

PMMA-CdI 2 Composite as X-Ray Sensor

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Abstract

With the development of digital x-ray sensing devices, demand for stable and highly sensitive material is continuously increasing. Various solid state materials have been discovered like mercuric iodide, lead iodide, potassium di chromate etc. These materials are used both in single crystal form and polycrystalline form. Most of the materials are found to have limited stability. In search of highly stable material, composite materials using polymers are searched. In present study cadmium iodide in PMMA is subjected to the study for their X-ray sensing properties. For these their electrical conductivity measurements were made both in absence and in presence of radiations (X-Rays and low intensity Gamma Rays). Results, obtained are analyzed in the light of photocurrent generated by high energy radiations. These composites are found to have high efficiency and stability for X-ray sensing. However x-ray switching response is limited.

Index terms— Composites, Poly-methyl methacrylate, High energy sensors, Electrical properties, High energy radiations, X-rays.

1 INTRODUCTION

In recent years there is continuously increasing digitalization in every field affecting human life. In diagnostics, use of X-ray computed tomography (CT) or computerized axial tomography scan (CAT scan) and digital X-ray imaging are now routine activities [1][2][3][4]. These techniques require the digital data which can be processed by a computer. Normally this data is obtained by X-ray detector. In earlier versions of such machines, cesium iodide crystals were used as scintillation detectors. Later in 1980s use of high pressure Xenon gas ion chambers were used [5]. In modern machines scintillation materials like rare earth oxide ceramics are in use. These materials absorb X-rays and re-emit the absorbed energy in the form of light. Light signals are then converted into electrical signals by photodiode and processed. However there is a possibility of direct conversion of X-ray signals into electrical signals with help of solid state X-ray detectors. These are basically semiconductor materials like silicon or germanium doped with lithium. X-rays passing through these materials are absorbed and are converted to electron-hole pairs to create electrical signals. For proper sensitivity, operations of such detectors require liquid nitrogen temperature. This helps in minimizing thermally generated electron-hole pairs. In 1990s many solid state detector materials were explored like alpha-selenium, poly cadmium zinc telluride, mercuric iodide [6], lead iodide etc. Basis for a good solid state detector material is based on the following major properties:-1. Material should have high band gap. This helps in minimizing thermally generated noise. 2. Constituent atoms should have 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. 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 detector should be simple with flexibility of design, shape and size. 8. Highly stable or have low degradation.

Every solid state detector material has some of the above properties but lacks in some other properties. One of the important issues is flexibility in design. X-Rays are high energy radiations. When they interact with these materials they are partially reflected and partially refracted through the material. Limited portion is

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

absorbed by the material. If 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 detector. Keeping this in mind, it was planned to develop composites detectors. To have better spectrum of physical and chemical properties it was planned to blend an inorganic material (cadmium iodide) with organic polymer (poly-methyl methacrylate). Cadmium iodide molecule contains elements having high atomic masses (cadmium-112.4u and iodine-126.9u). This helps in good absorption of X-rays. Further electronic band gap of cadmium iodide is high (3.3-3.1e.V.) [7]. This is especially helpful in reducing the dark current due to thermal agitation at room temperature. Poly-methyl methacrylate (PMMA) is well known polymer. It is selected due to its following properties [8][9][10].

1. Low linear mould shrinkage (0.003-0.0065 cm/cm)
2. Good mechanical properties {Hardness (63-97 Rockwell,M) and Tensile strength (47-79 MPa)}
3. Most resistant to direct sunshine exposure.
4. Low water absorption (0.3-2%) makes it very suitable for electrical device making.
5. Very low electrical conductivity (10^{-14} - 10^{-15} $\Omega^{-1} \cdot \text{cm}^{-1}$)
6. High dielectric strength (17.7-60kV/mm)

2 EXPERIMENTAL

Cadmium iodide (99%, Loba Chemie) is used as base material. White crystalline powder is fine grinded using agate mortar and pestle to a fine powder. No additive is used during this process. Due care is taken to keep the powder dry. PMMA granules were dissolved in chloroform (99% Fisher Scientific India) and mixed with fine powder of cadmium iodide. Uniform mixture is then kept to settle down for 48 hours in vibration free atmosphere. No further hot pressing is done to prevent any mechanical damaging to the sheets. After this fine sheets of PMMA-CdI 2 composite were obtained. They were cut in square sizes of 1cmX1cm for further study. Sheets, without air bubble are used for the study. Sheets were polished for smooth surfaces and coated with silver paste. Coated sheets were kept for drying for nearly two hours.

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

Composite sheets are found to be whitish in colour (Fig. 1(a)). These sheets are nearly 1mm in thickness and are flexible. When observed under low power optical microscope, small air bubbles are found to be trapped in some of these sheets. Optical micrograph (Fig. 1(b)), taken under polarized white light shows the formation of crystallites of CdI₂. Crystallite size is measured to be of the order of micrometer. It can be seen that small crystallites are suspended in PMMA matrix. Sheets with three concentrations (by mass) were prepared i.e. 9.71%, 13.95% and 19.09%. Micrographs of these sheets clearly indicate that PMMA gaps decreases with increase in concentration and increasing the filler contacts between cadmium iodide crystallites.

Electrically these sheets have very high resistance ($3.4 \times 10^{11} \Omega$) at room temperature. Two probe methods are used to study their electrical conductivity. Composite sheets with silver paste on both sides were gripped by two spring loaded electrodes. This assembly is kept in a PID controlled oven. Regulated power supply is used to provide voltage and current is measured by picoammeter which is calibrated by Keithley 6485. All measurements for band gap determination are done at low voltage (18V). Temperature is kept below 60 °C, as glass softening temperature of PMMA is 100 °C. When subjected to change in temperature these sheets show semiconducting behavior (Fig. 2).

Conductivity of such hybrid structures can be given by combining Mott Variable Range Hopping equation (For PMMA) and basic Arrhenius Equation for semiconducting materials (CdI₂). E_g is band gap and k is Boltzmann constant. Electrical conductivity of PMMA is negligible (10^{-14} - $10^{-15} \Omega^{-1} \cdot \text{cm}^{-1}$) in comparison to the conductivity of cadmium iodide ($2.5 \times 10^{-9} \Omega^{-1} \cdot \text{cm}^{-1}$ [11]). Cadmium iodide is a layered compound. I-Cd-I layers are piled one over the other. There is strong electrovalent bond between cadmium and iodine atoms. However two layers of I-Cd-I are attached to each other. It is found that number of charge carriers passes through the sheets increases with rise in temperature. This can be understood as the polymeric chains of PMMA and cadmium iodide crystallites act as traps of charge carriers. With rise in temperature, phonon excitation increases. Phonon assisted hopping process helps in releasing the trapped charges. These charges using π -bond electrons move through the polymer molecules to the nearby cadmium iodide crystallite. Further these electrons drift under electric field through the cadmium iodide crystallites. Electric field applied to the sheet is of the order of 1×10^4 V/m sufficient enough to cause the drift. (Fig. 3) Also when exposed to gamma radiations, voltage vs current variations shows a very small change in the variations of current with voltage. Similar variations are observed in all the sheets with different concentrations. It is found that there is small increase in the resistance of the sheet in presence of the gamma radiations. When gamma source is removed and again the variation of voltage and current is taken, small increase is further observed in the resistance. (Fig4). Following inferences can be drawn from the study: 1. These sheets are almost transparent to the low intensity Gamma radiations as very small changes are observed. This is primarily due to less thickness of sheets (thickness of 1mm). 2. Although interaction of Gamma radiations is limited, yet they are able to create some damage to the bonds and cause some additional trap centers. Sheets were exposed to X-rays (Cu target 30KV, 10 mA plate current) parallel to electrode plates (Fig. 5). X-ray intensity to which sheets were exposed is of the order of 10^{-2} W/cm². It was found that photo current increases by a factor of 230.7 in comparison to the dark current (Fig. 6 (a)). Material

used as a sensor should have very low response time. To evaluate response time switching studies were conducted on these films (Fig. 6(b)). Switching study reveals following important findings:

1. Rise time and fall time is nearly 2 second for 10 second pulse on these films. 2. Photocurrent does not stabilize very fast. It shows some zig-zag variation with time as seen in Fig. 6 (b). This variation is expected as charge trapping occurs on the surfaces of cadmium iodide crystallite. At higher temperature stability is higher. This is due to quick release of trapped charges under thermal agitation. Such materials still require improvements before they can be used as X-ray Imaging Detectors [14, ??5]. Similar results were obtained in all the sheets.

4 CONCLUSIONS

PMMA-cadmium iodide is a good X-ray sensor as photocurrent amplification is quite high (of the order of 230.7 for 19.09% concentrated composite). Although these sensors are not good for fast data switching as rise time and fall time is high. However at temperature close to 40-50 0 C stability of photocurrent is high. Such sheets are however transparent to low energy gamma rays.

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Figure 1:

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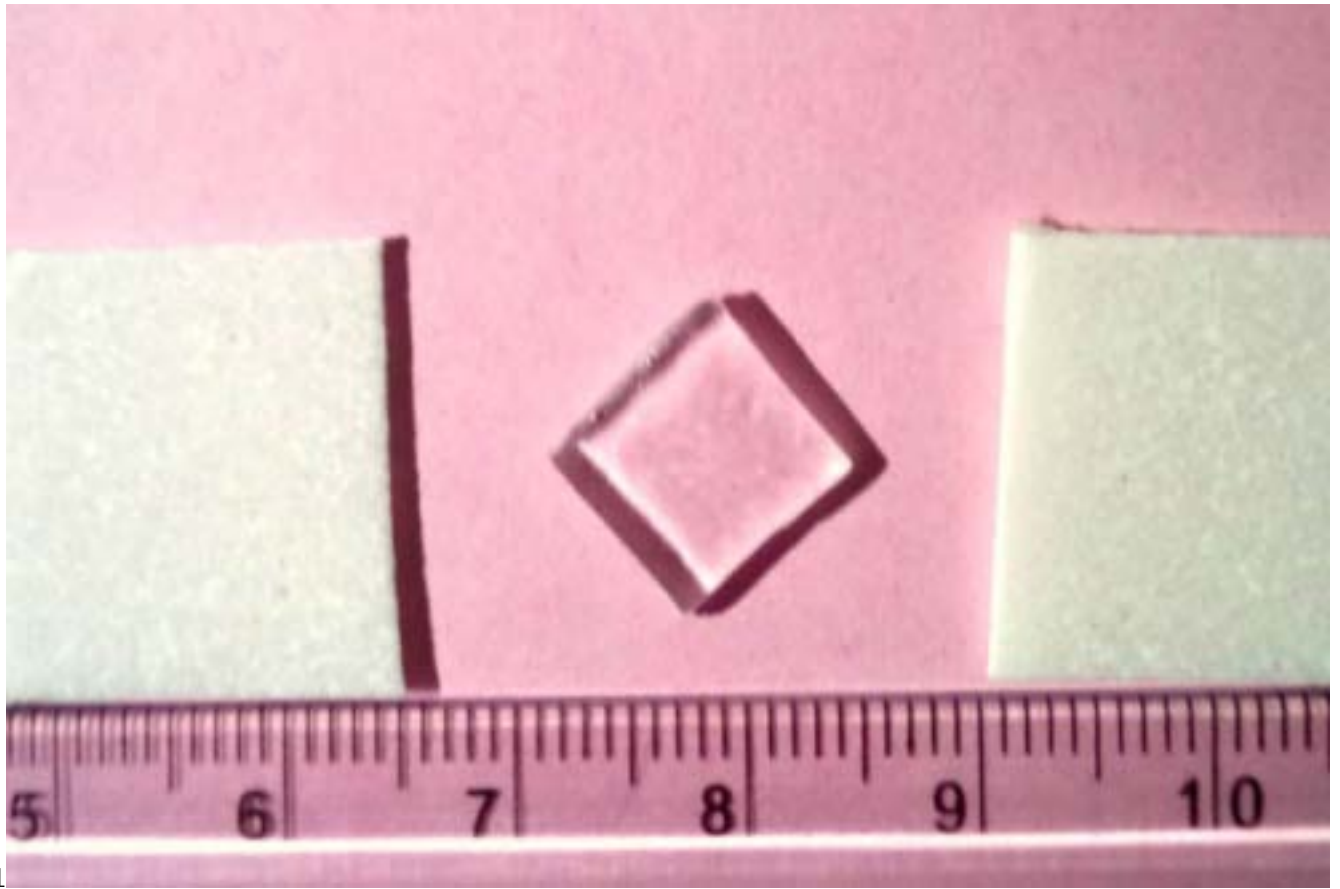


Figure 2: Fig. 1 :

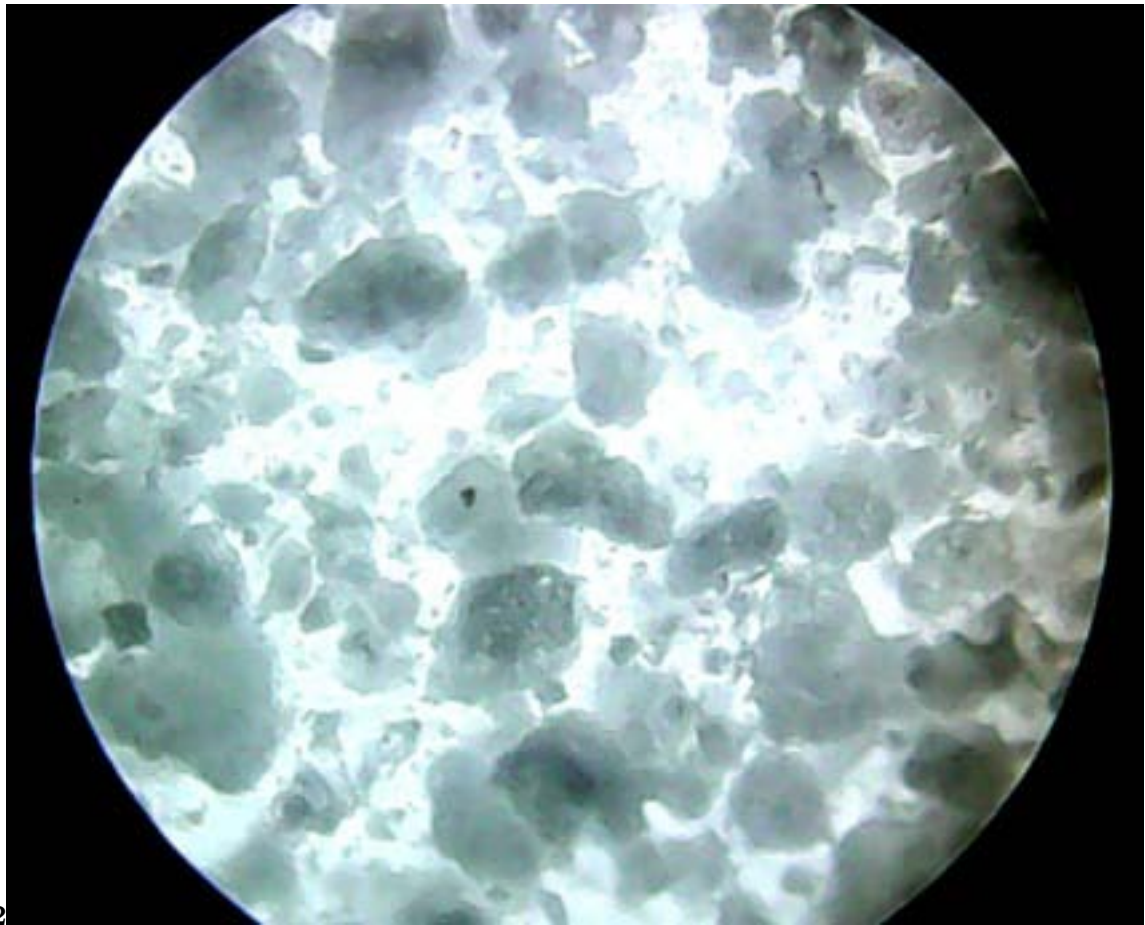


Figure 3: Fig. 2 :

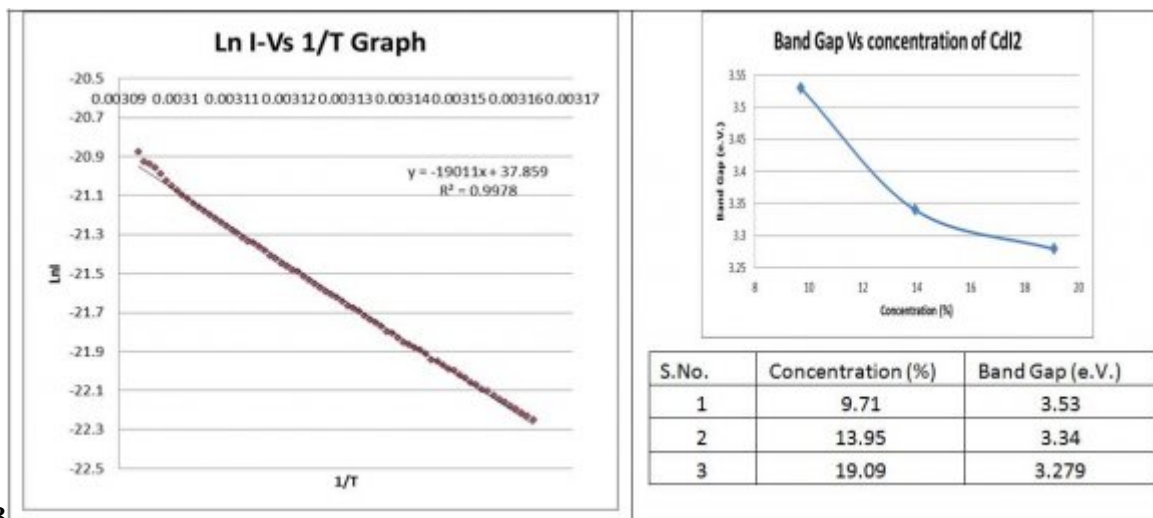


Figure 4: Fig. 3 :

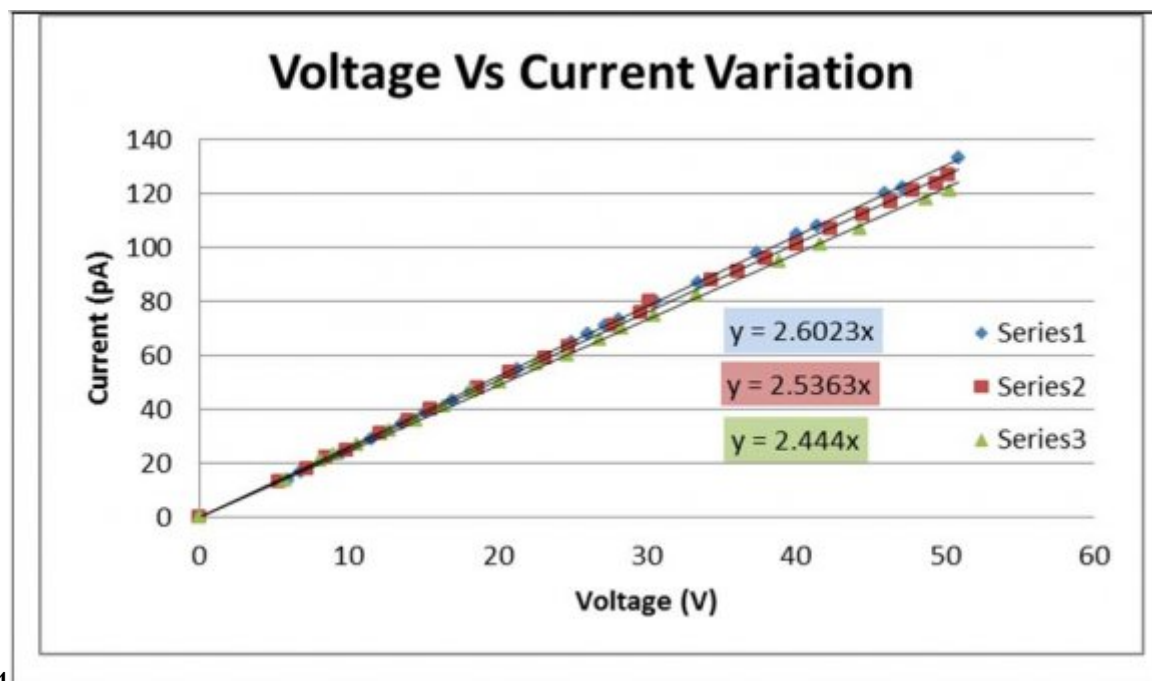


Figure 5: Fig. 4 :

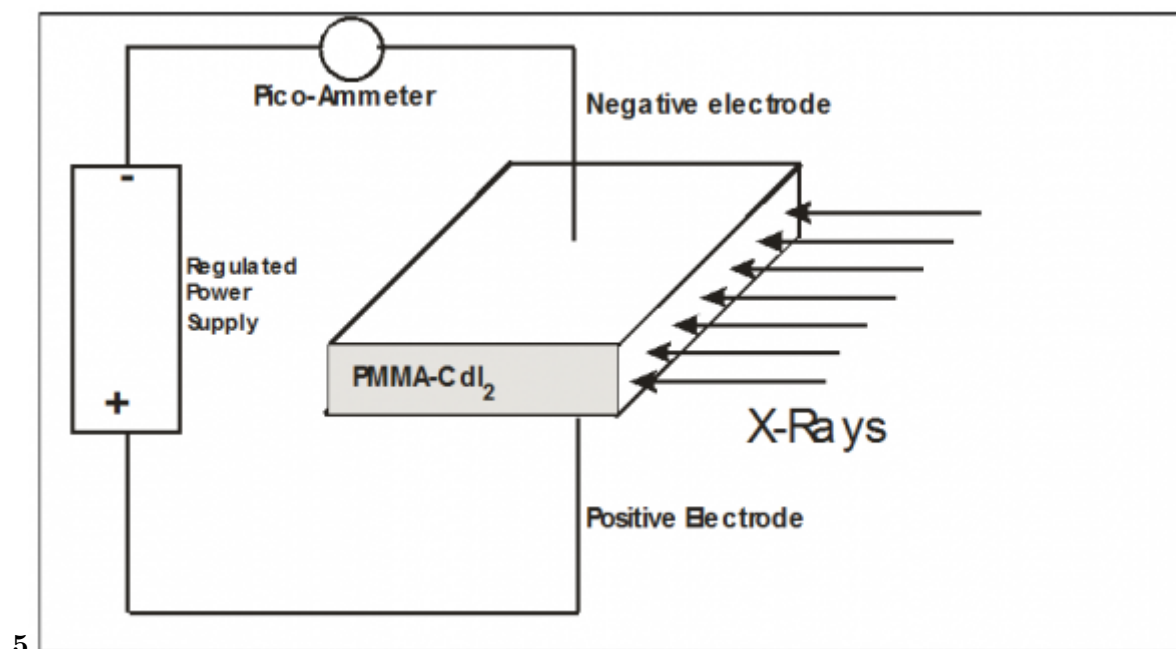


Figure 6: Fig 5 :

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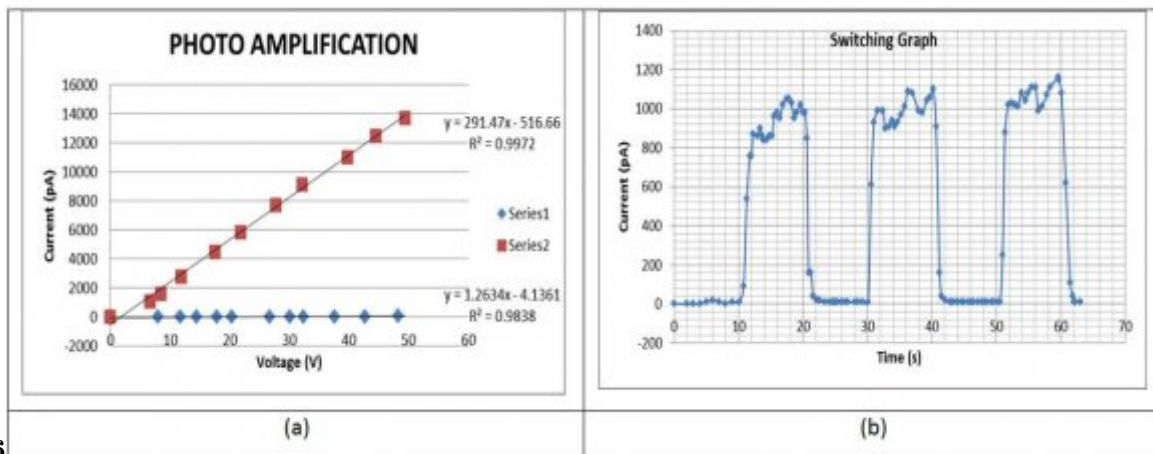


Figure 7: Fig. 6 :

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