Night-Time Power Generation by Night Howler Cells: A Review

[1]Mohammad Akram Qureshi, [2]Dr. Rajeev Arya, [3]Dr. Nilesh Diwakar
[1]M.Tech scholar, [2]Director, [3]Prof. & Head of Department of Mechanical Engineering
Truba Institute of Engineering and Information Technology Bhopal

Abstract - **Everyday a large amount of solar radiation falls upon the Earth. Among a wide portion of frequencies radio waves, visible, infrared, ultraviolet and reach the Earth's surface in the decreasing order as mentioned. A portion of this incident radiation gets absorbed in the atmosphere while the other portion is reflected back into space. The portion absorbed by Earth and its atmosphere regulates the temperature of Earth when there is no sun overhead termed as Earth's albedo. Earth overthrows extra heat into atmosphere by radiative cooling phenomenon. This phenomenon takes place in long-wave infrared region of the electromagnetic spectrum. In order to generate power from this resource a number of infrared sensitive materials were studied on the basis of their radiation absorption and spectral properties. Amongst them most prominent results are given by Mercury-Cadmium-Telluride (HgCdTe). By doping different quantities of Mercury and Cadmium on Tellurium substrate a number of different bands of infrared absorbing materials could be generated. The HgCdTe PV cell was studied and the results were compared to that with the currently available PV cells. The results showed about one and a half times to two times more power generation in comparison.**

keywords - **Radiative cooling, infrared radiation, Earth's albedo, infrared sensitive materials etc.**

I. Introduction:

Photovoltaic cells are now a days have become very common as the technology have reached to the peak of Research and Development but still it has not overcome from use of batteries in a typical solar photovoltaic system; it not only increases the risk of handling but also increases the cost of overall system, additionally it has most common disadvantage of being inactive during night time. However there is still radiation present during night time to harness power. This inactivity could be overcome by using infrared radiation from the surface of the Earth and from the radiation absorbing structures. In order to harness power from infrared light there must be a substance that is very sensitive to the infrared radiation. However there is a lot of work has been done in infrared detection technology from the World War I to the present; with a very common name "Night Vision". Hence the concept is to use the same materials that have been used in Night Vision and Infrared Detection to generate Power. Most of the Infrared detection devices use Mercury-Cadmium-Telluride as the key material therefore this material can find a way to generate power from the Infrared sources.

II. Literature review

*Guo Linyang, Ma Xiaohui, Zou Yonggang, Zhang Ran, Wang Jia'an, Zhang Da [1]*A wide-angle infrared perfect metamaterial absorber is experimentally verified. The perfect metamaterial absorber shows polarization-independent at normal incidence and displays high absorption rate at a large angle of incidence. The proposed sensing strategy can be applied in a large variety of nano-fabrication equipment, which can profound significantly in developing low cost sensor with simple measurement technologies.

*Yuping Tai, Xinzhong Li, Bingli Pan [2]*Down conversion involving emission of two near-infrared photons for one ultraviolet photon absorbed was achieved in Nd^{3+} and Yb^{3+} co-doped transparent YAG glass ceramics. Upon excitation of Nd^{3+} ions with an ultraviolet photon at 355 nm, Yb^{3+} ions emitted two near-infrared photons at 980 nm through an efficient two-step energy transfer process from Nd^{3+} to Yb^{3+}. The development of near-infrared down conversion transparent glass ceramics would allow an increase of the energy efficiency of the silicon solar cells.

*Sajal Agarwal, Y.K. Prajapati [3]*Study was done to analyze a nano absorber for thermo-photovoltaic cell application. Optical absorbance of two-dimensional materials is exploited to achieve high absorbance. It was found that few alternating layers of graphene/transition metal dichalcogenide provide high absorbance of electromagnetic wave in visible as well as near infrared region. The proposed absorber having wide operating range from 200 to 1000 nm with perfect absorbance for all over the desired range. It is very interesting to see that the proposed absorber is compatible for EM wave absorption with thickness of 26nm only.

*Wang-Hee Park , Gyeong-Nam Lee , Joondong Kim [4]*A high-performing infrared photodetector is achieved using a MoO_3 /p-Si heterojunction. A high-quality MoO_3 film is formed using the sputtering method, which enables the application of large-scale MoO_3 film-embedded Si devices. A partial oxygen flow was effective to form the preferential growth of the MoO_3 film. The MoO_3 /Si heterojunction is applied for use in a long wavelength (1100 nm) photodetector to provide a fast rise time (72.32 ms) and fall time (68.15 ms). The functional design of MoO_3 can provide a route to enhancing the utilization of long wavelength photons, which further improves the performance of solar cells and photodetectors.

*F. Marsili, V. B. Verma et al [5]*Single-photon detectors (SPDs) at near-infrared wavelengths with high system detection efficiency (> 90%), low dark count rate (< 1 counts per second, cps), low timing jitter (< 100 ps), and short reset time (< 100 ns) would enable landmark experiments in a variety of fields. The detector system has a system detection efficiency (SDE), including optical-coupling losses, greater than 90% in the wavelength range of 1520 – 1610 nm; device dark count rate (measured

with the device shielded from room-temperature blackbody radiation) of ≈ 0.01 cps; timing jitter of ≈ 150 ps FWHM; and reset time of 40 ns.

*Nick Brekke et al [6]*This work explores recent advancements of a concentrating hybrid photovoltaic/thermal (CPV/T) system, with an emphasis on detailed modelling and parametric performance studies. This system combines two widely researched methods of harnessing solar energy: photovoltaics (PV) and solar thermal. The CPV/T system proposed here uses a nanoparticle-based heat transfer fluid to spectrally absorb bands of the solar spectrum not efficiently utilized by the PV cell or below the bandgap of the cell with the remaining light transmitted to the PV. The fluid simultaneously transmits the portion of the spectrum which the PV cell can efficiently utilize. The GaAs system realized an overall higher energetic efficiency when compared to Si for a given concentration ratio and length.

*Fei Hu, Zhi-Quan Zhou, Lei Ma, Chi Zhang, Wen-Jie Zhou, Ming Lu [7]*Al nanoparticles (NPs) have been used to enhance the photovoltaic response of crystalline- or c-Si solar cell from the ultraviolet (UV) throughout the visible and near infrared (NIR) regimes. Al NPs were induced by solid thermal annealing and embedded in a SiO_2 layer that was to passivate the front side of solar cell. Upon the excitation of surface plasmons (SPs) on the Al NPs under light illumination, an enhancement of broadband absorption of the solar cell was observed. The results of this work may find practical application in improving c-Si solar cell performance.

*Bo-Cheng Wang et al [8]*A series of thienoisoindigo (TII)-based dyes (TII 1-4) using different electron-donating moieties (D) and π-linkers were synthesized. The bulk-heterojunction solar cell device fabricated by using TII 3/$PC_{61}BM$ as the active layer exhibited a power conversion efficiency (PCE) of 0.82%, showing the potential of TII -based dyes for NIR organic photovoltaics (OPVs).

*Bin Zhao, Mingke Hu, Xianze Ao, Gang Pei [9]*Building-integrated photovoltaic/thermal (BIPV/T) technology has been receiving considerable research at-tention because of its ability to generate electricity and thermal energy simultaneously. This study proposed a building-integrated photovoltaic–radiative cooling system (BIPV–RC) that can generate electricity via photovoltaic (PV) conversion during daytime and generate cooling energy via radiative cooling (RC) during night time to satisfy the demand in such areas. The selective plate, which is the main component of the BIPV–RC system, exhibits high spectral absorptivity (emissivity) in the PV conversion band of crystalline silicon solar cells and in the atmospheric window band (i.e., 0.3–1.1 μm and 8–13 μm), as well as low spectral absorptivity (emissivity) in other bands.

*Jinchao Tong, Landobasa Y.M. Tobing, Peinan Ni, Dao Hua Zhang [10]*The effect of interface quality on the performance of InAsSb based hetero *n-i-p* middle wavelength infrared (MWIR) photodiodes. By adopting heavily dopingwide bandgap p- and n-type layers and inserting a thin layer between the two doped layers and the absorbing InAsSb region, the interface quality can be improved.

*Taher Ghomian, Samaneh Fariman, Jin-Woo Choi [11]*The impacts of isopropylamine (IPAM) as a short ligand on a solution-processed infrared photodetector and a photovoltaic device using lead sulfide(PbS) colloidal quantum dots were studied. Original oleic acid capping is replaced by isopropylamine through a solution-phase ligand exchange process. A blend of poly[2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene] or MEH-PPV and the isopropylamine-capped PbS colloidal quantum dots was prepared for a photosensitive layer sandwiched by two different electrodes. Results illustrated that contribution of isopropylamine can improve the responsivity of a photodetector and enhance the photovoltaic performance by increasing the open circuit voltage and short circuit current.

*Lingling Yan, Yiming Bai, Bo Yang, Nuofu Chen, Zhan'ao Tan, Tasawar Hayat, Ahmed Alsaedi [12]*The efficient photon harvesting in near infrared wavelength range is still a challengingproblem for high performance $Cu(In_{1-x}, Ga_x)Se_2$ (CIGS) solar cell. Adjusting the energy band distribution of CIGS solar cell could provide significant academic guidance for devices with superior output electric power. To understand the role of each functional layer, the optimal 3000 nm CIGS absorber layer with 1.3 eV bandgap and 30 nm CdS buffer layer were firstly obtained via simulating the uniform band-gap structures. The best PCE of the device based on double gradient CIGS solar cell reaches 24.90% when its absorber layer is 2800nm, among the best values reported in literatures.

*M.R. Salem, R.K. Ali, K.M. Elshazly [13]*This paper presents a field study for the performance of photovoltaic thermal (PVT) system that uses aluminium cooling plate with straight and helical channels during July 2016. Three systems each of 0.37 m_2 commercial poly-crystalline PV panels have been installed at the facility of engineering at Shoubra, Benha University, Cairo, Egypt (30.1LN Latitude). Two of the systems are cooled using straight and helical channels with dimensions of 10x10 mm_2 and compared with the uncooled panel. While the corresponding average energy efficiency increases from 11.1% to 12.9% for straight channels and 11.5% to 13.5% for helical arrangement.

*Juhyun Park [14]*Conjugated polymers have been used to produce solar energy conversion materials in photovoltaicsdue to their outstanding light harvesting properties and low-cost processing. In thermodynamic terms, many visible/NIR absorbing conjugated polymers possess LUMO levels that are proper for the reduction of hydrogen.

*Chauhan, D. Perera [15]*For the infrared detection in the 3-5 μm range, p-GaAs/$Al_xGa_{1-x}As$ heterojunction is an attractive material system due to light hole/heavy hole and spin-orbit split-off intra-valance band transitions in this wavelength range. Varying the Al mole fraction provides the tuning for the wavelength threshold, while graded $Al_xGa_{1-x}As$ potential barriers create an asymmetry to allow a photovoltaic operation. At zero bias, the resistance-area product (R_0A) had a value of ~ $7.2\times10_8$つ cm_2, which is five orders higher in magnitude (with a corresponding reduction of the responsivity by only a factor of ~ 1.5), compared to the R_0A value without the blocking barrier. A photoresponse was observed up to 130K.

*Harkirat S. Mann, Brian N. Lang, and Yosyp Schwab [16]*Infrared radiation is used to radiatively transfer heat to a nanometric power generator (NPG) device with a thermoelectric Nb-doped TiO_2 film deposited by atomic layer deposition (ALD) as the active element, onto a borosilicate glass substrate. The linear rise of the produced voltage with respect to the temperature difference between the “hot” and “cold” junctions, typical of the Seebeck effect, is missing. The discovery of the violation of

the Seebeck effect in NPG devices combined with the ability of ALD to tune thermoelectric thin-film properties could be exploited to increase the efficiency of these devices for energy harvesting purposes.

*Z.B. Tian, T. Schuler-Sandy, S. Krishna [17]*The quantum-engineered interband cascade (IC) photodetector is a new type of infrared detectors with many unique and highly desirable features. The multi-stage design allows much flexibility in device optimization for different application environment, such as operation temperature, irradiance level, and possibly high-speed and fast frame-rate application scenarios. Results suggest that the dark current in MWIR IC detectors at lower temperatures are dominated by tunneling processes.

*Jeff Gray, Xufeng Wang, Raghu Vamsi Krishna Chavali, Xingshu Sun, Abhirit Kanti, John Robert Wilcox (18)*ADEPT/F solves Poisson's equation coupled with the hole and electron continuity equations in one spatial dimension in compositionally nonuniform semiconductors. It was originally written to model solar cells fabricated from a wide variety of materials, including amorphous silicon, copper indium diselenide, and cadmium telluride. Solar cell material systems modeled include ZnO/CdS/CIS, ZnO/CdS/CIGS, CdS/CdTe, a-Si, Si, AlGaAs/GaAs, GaSb, InP, and several others.

*K. Venkata Krishnaiah, J. Marques-Hueso, K.Suresh, G.Venkataiah, B.S. Richards, C.K. Jayasankar [19]*In this paper it is reported that the near infra-red (NIR) upconversion (UC) and spectroscopic properties of erbium (Er^{3+})-doped TeO_2-ZnO-Nb_2O_5-TiO_2 (TZNT) oxide glasses have increased spectroscopic responses for NIR. This reveals that the investigated glasses could find application in photonics, for example non-linear optics and photovoltaics.

*Yosyp Schwab Harkirat et al [20]*The mechanism that activates a bi-junction power generator under the effects of heat is the Seebeck effect, that is, the production of voltage difference $\Delta V(t)$ is directly proportional to the temperature difference $\Delta T(t)$ between the “hot” and “cold” junctions of the device. This phenomenon is well established and is known as thermoelectric power generation. The findings should be considered in the design, fabrication, and improvement of thermopiles, power meters, and IR energy-harvesting devices.

*Steven J. Byrnes, Romain Blanchard, and Federico Capasso [21]*Renewable energy can be generated whenever heat flows from a hotter to a colder body. One such flow is from the warm surface of Earth to cold outer space, via infrared thermal radiation. An emissive energy harvester (EEH) is a device that can generate energy from emitting thermal radiation into the clear sky. To calculate how much power is thermodynamically available, using a location in Oklahoma as a case study. There are two possible ways to make such a device: A thermal EEH (analogous to solar thermal power generation) and an opto-electronic EEH (analogous to photovoltaic power generation).

*Yang Cao, Jiayi Zhu, Jia Xu, Junhui He [22]*Reduced graphene oxide (RGO) thin films with 5, 10, 20, 30 and 50 RGO bilayers were prepared via the layer-by-layer assembly of oppositely charged RGO nanosheets. The effects of the number of RGO bilayers on the electrical, optical and photoelectric (including photovoltaic and photoconductive) properties under 850 nm near-infrared laser irradiation of RGO thin films were systematically studied. Photoresponse time of RGO thin film first decreased and then increased with increasing the number of RGO bilayers and the fastest photoresponse time occurred at 30 bilayers.

*Ronald J. Parise [23]*The Nighttime Solar Cell is a clean, silent, passive, solid-state device that has been developed to produce electric power day and night from a renewable energy source. The device produces electric energy by utilizing a thermoelectric generator (TEG) as a heat engine in the temperature difference that exists between the temperature of deep space at about 4K and the surface of the earth, nominally at 290K. The Nighttime Solar Cell panel arrays will provide about one-sixth the electric power at night that PVs can produce during the day, typically when electrical energy requirements are less, using the same array surface area.

*Richa Pandey et al [24]*This work was to examine the optical properties of tin naphthalocyanine dichloride ($SnNcCl_2$), and its performance as an electron donor material in organic photovoltaic cells (OPVs). As an active material, $SnNcCl_2$ is attractive for its narrow energy gap which facilitates optical absorption past a wavelength of k = 1100 nm. In $SnNcCl_2$, the infrared absorption is intrinsic to the molecule, arising as a result of the extended conjugation. Consequently, it is expected that $SnNcCl_2$ could be utilized in bulk heterojunction OPVs without sacrificing infrared absorption.

*Hin-Wai Mo, Tsz-Wai Ng, Chap-Hang To, Ming-Fai Lo , J. Antonio Zapien, Chun-Sing Lee [25]*A 1:1 volume ratio mixed film formed by co-evaporation of 4,4,4-tris(N-3-methylphenyl-N-phenylamino) triphenylamine (m-MTDATA) and copper hexadecafluor-ophthalocyanine ($F_{16}CuPc$) showed a broad optical absorption band from 900 to 1500 nm not observed from the two constituting materials. An organic photovoltaic device (OPV) which can generate electric power from pho-tons with longer than 1300 nm wavelength.

*A.Ferron, J.Rothman, O.Gravran [26]*The physical models implemented for HgCdTe infrared photodetectors are reviewed. In particular, generation–recombination models such as Shockley–Read–Hall through a trap level in a narrow bandgap and Auger recombination are included. This paper highlights both the unique set of trap parameters found to fit the dark current as a function of temperature and composition for mercury-vacancy *p*-type-doped photodiodes and their use in a finite-element code. An equivalent set of trap parameters is also proposed for indium *n*-type-doped material in a *p*-on-*n* photodiode simulated in three dimensions.

*D.C. Yu, X.Y. Huang, S. Ye, M.Y. Peng, Q.Y. Zhang [27]*A sequential two-step near-infrared (NIR) quantum splitting (QS) has been demonstrated in a $Ho_{3þ}$ - doped YVO_4 phosphor. The involved NIR-QS mechanism has been analyzed in terms of the static–dynamic photoemission, monitored excitation spectra and time-resolved emission spectra.

*Anne M. Itsuno [28]*A unipolar, barrier-integrated nBn detector structure is proposed to address the challenges associated with p-type doping in MBE grown HgCdTe. Numerically simulated performance characteristics of the HgCdTe nBn device predict values similar to comparable DLPH structures for a range of temperatures, motivating the experimental demonstration of mid- and long-wave IR HgCdTe nBn detectors. This work culminates with the simulation study of the novel, hybrid NBvN structure which addresses both technology limitations by combining the advantages and designs of the Auger-suppressed HOT and unipolar nBn detectors in a single configuration.

*Terry M. Tritt [29]*Over the past 10–15 years, there have been significant advances in the scientific understanding as well as in the performance of thermoelectric (TE) materials. TE materials can be incorporated into power generation devices that are designed to convert waste heat into useful electrical energy. These TE materials can also be used in solid-state refrigeration devices for cooling applications. This article discusses TE phenomena, the selection criteria for higher-performance materials, and a few key materials.

*N. Sekar , Rajesh K. Raut, Prashant G. Umape [30]*Near Infrared absorbing colorants have several applications in the high technology area like heat ray blocking, energy conversion, and optical data storage. The thermogravimetric analysis and UV-Vis analysis showed that synthesized carboxamide group containing metal complexes can have application as dye-sensitized colorants in solar collector's fabrication.

*Jeffrey Beck [31]*The operation of the mid-wave infrared (MWIR) HgCdTe cylindrical electron injection avalanche photodiode (e-APD) is described. A two-dimensional diffusion model calculates the time-dependent response and steady-state pixel point spread function for cylindrical diodes, and predicts bandwidths near 1 GHz for small geometries. Dark current data, at high gain levels, indicate an effective gain normalized dark density count as low as 1000 counts/ls/cm_2 at an APD gain of 444. A junction doping profile was determined from capacitance–voltage data.

*F. Xiong, H. Zhang, Z. M. Jiang, and P. X. Zhang [32]*The transverse laser-induced thermoelectric voltages in the tilted La2−xSrxCuO4La2−xSrxCuO4 (LSCO) thin films are observed for the first time. The detected signals are demonstrated to originate from the anisotropy of thermo-electricpower and depend on the Sr-doping level drastically. The largest voltage is observed in the LSCO films at x=0.15x=0.15 under the irradiation of different lasers with the wavelength in the spectrum range from infrared to ultraviolet.

*J.P.G. Price [33]*This paper describes the design, fabrication and performance of dual-band MW/LW infrared detectors made from HgCdTe (MCT) grown by Metal Organic Vapour Phase Epitaxy (MOVPE). In which the detectors are staring, focal plane arrays consisting of HgCdTe mesa-diode arrays bump bonded to silicon read-out circuits. Each mesa has one connection to the ROIC and the bands are selected by varying the applied bias. The development of the CONDOR II detector is showing very promising results with high pixel operability in both wavebands and excellent NETD performance.

*Jinzhuan Zhu, Yue Shen, Feng Gu, Junchao Tao, Jiancheng Zhang [34]*The electronic absorption spectra of TAMnPc and its polymer films both exhibit an intense Q-band beyond 800 nm in the near-infrared region. The current–voltage characteristics of TAMnPc polymer films in the dark and under infrared irradiation were studied.

*N. Kuze , E.G. Camargo, K. Ueno, T. Morishita, M. Sato, M. Kurihara, H. Endo, K. Ishibashi [35]*A miniaturized InSb photovoltaic infrared sensor (InSb PVS) that operates at room temperature was developed. The InSb PVS consists of an InSb $p_þ$-p -$n_þ$ structure grown on semi-insulating GaAs (1 0 0) substrate, with a $p_þ$ Al_xIn_1xSb barrier layer between $p_þ$ and p layers to reduce diffusion of photo-excited electrons.

*P. Ballet et al [36]*The successive steps for realizing dual-band in-frared detectors operating in the mid-wavelength infrared (MWIR) band were discussed. High crystalline quality HgCdTe multilayer stacks have grown by molecular beam epitaxy (MBE) on CdZnTe and CdTe/Ge substrates. Device processing and readout circuit for 128x128 focal-plane array (FPA) fabrication were described. The electro-optical characteristics of the devices show that devices grown on Ge match those grown on CdZnTe substrates in terms of responsivity, noise measurements, and operability.

Claudiu Romila [37]The influence of wind velocity, ground and outer cladding emissivity is analysed numerically for an insulated brick wall with an exterior wood cladding. Heat gains and losses are compared to a reference value and some results are shown. The computation was based on the steady-state approach of the physical phenomena during the warm season

*J. Piotrowski, J. Kaniewski, K. Regin Hski [38]*The performance of $In_xGa_{1~x}As$ detectors operating in the 2-3.4 lm spectral range and temperature of 300 K has been analyzed theoretically as a function of wavelength, band gap and doping level with special emphasis on 2-2.5 lm and 3-3.5 lm atmospheric window devices.

*W. E. Tennant, S. Cabelli, K. Spariosu [39]*Having low fundamental dark current at any given wavelength and temperature makes HgCdTe attractive for high temperature applications as well. We are exploring detectors with cut off wavelengths from the near to middle infrared region (~1.5 to ~4 µm). Theory allows applications from low light level imaging in starlight and "nightglow" to thermal imaging, both with useful sensitivities at room temperature. Current detector technology, being limited by SRH traps, appears to require modest cooling (to about 250K). Improved materials and processes should eliminate the need for even this cooling.

*J.P. Omaggio [40]*The model includes trap-assisted tunneling mechanisms in the back-side depletion region as well as the effects of fast surface states. Expressions for the net recombination rate are developed for situations in which trap-assisted tunneling transitions are allowed. Calculations for 12- mu m optical cutoff detectors operating at liquid-nitrogen temperature show that the properties of the back side, including surface fixed charge density, depletion region trap density, fast surface-state density, and majority carrier concentration, have a strong influence on the dark current levels of detectors on thin material.

Mark A. Goforth, George W. Gilchrist, Joseph D. Sirianni (41) Ventilated façades systems are more and more used for thermal rehabilitation of existing buildings. Their energy performance depends on many parameters, whose influence can be quantified by numerical and analytical models. When designing ventilated façades, the cooling effect of the night sky cannot be neglected because of increased thermal losses through the exterior walls. Heat gains and losses are compared to a reference value and some results are shown. The computation was based on the steady-state approach of the physical phenomena during the warm season.

III. Conclusion

In the present work number of research paper related to infrared detection and power generation have been studied. Most of research work done have spotted the lights on potential of Infrared radiation and sensitivity of various materials towards it. There is wide variety of infrared sensing materials some have good detectivity for near infrared range, some have better in mid-infrared light while some detect far infrared range best. In a comparative study of the applications of Mercury Cadmium Telluride (HgCdTe) as infrared sensing material it has found that specifications finds great relevance with the power released by the sun;

most of the structures and the Earth in the form of Infrared radiations. This work may put forward Infrared detecting material as power generating material and its further potentials.

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