Identified Gap and Possible Solutions

Chapter 3 Identified Gaps and Possible Solutions

3.1 Gaps in Zinc Oxide Detectors

Ionizing radiation detection is the subject of research since the discovery of X-rays. Several detectors were developed to date, which have certain advantages together with their limitations. Scintillator detector came in prominence over gas-filled detector after the advent of photomultiplier tubes in 1948. Later, the introduction of PMTs replaced the human's direct observation which was used for detection of light from interaction of alpha particles in conventional ZnS:Ag scintillator. Several scintillators were developed over the years, such as liquid organic scintillator, single crystal inorganic detector and plastic scintillator in 1945-1960 to detect alpha, beta and gamma radiations. There are several parameters, which a good scintillator must have, such as (1) It should convert ionizing radiation energy in detectable light with high efficiency (2) Emission wavelength should be matching with a wavelength range of PMT (3) scintillator should be transparent to own emitted light (4) luminescence decay time of the scintillator should be fast (5) The index of refraction should be near to glass which can match with PMT glass and (6) Scintillator material should be of good quality and can be made in large sizes for practical detectors. In these properties, the luminescence decay time is one of the essential parameters that should be as low as possible, making the scintillator detector fast. A fast scintillator detector is required in imaging application and high-intensity radiation measurement. A fast scintillator allows scintillation light signals to reach PMT without overlapping in high radiation dose rate. ZnS:Ag, GAGG:Ce, GPS and YAP are scintillator used in the detection and measurements of alpha particles. Table 3.1 summarizes the alpha particle detector material with their respective emission and luminescence decay times.

Table 3.1: Properties of Detector Materials used for Detection of Alpha radiation

Detector Materials	Wavelength of Emission	Luminescence decay time	Ref:
ZnS:Ag	450 nm	200 ns	(Knoll, 2010)
$Gd_3Ga_5O_{12}$:Ce (GAGG:Ce)	530 nm	165 ns	(Yanagida et al., 2013)
$Gd_2Si_2O_7$:Ce (GPS:Ce)	374 nm, 397 nm	52 ns	(Kawamura et al., 2007)
$YAlO_3$:Ce (YAP:Ce)	347 nm	28 ns	(Baryshevsky et al., 1991)
ZnO	385 nm	0.7 ns (edge luminescence)	(Rodnyi and Khodyuk, 2011)

Zinc oxide is a wide and direct band semiconductor that has application as a scintillator. Because of ultrafast edge luminescence with 0.7 ns decay time (table 3.1). The optical properties of zinc oxide can be tuned by doping n-type impurity(Lehmann, 1966). As discussed in the literature survey section, undoped and doped zinc oxide single crystals were synthesized using two main processes pressure melt (Nause and Nemeth, 2005; Reynolds et al., 2004) method and hydrothermal method (Maeda et al., 2005; Yanagida et al., 2012) and used to demonstrate the alpha sensitivity by pulse height spectra. Zinc Oxide transparent ceramics as an alternative to single crystal are developed using Uniaxial hot press (Gorokhova et al., 2008) and spark plasma sintering process (Neal et al., 2009). These processes require infrastructure and high processing temperature, pressure and time hence less cost-effective. Zinc oxide nanorods grown by the low-temperature hydrothermal method can be a low-cost alternative to bulk single crystals, single-crystalline film and transparent ceramics.

ZnO nanorods are one-dimensional structures that have emerged as multifunctional materials because of their unique optical and electronic properties. Electrochemically developed ZnO nanorod coated with P3HT:PCBM blend on ITO/Glass substrate as a solar cell (Hames et al., 2010). The crossed zinc oxide nanorods over a glass substrate with tungsten electrode showed as a sensor for UV radiation (Chai et al., 2009). Zinc oxide nanorods thick film over alumina substrate has demonstrated Ethanol sensor (Singh et al., 2008). The bandgap of ZnO ~3.37 eV and exciton binding energy ~60 meV make it a suitable candidate for optical application. ZnO nanorods/nanowire has been demonstrated for lasing action(Dong et al., 2017). The c-axis oriented ZnO nanorods are shown to emit ~385 nm with 0.3 nm width upon excitation with 266 nm laser (Huang, 2001). These properties of unidirectionally oriented nanorods can be used in efficient scintillation applications where other sources such as high-energy charged particles can be used as the source of excitation.

Another cost-effective alternative material is ZnO/polymer composite which has been widely explored as multifunctional materials. Composite consists of zinc oxide particles dispersed in polymer like Polystyrene, PANI, P3HT, PVDF,PVA, Cellulose, PSS and Others polymers and has many applications including sensing of gas and chemicals, Pressure, Temperature, Strain and UV Radiation (Ponnamma et al., 2019). P3HT:Au/ZnO-based device on Al_2O_3 substrate, where P3HT is a conducting polymer, is used to detect various oxidizing and reducing gases such as C2H5OH, NH3, CO H_2S, NO_2, etc. (Kruefu et al., 2014). ZnO/PANI polymer composite on Si substrate with interdigitated Pt electrode is reported for its application in UV detection (Talib et al., 2016). Optical properties ZnO polymer composite can be used for detection of Ionizing radiation which is still less explored.

3.2 Gaps in TiO2 based Detectors

TiO_2 is low cost chemically stable material, has wide applications such as gas sensors and UV detectors. Its unique optical and electronic properties make it a suitable candidate for sensing applications. Various structures such as thin film, nanowire and nanorods are explored for UV detection. Exposure to gamma radiation will change physical properties such as optical, electronic and even luminescence of TiO_2, which can be used to measure gamma radiation doses. The TiO_2 nanoparticles, prepared using the co-precipitation method, are used for thermoluminescence dosimetry of gamma radiation dose ranging from few Gy to kGy (Azorín-Vega et al., 2007; Sharmila et al., 2019). TiO_2 sols prepared using hydrolysis of titanium isopropoxide followed by condensation at room temperature, show strong absorption of 540 nm light when exposed to gamma doses ~0.2-1.6 kGy(Huang et al., 2001). RF magnetron sputtered TiO_2 thin films on glass substrate show a decrease in bandgap and PL emission after exposing gamma radiation of doses ~ 2-80 kGy(Gui-Ang et al., 2014). TiO_2 thin films, prepared by DC reactive TiO_2 on Si substrate and spin-coated TiO_2 thin films blended with an organic thin film of lead-phthalocyanine (Janu et al., 2008) are reported to measure gamma doses as low as of few tens of mR. The hydrothermal method is relatively easier and provides a low-cost fabrication without much-sophisticated instrumentation with more flexibility for varying the geometrical shape and size of nanoparticles (Yoshimura and Byrappa, 2008). TiO_2 nanorods arrays prepared using the hydrothermal method, are reported as UV sensors (Cao et al., 2011; Zheng et al., 2013). TiO_2 Nanorods are not investigated as gamma radiation sensor applications.

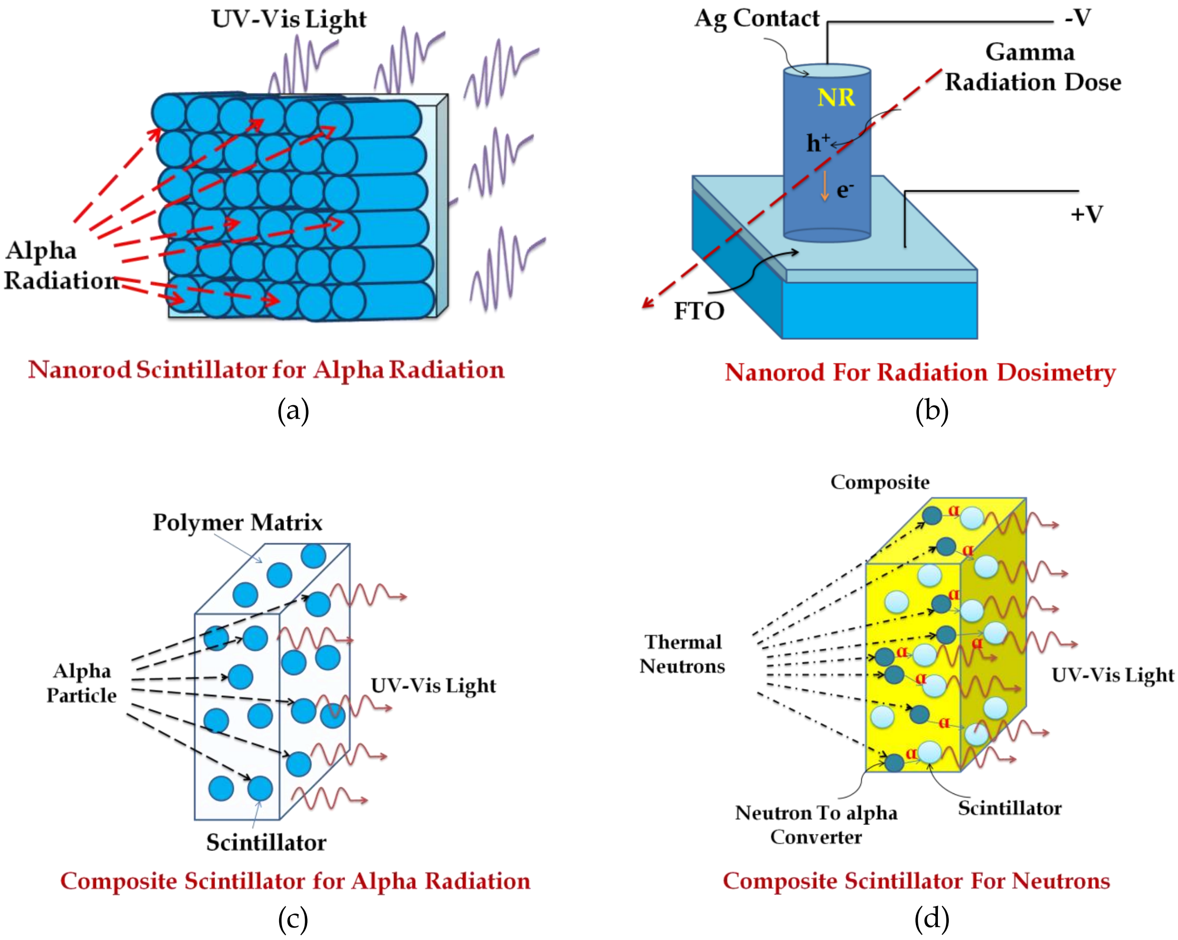

Figure 3.1: Identified Gaps in ZnO and TiO2 Materials

Approach

The following process steps are used to address some of the challenges in designing metal oxide materials in nanostructured and composite geometries and developing detectors for detecting and measuring ionizing radiations.

1. Synthesis of ZnO:Ga nanorods using low-temperature hydrothermal method and characterization of material properties
2. Investigation of ZnO:Ga nanorods as alpha particle scintillator
3. Fabrication of ZnO/Polystyrene composite film and study of optical and luminescence properties
4. Investigation of alpha-induced scintillation properties of ZnO/Polystyrene composite
5. Fabrication of ZnO-^{6}LiF/Polystyrene composite and investigation of scintillation with the thermal neutron.
6. Synthesis of TiO_2 nanorods using hydrothermal method and characterization of material properties
7. Study of gamma radiation-induced changes in I-V characteristics