Lead Iodide as Room Temperature X-Ray Detector and its Limitations

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Abstract**—**Lead Iodide is a very good room temperature detector. The properties of Lead Iodide are such that they match with the properties needed for a good room temperature X-ray detector. It is also having some limitations like degrading with time and having soft crystals. The concept of polymer composites of Lead Iodide will solve this problem in great extent. So with the polymer composites of Lead Iodide, we get a material act as excellent X-ray detector.

Keywords—*Lead Iodide; Polymer Composites; X-ray Detector, X-ray Switching, Zone Refining.*

I. INTRODUCTION

Lead Iodide (also called Plumbous Iodide) is a crystalline solid, having colour bright yellow, having no smell i.e. odourless and when it is heated it becomes orange & red. It is toxic in nature, so it is advised to work with this carefully because if it goes in our body through using with bare hands, it may be highly hazardous to health. The symbolic representation of Lead Iodide salt is PbI_2. The band gap of Lead Iodide is 2.3eV and melting point is 402ºC. The solubility of Lead Iodide in water is 0.044 g/100 mL (at temperature 0°C), 0.0756 g/100 mL (at temperature 20 °C) and 0.41g/100 mL (at temperature 100 °C). The crystal structure is Hexagonal closed packed structure. The density of lead iodide is 6.16 g/cc and density of water is 1 g/cc, so this material lead iodide is denser than water.

The magnetic property of any material is calculated in terms of susceptibility. If the material is paramagnetic, then susceptibility is positive and if material is diamagnetic, then susceptibility is negative. The susceptibility of lead iodide is negative, so the material lead iodide is diamagnetic.

Lead Iodide [1,2,3] is a very good room temperature detector but with the passage of time, it starts to degrade. So the stability of the material Lead iodide is affected, this problem is sorted by the concept of polymer composites. With these polymer composites the stability is regained and these polymer composites are also good detectors for X-Rays. There are many parameters by which we can show the preference of polymer composites over lead iodide as material. Some parameters are Imax/Imin, the switching graphs and also the band gap is not affected. Also basic nature of the material is not changed after adding polymer composites with lead iodide. So now we get a material with polymer composites having more stability, similar properties and good X-ray detector.

II. PROPERTIES FOR X RAY DETECTOR AT ROOM TEMPERATURE

The properties needed for a X-ray detector[4,5] operated at room temperature are explained as:

A. High Melting Point

The melting point should be high. If the melting point is low, so when high energy radiation will fall, it will melt down.

B. High Band Gap

If the band gap is low, at room temperature the electron will go to the conduction band, the thermal agitation will be there and contribute in current and we cannot measure the exact current due to X-rays fall on the material.

C. High Atomic Number

The large atomic number provides large stopping power for radiations. Also more number of electrons will there and these will contribute in current which will be helpful as X-ray detector.

III. PROPERTIES OF LEAD IODIDE

The properties of Lead Iodide [6,7,8] are very much matched with the X-ray detector at room temperature. Lead iodide is having very high melting point 402ºC and very high boiling point 872ºC. So while using as detector material, it will not melted or boiled easily.

The band gap 2.3eV of lead iodide is very much sufficient which is required for as X-ray detector so that thermal agitation will not be there.

Also the atomic number is lead iodide (Lead 82 and Iodine 53) is favorable for having large stopping power which is required for a good X-ray detector.

So we can compare the properties of Lead Iodide and can say that it is ideal to use as an X-ray detector when it is in its pure form. But if it is degraded by some reasons, then this quality to use as an X-ray detector is also affected.

IV. ZONE REFINING

In the method of Zone refining, the melt growth is done, here a narrow region is melted and this is moved along the crystal. Also narrower the zone, more impurities will be moved from one part to another. The impure solid is melted, the impurities are moved to other side and a wake of pure material is behind and it is solidified. The impurity will move with liquid due to segregation coefficient.

In this there are these things to care about: (1) Narrow zone for good growth (2) Temperature gradient (3) Segregation Coefficient for impurities (4) If the zone refining is done with lead iodide, the possibilities are there that the lead will make oxide, so this is another factor to remove the air from the container with Argon like gas.

The fig. 1 shows the zone refining pictorially about heater used to melt the material; a zone is shown as melt zone, is the zone on which the heater presently applied to melt it. Also the impurities are shown going toward the side which moves with the liquid and pure part remains toward the left side and when heater goes away from it the pure part solidify. So impurities are going toward another end and pure crystal remains on one side. After the zone refining the pure part may be cut with some sharp thing from the impure part and we get the pure crystal.

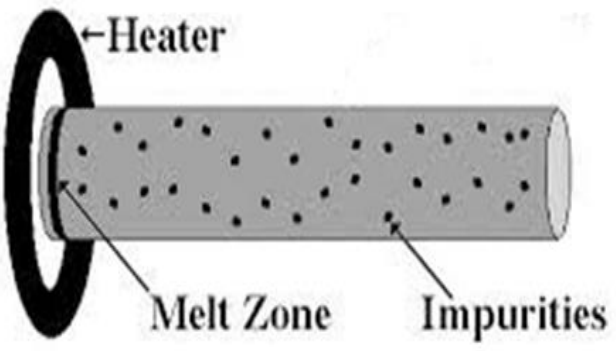

Figure 1: X-ray Sensing for Switching Studies

V. X-RAY SWITCHING STUDY

X-ray sensing of lead iodide is done and the dc conductivity is measured. Also switching study is done with X-ray switching. The change in current versus time is measured and it is found that with passage of time due to the degradation of lead iodide, the switching is also affected. The sharp rise and sharp fall should be there for a good detector. But if the material is affected, there will be delay in rise and similarly the fall will not be sharp, it will also delay.

Also the switching study polymer composites, it is found that the problem of delay in rise and delay in fall is removed. We get the sharp rise and sharp fall in current versus time whiling studying the dc conductivity. This is due to the polymer composite which removes the grain boundaries and other problems of degradation in stability. And the results favor for the X-ray detector.

The pictorial representation of X-ray falling on sample is in fig. 2 below:

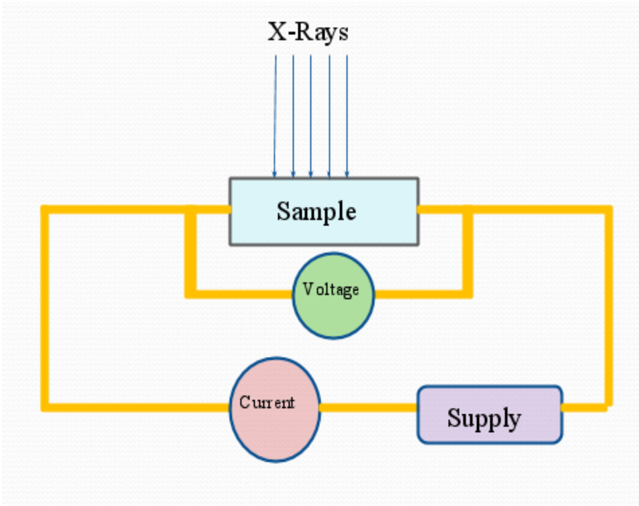

Figure 2: X-ray Sensing for Switching Studies

For a good X-ray detector, the X-ray switching should be like this as shown in fig. 3 below. In this figure the sharp rise in current is there and also sharp fall in current is there. So whenever an X-ray falls on the sample, the current will rise instantly and when we off the X-ray to fall on the sample, it must rise down sharply. So if the sample is degraded, the X-ray switching will not be ideal one. But in case of polymer composites, it is nearer to ideal one where the sharp rise and sharp fall is there.

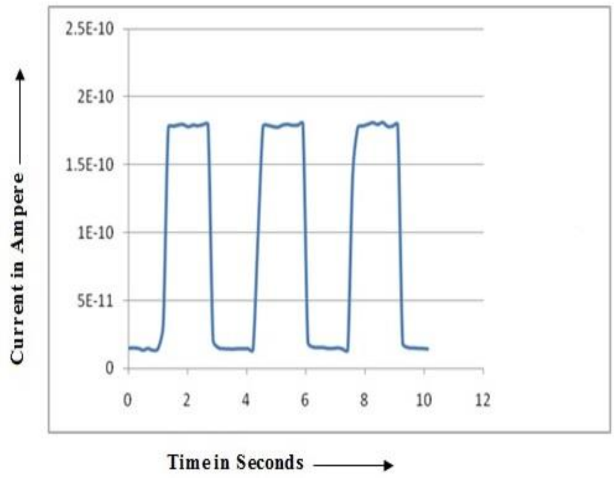

Figure 3: X-ray Sensing for Switching Studies

VI. LIMITATIONS OF LEAD IODIDE AND THEIR SOLUTION

The crystals of lead iodide also have some limitations. These crystals are soft and they degraded with time. After studying the limitations of Lead Iodide i.e. the softness and degradation with time, the concept of polymer composites will be introduced as the next to work on. The polymer composites will provide stability to the material and the basic characteristics to act radiation detector will remain in the material.

VII. CONCLUSION

Here we are concluding that why the polymer composites should be preferred over Lead Iodide [9,10] as detector material. In polymer composites, the properties are retained which are required for good X-ray detector. Also the stability of the polymer composite is more than the lead iodide. In polymer composite the current loss is not there which is there in case of lead iodide when it degrades with passage of time and grain boundaries are developed there. And during current rise, charge carries trap there in these grain boundaries and do not contribute to rise of current. Also during current fall the value of current will not be zero and soft & cracked lead iodide will not act as good detector if it is in degraded state. So the concept of polymer composites is introduced where grain boundary areas are filled with these polymers. So during the current rise, these contribute in current rise and during current fall, the charge carries do not trap there.

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VIII. REFERENCES

[1] K.S. Shah, "Lead iodide X-ray detection systems," Nuclear Instruments and Methods in Physics Research, Elsevier (1996).

[2] G. Zentai, L. Partain Ginzton, "Mercuric Iodide and Lead Iodide X-Ray," Technology Center of Varian Medical Systems, Mountain View, CA 94043 USA (2003).

[3] M. Hassan, M. Matuchora and K. Zdansky, "Performance of Lead Iodide Nuclear Radiation Detectors,"" Central European Journal of Physics, Vol. 4, No. 1, 2006.

[4] M. Matuchova, "Preparation of Lead Iodide as Input Material for X-Ray Detectors," Czech Academy of Science, Czech Republic, 2010.

[5] S K Chaudhary, "Impurity induced structural phase transformations in melt grown single crystals of lead iodide," Crystal Research and Technology (2011).

[6] A. M. Caldeira Filho, "Characterization of thermally evaporated lead iodide films aimed for the detection of X-rays," Elsevier (2011).

[7] DS Bhavsar, "Study on Properties of Lead Iodide Crystals," Scholar Research Library Journal, USA, Vol. 3 (6) 2011.

[8] Sunil Kumar Chaudhary, "Lead Iodide Crystals as Input Material for Radiation Detectors," Crystal Structure Theory and Applications, 2012.

[9] C. M. Handleya and C. L. Freeman "A New Potential for Methylammonium Lead Iodide," PCCP Jounal, Dec 2016.

[10] Z Fan, "Layer-by-Layer Degradation of Methylammonium Lead Iodide," Cell Press (2017).

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