ISBN: 978-3-95450-241-7 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2022-TUP29

ZnO(In) SCINTILLATION LIGHT SPECTRA INVESTIGATION FOR HEAVY ION DETECTOR APPLICATION*†

M. Saifulin[1,‡], P. Boutachkov, C. Trautmann[1], B. Walasek-Höhne
GSI Helmholtz Center for Heavy Ion Research, Darmstadt, Germany
P. Rodnyi, I. Venevtsev, Peter the Great Polytechnic University, St. Petersburg, Russia
E. Gorokhova, JSC S.I. Vavilov State Optical Institute, St. Petersburg, Russia
[1]also at Technical University Darmstadt, Darmstadt, Germany

Abstract

ZnO-based ceramics are known as promising scintillators exhibiting light emission in the ultraviolet (UV) spectral region (~390 nm) and ultrafast decay times (<1 ns). They are of great interest for applications in scintillation counters and screens at high-energy heavy ion accelerators. In this contribution, the deterioration of scintillating properties of ZnO-based ceramics subjected to heavy ion exposure at high doses is investigated. The scintillation light spectra of ZnO(In) as a function of fluence for 4.8 MeV/u ^{48}Ca and ^{197}Au ions were studied. We observed that the deterioration of the scintillation intensity with increasing fluence follows the Birks-Black model.

INTRODUCTION

Zinc oxide is a multi-functional material with many applications due to its interesting properties [1, 2]. In particular, since the 1960s it has been known as a promising scintillation material that exhibits sub-nanosecond fast light emission at room temperature [3–5]. Previously, pure and doped ZnO has been produced in various forms (powder, thin films, single- and poly-crystals, and ceramics) with the purpose of detecting different types of ionizing radiation [6–9].

Recent studies and technological advances have made it possible to produce bulk pieces of indium- and gallium-doped zinc oxide ceramics (ZnO(In) and ZnO(Ga)) by uniaxial hot pressing in vacuum [10, 11]. These scintillating ceramics become highly interesting for heavy-ion radiation detection at accelerator facilities like GSI and the future FAIR facility in Darmstadt, Germany [12]. ZnO(In) and ZnO(Ga) scintillators are considered as promising candidates to substitute plastic scintillator BC400 commonly used for beam intensity monitoring and spill micro-structure characterization at SIS-18 synchrotron, where ion beams from proton to uranium with energies from 150 MeV/u to 4.5 GeV/u can be obtained.

As a part of a research and development project for a radiation-resistant fast scintillation detector, we report on the performance and in-situ characterization of ZnO(In) ceramics scintillation light spectra change as a function of ion fluence.

ZnO(In) SCINTILLATION SPECTRA

The investigated ZnO(In) ceramic sampels were produced in the form of 8 mm × 8 mm × 0.4 mm size plates at the Joint Stock Company "Research and Production Corporation S.I. Vavilova" (St. Petersburg, Russia). The samples were produced with 0.046 at % In^{3+} dopping concentration. Samples density estimated from mass and volume measurements was 4.66 g/cm^2.

In-situ characterization of scintillation light spectra was performed using 4.8 MeV/u energy ^{48}Ca and ^{197}Au ions from UNIversal Linear ACcelerator (UNILAC) of the GSI Helmholtz Center for Heavy Ion Research GmbH (Darmstadt, Germany) [13]. The irradiations were carried out at room temperature in vacuum at a beam incidence angle of 45° with respect to the sample surface.

Scintillation light was collected with a lens placed in front of the ion-incident surface of the sample. The collected light was transfered via a light guide to an Ocean Optics QE-Pro spectrometer. The acquired spectra were corrected for dark counts and normalized by the number of ions that hit the sample during the spectrum acquisition.

Figure 1 shows how the scintillation light spectrum of ZnO(In) ceramic sample changes as a result of 4.8 MeV/u ^{48}Ca ion irradiation. The spectra have only one emission

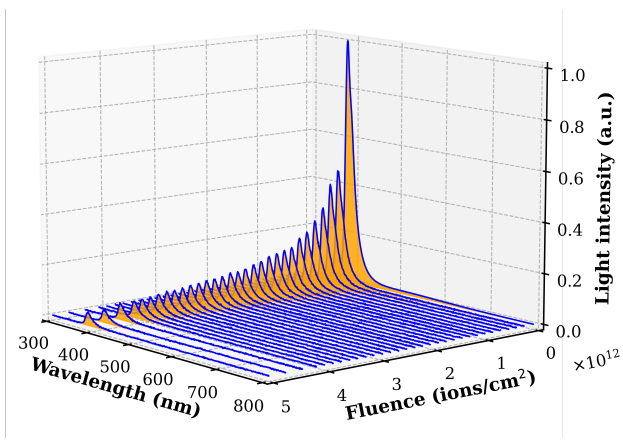

Figure 1: Spectra of ZnO(In) ceramic as a function of 4.8 MeV/u ^{48}Ca ion fluence.

band in the ultraviolet (UV) light region with a maximum at around 387 nm. The observed peak corresponds to the near-band-edge emission (NBE) known for scintillation decay times less than nanosecond. With increasing fluence, the

* The results presented in this contribution are based on the work performed before the 24th of February, 2022.
† DLR funded this work within the ERA.Net RUS Plus Project RUS_ST2017-051.
‡ m.saifulin@gsi.de (corresponding author)

ISBN: 978-3-95450-241-7 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2022-TUP29

intensity of this NBE band drops considerably. No new light emission bands are formed as a result of the ion irradiation, not even at the highest fluences reached, 5×10^{12} Ca-ions/cm^2 and 2×10^{11} Au-ions/cm^2.

BIRKS-BLACK MODEL FIT

The Birks-Black model [14] was used to fit the observed NBE peak intensity reduction as a function of Ca and Au ion fluence. According to this model, the reduction of the scintillation light intensity can be presented as:

$$\frac{I(\Phi)}{I_0} = \frac{1}{1+\frac{\Phi}{\Phi_{1/2}}}, \quad (1)$$

where I_0 is the initial scintillation light intensity, and $\Phi_{1/2}$ is the critical fluence at which the scintillation light intensity is reduced by 50% of the initial value.

Figure 2 shows the NBE peak intensity as a function of the Ca and Au ion fluence. The intensity evolution follows the Birks-Black model for both ion species. The critical fluence values extracted from a fit of Eq. (1) to the data are 3.3×10^{11} Ca-ions/cm^2 and 3.5×10^{9} Au-ions/cm^2, respectively.

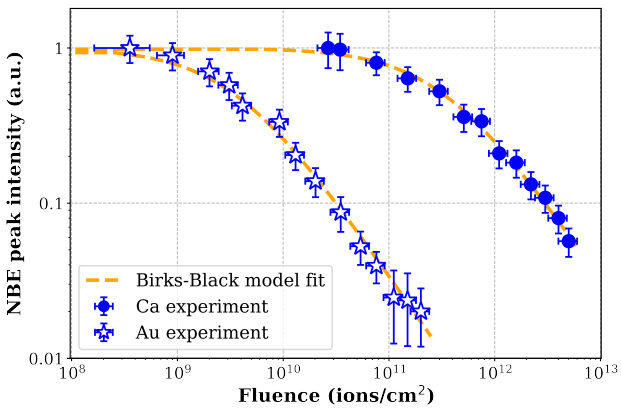

Figure 2: Intensity of the NBE peak (387 nm) of the scintillation spectrum as a function of irradiation fluence using ^{48}Ca ions (full circles) and ^{197}Au ions (open stars). The dashed line represent fits with Eq. (1) from the Birks-Black model.

CONCLUSIONS

ZnO-based scintillating ceramics are promising materials to be used for heavy-ion particle detection applications. In this work, ZnO(In) scintillating ceramics were exposed to 4.8 MeV/u ^{48}Ca and ^{197}Au ion beams in order to investigate the changes in scintillation light spectrum as a function of swift heavy ion fluence. The scintillation light intensity follows the trend predicted by the Birks-Black model. As a result of high fluence irradiation, no new peak formation was observed up to 5×10^{12} Ca-ions/cm^2 and 2×10^{11} Au-ions/cm^2 irradiation at 4.8 MeV/u energy.

REFERENCES

[1] Ü. Özgür *et al.*, "A comprehensive review of ZnO materials and devices," *J. Appl. Phys.*, vol. 98, no. 4, pp. 1–103, 2005. doi:10.1063/1.1992666

[2] C. Klingshirn *et al.*, "65 years of ZnO research–old and very recent results," *Phys. Status Solidi B*, vol. 247, no. 6, pp. 1424–1447, 2010. doi:10.1002/pssb.200983195

[3] W. Lehmann, "Edge emission of *n*-type conducting ZnO and CdS," *Solid-State Electron.*, vol. 9, no. 11-12, pp. 1107–1110, 1966.

[4] D. Luckey, "A fast inorganic scintillator," *Nucl. Instrum. Methods Phys. Res. A*, vol. 62, no. 1, pp. 119–120, 1968. doi:10.1016/0029-554X(68)90628-9

[5] T. Batsch, B. Bengtson, and M. Moszyński, "Timing properties of a ZnO(Ga) scintillator (NE843)," *Nucl. Instrum. Methods Phys. Res. A*, vol. 125, no. 3, pp. 443–446, 1975. doi:10.1016/0029-554X(75)90262-1

[6] J. S. Neal, L. A. Boatner, N. Giles, L. Halliburton, S. Derenzo, and E. Bourret-Courchesne, "Comparative investigation of the performance of ZnO-based scintillators for use as α-particle detectors," *Nucl. Instrum. Methods Phys. Res. A*, vol. 568, no. 2, pp. 803–809, 2006. doi:10.1016/j.nima.2006.09.041

[7] J. S. Neal *et al.*, "Investigation of ZnO-based polycrystalline ceramic scintillators for use as α-particle detectors," *IEEE Trans. Nucl. Sci.*, vol. 56, no. 3, pp. 892–898, 2009. doi:10.1109/TNS.2008.2004702

[8] C. Liang *et al.*, "Experimental study on scintillation efficiency of ZnO:In to proton response," *Chin. Phys. C*, vol. 35, no. 11, p. 1037, 2011. doi:10.1088/1674-1137/35/11/011

[9] R. Sahani, C. Kumari, A. Pandya, and A. Dixit, "Efficient alpha radiation detector using low temperature hydrothermally grown ZnO:Ga nanorod scintillator," *Sci. Rep.*, vol. 9, no. 1, pp. 1–9, 2019. doi:10.1038/s41598-019-47732-1

[10] E. Gorokhova *et al.*, "Development and study of ZnO:In optical scintillation ceramic," *J. Opt. Technol.*, vol. 82, no. 12, pp. 837–842, 2015. doi:10.1364/JOT.82.000837

[11] E. I. Gorokhova *et al.*, "Structural, optical, and luminescence properties of ZnO:Ga optical scintillation ceramic," *J. Opt. Technol.*, vol. 85, no. 11, pp. 729–737, 2018. doi:10.1364/JOT.85.000729

[12] G. Rosner, "Future facility: FAIR at GSI," *Nucl. Phys. B*, vol. 167, pp. 77–81, 2007. doi:10.1016/j.nuclphysbps.2006.12.089

[13] W. Barth, L. Dahl, J. Glatz, L. Groening, S. G. Richter, and S. Yaramishev, "Achievements of the High Current Beam Performance of the GSI Unilac," in *Proc. EPAC'04*, Lucerne, Switzerland, Jul. 2004.

[14] J. Birks and F. Black, "Deterioration of anthracene under α-particle irradiation," *Proc. Phys. Soc. London, Sect. A*, vol. 64, no. 5, p. 511, 1951. doi:10.1088/0370-1298/64/5/112