20 keV is much worse than it would be expected according to the simulation. Probably, this is given by the magnification limit (40x) of the recording optics, which results in an inaccuracy at the edge spread function scaling for such a small distance.

References

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