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# X-RAY Switching Studies on Mercury-Poly-Methyl-Methacrylate Composites

KEYWORDS: Metal-polymer composite, X-ray detector, Switching studies, Photoconductivity, Digital X-ray imaging.

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**ABSTRACT** *Mercury-poly-methyl-methacrylate composites were prepared by vigorously mixing liquid mercury with PMMA in chloroform. Hard sheets obtained were subjected to X-ray switching studies. Composites of mercury and PMMA are found to sense the existence of X-rays. However switching studies reveal their unusual behavior with increasing electric field. They are found to show the decreasing trend in the maximum to minimum current when exposed to X-rays repeatedly with increasing field. This behavior is attributed to the polarization of conducting metal particles in the surrounding of non-conducting polymer.*

## INTRODUCTION

In medical diagnostic, digital X-ray imaging techniques like X-ray computed axial tomography (CAT-scanning), radiovisiography (RVG) etc. are growing at fast pace. These are continuously becoming important and popular due to reduced X-ray dose to the patient and having advantage of post-processing and analyses [1-2]. Apart from medical diagnostic, X-ray imaging is also used in applied mineralogy [3]. These techniques make use of sensitive X-ray detectors. Advanced machines are using solid state detectors which can operate at room temperature. One of the important requirements is very low room temperature noise. Further these detectors should have fast switching. It mean when X-rays are on, photocurrent produced in the detector material should increase fast and have high value. Similarly when X-rays are off, current through detectors should go down fast. Many solid state detectors like alpha-selenium, cadmium zinc telluride mercuric-iodide, lead-iodide, cadmium-iodide etc. are found to be good detectors [4]. Single crystals of this material are excellent detectors in terms of quantum efficiency and switching characteristics. However they have limited mechanical flexibility in designing the detectors. More-over they are sensitive to purity issues. As impurities and grain boundaries cause damage to their efficiency.

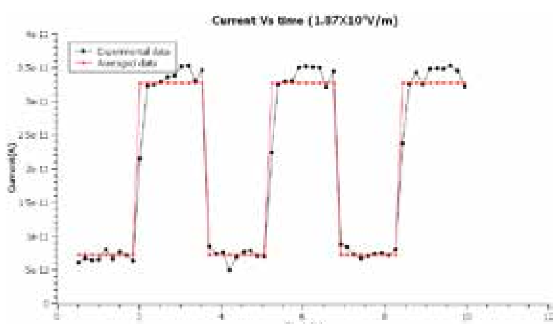
Processes involved after single crystal growth such as cutting, polishing, electrodes formations etc. further cause mechanical damage to the crystals. In order to enhance its mechanical properties and design flexibility, metal-polymer composites are promising options [5]. Many metal-polymer composites were found to possess extraordinary properties like high mechanical strength [6-7].

## EXPERIMENTAL

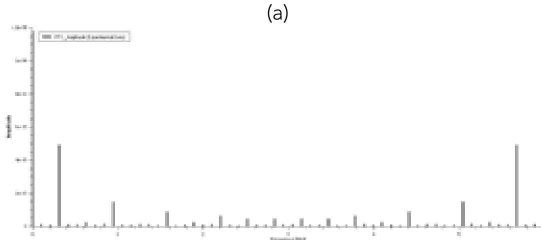
Mercury-poly-methyl-methacrylate composites (Hg-PMMA) were prepared by vigorous mixing of liquid mercury (99% pure) with PMMA in chloroform (99% Fisher Scientific India). Uniform mixtures were left to settle for nearly 48Hr. It was found that mercury proportion up to 15% by weight mix-up uniformly. Beyond this mercury granules are left unmixed even after prolonged mixing. Density of these composites were found in the range 2-3.8g/cc. These composite sheets are mechanically hard. Samples of 1cm X 0.5 cm are cut and subjected to X-ray switching studies. X-ray source with copper target is used. X-ray generator is operated at 30KV (nickel filtered) with 10mA plate current. For X-ray beam chopping, switching rotor device was used. For blocking X-rays 4mm semicircular lead disc was used. Rotation is controlled by a stepper motor using microprocessor P89C51RD2. Photocurrent was recorded by Keithley 6485 pico-meter.

## RESULTS AND DISCUSSION

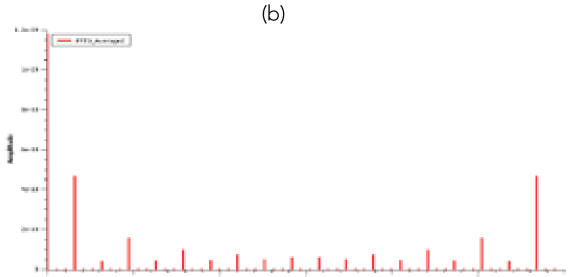
Composite sheets were found to have low electrical conductivity at room temperate (~300K). Switching curves were obtained at varying electric field through the sample. Fig 1.




(a)



(b)



(c)

Fig1(a) Photo-current Vs time graph (b) Fast Fourier Transform of experimentally observed data (c) Fast Fourier

Transform of experimentally observed data

To understand the photo charge carrier generation, let X-rays of wavelength λ and of intensity $I_0$ is allowed to fall normally on the sample of thickness 't'. We used X-ray of wavelength 0.154nm. Photons of these X-rays have energy ~8X10$^3$ e.V. This energy is sufficient to produce secondary even electrons. Let 'r' is reflectance co-efficient of material. It means that only $I_0$(1-r) intensity of X-ray enters into the material. Intensity of X-rays decreases as they pass through the material. Decrease in intensity is directly proportional to the intensity itself, according to the relation

$$\frac{dI}{dx} \propto I \quad \text{…………………(1)}$$

Here x is the depth of the sample and λ is absorption co-efficient. Hence the intensity of X-rays leaving the material is

$$I_L = I_0(1-r)\exp^{-\beta t} \quad \text{……………..(2)}$$

Thus the intensity absorbed by the material is

$$I_a = I_0(1-r)(1-\exp^{-\beta t}) \quad \text{…………(3)}$$

If area exposed is 'A' and it is assumed that it remains almost same throughout (as refractive index of most of the materials for X-ray is nearly 1), light energy absorbed by the material per unit time is given as:

$$E_a = I_0 A(1-r)(1-\exp^{-\beta t}) \quad \text{………(4)}$$

Total number of photons absorbed per unit time is

$$N_a = \frac{E_a \lambda}{hc} \quad \text{………………(5)}$$

When an X-ray photon is absorbed by the material two major phenomenon occur i.e.

Multiple production of electron-hole pairs as energy is high

Recombination of electron–hole pairs due to defects and impurities present in the material

Let the total number of charge generation, by all the three processes together is 'ξ' per photon. Hence the total number of actual charge generation per unit time is

$$N_{acc} = \frac{E_a \lambda}{hc}\xi \quad \text{………………(6)}$$

Here ξ is called quantum efficiency. The photo current generated is

$$I_P = \frac{\xi \lambda e I_0 A(1-r)(1-\exp^{-\beta t})}{hc} \quad \text{………(7)}$$

This clearly indicates that photo current so generated is dependent on

1. Quantum efficiency of material (ξ)
2. Area exposed (A)
3. Reflectance co-efficient (r)
4. Intensity-wave length product ($I_0$λ). For fixed intensity larger wavelength means more photons
5. Thickness of sample (t)

As theory reveals that number of actual charge generation is directly proportional to the electric field applied (Equation 6). However experimental data obtained show that maximum (when x-rays are on) to minimum current (when X-rays are off) ratio ($I_{Max}/I_{min}$) decreases on increasing the electrical field applied to composite sample [Fig.2].

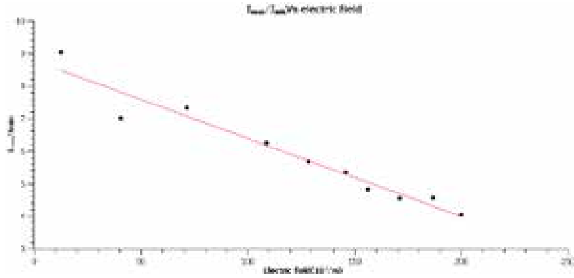


**Fig2 Imax/Imin vs electricfield**

Metal-polymer composites are known to have unusual properties. These composites contain conductive filler dispersed in an insulating polymer matrix. It was shown [8] that the fillers have sharp surface tips. The electric field strength at these tips is very high and results in field assisted tunneling (Fowler–Nordheim tunnelling [9]). Conducting metal particles are covered by the non-conducting polymer. Overall resistivity is high. In the presence of X-rays these conducting particle get excited. This increases the photocurrent. When X-rays are made off, field generated could not release itself in absence of the conducting path through the composite(polarization effect). This keeps the dark current ($I_{min}$) on higher side. With the increase in the electric field this effects becomes stronger. As a result $I_{max}/I_{min}$ decreases with increasing field.

## CONCLUSIONS

Composites of mercury and PMMA are found to behave unusually showing the decrease in the $I_{max}/I_{min}$ current when exposed to X-rays repeatedly. This behavior is attributed to the polarization of conducting metal particles in the surrounding of non-conducting polymer.

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