Neutron and Gamma-Ray Radiation Detectors Based on Quantum Dots

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Final Report

Through this funded project, our research group at the Oak Ridge National Laboratory has pioneered and been successful in preparing and evaluating the performance of prototypes of neutron, alpha, and gamma-ray detectors based on various types of nanoparticles. These include organic fluors [2,5-diphenyloxazole (PPO) and 1,4-bis-2-(5-phenyloxazolyl)-benzene (POPOP)]-doped polystyrene and polyvinyltoluene nanoparticles, highly crystalline inorganic ZnS-capped CdSe, ZnS, three-component CdSxSe1-x, Ce3+-doped Y2O3, and Ce3+-doped LaPO4 (LaPO4:Ce) nanocrystals (NCs) in polystyrene (PS) or polyvinyltoluene (PVT) [Dai, S. et. al., In Polymers and Materials for Anti-Terrorism and Homeland Defense; American Chemical Society, accepted, 2006; *J. Colloid Interface Sci*. 292, 1, 127 (2005); *J. Mater. Chem*. 14, 1207 (2004); In *Unattended Radiation Sensor Systems for Remote Applications*; American

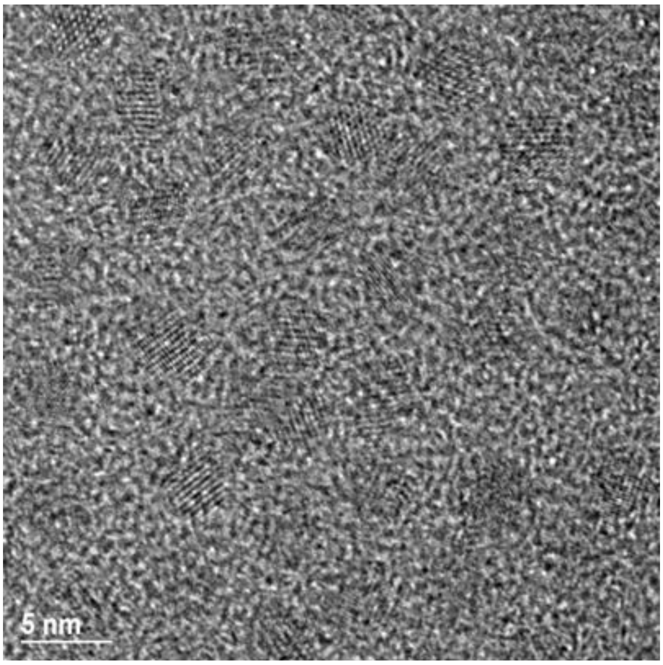

Figure 1. High-resolution TEM image of monodisperse, highly crystalline, 4-nm CdS0.05Se0.95 NCs.

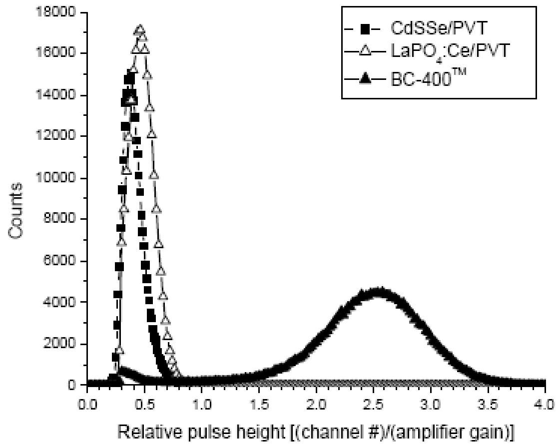

Figure 2. Comparison of pulse height spectra from alpha particle detection, showing high count rates exhibited by NC-based scintillators.

Institute of Physics, 632, 220-224, (2002)]. Previously, this effort identified two strong candidate nanoparticles for neutron and gamma detection applications. These two NCs are LaPO4:Ce and CdSxSe1-x (Dai, S. et. al. manuscript in preparation; see Figures 1 and 2). Another key accomplishment of the previously funded project is the development of 6Li3PO4 nanoparticles as a neutron-absorbing material (Dai, S. et. al. manuscript in preparation). Because the size of these nanoparticles is well under the diffraction limit for visible light, the 6Li3PO4 nanoparticles can be utilized as a vehicle for doping large percentages of Li-6 into plastic scintillators for detection of thermal neutrons. Our preliminary results indicate that a transparent polymer composite containing as high as 16 wt% of the 6Li3PO4 nanoparticles can be fabricated. Figure 3 shows the pulse height spectra from thermal neutron detection of plastic scintillators made with 6Li3PO4 nanoparticles and organic fluors, PPO and POPOP. This result confirms the energy transfer from neutron capture reaction at Li-6 ions in the nanoparticles to the scintillation dyes. Polystyrene-based polymers were also proven to be good matrices for 6Li3PO4 and scintillators in neutron detection.

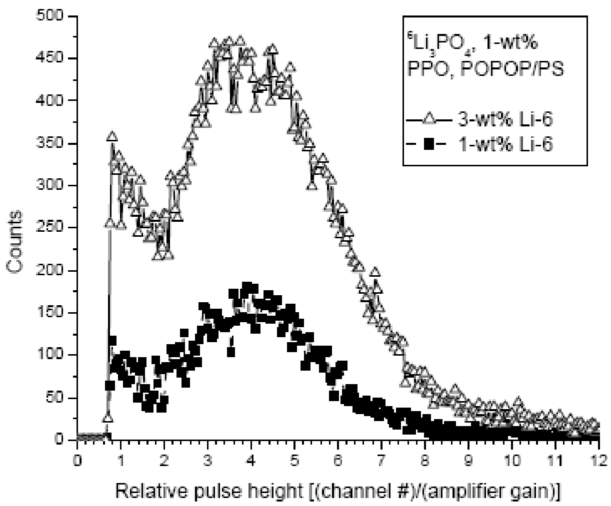

Figure 3. Pulse height spectra from neutron detection, showing high energy photon pulses.

This may be due to the fact that they are hydrogeneous matrices, which slow down neutrons and facilitate the neutron capture event. The fact that the plastic matrix has low *Z* also helps to discriminate the gamma background from the neutron detection. A patent application for Figure 1 High-resolution TEM image of monodisperse, highly crystalline, 4-nm CdS0.05Se0.95 NCs. the radiation detection based on nanoparticles in polymer matrices has been filed (Dai, S. et. al., “Composite scintillators for detection of ionizing radiation”, US patent application, September 14, 2004) and tech-transfer with a local collaborating company (Neutron Sciences, Inc.) has been established. During the course of this study, more understanding of the scintillation behavior of inorganic NCs was also gained. Like bulk inorganic scintillators, a positively correlated relationship between the wt% of scintillating NCs in the detector matrix (both plastic and sol-gel) and the detector sensitivity was observed. For the neutron capturing 6Li3PO4 NCs, the positively correlated relationship between wt% of Li-6 and neutron sensitivity was also observed. The positive correlations between concentration and sensitivity indicate that we are probably below the optimum concentrations for these particles. However those concentrations were not determined because of the difficulty in maintaining perfectly dispersed NP systems. Hence, the dispersibility of nanoparticles in matrices of choice for radiation detection in order to maintain optical transparency is of critical importance.