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X-Ray Sensing by Mercury Iodide Poly-Vinyl Alcohol Composite

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Abstract:
Technology has modified nearly every aspect of modern life and digital devices have made an important place in every field. In medical field also the digital X-ray applications have contributed a lot. The most important component of digital imaging system is X-Ray sensor. Solid state sensor materials are used as X-ray sensors, like lead iodide, Zinc Sulphide, Titanium dioxide and Mercuric idodide, etc. Mercury Iodide has some favourable properties which make it most suitable material for X-Ray sensor. In present study, polymer composites of Mercury Iodide were prepared using polyvinyl Alcohol (PVA) at room temperature. Studies revealed that Mercury Iodide - PVA sheets show a stable detection of X-rays for all concentrations and the value of (I_{max}-I_{min}) increases with increase in the concentration of Mercury iodide to 32 %, and after concentration of 61 % value of (I_{max}-I_{min}) starts decreasing. An optimized range of concentration is worked out (32 % to 61%) at which the maximum value of photocurrent is obtained. X-ray switching studies conducted on these sheets show low rise and fall time making the material good for imaging applications. For the concentration of 32.2 % concentration rise time was recorded as 0.99 for a pulse of 2s and more.

INTRODUCTION:

Technology has modified nearly every aspect of modern life and digital devices have made an important place in every field. In medical field also digital X-rays applications has contributed a lot to diagnose a problem. As X-rays are not secure to human body and radiation exposure can cause cell mutations that lead to cancer. Therefore, there is need to limit X-ray dose to patient. It can be done only if our x-rays sensors are very sensitive to high energy radiation. So, a good X-ray sensor is always in demand. Many solid state materials are used as X-ray sensors like Lead iodide, Cadmium iodide, Zinc sulphide, Titanium dioxide and Mercury iodide etc. Mercury Iodide is very much suitable for making X-ray sensor and has favourable properties to fabricate a sensor [1,2]. It is very difficult to handle single crystals mechanically and previous study revealed that, composites are best among the three forms i.e. single crystal, thin film, composites [3]. It was decided to prepare composites of Mercury Iodide with the polymers with different concentrations of mercuric Iodide. Some of the latest sensor materials are listed in table-1 and its environmental hazards are also listed:

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S. No	Sensor	Health Hazards (NFPA)(0-4)
1	Mercuric iodide	3
2	Cadmium Iodide	3
3	Bismuth (III) oxide	1
4	Lead Iodide	3
5	Cadmium Iodide	3
6	Titanium dioxide	1

Table1. Material Safety Data Sheet (MSDS) rating of several solid state detector materials along with Mercuric Iodide in respect of health hazards caused by them (sciencelab.com).

The data from table-1 reported that Mercuric Iodide is a poisonous material that is harmful to the environment if it is used directly as a sensor. Polymer composites are heterogeneous substances consisting of two or more materials that have their individual characteristics. The combination of materials brings about new physical, chemical, and mechanical desirable properties [4]. Therefore, its toxic nature can be reduced to no harmful level by making its polymer composites and it can be used as a sensor without any adverse health effects. A good solid-state detector material is based on the following major properties [3]:

1. Material should have a high band gap. This helps in minimizing thermally generated noise.
2. Constituent atoms should have a high atomic number. This is for maximum absorption of X-ray energy.
3. Mobility-life time product of the material should be high. This helps in better charge collection.[5]
4. Operating electric field should be low. It helps in keeping electronics involved simple.
5. Operating temperature likely to be room temperature for ease in operation.
6. Response time should be small for faster data processing.
7. Fabrication of the detector should be simple with the flexibility of design, shape, and size.
8. Highly stable or have low degradation.

Mercuric iodide is the most important material, due to its following promising properties: [8]

1. It is a wide band gap semiconductor (having a band gap of 2.13 e.V. which leads to a reduction in the density of thermally generated free carriers as compared to the density of X-ray generated carriers. This helps in keeping a low dark current in comparison to a photocurrent.

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2. Due to the high atomic number (Hg-80u and I-53u) of its constituents, it has a high photon absorption coefficient.
3. Mobility-life-time product of the material is quite high i.e. 10 – 5cm^2/V, which ensures better charge collection.
4. The operational electric field is fairly low | 10^4 V/cm which removes the requirement for a high voltage power supply.
5. Material processing temperature is low i.e. 100^0C therefore, its processing is easy.

Each solid-state detector has properties that make them suitable for the detector, but the most important thing is flexibility in designing the shape of the detector. X-rays are high-energy radiations. When they interact with these materials they are partially reflected and partially refracted through the material. Photocurrent induced on the exposure of X-rays depends on the Quantum efficiency of material, the area exposed, reflectance coefficient, intensity wavelength product, and thickness of the sample [8]. The limited portion is absorbed by the material. If the detector is properly shaped, it is possible to maximize the absorption of X-rays. Single crystalline material gives limited flexibility in designing the shape of the detector. Keeping this in mind, it was planned to develop composite detectors. To have a better spectrum of physical and chemical properties it was planned to blend Mercuric Iodide with polymer (poly-vnyl Alcohol) PVA is a well known polymer. It is selected due to its following properties .

1. PVA shows high tensile strength and flexibility.
2. It is soluble in water and has no odor.
3. PVA molecular weight or polyvinyl molecular weight ranges between 26,000-30,000.
4. Its melting point is 185°C.
5. It is insoluble in organic solvents but slightly soluble in ethanol.

Therefore, composites are the best option to enhance its mechanical properties. Polymers provide additional strength and flexibility in the shape of such detectors. In present study, a polymer composite of Mercuric Iodide has been fabricated with PVA as polymer matrix and reinforcement material as Mercuric Iodide. [11]. Further, they are subjected to X-ray switching studies.

MATERIAL AND SENSOR DEVELOPMENT:

Mercuric Iodide has been purified by recrystallization using a multiple sublimation technique [1]. Fig. 1 shows crystals having dendrite growth which is attributed to the fast growth rate. On reducing the growth rate, it is found that crystals are very small in size therefore it is very difficult to separate them from the residual charge.

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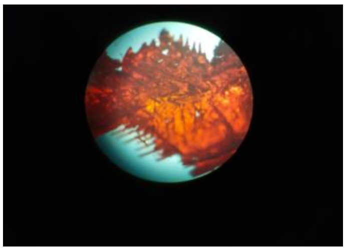
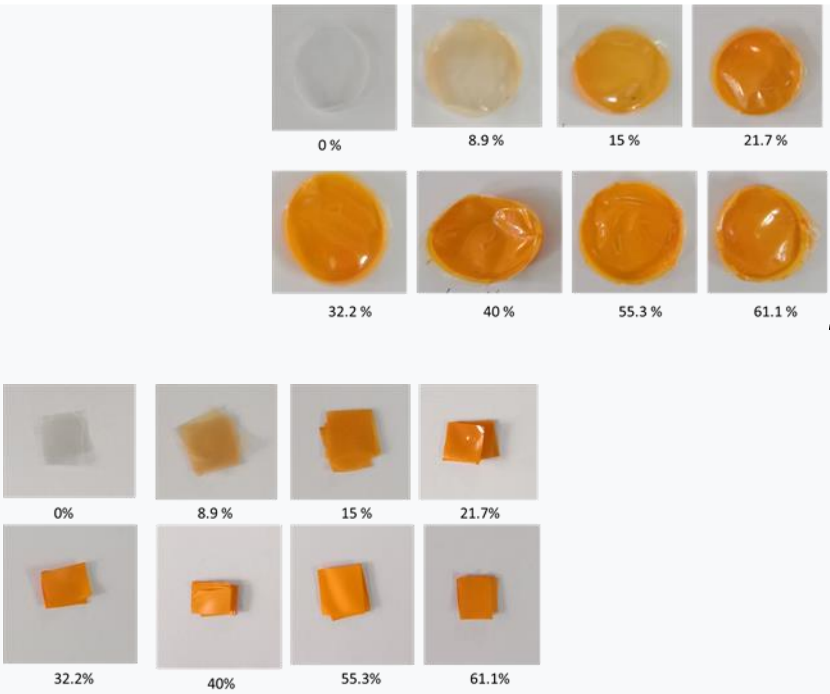


Fig1. Dendrite growth of purified Mercuric Iodide Crystals.

Polymer composites of Mercuric Iodide were prepared by setting of solution due to gravity at room temperature. Polymer Composites were prepared by dissolving a polymer and Mercuric iodide in a suitable solvent. PVA polymer was used as matrix material with different concentrations of Mercuric Iodide. Eight samples of composites of mercuric iodide with different concentrations were prepared. Samples of polymer composites with different concentrations of Mercuric iodide were shown in fig 2. While making the composite, the amount of mercuric iodide has been taken from 0% to 61.1%, as can be seen in the figure 2.



Samples

Sensors

Fig 2: Polymer composites of Mercuric iodide with different composition.

These samples were cut in the form of rectangular sheets. Samples were then subjected to microscope studies to find out any possibility of cracks etc. Only those samples were used for studies that were found free from any crack.

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X-RAY SWITCHING STUDIES:

X-ray switching studies have been performed on composites of Mercuric iodide with PVA to know about the response time of the sensors .The experimental setup used for X-ray switching studies consist of:

- X-ray source
- Time controller device
- Sensor holder
- Software/hardware to record photocurrent.

The voltage across the samples was fixed of the order of 25 V. All the samples were repeatedly exposed to an X-ray. Each exposure was of 2 sec. The photocurrent was recorded by Keithley 6485Pico meter. The schematic longitudinal configuration of device is shown in fig 3.

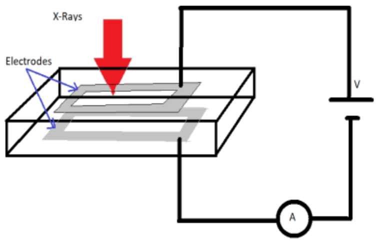

Fig 3: Circuit Diagram to measure photocurrent

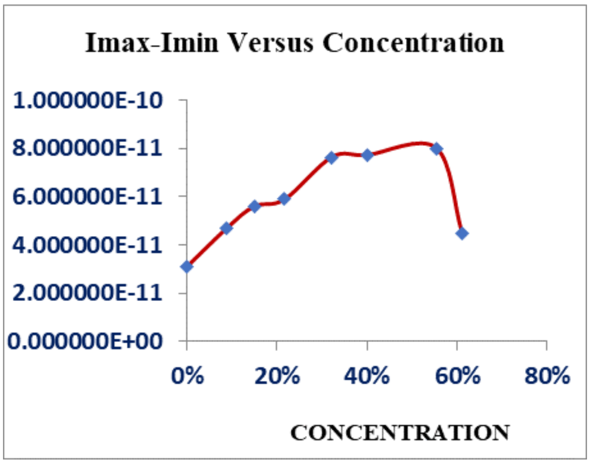

Fig 4: ***The variation of*** **(I_{max}-I_{min}) at different concentrations**

Voltage applied to the sheets is of the order of 25 V and the variations in (I_{max}-I_{min}) were observed for all concentrations as shown in table 3. The graph in fig 4 shows the variation of (I_{max}-I_{min}) at different concentrations:

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Concentration	I_{max}- I_{min}
0%	3.113850E-11
8.90%	4.71218E-11
15%	5.60540E-11
21.70%	5.89086E-11
32.20%	7.63331E-11
40%	7.71602E-11
55.30%	8.00924E-11
61.10%	4.488100E-11

Table 3. Observations of (I_{max}- I_{min}) with different concentrations.

It is observed that,for a particular value of electrode voltage of the order of 25V the value of (I_{max}-I_{min}) increases with increase in the concentration of Mercuric iodide to 32.2 % value and the value of (I_{max}-I_{min}) becomes saturate inbetween 32.2 % to 55 % and then starts decreasing after 55% concentration. In the case of polymer composites, PVA is acting as a charge bridging material between Mercuric Iodide grains [9]. Switching curves were obtained for all eight concentrations, and (I_{max}–I_{min}) was observed as shown in table 3. The optimized range of concentration of mercuric iodide at which maximum photocurrent was observed is 32.2 % to 55.3 %. Swiching curves for 32.2% concentration at 25 V electrode voltage were shown in Fig 5

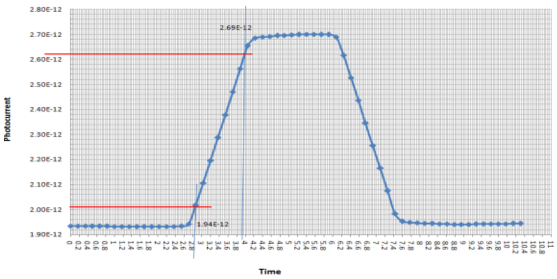

Fig: 5: Switching curve of PVA-Mercury Iodide

CONCLUSION:

Mercury Iodide – PVA composite sheets show stable detection of X-rays for all concentrations but the value of (I_{max}-I_{min}) increases as we increase the concentration of Mercury iodide up to 32.2 % and Photocurrent becomes saturate after 32.2 % concentration to 55.3 % concentration and value of I_{max}-I_{min} starts decreasing after 55.3 %. This can be understood as initially increase in concentration of mercuric iodide, increases charge carriers. At low concentration of mercuric iodide, structural deformations were limited. As concentration of mercuric iodide is increased, structural deformation become significant[11]. Thus, on increasing concentration beyond this limit, structural deformation starts playing dominating role. Hence, increasing the concentration of Mercuric Iodide in composite, polymer chains of PVA starts breaking. This results in the trapping of charge carriers [7]. Thus, overall photoelectrons collection reduces.

So, an optimised range of concentration(32.2 % to 55.5 %) has been obtained at which the sensor shows the maximum value of photocurrent. These sheets show quite low thermally generated charges at room temperature and high photocurrent. X-ray switching studies conducted on these sheets show low rise and fall time making the material good for imaging applications. Rise time was recorded as 0.99 sec for concentration 32.2 % for a pulse of 2 second and more.

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