



# INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X

Impact factor: 4.295

(Volume 5, Issue 2)

Available online at: [www.ijariit.com](http://www.ijariit.com)

## Characterization of hybrid thin films for application in the field of solar cells – A response to climate change

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### ABSTRACT

The enhancement of greenhouse gases due to the increased usage of fossil fuels leads to global warming followed by climate change. To overcome these researchers have been concentrating on renewable energy. Solar energy is an inexhaustible source of energy. It could supply all the present and future energy needs of the world. The amount of solar radiation reaching the earth differs from the radiation reaching the top of the earth's atmosphere. Flat-plate collectors are used to collecting solar energy and the collected energy is stored in different types of energy storage systems and used for different applications like water heating systems, thermoelectric systems. Solar cells are used for the direct conversion of solar energy into electrical energy. In this study, the importance of more economic hybrid thin films for application in the field of solar cells and photodetectors were highlighted. The optical absorption and photoconductivity for the hybrid thin films were found to increase with increasing concentration of zinc telluride.

**Keywords**— Hybrid thin films, Renewable energy, Photoconductivity, Climate change

### 1. INTRODUCTION

The most serious and important problem humankind has ever had to face might be global warming. Global warming results from the imbalance between the heat received by the Earth and, the heat reradiated back to space [1]. Climate change is the biggest threat to humanity today and will jeopardize the ecological security of the Earth and wellbeing of humans. Achieving solutions to environmental problems that humanity faces today requires long-term potential actions for sustainable development. The core of mitigating climate change is reducing greenhouse gas (GHG) emissions, mostly CO<sub>2</sub> emissions in energy consumption. In this respect, renewable energy resources appear to be one of the most efficient and effective solutions. Developing new sustainable renewable energy will replace the high-carbon energy system dominated by fossil energy, and near-zero CO<sub>2</sub> emission will be achieved [2].

#### 1.1 Renewable energy

The combustion of fossil fuels in the past has already created harmful effects on the delicate balance of nature of our planet. Today about 10<sup>12</sup> kg of carbon dioxide is let out into the atmosphere every year, mainly by burning fossil fuels [3-5]. As a result, the CO<sub>2</sub> concentration in the atmosphere continues to increase adding considerably to the greenhouse effect, which will, in turn, increase the global mean surface temperature depending on future emission scenario and this increases the actual climate sensitivity by another 1.5 -4.5 °C in future [4].

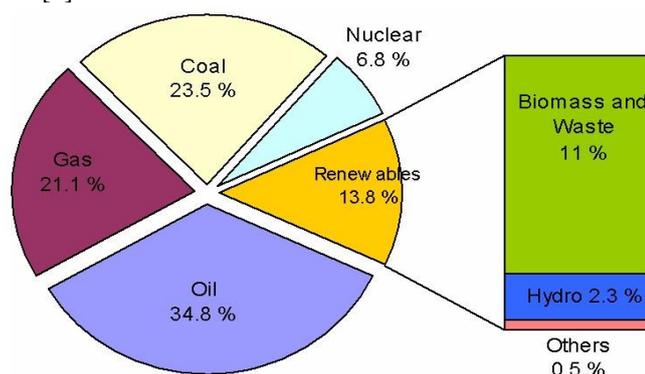


Fig. 1: Global primary energy supplies

Figure 1 shows the energy sources and global primary energy supplies. The demand for oil seems to be higher compared to other energy supplies. Currently, we are using only 13.8 % of renewable energy sources. Thus, there is a need to develop low-cost technologies for renewable energy sources by considering the costs of environmental hazards of the majority of existing power sources at present. One such source is the sun, the primary source.

There are many alternative energy sources which can be used instead of fossil fuels. The decision as to what type of energy source should be utilized must, in each case, be made on the basis of economic, environmental and safety considerations. Because of the desirable environmental and safety aspects, it is widely believed that solar energy should be utilized instead of other alternative energy forms, even when the costs involved are slightly higher.

### 1.2 Solar radiation at the earth's surface

In our planetary system, the sun is at present the source of infinite energy. The surface of the sun has a temperature of approximately 5,760 K [6] and emits mainly electromagnetic radiation. The amount of energy that reaches the earth surface from the sun is 89,000 terawatts per day ( $89 \times 10^{15}$  watts). As the conventional energy here on earth is also getting depleted, we need to depend on the sun for a continued energy source.

### 1.3 Solar energy storage

Solar energy is a time-dependent and intermittent energy resource. The need for energy storage of some kind is almost immediately evident in a solar electric system. Some of the solar energy storage systems are Thermal, electrical, chemical and electromagnetic energy storage.

#### 1.3.1 Applications of solar energy

- The direct thermal application makes use of heat, resulting from the absorption of solar radiation, for providing hot water service for building, and to supply heat for agricultural, industrial and other processes that require only moderate temperatures.
- Solar electrical applications are those in which solar energy is converted directly or indirectly into electrical energy. Some of the conversion methods are, solar thermoelectric conversion in which water is boiled to run steam turbines which drive electric generators. Photovoltaic methods make use of solar cells to convert solar energy directly into electrical energy without machinery. This comes under solar photovoltaic conversion.

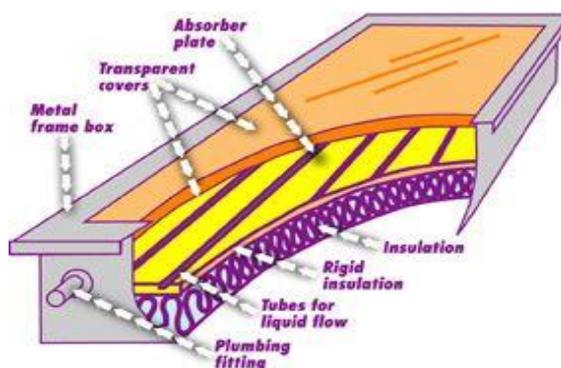
### 1.4 Solar cells or photovoltaic energy

We can also change the solar light directly to electricity using solar cells. Solar cells are also called photovoltaic cells - or PV cells for short - and can be found on many small appliances, like calculators, and even on spacecraft. They were first developed in the 1950s for use on U.S. space satellites. Solar cells are made of silicon, a special type of melted sand. When solar light strikes the solar cell, electrons are knocked loose. They move toward the treated front surface. An electron imbalance is created between the front and back. When the two surfaces are joined by a connector, like a wire, a current of electricity occurs between the negative and positive sides. These individual solar cells are arranged together in a PV module and the modules are grouped together in an array.

### 1.5 Solar collectors

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector. The solar energy thus collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to thermal energy storage tank from which can be drawn for use at night and/or cloudy days. There are basically two types of solar collectors: nonconcentrating or stationary and concentrating. A nonconcentrating collector has the same area for intercepting and for absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun's beam radiation to a smaller receiving area, thereby increasing the radiation flux. A large number of solar collectors are available in the market [7].

### 1.6 Flat-plate collectors



**Fig. 2: Flat-plate solar collector**

A typical flat-plate solar collector is shown in figure 2. When solar radiation passes through a transparent cover and impinges on the blackened absorber surface of high absorptivity, a large portion of this energy is absorbed by the plate and then transferred to

the transport medium in the fluid tubes to be carried away for storage or use. The underside of the absorber plate and the side of casing are well insulated to reduce conduction losses. The liquid tubes can be welded to the absorbing plate, or they can be an integral part of the plate. The liquid tubes are connected at both ends by large diameter header tubes.

The transparent cover is used to reduce convection losses from the absorber plate through the restraint of the stagnant air layer between the absorber plate and the glass. It also reduces radiation losses from the collector as the glass is transparent to the short wave radiation received by the sun but it is nearly opaque to long-wave thermal radiation emitted by the absorber plate (greenhouse effect). FPC is usually permanently fixed in position and requires no tracking of the sun. The collectors should be oriented directly towards the equator, facing south in the northern hemisphere and north in the southern. The optimum tilt angle of the collector is equal to the latitude of the location with angle variations of 10–15° more or less depending on the application [7].

### 1.7 Solar collector applications

Solar collectors have been used in a variety of applications like Solar water heating, Space heating and cooling, Heat pump systems, Industrial process heat, Industrial air and water systems, Steam generation systems, Solar desalination, Solar thermal power systems, Parabolic trough collector systems, Parabolic tower systems, Parabolic dish systems, Solar furnaces, etc.

### 1.8 Solar water heating systems

The main part of an SWH is the solar collector array that absorbs solar radiation and converts it into heat. This heat is then absorbed by a heat transfer fluid (water, non-freezing liquid, or air) that passes through the collector. This heat can then be stored or used directly. Portions of the solar energy system are exposed to the weather conditions, so they must be protected from freezing and from overheating caused by high insolation levels during periods of low energy demand.

In solar water heating systems, potable water can either be heated directly in the collector (direct systems) or indirectly by a heat transfer fluid that is heated in the collector, passes through a heat exchanger to transfer its heat to the domestic or service water (indirect systems). The heat transfer fluid is transported either naturally (passive systems) or by forced circulation (active systems). Natural circulation occurs by natural convection (thermosyphoning), whereas for the forced circulation systems pumps or fans are used.

### 1.9 Thermosyphon systems (passive)



**Fig. 3: Thermosyphon system**

Thermosyphon systems, shown schematically in Fig. 3, heat potable water or heat transfer fluid and use natural convection to transport it from the collector to storage. The water in the collector expands becoming less dense as the sun heats it and rises through the collector into the top of the storage tank. There it is replaced by the cooler water that has sunk to the bottom of the tank, from which it flows down the collector. The circulation is continuous as long as there is sunshine. Since the driving force is only a small density difference larger than normal pipe sizes must be used to minimize pipe friction. Connecting lines must be well insulated to prevent heat losses and sloped to prevent the formation of air pockets which would stop circulation. At night, or whenever the collector is cooler than the water in the tank the direction of the thermosyphon flow will reverse, thus cooling the stored water. One way to prevent this is to place the top of the collector well below (about 30 cm) the bottom of the storage tank. The main disadvantage of thermosyphon systems is the fact that they are comparatively tall units, which makes them not very attractive aesthetically. Usually, a cold water storage tank is installed on top of the solar collector, supplying both the hot water cylinder and the cold water needs of the house, thus making the collector unit taller and even less attractive. Additionally, extremely hard or acidic water can cause scale deposits that clog or corrode the absorber fluid passages.

### 1.10 Demerits of Flat-plate solar collectors

Flat-plate solar collectors have been in service for the last 30 years, without significant changes in their design and operating principles. Collectors are usually oversized in order to satisfy a heat demand and this increases their manufacturing cost. In order to reduce the manufacturing cost, researchers have been concentrating on thin films for the application in solar cells and also in flexible electronics and in photodetectors, which could be more economical, smaller in size and less in weight.

### 1.11 Photodetectors

Photo detectors are used primarily as an optical receiver to convert light into electricity. The principle of photo detectors is the photoelectric effect, which is the effect on a circuit due to light. A photo detector operates by converting light signals that hit the junction to a voltage or current. The junction uses an illumination window with an anti-reflect coating to absorb the light photons.

The result of the absorption of photons is the creation of electron-hole pairs in the depletion region. Examples of photo detectors are photodiodes and phototransistors. Other optical devices similar to photo detectors are solar cells which also absorb light and turn it into energy.

**1.11.1 Applications of photo detectors:** Photo detectors are used in various different applications such as radiation detection, smoke detection, and flame detection and to switch on relays for street lighting. In the present work, the material chosen ZnTe and MgPc is not only good photoconductors but also as a good photo detector which find its application in the field of radiation detectors.

One such attempt is making use of solar radiation to excite photosensitive materials in order to generate electrical energy in the form of electrical conductivity through excitation, generation and conduction of charge carriers. In this paper, two such materials, namely, Zinc-Telluride (ZnTe) and Magnesium-Phthalocyanine (MgPc) would be studied as hybrid materials of electrical energy source to be activated through optical excitation [8].

## 2. MATERIALS AND METHODS

ZnTe and MgPc (Aldrich) were mixed together (in the ratio of 60:10, 70:10, 80:10, 90:10, 100:10 mg respectively) and ground well for several hours, before sublime in vacuum (Hind Hivac 12 A4-D) at a pressure of 10-5Torr. Glass substrates used were first cleaned thoroughly with liquid detergent; then washed with distilled water; and agitated ultrasonically in acetone. Finally, the substrates were dried in hot air. The coated films were air annealed at 150°C to attain crystallinity. Thickness measurements were recorded using Surface Profilometer (Dektak 6M, M/S. Veeco (USA)). UV-VIS absorption spectra of the films were recorded using UV-VIS spectrophotometer (Shimadzu UV-2450). Photoconductivity and temperature dependent conductivity were measured using Keithley picoammeter (model 6485).

## 3. RESULTS AND DISCUSSION

For ZnTe/MgPc thin films deposited onto glass substrates, we could experimentally establish that the samples obtained stable structure and they exhibited reproducible optical and photoconductive properties provided they were subjected to annealing. These heat treatments consisted of several successive heating-cooling cycles within a temperature range, 300-500 K [9].

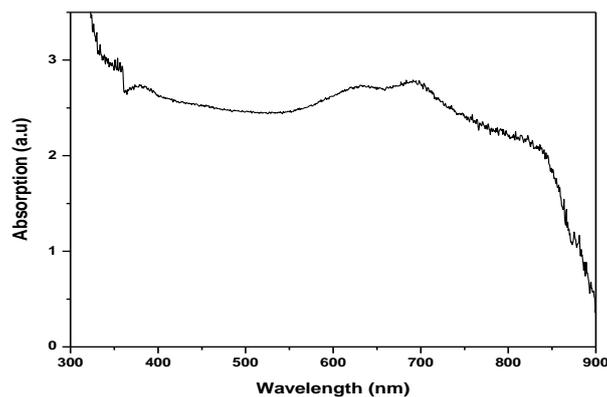


Fig. 4: Absorption spectra of hybrid ZnTe/MgPc air annealed at 150°C for 1 hour

Figure 4 shows the UV-VIS absorption spectra of hybrid ZnTe/MgPc thin film air annealed at 150°C. It is observed that the hybrid thin films have a very wide absorption range over the whole visible region with a significant peak around 700 nm. The air-annealed sample has a better absorption compared with as-deposited thin films.

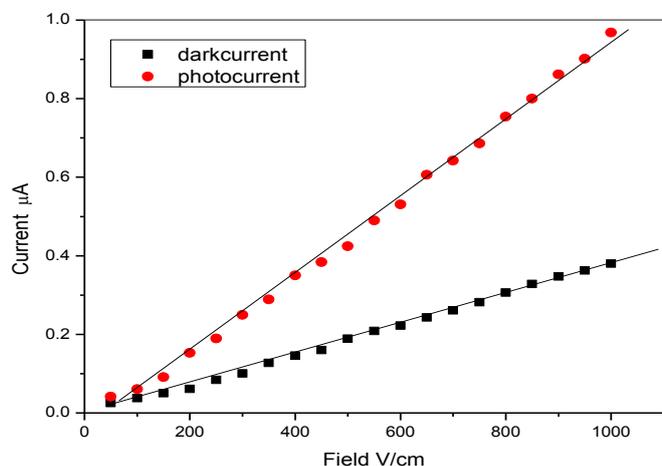
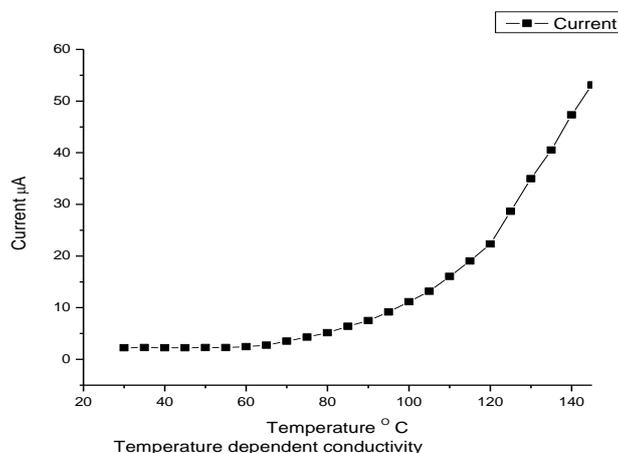


Fig. 5: Field dependent dark and photoconductivity hybrid ZnTe/MgPc Thin films with ratio 100:10 mg annealed at 150°C for 1 hr

Figure 5 shows the field dependent dark and photocurrent plots for hybrid ZnTe/MgPc thin film. A linear increase of dark and photocurrent was observed for the samples. There was a significant rise in photocurrent over dark current, when the sample was illuminated with visible light (100 watts halogen lamp). The enhancement of photocurrent in the hybrid film is due to its capability to absorb overall regions of visible light.

Figure 6 shows the variation of dark current with temperature for the thin film samples. The temperature was varied in the range 30°C-150°C for a constant applied field of 500V/cm. The plots indicate the exponential increase of temperature dependent current confirming the semiconducting nature of the samples.

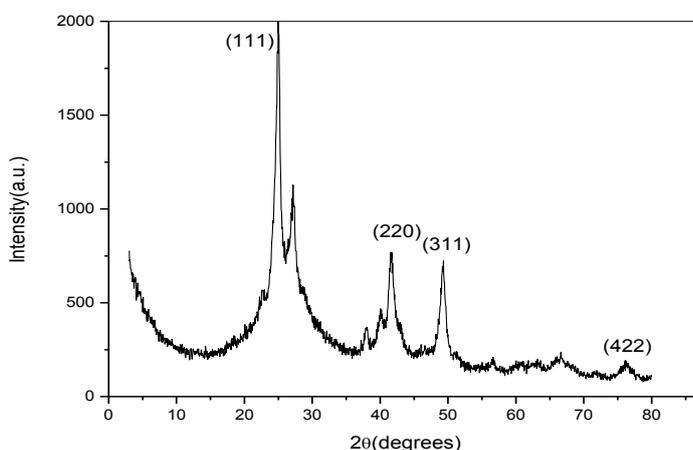


**Fig. 6: Variation of dark current with temperature.**

From the  $\ln I$  versus  $1/KT$  plot, the activation energies of various concentration of ZnTe (60:10, 70:10, 80:10, 90:10, 100:10) in the hybrid ZnTe/MgPc films were calculated as 2.71eV, 2.3eV, 1.802eV, 1.627eV and 1.34eV respectively. The activation energy is found to decrease with increase in concentration of ZnTe in the hybrid ZnTe/MgPc combination.

### 3.1 X-ray diffraction analysis

The ZnTe powder, as well as thin film, MgPc doped film all, correspond to the cubic form of ZnTe. ZnTe crystal unit cell dimension is 6.08 Å. The face-centered cubic system has four lattice points and volume corresponds to one lattice point is 56.18 Å<sup>3</sup>. MgPc crystallizes in monoclinic system with cell parameters 14.368 Å, 4.898 Å,  $\beta = 119.860$  with a unit cell volume of 1153 Å<sup>3</sup>. The average volume occupied by a molecule is 288 Å<sup>3</sup>.



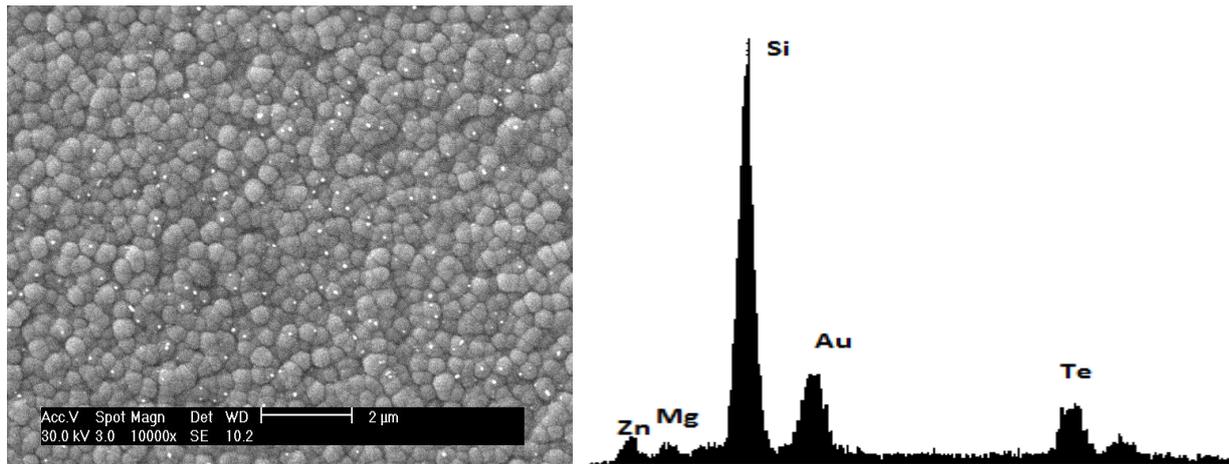
**Fig. 7: XRD of hybrid ZnTe 100mg/MgPc 10mg thin film annealed at 150°C for 1 hour**

These crystal data show that the phthalocyanine molecules cannot replace ZnTe molecules in the ZnTe lattice. As MgPc volume is much higher than the primitive cell volume of ZnTe, the interaction between these two substances in the thin film is possible only through surface interactions. This is evident from the SEM micrograph of doped thin films. The powder diffractogram of the thin film shows the peaks corresponding to ZnTe only. It may be inferred that the MgPc molecules/particles are randomly distributed on the surface of ZnTe thin film with no individual crystal regions.

However, the possibility of some Magnesium and Zinc atoms or some Magnesium atoms from Phthalocyanine exchanging positions with Zinc in the Telluride cannot be ruled out. The ZnTe lattice might be containing a small percentage of Magnesium atoms in the position of Zinc atoms. This could have changed the physical properties.

### 3.2 SEM analysis

Figure 8 shows the SEM results of the samples. By analyzing the pictures, it is evident that the film is uniformly distributed for both Pure ZnTe and MgPc thin films.



**Fig. 8: SEM micrograph and EDAX of the hybrid ZnTe 100mg / MgPc 10mg thin film.**

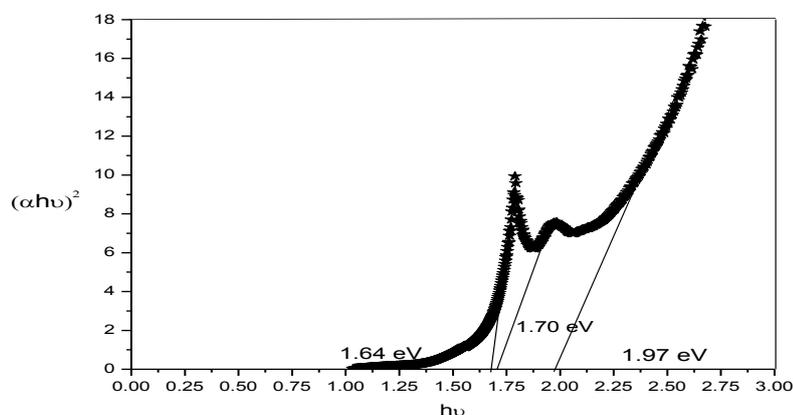
The surface of the films are very smooth and there is no pinhole observed. The grain boundaries are also not observed. This suggests that the film is a good photoconductor. It can be seen from the picture that ZnTe and MgPc are mixed uniformly in the hybrid samples and the surface of films are observed smooth.

### 3.3 EDAX analysis

EDAX results are shown in Fig: 8. Elements present in the thin film are Silicon (Si), Gold (Au), Tellurium (Te), Magnesium (Mg) and Zinc (Zn). Since a glass substrate was used, thin films Si is observed as maximum and during characterization of EDAX, the sample is gold plated. These are the reason for having a maximum percentage of Si, followed by gold (Au). The elements of ZnTe are present and that of MgPc, magnesium is present but the elemental composites of Pc were not able to detect.

### 3.4 Band gap

Zinc Telluride has a direct band gap of 2.26 eV and Magnesium Phthalocyanine has a band gap 2.6 eV at room temperature. It is observed that the band gap decreases from 2.6 eV to 1.97eV for the hybrid thin films.



**Fig. 9:  $(\alpha h\nu)^2$  vs  $h\nu$  plot for the hybrid ZnTe/MgPc thin films (100:10) mg deposited at substrate temperature 423 k and annealed at 150°C for one hour**

## 4. CONCLUSION

The hybrid ZnTe: MgPc thin films with different ratios were coated by a thermal evaporation method. The prepared films were annealed at 150°C and it enhanced the absorption and photoconductivity. The hybrid thin films absorbed almost the entire range of visible light and its absorption increased with the increasing concentration of ZnTe. The photoconductivity increased with increasing concentration of ZnTe in the hybrid thin film. The temperature dependent conductivity of the hybrid thin films indicated exponential behaviour of temperature dependent current, confirming the semi-conducting nature of the samples. From the graph of  $\ln I$  vs  $1/KT$  plots for all the five samples, the activation energy was found out. Activation energy is found to decrease with increasing ZnTe concentration. The thickness of the films ranged from 300nm to 400nm. The band gap of the films calculated ranged between 2.2eV to 1.97eV. Thus ZnTe plays an enhancing role in the hybrid film of ZnTe/MgPc as an effective photoconductor and as it is shown to be effective photoconductor, the hybrid thin films could be an excellent candidate to be a solar-cell material.

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