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(54) Title: LINEAR-RESPONSE NANOCRYSTAL SCINTILLATORS AND METHODS OF USING THE SAME

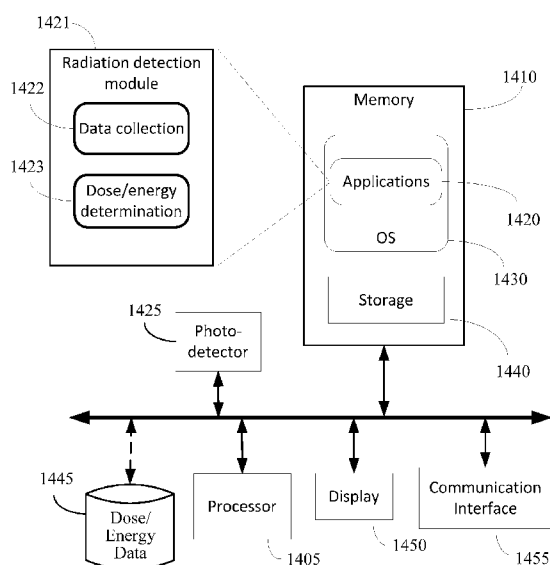


FIG. 14

(57) Abstract: Systems and devices incorporating radiation detection, and techniques and materials for improved radiation detection are provided that involve a nano-scintillator exhibiting a linear luminescent emission response to stimulating electromagnetic radiation. The nano-scintillator can include at least one nanocrystal comprising a rare earth element, a lanthanide dopant, and a spectator dopant, wherein the nanocrystal exhibits a linear luminescent emission response to stimulating electromagnetic radiation of wavelengths less than 100 nm. As one example, the nanocrystal is $[Y_{2-x}O_3; Eu_x, Li_y]$, where x is 0.05 to 0.1 and y is 0.1 to 0.16, and has an average nanoparticle size of 40 to 70 nm. These nanocrystals can be fabricated through a glycine combustion method.



— *with amended claims (Art. 19(1))*

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AMENDED CLAIMS

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1. A system comprising:
 - a nano-scintillator exhibiting a linear or near linear luminescent emission response to stimulating electromagnetic radiation of wavelengths less than 100 nm;
 - a light sensor configured to sense light emitted from the nano-scintillator; and
 - a processor comprising:
 - a data collection module configured to receive calibration data from the light sensor during a calibration mode, and generate a linear response equation from the calibration data; and
 - a dose/energy determination module configured to convert response information received from the light sensor during normal operation into radiation information using the linear response equation.
2. The system according to claim 1, wherein the nano-scintillator comprises at least one nanocrystal comprising a rare earth element, a lanthanide dopant, and a spectator dopant.
3. The system according to claim 2, wherein the lanthanide dopant percentage of the nano-scintillator is optimized for a highest scintillation to dose efficiency while maintaining a linear scintillation response to radiation dose or energy.
4. The system according to claim 2 or 3, wherein the spectator dopant percentage of the nano-scintillator is optimized for a highest scintillation to dose efficiency while maintaining a linear scintillation response to radiation dose or energy.
5. The system according to claim 1, wherein the calibration data comprise data received from exposure of the nano-scintillator material to a known radiation source with known energies during the calibration mode.
6. The system according to claim 5, wherein the known radiation source is between 0 and 100 MV, an x-ray source, and/or a gamma ray source.

7. The system according to claim 1, wherein the nano-scintillator has a linear scintillation response to radiation energy from about 17 kV to about 180 kV.
8. The system according to claim 1, wherein the nano-scintillator has a linear scintillation response to radiation energy from about 0.18 MV to about 50 MV.
9. The system according to claim 1, wherein the nanocrystal is $[Y_{2-x}O_3; Eu_x, Li_y]$, where x is 0.05 to 0.15 and y is 0.1 to 0.25, with an average nanoparticle size of 40 to 70 nm.
10. The system according to claim 1, wherein the processor is configured to calculate and output an average real-time dose, and total integrated dose for a duration of a period in time.
11. The system according to claim 1, further comprising a communication interface configured to transmit a signal from the processor.
12. The system according to claim 11, wherein the dose/energy determination module is further configured to output an alert from the communication interface in response to a determination that the radiation information exceeds a threshold.
13. A nano-scintillator comprising:
at least one nanocrystal comprising a rare earth element, a lanthanide dopant, and a spectator dopant, wherein the nanocrystal exhibits a linear or near linear luminescent emission response to stimulating electromagnetic radiation of wavelengths less than 100 nm.
14. The nano-scintillator according to claim 13, wherein the rare earth element is Y, Th, Sc, or a lanthanide element different than the lanthanide dopant.
15. The nano-scintillator according to claim 13, wherein the rare earth element is Y, La, or Gd and the lanthanide dopant is Eu, Gd, or Nd, the rare earth element and the lanthanide dopant being different elements.

16. The nano-scintillator according to any of claims 13-15, wherein the spectator dopant is Li.
17. The nano-scintillator according to claim 13, wherein the nanocrystal is lithium-doped $[Y_2O_3; Eu]$ with an average nanoparticle size of 40 to 70 nm and is substantially crystalline.
18. The nano-scintillator according to claim 17, wherein the lithium-doped $[Y_2O_3; Eu]$ is $[Y_{2-x}O_3; Eu_x, Li_y]$, where x is 0.05 to 0.15 and y is 0.1 to 0.25.
19. The nano-scintillator according to claim 18, wherein the lithium-doped $[Y_2O_3; Eu]$ is $[Y_{1.9}O_3; Eu_{0.1}, Li_{0.16}]$.
20. The nano-scintillator according to claim 13, wherein the linear luminescent emission response has a peak wavelength of approximately 612 nm.
21. The nano-scintillator according to claim 13, wherein the stimulating electromagnetic radiation is x-ray and/or gamma-ray.
22. The nano-scintillator according to claim 13, wherein the nanocrystal also displays a linear luminescent emission response to stimulation by electron beam, beta, alpha, proton, or neutron particles.
23. The nano-scintillator according to claim 13, comprising a plurality of the at least one nanocrystal, the nanocrystals being in the form of a plate or a film.
24. The nano-scintillator according to claim 23, further comprising a binder and/or a coating.
25. The nano-scintillator according to claim 24, wherein the coating comprises a filter for restricting the wavelengths of electromagnetic radiation stimulating the nanocrystals.

26. The nano-scintillator according to claim 13, further comprising a second scintillating material, wherein the second scintillating material emits a peak wavelength at a different peak wavelength than the nanocrystal.

27. The nano-scintillator according to claim 26, wherein the second scintillating material comprises a polycrystalline plate on which the at least one nanocrystal is deposited or particulates dispersed with the at least one nanocrystal.

28. A method of preparing a nano-scintillator according to claim 13, comprising:
providing an aqueous solution comprising a rare earth metal nitrate, at least one lanthanide metal nitrate, a lithium nitrate, and glycine, wherein the glycine to nitrate ratio is at least 1.5;
heating the solution in air to combustion; and
heating the combustion residue to burn off residual nitrates.

29. The method according to claim 28, wherein the rare earth metal nitrate is $\text{Y}(\text{NO}_3)_3$ and the lanthanide metal nitrate is $\text{Eu}(\text{NO}_3)_3$.

30. The method according to claim 29, wherein the $\text{Y}(\text{NO}_3)_3$ is supplied at a mole fraction of 0.826, the $\text{Eu}(\text{NO}_3)_3$ is provided at a mole fraction of 0.044, and the LiNO_3 is provided at a mole fraction of 0.070 relative to all metals, wherein the prepared nano-scintillator is $[\text{Y}_{1.9}\text{O}_3; \text{Eu}_{0.1}, \text{Li}_{0.16}]$.

31. An x-ray detector screen comprising:
a light sensor having a plurality of pixels; and
a nano-scintillator according to any of claims 13-27 optically coupled to each pixel of the plurality of pixels, wherein the nano-scintillator has a size to fit within a single pixel without overlapping adjacent pixels.

32. The x-ray detector screen of claim 31, wherein the light sensor is a CCD or a photodiode sensor.

33. A portable radiation detector comprising:
a nano-scintillator according to any of claims 13-27;
a light sensor to which the nano-scintillator is optically coupled; and
a low-power portable processing and display unit connected to the light sensor to receive a response signal from the light sensor.
34. The portable radiation detector according to claim 33, wherein the nano-scintillator is overlaid a corresponding pixel of a plurality of pixels of the light detector.
35. The portable radiation detector according claim 33, wherein the light sensor is a CCD or a photodiode sensor.
36. The portable radiation detector according to claim 33, wherein the low-power portable processing and display unit are configured in a cellular phone, a watch, or a GPS-enabled device.
37. A method of detecting radiation comprising measuring the response of one or a combination of more than one scintillator material with different stimulation properties and peak emission wavelengths, wherein the one scintillator material or at least one of the combination of more than one scintillator material is a nano-scintillator comprising:
at least one nanocrystal comprising a rare earth element, a lanthanide dopant, and a spectator dopant, wherein the nanocrystal exhibits a linear luminescent emission response to stimulating electromagnetic radiation at least between 17 kV to 180 kV or 0.18 MV to 50 MV.
38. The method according to claim 37, further comprising: spatially resolving by wavelength, the response of the combination of more than one scintillator material using a spectrometer or a light detector with wavelength filters
39. The method according to claims 37 or 38, further comprising: discriminating the different stimulation properties by intensity using a multi-channel analyzer producing a pulse-height spectrum.