New Scintillator Materials for EM

P. Horodysky[1], K. Blazek[1], J. Jiruse[2], V. Nedela[3], J. Spinka[4] and M. Nikl[5]
[1]Crytur Ltd., Turnov, Czech Rep.
[2]Tescan Ltd., Brno, Czech Rep.
[3]Institute of Scientific Instruments, Academy of Sciences of CR, Brno, Czech Rep.
[4]Faculty of Electrical Engineering and Communication, Brno University of Technology, Brno, Czech Rep.
[5]Institute of Physics, Academy of Sciences of CR, Prague, Czech Rep.

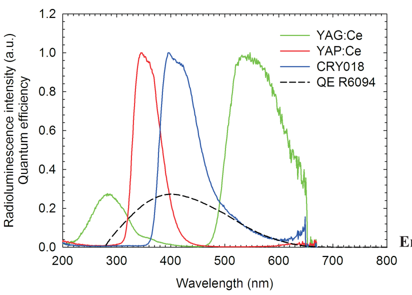
Introduction

Classical YAG:Ce ($Y_3Al_5O_{12}$) and YAP:Ce ($YAlO_3$) scintillators are being used in scintillation detection of signal electrons in EM since the 80's. Those materials exhibit absolute radiation hardness and absolute reliability in any vacuum or gazeous condtions. YAG:Ce is an excellent choice both for back-scattered electron (BSE) and secondary electron (SE) detection. YAP:Ce shows the fastest response among nowadays highly efficient scintillators (25 ns decay time).

Modern EM methods require still more signal output. This can be satisfied by 1) better signal electron collection 2) more efficient scintillator materials or 3) better light collection. In this work we show that A) nowaday scintillator detectors operate at their fundamental limits and B) there is space for new special scintillator detectors.

Single crystal scintilllators YAG:Ce
∅1–∅50

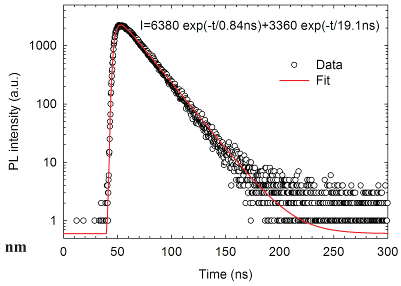
Scintillator properties



Emission spectra, PMT quantum efficiency

Scintillator properties	Refraction index	Light output (%NaI:Tl)	Emission wavelength @maximum	Photon yield (Ph/keV)	Decay constant (ns)
YAG:Ce	1.82	40	550	35	70
YAP:Ce	1.95	70	370	25	25
CRY18	1.79	80	420	32	45

Light output characteristics



YAP:Ce PL decay at 355 nm

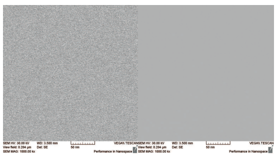
SE detection with different single crystal scintillators

I. The experimental part was carried out using Tescan VEGA II SEM. The standard ETD detector was modified. Apart the PMMA lightguide also quartz lightguide was fabricated as PMMA does not transmit well UV light for shorter λ than 350 nm.
A series of measurements was carried out testing different combinations of lightguide material, scintillator crystal and PMT.
Signal from the ETD can be increased approx. 2.5 times if CRY018 scintillator is used instead of YAG:Ce. YAP:Ce yields twice signal compared to YAG:Ce, but quartz lightguide has to be used.

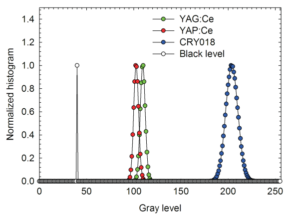
PMT/lightguide Scintillator	R6094/ PMMA	R6094/ Quartz	R3550A/ PMMA	R3550A/ Quartz
YAG:Ce	100	100	100	100
YAP:Ce	89	207	117	268
CRY18	246	249	269	257

SE signal amplitude for different modifications of SE detector

II. Noise histograms in recorded images were analyzed. Defocused images of samples of polished silicon, aluminum, gold and platinum were recorded at different scanning speed. Those images have uniform gray level with only Poisson noise broadening. The FWHM of the histogram and its position relative to the black level value determine the noise to signal ratio (N/S).



Defocused SE images of polished silicon at 0.2μs/pxl and 146 μs/pxl.

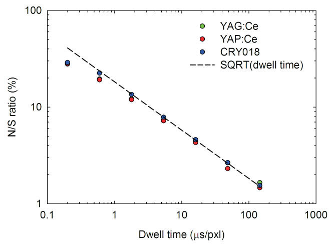


Histograms of different scintillators with R6094 PMT, PMMA lightguide

III. The dependence of N/S ratio on number of electrons per pixel is governed by Poisson statistics:

$$\frac{S}{N} \approx \sqrt{electrons/pxl}$$

N/S ratio of image is absolutely independent of used scintillator crystal!



IV. Explanation:
The mean number of photons generated by absorption of a single 10 keV electron in YAG:Ce is roughly 300. The efficiency of light transport to the PMT window is 40%. Mean spectral quantum efficiency of photocathode is estimated as about 20%. Thus, a single, **detected SE electron generates** about **24 amplified pulses** in the PMT electronics.
The fluctuation that influences the N/S ration of image is then given uniquely by fluctuations of number of electrons per pixel. E.g. at speed 0.2 μs/pxl at 100 pA current, only 125 electrons hit the sample. With a typical SE yield of 20%, only several tens of electrons are emitted. Hence, the efficiency of SE collection is the only parameter that can be improved in order to decrease the noise of SE image in a modern SEM.

Conclusion

A. Nowadays modern scintillator-PMT ET SE detector operates at the edge of physical limits. The scintillator adds no noise to the detection chain. **Use of a more efficient scintillator than YAG:Ce does not bring any improvement of image quality.**

B. CRY018 scintillator provides 2.5 times more signal than YAG:Ce with the same classical bialcali PMT. Such material is thus well suitable for detection of low energy electron beams, where a single electron generates only a few signal photons. Typical use of CRY018 will be the detection of BSE electrons with energies below 1 keV and also BSE detectors covering small solid angle.

Classical YAG:Ce BSE scintillators

The support of Czech GA AV project KAN300100802 is gratefully acknowledged.