Contribution ID: **77** Type: **Oral presentation**

Some trends in the yield of the hot intraband luminescence

Thursday, September 21, 2017 8:45 AM (15 minutes)

Recent progress in various fields of scintillator applications has created a high demand for fast scintillators. In particular, the Time-Of-Flight Positron Emission Tomography (TOF-PET) technique requires coincidence time resolutions (CTRs) better than 100 ps FWHM in order to improve the image signal to noise ratio offering shorter scanning times, lower patient doses and better image quality. The CTR of 10 ps will potentially yield a breakthrough in PET allowing direct imaging without reconstruction. Developments in high energy physics also demand improving the timing capabilities of calorimeters down to 10 ps to distinguish several events per bunch crossing and make better use of high luminosity storage rings. Achieving such time resolution was set as an ultimate goal for European COST Action TD1401 "FAST".
Conventional Ce-doped scintillators were demonstrated to provide a CTR of about 73-120 ps FWHM when used with Silicon Photomultiplier (SiPM) detectors [1]. The time resolution in this case is limited by the photon time-density at the onset of the scintillation process and can be further improved only by using a different scintillation mechanism featuring a prompt response. It has been shown that already 40 prompt photons produced by 511 keV gamma quantum can significantly improve CTR below 70 ps, whereas for achieving 10 ps CTR about 500 are required together with corresponding advances in SiPM technology [1,2].
Hot intraband luminescence (IBL) is a good candidate for providing at least some of those prompt photons, alongside with Cherenkov radiation and quantum confinement driven luminescence [2]. IBL is a low yield ultrafast emission connected with the radiative transitions of hot electrons or hot holes between the sub-levels of the conduction or valence band of a crystal, respectively. The continuous and structureless spectrum of IBL covers the whole transparency region of a material, with increase of the intensity in NIR [3]. The IBL decay time and yield are defined by the competitive process of nonradiative transitions which are far more probable than the radiative ones. The decay time of IBL is expected to be below 1 ps, but the highest scintillation light yield (LY) measured so far is only about 30 ph/MeV (CsI at 120 keV electron beam excitation). Therefore, to achieve 10 ps CTR the LY has to be increased significantly. We demonstrate an inverse correlation between the LY and the energy of the highest phonon mode of the material, confirming the yield dependence on nonradiative transitions probability. However, the probabilities of radiative intraband transitions are not understood yet. Some materials, e.g. molybdates, display high spectral LY and simultaneously high-energy phonon modes, showing that the possibilities to increase LY are not yet exhausted. Extensive search of empirical trends in the LY as well as theoretical modeling are required to fully understand the IBL phenomenon. We have developed a technique which allows to compare the LY of solids in a reliable and reproducible way. The results of LY studies in various compounds will be reported, including alkali halides, binary oxides, silicates, garnets, tungstates, molybdates, simple and complex fluorides, oxyfluorides, etc.

[1] S. Gundacker, et al, J. Instrum. 11 (2016) P08008
[2] R. Turtos, et al, J. Instrum. 11 (2016) P10015
[3] S. Omelkov, V. Nagirnyi, A.N. Vasil'ev and M. Kirm, J. Lumin. 176 (2016) 309

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Session Classification: Scintillation Mechanisms

Track Classification: S11_Mechanisms 2 (Orals)