Spartūs scintiliaciniai detektoriai būsimiems CERN aukštų energijų fizikos eksperimentams ir medicininei vaizdinimo įrangai

Fast scintillation detectors for future high energy physics experiments at CERN and medical imaging devices

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Faster response, higher light yield, and stronger radiation tolerance have been the hallmark properties of scintillation detectors of ionizing radiation like the Olympic motto *Citius*, *Altius*, *Fortius*. The future high-luminosity high energy physics experiments at CERN and other large facilities put forward a substantial improvement in the response time as the key challenge in the development of the scintillation detectors. A faster scintillator response would also serve for a better spatial resolution of medical imaging devices, in particular, for that of positron emission tomographs operated in time-of-flight mode. This demand encouraged the CERN Crystal Clear Collaboration, where our research team studying scintillation materials at Vilnius University is a participant, to put forward the ambitious target of 10 picoseconds for the time resolution of radiation detectors [1].

This report is intended to review our recent advances in adopting nonlinear optical techniques, which are well developed for the study of semiconductor materials, to investigate the processes in scintillators limiting their response time [2]. The transient absorption (TA) technique in pump and probe configuration turned out to be very informative for studying fast scintillators. The time resolution in TA experiments is limited only by the duration of the pump and probe pulses and might easily be in subpicosecond domain, provided that the pulses are delivered by a femtosecond laser. Equipping the channel to deliver the pump pulses by harmonics generators enables changing the energy of the pump photons in a wide spectral range, whereas the application of optical parametric oscillators allow for a fine tunability of the pump photon to ensure a selective excitation of targeted optical transitions in the studied material. As a result, the TA signal reflects the populations of certain centers in the scintillating material. Probing the scintillator with white light continuum pulses at variable delay enables simultaneous tracing of TA in time and spectrum and is useful for revealing the populations of the centers and their energy levels important for scintillator performance.

The application of the transient absorption technique will be demonstrated in two types of Ce-doped scintillators prospective for fast scintillation detectors. Garnet-type scintillator $Gd_3Al_2Ga_3O_{12}$:Ce (GAGG:Ce) [3,4] is currently considered to be the most prospective candidate for future applications in high energy physics experiments, whereas $Lu_{2(1-x)}Y_{2x}SiO_5$:Ce (LYSO:Ce) [5] is currently used in PET devices and considered as the material of choice for the barrel timing layer in the current upgrade of the Compact Muon Solenoid (CMS) experiment at CERN. Our TA characterization is one of the techniques to select scintillators appropriate for this upgrade. The comparison of the results obtained theoretically [4,5] with the results obtained by TA and the coincidence time resolution technique, which is conventional for the characterization of the response time of scintillator materials [3-5], showed that the major factor limiting the scintillation response time is the excitation transfer to the activator ion, which is strongly affected by electron trapping. We demonstrated that the TA measurements might be successfully exploited to study the transfer. Our study revealed that the aliovalent codoping is effective in improving the response time even at low codoping concentrations. The application of the global analysis technique to analyze the TA data enabled us to estimate several rate constants for the processes important for the fast luminescence response and revealed ways for improving the scintillator timing properties by engineering of the composition of the scintillator matrix.

Reikšminiai žodžiai: scintiliatoriai, jonizuojančiosios spinduliuotės detektoriai, netiesinės optikos metodai.

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