HOLOGRAPHY : NEW BREAKTHROUGH IN SOLAR POWER CONVERSION TECHNOLOGY

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Abstract :
In this paper, holographic film technology and its application to solar power conversion techniques has been discussed. Investigation on Technical viability of using holographic film in a solar module has been carried out. The benefits of such system over conventional system and the work carried out by manufactures have been demonstrated. The working principle of holographic film and its benefit has been explained. The design aspect of HPC solar module has been analyzed and discussions on its performance parameters like material cost, plant size, flexibility, power, energy etc has been carried out.

Keywords : HPC holographic concentrator; PV: Photovoltaic; kWh: Kilowatt hour etc.

1. Introduction

Holography is a technique that allows the light scattered from an object to be recorded and later reconstructed so that when an imaging system is placed in the reconstructed beam, an image of the object will be seen even when the object is no longer present. The technique of holography can also be used to store, retrieve, and process information optically. Dennis Gabor is considered as the Father of Holography and Holographic Technologies [1]. The first practical optical holograms that recorded 3D objects were made in 1962 by Yuri Denisyuk in the Soviet Union [2] and by Emmett Leith and Juris Upatnieks at University of Michigan, USA. [3]. Advancement in photochemical processing techniques to produce high-quality display holograms were achieved by Nicholas J. Phillips [4]. The new holographic film developed for HP Concentrator [5] when used with solar cell delivered increased power at much reduced size thus eliminating the necessity for large size as well as number of solar array. This increases the solar cell efficiency roughly by 40% resulting in reduction in the cost of power generation. The holographic film and its integration with solar module has been shown in Figure 1(a) and 1(b) respectively.

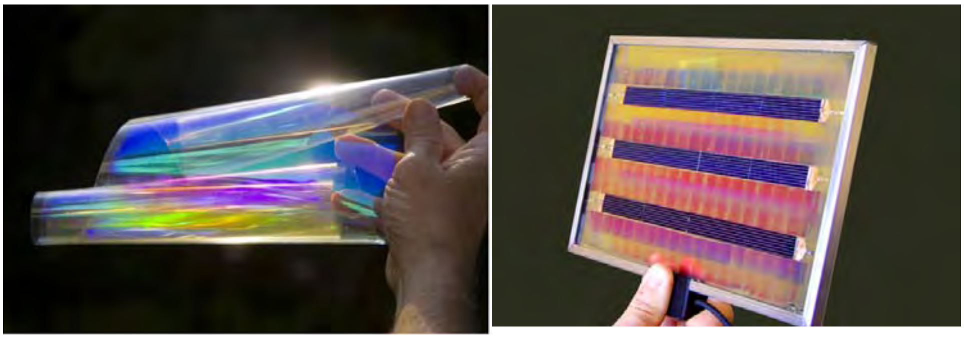

Fig.1. (a) Holographic (HPC) Film (b) HPC Concentrators

The lower cost of the energy produced, coupled with the fact that the HPC panels are cheaper to make because they use 60% less silicon consequently, means that those who decide to use them will not only be helping the environment, but they will also save huge amount of money with this new technology. The HPC panels can be used vertically as well as horizontally. This means that in future, windows in buildings could be made from the solar panels. The advantages of this are really quite extraordinary. Just imagine a huge high rise building being designed to use the HPC from the start. The building would be able to create its own power. The significance of this is that buildings create roughly 30% of the world's greenhouse gases because of the amount of fossil-fuels they use to generate electricity. The new technology replaces unsighted (usually will not be noticed as being used as window panels) concentrators with sleek flat panels laminated with holograms. The system needs 25% to 85 % less silicon than a crystalline silicon panel for equivalent power. Further, the photovoltaic material need not to cover the entire surface of a solar panel due to integration of holographic film. This form holographic planar concentrator (HPC) and is shown in Figure 1(b).

2. How Holographic Solar Module Works

A detailed theoretical account of how holography works in a solar module is provided by Hariharan [6] as shown in Fig.2.

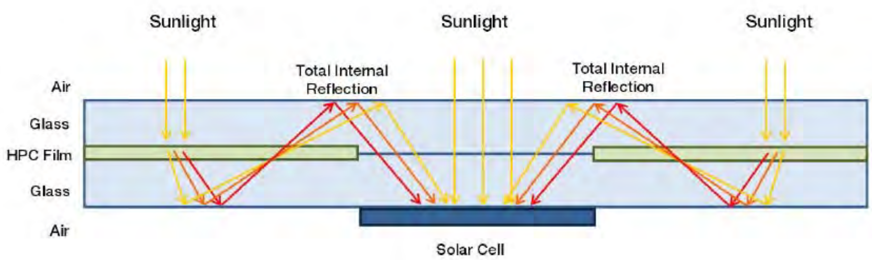

Fig.2. Working principle of Holography

3. Holographic Film and Solar Cell Performance

Worldwide, solar energy output has grown dramatically in recent years, particularly in China, Europe, and the U.S. The total output from all solar installations worldwide, however, still remains around seven giga-watts, only a tiny fraction of the world's energy requirement. High material and manufacturing costs, low solar module efficiency and a worldwide shortage of refined silicon have all limited the scale of solar-power development required to effectively compete against coal and liquid fossil fuels. A number of approaches are being explored to improve the cost per kW of solar power, primarily by improving the efficiency of the solar-collecting cells that comprise solar modules, or by concentrating greater amounts of solar energy onto the cells by tracking system. The Holographic Planar Concentrator (HPC) is one solution that achieves both of these goals.

An HPC is built up from several layers of gelatine - on - PET films. In each film holographic optical elements are imprinted using diode-pumped, solid state lasers. The holographic stack diffracts wavelengths that are usable by the solar cells while allowing unusable wavelengths to pass through, unabsorbed. The usable energy is guided via total internal reflection at the glass/air interface to strings of solar cells, resulting in up to a 3X concentration of energy per unit area of photovoltaic material.

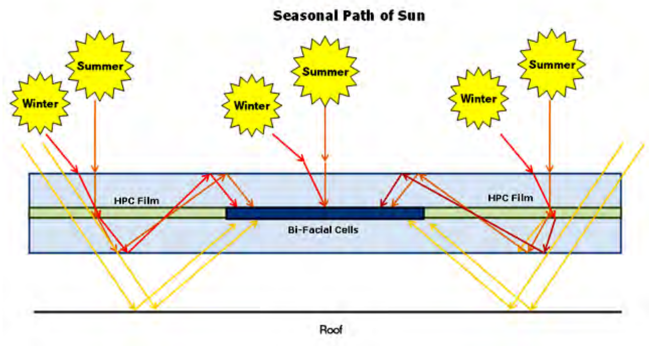

Fig.3. Bi-facial module of solar plate

Fig.3 shows a bi-facial module based on this design. Because of the HPC film this module uses 50% less PV material than a traditional, fully populated module. The reduction in expensive silicon greatly lowers the module's material cost and also results in manufacturing savings through reduced assembly and processing requirements.

4. Design aspect and Layout of HPC Solar Modules for Power Generation

The following parameters are to be considered to design HPC solar module :

- PV Sizing
- PV to Hologram Ratio
- Technology of PV cell and their Conversion Efficiency
- Hologram Stacks Layout Design

The design of HPC solar module is based on harvesting of solar energy. The PV size depend on the load energy requirement of users to be considered. Hologram to PV ratio is the width of two holograms divided by the width of a PV cell. Two holograms are used in this calculation because the two holograms next to the PV cell both concentrate light onto the cell. The data from these modules not only shows the performance of the module but also allows us to predict the performance of modules with different layouts. The layout design of a solar module and practical HPC module has been shown in Fig.4.

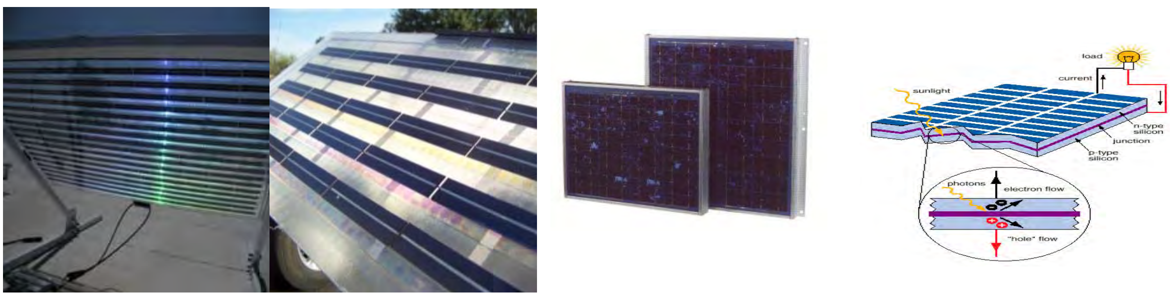

Fig..4.(a) HPC solar stack layout design (Left) (b) Standard solar module (Middle) (c) Solar Power Conversion (Right)

4.1 Design: HPC PV module Sizing

Based on energy balance equation, the empirical formula has been used to compute the optimal size of HPC PV module for demand based load energy requirement at user end as stated below. For energy balance condition [13].

PV stored energy (Wh) = Load Energy(Wh) *S.F (1)

i.**e** P_{PV} (Wp) * Sun hour * Area of equalization = P_{TL} (Wh) * S.F (2)

Where,

- P_{PV} (Wp) is the required peak power of PV power delivered at noon @STP
- Area equalization factor = 0.5 (approx)
- Sun hour = 6.2hr (total duration during day time in a day) for adopted area
- P_{TL} is total load energy in watt- hours (i.e Total load power over a period of 24 hours in a day assuming hourly load power (P_L) as constant.)

  i.e P_{TL} (Wh) = $\sum_{0h}^{24} (P_L)$ [Watt-Hours] (3)
- Safety Factor (S.F) = 1.5 for cloudy weather/low insulation (sun radiation)

From equation (2) and equation (3), considering the PV to Holographic ratio for optimum output :
The optimal number of HPC PV module = (PV to Holographic Ratio x P_{PV} (Wp) **/** Standard (75Wp or dual 2x36Wp) PV Module (4)

Where, PV to Holographic ratio can be considered as 0.5 or even less.

5. Performance Characteristics of HPC Concentrator: Case study

A) Conversion Efficiency **:** Prism Solar Technologies, Inc. USA has developed a unique proprietary holographic planar concentrator (HPC) [7] for use in photovoltaic (PV) module applications. The company manufactures a transparent holographic film that collects sunlight, selects the most useful portions of the spectrum, and focuses that light onto adjacent solar cells in a new type of proprietary PV module. Prism solar’s strategic advantage lies in the core, patented HPC technology by incorporating holographic film into a photovoltaic module - 50% of solar cells, the most expensive component of a PV module are replaced with inexpensive holographic film, which lowers the module cost per watt dramatically. The result of an HPC module produces 25% or even higher more energy (kWh) over a year’s time compared to a conventional module with an equivalent peak watt rating extrapolated over the life of a PV system. This additional kWh energy production represents a substantial increase in revenue.

B) Size **:** A prism solar system can be sized smaller and produce the same amount of energy e.g. a 200mW conventional solar plant will produce the same amount of energy in kWh as a 150mW prism solar plant. Increasing the energy yield offers numerous advantages on the system level by reducing the number of peak watts rating of solar cell needed to produce a given amount of energy in kWh. The more kWh generated per peak watt means an effective low cost-of-energy through reduced capital expenditure-including fewer interconnections and a smaller inverter size and a reduction in operation and maintenance costs for the system. Prism solar modules are also unique due to high performance in diffuse light or cloudy conditions.

C) Power Generation **:** Prism solar has a potential to generate one giga-watt with solar module using HPC film by manufacturers worldwide. Currently, most major PV module manufacturers remain in a “commodity” module market with little product differentiation. This provides a significant opportunity for prism solar to offer greater margins and unique benefits enabling to achieve the increased kilowatt harvesting made possible by prism’s technology (Fig. 5).

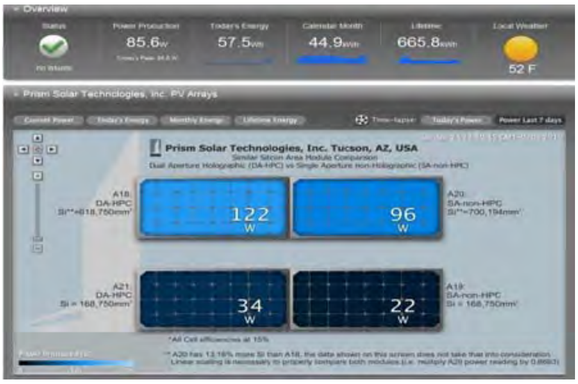

Fig.5. Power generation by HPC at different temperature

D) Field Tests : The study reveal that the holographic concentrator system were tested by manufacturer and one such test report can be seen as reported by W. Gowrishankar [8]. The field tests include comparison with other flat plate non-tracking PV systems at the same test yard.

E) Concentration Power : Holograms in concentrating photovoltaic (CPV) modules diffract light to increase irradiance on PV cells within each module. No tracking is needed for low concentration ratios, and the holographic elements are significantly less expensive than the PV cells. One such Holographic concentrators incorporated into PV modules were used to build a 1600W grid-tied PV system at the Tucson Electric Power solar test yard. Additional advantages include bi-facial acceptance of light, reduced operating temperature, and increased cell efficiency. These benefits are expected to result in higher energy yields (kWh) per unit cost (Figure 6).

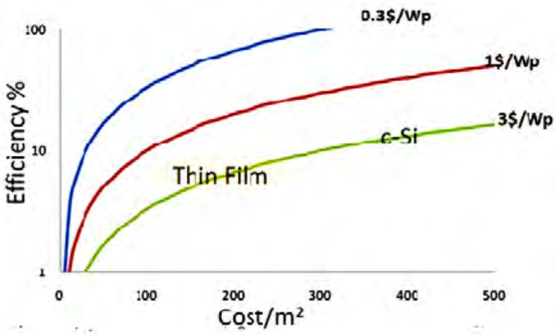

Fig.6. Cost reduction with increase in efficiency

In their ability to concentrate light, holograms are not as powerful as conventional concentrators. They can multiply the amount of light falling on the cells only by as much as a factor of 10, whereas lens-based systems can increase light by a factor of 100, and some even up to 1,000 [7].

F) Material Costs **:** The cost may be reduced and electrical properties improved by utilizing thinner solar cells. Light trapping makes it possible to reduce wafer thickness without compromising optical absorption in a silicon solar cell. In this work, we present a comprehensive comparison of the light-trapping properties of various bi-periodic structures with a square lattice. The geometries that we have investigated are cylinders, cones, inverted pyramids, dimples (half-spheres), and three more advanced structures, which we have called the roof mosaic, rose, and zigzag structure. Through simulations performed with a 20 μm thick Si cell, we have optimized the geometry of each structure for light trapping. Investigated the performance at an oblique angle of incidence, and computed efficiencies for the different diffraction orders for the optimized structures. We find that the lattice periods that give optimal light trapping are comparable for all structures, but that the light-trapping ability varies considerably between the structures. A far-field analysis reveals that the superior light-trapping structures exhibit a lower symmetry in their diffraction patterns. The best result is obtained for the zigzag structure with a simulated photo-generated current J_{ph} of 37.3 mA/cm^2, a light-trapping efficiency comparable to that of Lambertian light-trapping is noticed [9]. The main limitation of solar power right now is cost, because the crystalline silicon used to make most solar (PV) cells is very expensive. One approach to overcoming this cost factor is to concentrate light from the sun using mirrors or lenses, thereby reducing the total area of silicon needed to produce a given amount of electricity. But traditional light concentrators are bulky and unattractive - less than ideal for use on suburban rooftops.

G) Flexibility*:* Next, there's the installation cost; as you may notice that in a household PV system, quite a bit of hardware is needed. As of 2009, a residential solar panel setup averaged somewhere between $8 and $10 per watt to install. [Source: National Renewable Energy Laboratory]. It is imperative that larger the system, the less it typically costs per watt. It's also important to remember that many solar power systems don't completely cover the electricity load cent percent of the time. Chances are, you'll still have a power bill, although it'll certainly be lower than if there were no solar panels in place.

I) Temperature Compatibility: High temperatures can cause solar cells to operate at lower efficiency and produce less energy keeps the solar plate cooler and give benefits like :

- HPC Film allows wavelengths that cannot be converted by the PV cells to pass through the module rather than being absorbed as heat.
- With HPC Film, the cells operate closer to their ideal temperature.
- HPC modules operate approximately 10 degree C cooler and thus increases the efficiency.

J) Power **:** HPC can produce more power than the ordinary concentrators.

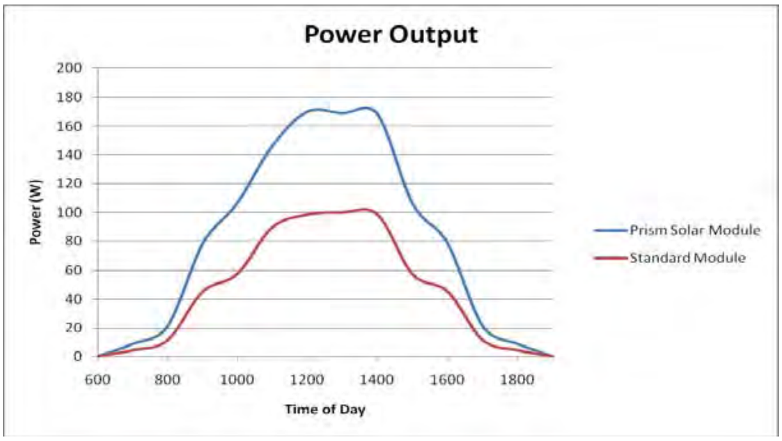

Fig. 7. Power generation with/without HPC

Figure 7 shows the power produced throughout the day Power output of a 100W standard module and the same module with HPC is measured. This data was taken on January 26th 2009. All data was taken when the sun was not blocked by clouds.

K) Energy : Greater amount of energy is also produced with the use of HPC. Figure 8 shows amount of energy produced during the day for this module as compared to a standard module. The peak power increase of typical module is 55%; however, the total power produced in one day is 60% greater due to the greater efficiency at low light levels.

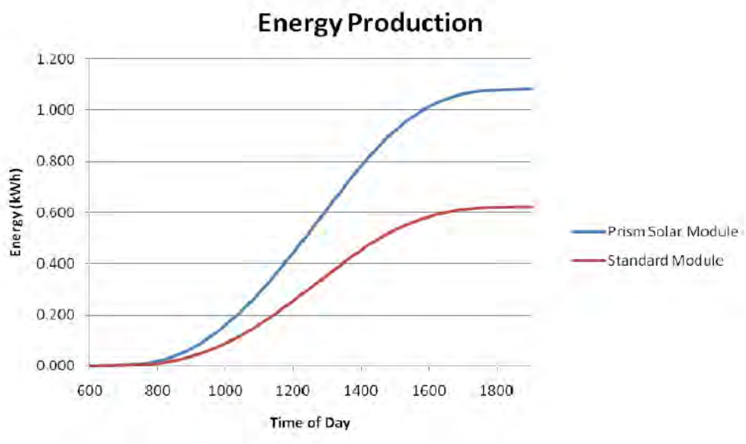

Fig. 8. Total Energy produced in a day

6. Discussion

Hopefully one day, technologies like the HPC solar module will help us to eliminate or reduce the need for fossil-fuels, and will also help us to create the greener environment. The future of holographic film implementation in solar panels for power generation in India is yet to be initiated. The Government has not paid due interest and attention towards this field. The implementation of this project in India largely depends on self-production of holographic films in our country on a large scale. This theory has become possible in China because they can produce these films on their own so that when these plates are implemented in solar cells, the cost increases negligibly. This theory has also been adopted in a few more countries like USA & UK. The method used in USA relies heavily on large-scale development of this technology so that the overall cost decreases, whereas in UK, these have been more or less implemented in conservatories. Despite the sticker price, there are several potential ways to defray the cost of a PV system for both residents and corporations willing to upgrade and go solar. These can come in the form of tax incentives, subsidies, utility company rebates and other financing opportunities. Plus, depending on how large the solar panel setup is and how well it performs it could help pay it off faster by creating the occasional surplus of power. Finally, it's also important to factor in home value estimates. Installing a PV system is expected to add thousands of dollars to the value in the cost of a home.

Right now, solar power still has some difficulty competing with the utilities, but costs are coming down as research improves the technology. Engineers are confident that PV will one day be cost-effective power supply unit both in urban areas as well as remote ones. Part of the problem is that manufacturing needs to be done on a large scale to reduce costs as much as possible. That kind of demand for PV, however, won't exist until prices fall to competitive levels. Even so, as demand and module efficiencies rise constantly, prices fall, and the world becomes increasingly aware of the environmental concerns associated with conventional power sources, its likely solar cell will have a promising future. It can be easily installed on rooftops as well as outside window glasses & door glasses. It is tremendously flexible & can be installed in conservatories too to avoid the greenhouse effect. So, it can be installed absolutely anywhere in the world.

7. Conclusion and Future Scope

The future for HPC solar module looks incredibly bright. The HPC solar panels can be used vertically as well as horizontally. This means that in the future, windows in buildings could be made from the solar panels. The advantages of this are really quite extraordinary. Just imagine a huge high rise building being designed to use the HPC solar module from the start. The building would be able to create its own power. The significance of this is that buildings create roughly 30% of the world’s greenhouse gases because of the amount of fossil-fuels they use to generate electricity.

In the proposed scheme, the use of HPC embedded solar module has been explained. To implement this holographic theory in India, a large-scale planned production or self-production is compulsory. That is, the future of this tremendous concept is not far away in India too. The application of such system has been discussed by authors as reported in their paper [10,11,12].

The test results as reflected by different authors show a promising aspect of such system. From the result, it has also been revealed that HPC increases solar cell efficiency by 40-50%. The green electricity generated by the proposed system as discussed reduces the level of hazardous gases such as SO_2, CO2 emitted from fossil fuel in convention system and thus keep the environment clean.

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