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Vinod Kumar Jain
Sunita Rattan
Abhishek Verma *Editors*

Recent Trends in Materials and Devices

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Preface

Today, the global challenges are too complex to be addressed with the traditional disciplinary boundaries. To tackle these intricate challenges, interdisciplinary research is the only solution. From research funders to journal editors, policymakers to think tanks—all seem to agree that the future of research lies outside firm disciplinary boundaries. The field of materials and devices intrinsically is a perfect example for the same, which is generating an efficient outcome.

“International Conference on Recent Trends in Materials and Devices” (ICRTMD) was organized at Amity University Uttar Pradesh, Noida, India, from 18 to 19 December 2019, with the aim to provide a common forum for eminent scientists, technologists, entrepreneurs and scholars from different disciplines to interact and collaborate to solve scientific challenges. The purpose and objective of this meeting was also to share the vast knowledge and latest investigations with the scientific industrial community and how to include in the production to get more efficient devices or system. The conference also provided an opportunity for the participants to interact and develop collaborative partnership.

The book *Recent Trends in Materials and Devices* is a collection of recent scientific contributions from different veins of semiconductors, composites, polymeric materials, energy generation, energy harvesting, devices and the other related technologies. The contributions have been made by various researchers and eminent scientist, who presented their papers in this International Conference. The chapters include various latest and significant topics, i.e. **semiconductor materials & devices, smart materials, polymeric materials, sensors, photovoltaics, solar thermal energy storage, optoelectronics, nanotechnology/nanomaterials and other emerging technologies**. The book gives the cutting-edge technologies and other significant aspects related to material synthesis, optimization, characterization and device fabrication.

It includes the latest findings of eminent scientists and researchers discussing the thermophysical properties of nanoparticle-enhanced phase change materials for thermal energy storage; fabrication of in-line PERT bifacial solar cells, concept of agrivoltaics; graphene nano-material, amicable approach for nuclear reactors; nano-fibers for antimicrobial wound dressing; optoelectronic properties of iridium

(III) complexes; liquid crystal display materials; synthesis and characterization of nanoalloy for thermal applications; water purification using graphene-functionalized nanoparticles; nano-composites; nano-material-based sensors; bio-sensor; preparation and characterization of influenza virosomes; photonic crystals; rheological properties of magneto-rheological fluid; nonlinear optical susceptibilities of a piezoelectric semiconductor; modelling & simulations; and a many more.

These contributory papers provided new insights, thought-provoking ideas and exchange of scientific solutions. We are sure that all the latest results and findings reported here will be useful to the young researchers or scientists working in these areas and will serve as an important document for all those associated with research and development in materials and its usage.

We are immensely grateful to all the eminent speakers who delivered the talks and contributed the rich and dense programme of the conference. We are also thankful to all the members of the team ICRTMD 2019 who worked with full commitment and provided their guidance and support.

The editors wish to place on record our profound gratitude to Dr. Ashok K. Chauhan, Chief Patron—ICRTMD 2019 and Founder President, Amity University, Noida, for his continuous guidance and encouragement to organize this important conference. Editors are also highly thankful to Prof. (Dr.) Balvinder Shukla, Vice Chancellor, Amity University, for her tremendous support, in making this conference a success event. Our sincere thanks and gratitude goes to all Co-Chairpersons—Dr. Sangeeta Tiwari, Dr. R. S. Pandey, Dr. Prakriti Rai, Dr. Dheeraj Pawar, Dr. Christine J., Dr. Suman; and Secretaries—Dr. Rohit Verma, Dr. Deepshikha Gupta, Dr. Kuldeep Chaudhary; and all the members of International Conference on the Recent Trends in Materials and Devices, 2019 (*jointly organized by Amity Institute for Advanced Research and Studies (AIARS) and Amity Institute of Applied Sciences (AIAS), Amity University, Noida*), for their support in organizing this conference.

Noida, India

Vinod Kumar Jain
Sunita Rattan
Abhishek Verma

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Chapter 1

Improved Thermal Conductivity and Energy Storage Properties of Graphitized Carbon Black Based Magnesium Nitrate Hexahydrate Composite



Neeraj Gupta, Amit Kumar, Hrishikesh Dhasmana, Avshish Kumar, Vivek Kumar, Abhishek Verma, S. K. Dhawan, and V. K. Jain

Abstract Latent heat thermal energy storage (LHTES) using phase change materials (PCMs) are an effective way to store energy. Here we demonstrated the effect of carbon nano-material include graphitized carbon black on the thermal conductivity and energy storage properties of magnesium nitrate hexahydrate (MNH), an inorganic salt hydrate phase change material. The MNH-carbon nanocomposite was prepared using melt mixing method by dispersing the carbon nano-material at a mass fraction of 0.5 wt% in MNH. The as-prepared composite was analyzed by scanning electron microscopy. The Fourier-transformed infrared (FTIR) confirmed no chemical interaction between the MNH and carbon nano-material in MNH-carbon nanocomposite. The thermal conductivity of the sample in the solid phase was measured using the transient hot-wire method and found that the thermal conductivity of MNH-carbon nanocomposite increased by 62.5% with respect to pristine MNH. The energy storage properties include charging and discharging was also analyzed by a conventional heating system, which confirmed that the presence of carbon nano-material enhances the heat transfer rates. The result implies that the materials used in this study could be used as a potential candidate for thermal energy storage.

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1.1 Introduction

The rapid depletion of fossil-based energy resources and the increase of environmental pollution, renewable energy utilization have been an area of interest for research and development. Solar radiation is one of the most important sources of energy. Solar energy is available during day time; hence its application requires an efficient thermal energy storage system to store the energy for later use. Latent heat thermal energy storage (LHTES) using phase change material (PCMs) is getting popular because it offers a much higher storage density and constant operating temperature [1]. PCMs are those materials that can absorb and release a large amount of thermal energy at their phase transition temperature. Owing to their excellent energy storage property, PCMs have been utilized in the fields of smart textile, surplus heat management, building, and solar energy harvesting [2–6]. According to the different phase forms and chemical nature, PCMs are divided into two types, organic and inorganic. Compared with organic PCMs, inorganic salt hydrate has huge advantages in LHTES, such as high latent heat and thermal conductivity, lower price, and incombustibility [7, 8]. However, the inherently low conductivity of salt hydrates limits the efficiency of thermal energy storage system and their application in actual engineering [9, 10]. To solve the above problem, several techniques have been proposed, such as the uses of heat pipes and fins, macro-encapsulation and microencapsulation, dispersion of high conductivity materials [11–13]. The dispersion of high thermally conductive material such as nanoparticles is one of the best ways to enhance the thermal conductivity of PCMs is currently of great interest and receiving attention [14–16]. Harikrishnan and kalaiselvam [17] added the 2 wt% of CuO nanoparticles in oleic acid, the pristine PCM. It was found that by adding the nanoparticles, thermal conductivity significantly improved by 98.66%. Zeng et al. [18] prepared the PCM-nanocomposite by dispersing copper nanowires (11.9 vol%) into tetradecyl alcohol. It was interesting to find that the thermal conductivity reached $2.86 \text{ W m}^{-1} \text{ K}^{-1}$, nine times higher that of pure tetradecyl alcohol. Said et al. [19] study the performance of the air conditioning system using rubitherm commercial (SP24E) as the base PCM and PCM mixed with nanoparticles. It was found that the heat transfer characteristics of the composite increased in comparison to the pristine PCM.

Besides metallic and metallic oxide nanoparticles, carbon-based nano-materials have received great attention, to enhance the thermal conductivity of PCMs, because of their extremely high thermal conductivity (e.g. $3000\text{--}6600 \text{ W m}^{-1} \text{ K}^{-1}$). For instance, wang et al. [20] dispersed the 2 wt% of MWCNT into the paraffin, the thermal conductivity increased by 35% and 40% in solid and liquid states, respectively. Hashempur et al. [21] used the surfactant to stabilize the MWCNTs in the butyl stearate as the PCM matrix to improve its thermal properties. The thermal conductivity increased from 0.16 to $0.185 \text{ W m}^{-1} \text{ K}^{-1}$ at $50 \text{ }^\circ\text{C}$. Sahan et al. [22] used the MWCNTs and activated carbon to form the composite with the paraffin. Their finding shows that the thermal conductivity of the AC/paraffin and MWCNTs/paraffin composites increased by 17.2% and 38.5%, respectively. Li et al. [23] measured the

thermal conductivity of paraffin by dispersed the nano graphite at 10 wt%. The thermal conductivity reached $0.9362 \text{ W m}^{-1} \text{ K}^{-1}$, which was 7.41 times higher in comparison to raw PCM. Colla et al. [24] prepared the nano-enhanced PCMs by embedded the carbon black nanoparticles into the paraffin. It was found that the thermal conductivity enhances to more than 25%. This article presents the preparation and thermal characterization of MNH-carbon nanocomposite for solar thermal application using magnesium nitrate hexahydrate and carbon nano-material includes graphitized carbon black. The main aim of this research work is to form the nano-enhanced composite with desirable property, especially with high thermal conductivity for the effective utilization of solar thermal energy systems. The chemical and thermal properties of prepared MNH-carbon nanocomposite were characterized by SEM, FTIR, and thermal conductivity measurement. The heat transfer properties of the MNH-carbon nanocomposite were further analyzed by measuring its melting and solidification cycle with respect to base PCM using a conventional heating system.

1.2 Experimental Description

1.2.1 Materials and Method

Magnesium nitrate hexahydrate (MNH), an inorganic salt hydrate PCM was purchased from Alfa-Aesar. Carbon nano-material (graphitized carbon black) was procured from Sigma Aldrich. All the materials were used directly as received without any further purification.

1.2.2 Preparation of MNH-Carbon Nanocomposite

The MNH-carbon nanocomposite was prepared using the melt-blending method [25]. In this method, MNH was heated above its melting point i.e. $89 \text{ }^\circ\text{C}$ to ensure its melting. The carbon nano-material was added to the molten MNH and mixed thoroughly by using a mechanical stirrer for 20 min and then ultrasonicated to obtained the homogenous dispersion of carbon nano-material in MNH matrix for the formulate of stable MNH-carbon nanocomposite. The optimal mass fraction 0.5 wt% carbon nano-material was used for the preparation of MNH-carbon nanocomposite.

1.2.3 Characterization Techniques

The morphology analysis of the material was done using Zeiss (EVO-18) scanning electron microscope (SEM). The SEM micrographs were used to observe the

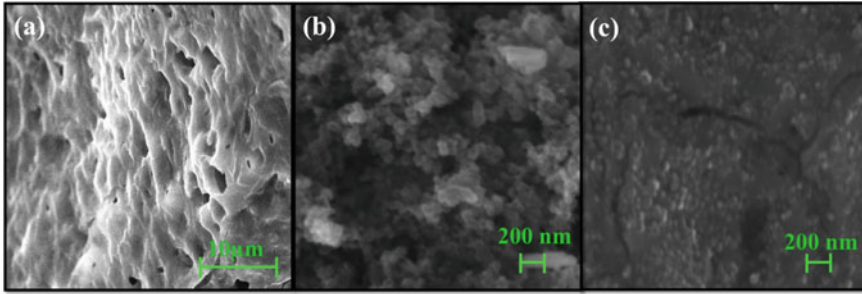


Fig. 1.1 SEM micrographs of **a** PCM (Magnesium nitrate hexahydrate) (MNH), **b** carbon nanomaterial (graphitized carbon black) and **c** MNH-carbon nanocomposite

dispersion of the carbon nano-material in the PCM matrix (MNH). The chemical interaction between MNH and carbon nano-material in MNH-carbon nanocomposite was investigated by using Fourier Transformed Infrared spectrophotometer (FTIR, VERTEX 70 BRUKER). Heat transfer characteristics were analyzed by carrying out the charging-discharging cycle of PCM-carbon nanocomposite with respect to pristine PCM using a conventional heating system [26]. The thermal conductivity of solid PCM-nanocomposite was measured by using a Linseis Transient Hot bridge-Thermal Conductivity Meter (THB6N43) under lab conditions.

1.3 Results and Discussion

1.3.1 SEM Analysis

The microstructure of the PCM, carbon nano-material (graphitized carbon black), and MNH-carbon nanocomposite are present in Fig. 1.1. It can be seen from Fig. 1.1a that pristine PCM characterized as a solid crystalline structure. The micrograph of carbon nano-material, as shown in Fig. 1.1b had a glossy structure and was used as a filler to increase the thermal conductivity of the base MNH matrix. The SEM image of MNH-carbon nanocomposite, as shown in Fig. 1.1c, which reveals that composite is homogeneous, and the carbon nano-material is well distributed over the surface of the MNH without any agglomeration.

1.3.2 FTIR Analysis

Figure 1.2 presents the FTIR spectrums of MNH and MNH-carbon nanocomposite. A series of absorption peaks can be observed in the FTIR spectrum of $\text{Mg}(\text{NO}_3)\cdot 6\text{H}_2\text{O}$ (MNH), as shown in Fig. 1.2a. For instance, the absorption peaks for N=O bending at

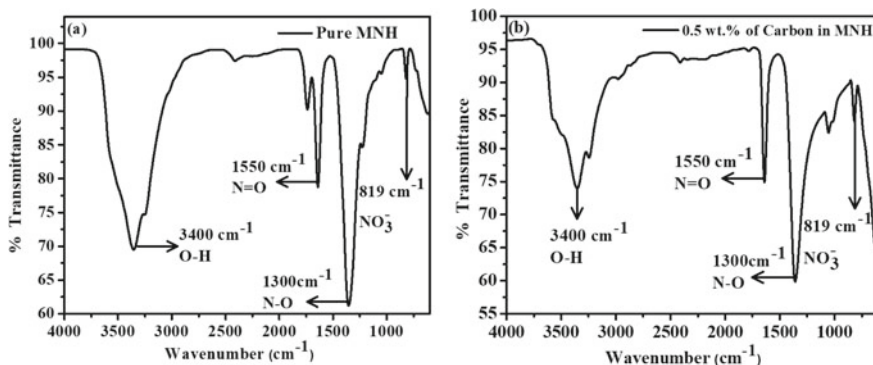


Fig. 1.2 FTIR spectra of **a** magnesium nitrate hexahydrate (MNH) and **b** MNH-carbon nanocomposite

1550 cm^{-1} , O–H stretching at 3400 cm^{-1} , a mixture of N–O stretching and bending of N=O at 1300 cm^{-1} , plus a sharp peak at 819 cm^{-1} for NO_3^- can be seen and are in well agreement with the reported literature [27]. In the spectrum of MNH-carbon nanocomposite as shown in Fig. 1.2b, no new shift or peaks is observed in comparison to pristine MNH. It means that no considerable chemical interaction between MNH and carbon nano-material, indicating that both the materials were merely physically mixed to form a stable MNH-carbon nanocomposite. Similar results were also reported by the other group, where they reported the simple physical interaction between the filler and the PCMs [28].

1.3.3 *Meting and Solidification Experimental Results*

The conventional heating system was used to evaluate the heat transfer characteristics of MNH and MNH-carbon nanocomposite by comparing their charging (melting) and discharging the solidification cycle. The melting cycle of MNH-carbon nanocomposite at a mass fraction of 0.5 wt% carbon nano-material and MNH, as shown in Fig. 1.3a. Both the MNH-carbon nanocomposite and MNH were kept at room temperature at the beginning of the melting cycle. The temperature of MNH-carbon nanocomposite and MNH were increased gradually by $2\text{ }^\circ\text{C}/\text{min}$ until they reached their phase transition point. A drastic decrease in the melting time of MNH-nanocomposites at a mass fraction of 0.5 wt% carbon nano-material was observed. This shows the overall reduction of 5.8% in melting time for MNH-carbon nanocomposite was observed as compared to that of pristine MNH.

The solidification experiment on MNH-carbon nanocomposite and Pristine MNH was also performed as shown in Fig. 1.3b. The temperature of MNH and MNH-carbon nanocomposite was found to be at $120\text{ }^\circ\text{C}$ at the initial stage of the solidification cycle. Both the materials were allowed to cool; naturally, the temperature of MNH-carbon

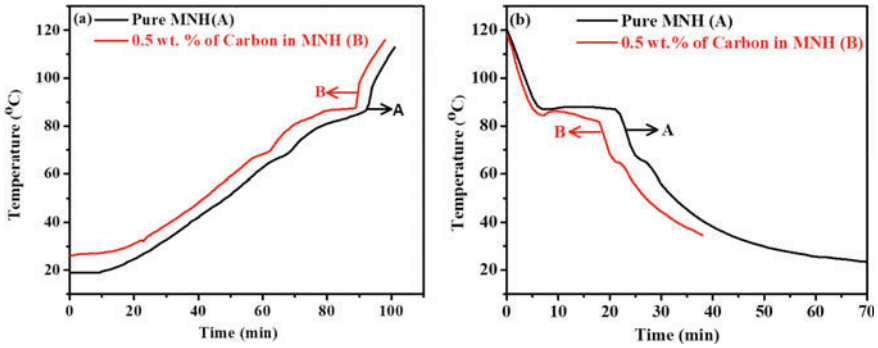


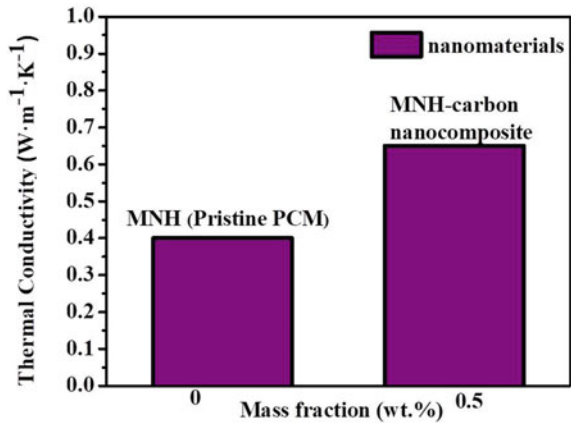
Fig. 1.3 **a** Melting curve of MNH and MNH-carbon nanocomposite at a mass fraction of 0.5 wt% nano-material and **b** solidification curves of MNH and MNH-carbon nanocomposite at a mass fraction of 0.5 wt% nano-material

nanocomposite at a mass fraction of 0.5 wt% nano-material and MNH decreased until they reached their respective solidification point. The results showed the overall reduction of 30% in solidification time for MNH-carbon nanocomposite is observed as compared to MNH, due to the enhancement in thermal conductivity of the material.

1.3.4 Thermal Conductivity

Thermal conductivity determines the speed of heat transfer within the material. It is an important parameter for selecting phase change material for the thermal energy storage application. The main aim of this work is to analyze the effect of adding high conductivity carbon nano-materials on the effective thermal conductivity of inorganic salt hydrate PCMs. In nanocomposites, the heat transfer occurs due to the acoustic phonons with different frequencies. However, for the enhancement of thermal conductivity in nanocomposites, the interface resistance plays an important factor. Figure 1.4. describes the thermal conductivity results between the pristine MNH and MNH-carbon nanocomposite at a mass fraction of 0.5 wt% carbon nano-material. The results display that MNH-carbon nanocomposite has the thermal conductivity ($0.66 \text{ W m}^{-1} \text{ K}^{-1}$) much higher than that of pristine MNH ($0.4 \text{ W m}^{-1} \text{ K}^{-1}$). The high thermal conductive network established by the filler in MNH matrix enhances the thermal conductivity of MNH-carbon nanocomposite. This enhancement in thermal conductivity decreases the phase transition time, i.e. (reduction in melting and solidification time), thereby providing a better solution for the proper functioning of the thermal energy storage system to respond to fast load variation.

Fig. 1.4 Thermal conductivity curve of MNH and MNH-carbon nanocomposite at a mass fraction of 0.5 wt% nano-material



1.4 Conclusion

In this paper, MNH-carbon nanocomposite was prepared by the melt-mixing technique by adding carbon nano-material at a mass fraction of 0.5 wt% in MNH. The characterization results of SEM revealed that carbon nano-material is uniformly distributed in the MNH matrix without any agglomeration. The FTIR analysis shows that carbon nano-material does not show any chemical interaction with the MNH matrix, as they are attached physically. The prepared MNH-carbon nanocomposite shows the rapid melting (charging rate increased to 5.8%) and solidification (discharging rate increased to 30%) for 0.5 wt% carbon nano-material as compared to Pristine MNH. The thermal conductivity of MNH-carbon nanocomposite enhances by 65% as compared to pristine PCM. Therefore MNH-carbon nanocomposite can be used as an effective material for the Latent heat thermal energy storage system.

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Chapter 2

Effect of Additional Heat Treatment in Fabrication Line of n-PERT Bifacial Solar Cell to Improve the Surface Passivation



Virender Sharma, C. V. Kannan, Yash Pal, Hrishikesh Dhasmana, Amit Kumar, Abhishek Verma, and V. K. Jain

Abstract This work presents optimization of preannealing step at the end of the existing process line of Silicon solar cell device fabrication and compared it with regularly processed n-Passivated Emitter Rear Total (n-PERT) bifacial solar cell. For preannealing purpose, rapid thermal process (RTP) treatment of the device has been performed in the temperature range of 500–900 °C for 20 min duration in the existing process line. The electrical evaluations of the devices are performed via I–V measurements which are depicting variation in respective solar cell output parameters such as open circuit voltage, short circuit current and fill factor with annealing temperature. An optimized heat treatment of RTP at 700 °C suggests appreciable improvement of 0.31% in the device efficiency with improvement in other solar cell parameters such as short circuit current and open circuit voltage by 51.6 mA and 4.8 mV respectively. The measured cell parameters are analysed in detail with the variation of RTP temperature and suggest that additional heat treatment at the end of process line can results into device improvement with the increase of annealing temperature upto 700 °C, via reduction of bulk recombination in the base region without much affecting junction properties in the crystalline Si solar cell. However, high temperature (>700 °C) annealing in the device fabrication line is deteriorating device parameters as well as its efficiency which can be attributed to depletion of hydrogen in passivating layer and degradation of p–n junction properties.

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2.1 Introduction

Photo generation and thereby photovoltaic phenomenon into silicon (Si) based p–n junction device involves process of converting sunlight directly into electricity. The photovoltaic generation of electric energy by solar cells from incident solar irradiation energy is an important part of the renewable energy concept. This aims to reduce global warming by replacing fossil energy sources by renewable ones. By the end of 2018, an accumulated PV power installation is nearly 480 GW with nearly 95% share of crystalline silicon [1]. Hence, crystalline silicon cells are the workhorse of a multibillion dollar photovoltaic (PV) industry. Way back in 1950s with the first monocrystalline single junction solar cells made for space applications had an efficiency of about 6% and known as oldest type of solar cells [2]. Since then, by many years of continuous research and development, the efficiency of silicon solar cells have been improved to a record level of 26.7%/22.3% for mono-Si/multi-Si [3]. In recent past, the major efforts amongst research community are driven towards reducing the cost of Si solar cell device via enhancing efficiency and adopting low cost process. Since silicon material is abundant, nontoxic and related device fabrication technology is well matured, therefore, silicon wafer-based solar cells are currently dominating this dynamic photovoltaic market. Single junction Si solar cells have relatively simple device architecture. They consist of an electrically contacted large area p–n junction, which is equipped with a top grid contact so that the semiconductor material can be illuminated [4, 5]. Amongst different type of wafer based solar cell, *p*-type (typically boron doped) silicon solar cells have dominated all industrial development for decades due to its relative insensitivity to the degradation caused by exposure to cosmic rays [6]. For today's industrial mass production for terrestrial electricity generation, a typical state of the art *p*-type c-silicon solar cell with a homogeneous emitter and full aluminium back surface field (Al-BSF) has an efficiency of ~19% with the standard silicon nitride passivation and screen printed silver paste metallization on the front [7]. But during field application of these solar cells, Light Induced Degradation (LID) due to boron oxygen complex formation in base region of solar cell affects working efficiency of the device [8]. Therefore, a lot of research has been conducted in the field of *n*-type (typically phosphorus doped) silicon based solar cells. It provides several advantages over *p*-type which includes better tolerance to common impurities (e.g., iron) [9], high bulk lifetime with negligible LID. Thus, *n* type silicon solar cells with high efficiency with better surface passivation features can be potentially more cost effective than *p* type silicon based cells during their field applications. There has been continuous development to achieve cost-efficient processes such as wafer surface passivation [10, 11], laser opening [12] and screen-printed aluminium local back surface field [13]. Based on surface passivation concept, various solar cell structures such as Passivated Emitter Rear Contact (PERC), Passivated Emitter Rear Locally Diffused (PERL), Passivated Emitter Rear Totally (PERT) etc. are suggested for fabricating high efficiency Si solar cells [14, 15]. Out of these solar cell technologies, *n*-type silicon based PERT solar cell has provided advantage of fabricating high efficiency bifacial solar cell which