Performance of YAG:Ce single crystal screens for TEM

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Originally, the YAG:Ce single crystals were developed for use in scintillation detectors of scanning electron microscopes (SEM). They have been studied extensively, and nearly all properties relevant to their application as scintillators are known (the most important are shown in Table 1). Nevertheless, the YAG:Ce is also a very appropriate crystal for imaging screens because of its well defined optical properties, in particular its optical homogeneity. Moreover, the crystals can be shaped precisely, even into very small elements for forming a small image intended for further processing. However, screen materials can not be used without an analysis of the cathodoluminescent (CL) image. The best characteristic to express imaging properties (including spatial resolution) is the modulation transfer function (MTF). Finding out the MTF of the YAG:Ce single crystal screen is the topic of this work.

1. Materials and Methods

The YAG:Ce^{3+} single crystal plate with both sides polished was used as the investigated screen. The single crystal was pulled in cooperation with the firm Preciosa (Czech Republic) by the Czochralski method [1]. The measurement of basic CL properties was accomplished using the computer controlled CL equipment built at our laboratory [2]. The measurement of MTF was realized in the Philips CM 12 TEM by the spread function method, using the sharp edge projection on to the examined screen, as sketched in Figure 1. A unit step image was formed on the screen specimen, placed near the column bottom. As a projection object the silicon single crystal plate with an orientation-etched hole was used. The edge image from the screen was recorded by the optical equipment consisting of an eyepiece-objective system with two prisms that enabled us to take a photograph of the image with the magnification 40x. The measuring system was calibrated by using the Agar 300 grid. The measurement was accompanied by the Monte Carlo (MC) simulation of the absorbed energy distribution, corrected for electron diffusion. The MC model used was based on the single scattering utilizing the screened Rutherford cross-section and Bethe slowing down approximation [3]. Only primary processes were included in the model. The MC program was written for and executed on the IBM compatible (Pentium) personal computer.

2. Results and Conclusion

Basic CL properties of the YAG:Ce crystal are summarized in Table 1. The energy conversion efficiency of all oxygen dominated phosphors has to be significantly lower, compared with that of sulphides. So, the 5 % efficiency is quite a prospective value, and together with its wide emission band (spectrally applicable to both a human eye and a CCD camera) the YAG:Ce crystal is a promising screen material. The values of spatial resolution for 20, 60 and 100 keV electrons have been taken from the MTF characteristics presented in Figure 2. Experimental curves of MTF (solid lines) were obtained using photographs of the edge images. After the correction to the film emulsion response, the magnitude of the intensity in the direction perpendicular to the edge (edge spread function) was obtained for each energy

1 Properties of the YAG:Ce single crystal. [1]Value calculated using the chemical formula. [2]Spectral matching of the scintillator-photomultiplier system related to that with an ideal photocathode.

Basic properties		
Chemical formula		$Y_3AL_5O_{12}:Ce^{3+}$
Crystal structure		cubic
Effective atomic number		14
Mean atomic weight[1]		29.7
Density		4.7 $g.cm^{-3}$
Melting point		1970 °C
Hardness		8.5 Moh
Optical properties		
Index of refraction (º = 560 nm)		1.84
Absorption coefficient (º = 560 nm)		0.074 mm^{-1}
Cathodoluminescent properties		
Energy conversion efficiency		5 %
Wave length of maximum emission		560 nm
FWHM		120 nm
S20 photocathode matching[2]		78 %
S11 photocathode matching[2]		46 %
Decay time		100 ns
Afterglow (5 µs after excitation)		2 %
Spatial resolution for	20 keV	8 lp/mm
	60 keV	18 lp/mm
	100 keV	150 lp/mm

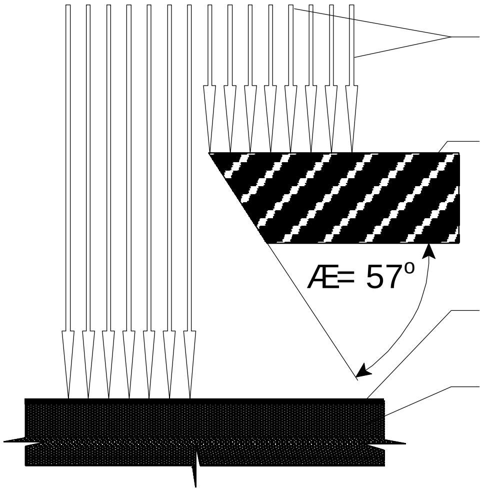

Figure 1 Outline of an arrangement for unit step image creation by using the edge projection method.

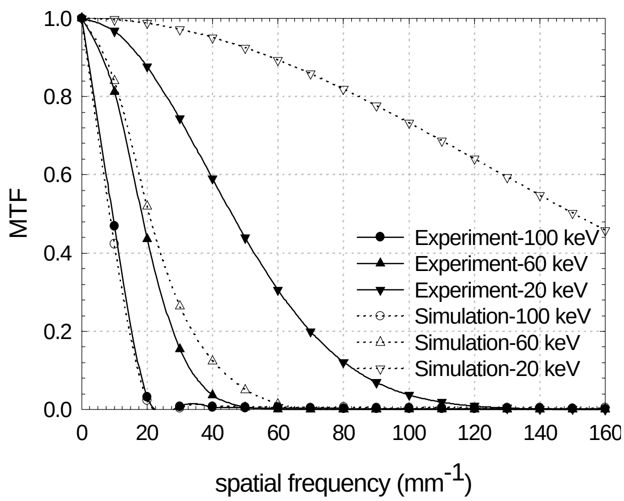

Figure 2 Modulation transfer function of the YAG:Ce single crystal screen for different incident electron beam energies.

of the primary electron beam. By a differentiation of edge spread functions the line spread functions were received, and using the modulus of the Fourier transform, the MTFs of the measured edge responses in the YAG:Ce screen were obtained. Calculated curves of MTF (Figure 1 - dotted lines) were obtained using the modulus of the Fourier transform of the deposited energy distributions utilizing the MC simulation. With regard to only primary processes involved in the MC model, the results of simulation should be understood as an estimation. Experimental and simulated MTFs are in good agreement for energies of 100 and 60 keV. For the 20 keV electron beam energy, the magnification (40x) of the recording optics results in a relevant inaccuracy at the edge spread function scaling. Therefore, the magnification must be considerably increased, otherwise only the simulated curve can be used for the determination of the spatial resolution of YAG:Ce single crystal screens at such a low energy.

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References

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