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Incorporation of PCM in TLSC for Optimum Efficiency of the System

Umang Mittal[1], Mohit Hattar[2] and Anirudh Dube[3]

[1,2,3]Deptt. Of EEE Maharaja Agrasen Institute of Technology, Delhi
E-mail: [1]mail.umangmittal@gmail.com, [2]mohithattar@gmail.com, [3]anirudhdube12@gmail.com

Abstract: *This paper emphasises on the fact that electrical efficiency of transparent luminescent solar concentrator (TLSC) can be improved using phase change material (PCM) with it. TLSC is a transparent plastic slab which is used to concentrator energy from the sun allowing the visible radiations to pass and trap infrared radiation.*

1. INTRODUCTION

As we know, harnessing solar energy is one of the fastest growing fields in technology. A righteous and sustained application of solar energy conversion technology can be of great use for mankind. Particularly, the generation of electricity from solar radiation. The most vastly used solar cells use the direct sunlight falling on the surface of earth and convert it to usable electricity.

Luminescent Solar Concentrator (LSCs) are also used for the same purpose. But instead of using the sunlight directly, a slab of LSC concentrates the photons in radiation in the bulk and then emits electrons towards the sides of the slab. By this phenomenon, we can harness direct as well as diffused sunlight by coating the sides of the LSC by a photovoltaic material. The efficiency is governed by various optical hindrances such as re-absorption, Stoke's shift and etc. Also affecting the efficiency is the heat produced due to the heating up of the slab in sunlight and also due to the copper losses in the photovoltaic cell and the external circuit.

The motive of this paper is to provide enhancements to the LSC (or Transparent-LSC as used in this paper as it has more practical applications) so that the heating losses can be reduced. This is done with the help of Phase Change Materials (PCMs).

2. TRANSPARENT LUMINESCENT SOLAR CONCENTRATOR

A team of researchers at Michigan State University has developed a new type of solar concentrator that when placed over a window creates solar energy while allowing people to actually see through the window. It is called a transparent luminescent solar concentrator and can be used on buildings, cell phones and any other device that has a flat, clear surface. We harness the structured absorption of molecular dyes to produce near infrared (NIR) Luminescent Solar Concentrator (LSC) architectures that selectively harvest NIR photons by wave guiding deeper-NIR luminophore emission to high efficiency segmented solar cells(see Fig. 1). These transparent NIR LSCs can eliminate the visual impact and minimize the amount of expensive solar materials required while extending the photon harvesting range into the NIR. The solar harvesting system uses small organic molecules developed by Lunt [1] and his team to absorb specific non-visible wavelengths of sunlight. The efficiency of the transparent LSCs is governed by: the solar spectrum absorption efficiency, luminophore photoluminescence efficiency, waveguide (trapping) efficiency, transport (re-absorption) efficiency and solar cell quantum efficiency and photo voltage.[2] The optical efficiency consists of wave guiding efficiency, transport efficiency, and luminescence efficiency. The EQE consists of the optical efficiency and the quantum efficiency of the PV at the emission wavelength. Due to the monochromatic emission nature of the LSC, only single junction PVs can be attached around each individual LSC, which ultimately limits the overall system efficiency without LSC stacking to that below the PV efficiency directly.

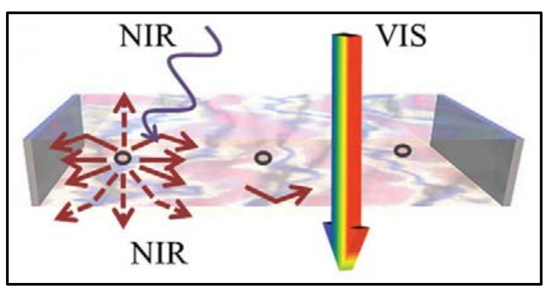

Fig. 1: Transparent LSC

2.1 Heat Losses

The efficiency of the TLSC is partly affected by the heating up of the slab, apart from the re-absorption losses. We here provide the data as to at what levels of temperature the TLSC starts conducting heat to PV cells.

Further the heat caused by sun's luminescence has two effects. The first one is to provide resistance to path of the electron flow towards to the PV cell. And second to heat up the cells causing I^2R losses.

2.2 Chemical Structure and Formula

The formula of the compound used to make TLSC is as 2-[7-(1,3-dihydro-1,3,3-trimethyl-2H-indol-2-ylidene)-1,3,5-heptatrienyl]-1,3,3-trimethyl-3H-indolium (HITC) iodide (HITCI) and 1-(6-(2,5-dioxopyrrolidin-1-yloxy)-6-oxohexyl)-3,3-dimethyl-2-((E)-2-((E)-3-((E)-2-(1,3,3-trimethylindolin-2-ylidene)ethylidene) cyclohex-1-enyl)vinyl)-3H-indolium chloride (CY). The CY and HITCI molecular structures are shown in Fig. 2**.**

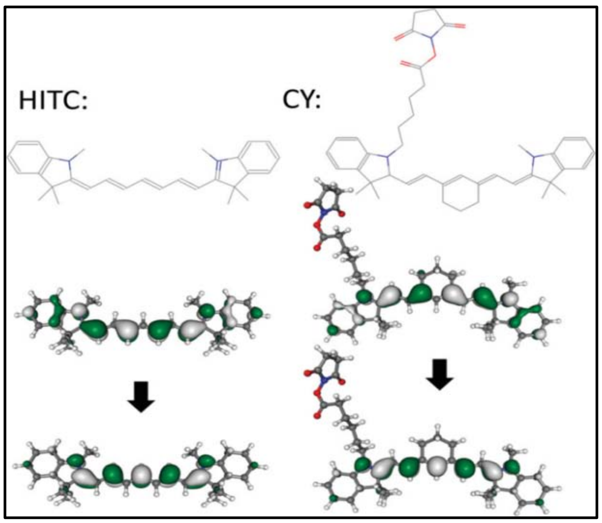

Fig. 2: Molecular Structures

3. PHOTOVOLTAIC MATERIAL

Photovoltaic (PV) materials are substances which are used to convert solar energy to direct current electricity and store them in batteries if not consumed directly. They are mainly semiconducting materials that exhibit the photovoltaic effect. Commercially available PV materials have conversion efficiencies [3] (as shown in table 1).

Table 1: Conversion Efficiency[3]

Technology	Module Efficiency
Mono-Crystalline Silicon	12.5%-15%
Poly-Crystalline Silicon	11-14%
Copper Indium Gallium Selenide (CIGS)	10-13%
Cadmium Telluride (CdTe)	9-12%
Amorphous Silicon(a-Si)	5-7%

The performance of a PV material in fact are defined by manufactures according to the "Peak Power", which identifies the maximum electric power supplied by the PVM panel when it receives a insolation of 1 kW/m^2 and the cell temperature is maintained at 25^{o}C [4].

4. PHASE CHANGE MATERIALS

Phase Change Materials (or PCM) as described by Wikipedia is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and viva versa.[5]

These materials are very commonly being used as coolants in both Electrical and Electronics equipments.

The specific heat of a PCM varies as a function of its temperature, reaching it maximum value during the phase transition. In general the changing phase is not completely isothermal, although the temperature remains with a limited range of variation.

There are a wide range of PCMs that are available that can used for various applications. Such as in Table 2.

Table 2: Phase Change Materials

Material	Melting Point o C	Heat of Fusion kJ. kg-1
Paraffin 18-carbons	28	244
p-Lattic Acid	26	184
Methyl palmitate	29	205

4.1 The Finite Difference Method

The finite difference method [4] is based on the approximation of spatial and temporal derivative of heat diffusion equation with relations between space and time finite differences.

In contrast to an analytical solution a numerical solution enables determination of the temperature at only discrete point. The original domain can be subdivided in a finite number of parts, assigning to each a reference point at its centre (node).

Each 'n' node represents a certain region, and its temperature is a measure of the average temperature of the region. The value of this derivative at the 'n' nodal point may be approximated as:

$$\frac{\partial^2 T}{\partial x^2}\Big|_n \approx \frac{\frac{\partial T}{\partial x}_{n+\frac{1}{2}} - \frac{\partial T}{\partial x}_{n-\frac{1}{2}}}{\Delta x} \quad (1)$$

The temperature gradient may in turn be expressed as a function of the nodal temperatures:

$$\frac{\partial T}{\partial x}_{n+\frac{1}{2}} \approx \frac{T_{n+1}-T_n}{\Delta x} \quad (2)$$

$$\frac{\partial T}{\partial x}_{n-\frac{1}{2}} \approx \frac{T_n-T_{n-1}}{\Delta x} \quad (3)$$

Substituting equations (2) and (3) in (1):

$$\frac{\partial^2 T}{\partial x^2}\Big|_n \approx \frac{T_{n+1}+T_{n-1}-2T_n}{\Delta x} \quad (4)$$

Considering the time discretisation, dividing the observation time 't' of the phenomenon in a finite number of time steps 'p' with amplitude Δt: $t = p.\Delta t$; therefore, the time derivative present in the second member of heat diffusion equation can be replaced with the finite difference approximation by using the "central difference" operator:

$$\frac{\partial^2 T}{\partial x^2}\Big|_n \approx \frac{T_n^{p+1}-T_n^p}{\Delta t} \quad (5)$$

Where 'p+1' is the current time step and 'p' is the previous time step. Finally, in on dimensional system the heat diffusion equation at the finite difference method becomes:

$$\frac{\Delta^2 \mathrm{T}}{\Delta x^2} = \frac{1}{\alpha}\frac{\Delta T}{\Delta t} \quad (6)$$

Where 'α' is the thermal diffusivity; and replacing equations (4) and (5) into (6), is obtained:

$$\frac{T_{n+1}+T_{n-1}-2T_n}{(\Delta x)^2} = \frac{1}{\alpha}\frac{T_n^{p+1}-T_n^p}{\Delta t} \quad (7)$$

In other word, explicit finite difference method can calculate the state of a system at a later time from the state of the system at the current time.

4.2 PV-PCM Model

Considering a pv panel coupled with PCM system, the energy balance must take into account the presence of phase change material. Schematically, the energy exchanges in a PV-PCM system can be exemplified by Fig. 3.

The PV-PCM system is presented as a multi-layer plate invested by solar radiation and exchanging heat with the external environment by convection and radiation. Depending on the properties of the PCM and on the amount of energy captured the panel, the later of PCM can partially or totally melt during maximum insolation, and returns that amount of energy, possibly solidifying again, during the night. The first hypothesis is that the phase change is isothermal. In case of non-isothermal transition having the value of C_p with temperature, the problem is reduced to a heat conduction case. The occurrence of a phase change that blocks the temperature at a given value is a more interesting case and implies the determination of PCM liquid fraction. The Thermo Physical Characteristics of PCM are shown in Table-3.

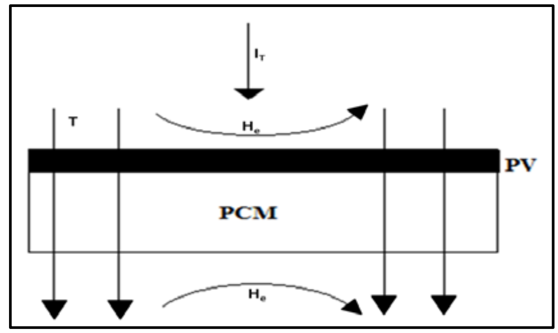

Fig. 3: PV-PCM Schema

Table 3: Thermo Physical characteristics of PCM

Characteristics	PCM	
Transition Phase	26-28	oC
Solid Density	0.87	kg/l
Liquid Density	0.75	kg/l
Heat Capacity	179	kJ/kg
Specific enthalpy of Phase Change	1.8-2.4	kJ/kgK
Conductibility	0.2	W/mK
Volumetric Change	10	%

This hypothesis is not very far from reality because many PCMs are characterized isothermal phase by hange, while some paraffin and eutectic mixtures have a very short range of temperature during transition. The following Fig. 4 shows the temperature trend of the measured and simulated temperatures.[4]

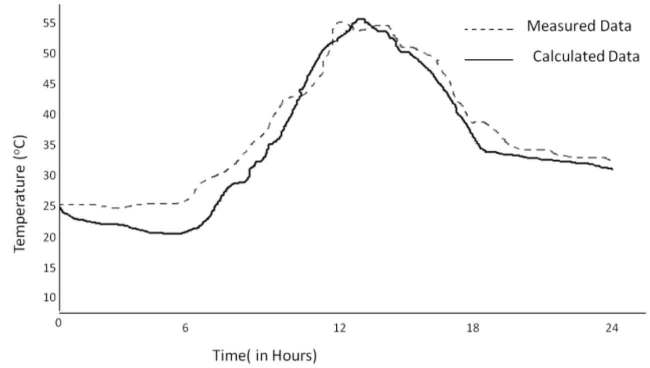

Fig. 4: Temperature Trends

5. TLSC-PCM INCORPORATION

The efficiency of the TLSC slab is extremely low when compared to the conventional solar cells having an average efficiency from 0.6% to 5%. The objective of incorporation of

PCM is to minimize the losses caused by insolation and the PV circuit losses mainly due to heat.

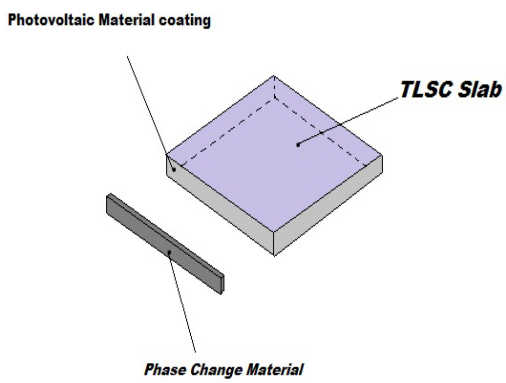

Fig. 5: Incorporation of PCM in TLSC

In our research we have designed a method in which the edges of TLSC slab having the PV material be coated with a PCM(as shown in Fig. 5) which will not only act as a heat sink but also be used to generate electricity using a different circuit. This way we can increase the efficiency significantly so that TLSC has a many practical applications. The heat generated in the PV material is spontaneously conducted to the Phase Change Material majorly through conduction. The PCM absorbs this heat and commences its isothermal phase change from solid to liquid hence acting as a rapid heat sink.

6. APPLICATIONS

The efficiency of the whole system is increased such that it can be used in real life as following:

- Window Panes can be made of TLSC and be glued to the frame with a PCM with suitable properties.
- In screens of electronic equipment such as mobile phones, tablets, laptops and etc.
- Wrist watch glass can be made of the above material.

These applications are required these days with change in lifestyle and a non-availability of electricity in mobile and isolated places.

7. CONCLUSIONS

The effect of heat sinking and generation of electricity as whole is greatly improved by the use of PCM than just using TLSC alone. We observed that the properties of PV material also impact the efficiency. Hence, the PCM was selected taking into account both TLSC and PV Material. in conclusion, the increase in efficiency of TLSC was approximately 2% making the overall efficiency almost upto 4%.

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