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A review of holographic optical elements in solar concentrator applications

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ABSTRACT

Photo voltaic cells are used to convert sunlight into electricity; the commercial photo voltaic cells made up of silicon but the main drawback of the solar cells is low conversion efficiency. In order to improve conversion efficiency generally mirrors and lens system is used as conventional solar concentrators, in the fact they have some drawback of bulky in nature, high installation cost, need a tracking system to face the sun, and also concentrating both light and heat on the solar cell. To overcome these problems holographic solar concentrators were used as solar concentrators. Holography is one of the very promising technologies to produce solar concentrators; mostly volume phase holograms are used as holographic solar concentrators. The holographic solar concentrators have some major advantages of light weight, cool light concentration, and selective wavelength concentrations for wavelength dependable solar cells. In this paper, a brief review and basic study of holographic solar concentrators have been discussed. The key contributions of each work examined here and different technologies also discussed. This review is useful to study basic foundations and create new ideas for future research work.

Keywords: *Holographic lens, Holographic grating, Volume phase holograms, Solar concentrator, Holographic optical elements, Solar energy, Wavelength multiplexing, Diffraction efficiency, Solar cells.*

1. INTRODUCTION

Holography was invented in 1948 by Hungarian physicist Dennis Gabor (1900–1979), work for which he received the Nobel Prize in Physics in 1971 [1]. In 1962 Emmett Leith and Juris Upatnieks of the University of Michigan recognized their work in side-reading radar that holography could be used as a 3-D visual medium [2]. Yuri N. Denisyuk combined holography with 1908 Nobel Laureate Gabriel Lippmann's work in natural color photography. Denisyuk's approach produced a white-light reflection hologram which, for the first time, could be viewed in light from an ordinary incandescent light bulb [3]. The hologram is a record of the interference pattern created when two coherent beams of laser light interfere on the holographic surface [4]. It has many applications in all branches of science, engineering, technology, bio-engineering, bio-medicine, art and advertising, high-resolution imaging, information storage and security coding, and Holographic Optical Elements (HOE).

A huge issue is the fact that fossil fuels are limited resources, we need to look at alternative sources of energy. Solar Energy (SE) is abundant in nature, clean, non- a pollutant, cost-free, and renewable. There are two types of concentrators were involved in conversion technology like Conventional Solar Concentrators (CSC) and Holographic Solar Concentrators (HSC). Many researchers till now investigated and creating new ideas to produce holographic concentrators. Mostly volume phase holograms like mirrors, lenses, gratings are used as holographic solar concentrators. Because the volume phase holograms can able to achieve nearly 100% efficiency for certain wavelength and direction. Holograms have mainly three characteristics, Angular Selectivity, Diffraction, and Dispersion; these all strongly depend on the recording geometrics and the holographic recording materials. In this way, the major role of fabrication for holographic solar concentrators is depending upon the recording material selection [5]. There are several kinds of materials using in holography like silver halide, photopolymer, photo resist, dichromate gelatin, chalcogenide, etc, But photopolymer, silver halide, and dichromate gelatins were suitable for holographic solar concentrator fabrication. In this paper, we review recent attempts to more fully understand what is needed to optimize the performance of holographic optical elements for holographic solar concentrator applications. The paper is structured as follows, In Section 2; we discuss the HSC recording processes. In Section 3, a description of important holographic recording materials is presented. In Section 4, we begin by briefly reviewed a journey of holographic solar concentrators. A brief conclusion is given in Section 5.

2. HSC RECORDING PROCESS

The recording of the hologram is based on the phenomenon of interference; it requires a laser source. The LASER was invented to produce coherent light. Incoherent light travels in different frequencies and in different phases. Coherent light travels in the same frequency and in the same phase. A LASER is used as the light source to record holographic solar concentrators. There was needful of the electronic shutter, a beam splitter, aluminum coated mirror, spatial filter an object and a photographic plate. To make a hologram by reflecting or scattering a laser beam off the object we want to capture. In fact, split the laser beam into two separate halves by shining it through a beam splitter. One half of the beam bounces off a mirror, hits the object, and reflects onto the photographic plate inside which the hologram will be created. This is called the object beam. The other half of the beam bounces off another mirror and hits the same photographic plate. This is called the reference beam. A hologram forms where the two beams meet up in the plate. The superposition of these two beams produces an interference pattern (in the form of dark and bright fringes) and this pattern is recorded on the photographic plate. The photographic plate with recorded interference pattern is called hologram.

3. IMPORTANT RECORDING MATERIALS

There are several kinds of recording materials using in holographic solar concentrator fabrication but especially Silver Halide, Dichromate Gelatin, and Photopolymer are the materials using by most of the authors because of its major advantages.

3.1 Silver halide photographic emulsion

The silver halide photographic emulsion is one of the oldest and most widely used recording materials for holography [6]. It consists of a gelatin layer in which microscopic grains of silver halide (usually silver bromide) are dispersed. This layer is usually coated onto glass or film substrate, with an emulsion thickness in the range of 5 to 15 µm. The material works by recording a latent image which is then developed by chemical post-processing. An advantage of the formation of a latent image is that the optical properties of the recording material do not change during exposure, unlike materials in which the image is formed in real-time. This makes it possible to record several holograms in the same photographic emulsion without any interaction between them. Because of the high sensitivity (10-5 to 10-3 mJ /cm2) and good resolution (greater than 6000 lines/mm). Agfa-Gevaert and Eastman Kodak plates are the commonly used commercial silver halide photographic materials for holography in the 1980s [7].

3.2 Dichromate Gelatin (DCG)

DCG was first applied to holography in the late 1960s. DCG consists of a gelatin layer that contains ammonium dichromate which becomes progressively harder on exposure to light. This hardening is due to the photo chemically produced Cr3+ ion forming localized cross-links between the carboxylate groups of neighboring gelatin chains [6]. Compared to silver halide photographic emulsions, DCG has low energy sensitivity, but, it has higher efficiency and quite high resolution. Large refractive index modulation capability, high diffraction efficiency, high resolution, low noise and high optical quality make DCG an almost ideal recording material for volume phase holograms [8]. However, it is very sensitive to environmental changes and needs chemical post-processing. It has to be prepared in the laboratory before use as it has a useful life of only a few hours [9, 10].

3.3 Photopolymers

Photopolymers are systems of organic molecules that rely on photo initiated polymerization to record volume phase holograms. Characteristics such as good light sensitivity, real-time image development, large dynamic range, good image stability and relatively low cost make photopolymers one of the most promising materials for holographic applications. Photopolymer systems for recording holograms usually comprise of one or more monomers, a photo imitation system and an inactive component called binder [11]. Other components are sometimes added to control a variety of properties such as pre-exposure shelf life and viscosity of the recording medium.

4. JOURNY OF HOLOGRAPHIC SOLAR CONCENTRATORS

At 1982, Jacques E. Ludman introduced holographic concentrators [12]. He reported about dielectric volume holograms with transmission type in dichromate gelatin layer. Says it is easy to complete the design of a three-level holographic system that effectively concentrates the visible spectrum over a 100o daily angular variation and for an annual 45o variation. The fig 1 shows three-level hologram region 3 works in the morning, region 1 works at noon and region 2 in the afternoon. Depending upon the application, a large area concentrator can focus all the energy in one length of absorber, or several concentrators may be focused onto several separate lengths of absorber. Such a holographic system should have the advantage of concentrate with no moving parts and minimal space requirements. Finally, there are several observations that can be made about this system. First, it does not violate the brightness theorem. In the case shown here the focused points are displaced along a line but not superimposed. The 4:1 concentration is quite adequate for an effective solar system, and the collection of 100o of the sun's daily angular variation is ample.

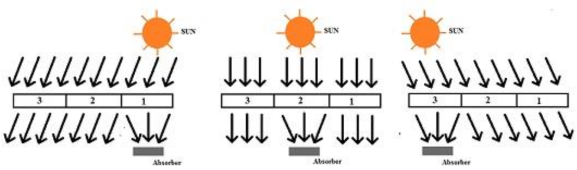

Fig-1

In 1985, Wilbert Windeln and Cristo G. Stojanoff proposed a paper about development of high efficiency holographic solar concentrators [13]. Using Dichromate Gelatin (DCG) as a recording material and got output efficiency up to 97%. Output efficiency of holograms highly depending on the film thickness, refractive index variation, thickness of the layer and reconstruction angle. The maximum efficiency obtained only if the angle of illuminating wave during reconstruction coincidence with the Braggs angle. Basic research on holographic optical elements reported was used to manufacture and test under desert conditions. Several small aperture solar concentrators the solar radiation is collected via several apertures and focused onto the absorber. Each aperture of the holographic concentrator fulfills the Bragg conditions for a given solar position. For thick holograms a Bragg angle of 5o is a good choice. The diffraction efficiency of two lens systems generated in a single gelatin layer via double exposure and correspondingly matched Bragg conditions. The two lenses become effective at different reconstruction angles as the sun position changes. Hence, the requirements of the Brightness theorem are fulfilled. Then after eight lenses were generated in two gelatin layers and pasted together with epoxy cement. The same adhesive was used to encapsulate the films between the two glass substrates. This method was tested for one year under desert condition and proved to be very effective.

1987, J. Hull investigated the reflection hologram in a line focus system same as DCG layer with stacked holograms [14]. Two main problems discussed here, First one of the measurement of output efficiency for specific wavelength, it gives 90% but the optical efficiency over the spectrum is 25 % only. Then he made a solution like creating number of holograms with stacked system, each one can effective with limited spectral range and to combine them to cover the entire solar spectrum it will be gives up to 51% of optical efficiency and the individual hologram efficiency is 69%. The second problem of cost for mass produced line focus holographic solar concentrators has been analyzed and compared to conventional line focus concentrators. Consequently, the cost of mass produced line focus holographic solar concentrators is expected to be around 75% of the cost of conventional line-focus solar concentrators. Increasing the performance of line focus holographic solar concentrators from the current 50% efficiency range to better than 70% would make them cost-effective. This may be achieved with a five hologram stacked position. A similar cost analysis for point focus concentrators gives an indication that an optical efficiency of 63% is required to make point focus holographic solar concentrators cost effective.

J. A. Quintana demonstrates transmission and reflection type of holoconcentrators and its broad band behavior at 1989 [15]. Transmission holographic off-axis lenses were made on Silver Halide Gelatin (SHG) 8E75HD plates using the 633nm radiation from He-Ne laser. Almost 80% of efficiency was obtained. But the major disadvantage of SHG regarding Dichromate Gelatin (DCG) is the limitation in their response for high spatial frequencies maximum efficiency is only obtained in the range between 600 and 1200 lines /mm. At higher frequencies, the efficiency is limited because of the granular distribution of silver halide crystals in the emulsion and the eventual diffusion of trivalent chromium ions towards the unexposed regions. Reflection type of holograms made up with DCG layer, the spectral response depends on the spacing of the interference surfaces. And the operating wavelength of a Dichromate Gelatin reflection hologram is slightly higher than the recording wavelength because DCG films swell while processing and some of this swelling remain after drying. Reflection holograms behave as narrow band reflection filters. However, their bandwidth (typically 20nm) is about two or three times the value calculated from the Couple Wave Theory. Note that this method, which leads to red and green spectrally responsive broad -band holograms (typically 100nm) increases the operating wavelength and must be used with special care at shorter wavelengths because the scattering due to precipitations reduces efficiency. They obtained violet spectrally responsive holo concentrators of about 30nm. The bandwidth, 80nm, is the widest they could obtain without increasing the scattering. The size of the holo concentrator was 10x10cm.

Again 1994, Jacques Ludman et al. demonstrate important three points of holographic concentrators [16]. Heat sinking, Spectral splitting and Cost analysis, a prototype holographic solar concentrator system was used to find the constant efficiency over a period of 15 minutes without a heat sink, whereas the efficiency of a Fresnel system, using the same aperture and cell, dropped a factor of two within 30 seconds when used without a heat sink. Then the spectral splitting is well known that flat Si solar panels operate about 10% efficiency. If solar energy with a concentrating system will increase this efficiency up to 20%. A holographic device that greatly improves the efficiency of solar energy conversion by both concentrating and spectral splitting. This technology uses a single element hologram to spectrally separate light and focuses it perpendicular to the hologram in a thin, concentrated line. Two or more different solar cells are placed along this line such that each cell absorbs only those wavelengths of the spectrum shows in fig 2. A major advantage of this technology is reduced cooling requirements; spectral separation prevents overheating by diffracting unwanted infrared radiation away from the cells. The third point of cost analysis for a renewable energy source is in the 10 to 351 per kWh range, depending on such variables as location, demand, availability, and region. This technology reduces the cost to around 5.715 per kWh has been clearly explained in this paper.

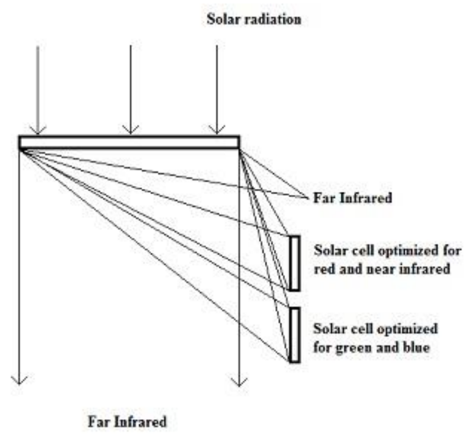

Fig-2

2006 Colin Dalton explained multiple gratings in photopolymer for holographic solar concentrators [17]. There were achieved three transmission gratings at different spatial frequencies. Spatial response of two gratings recorded at a low spatial frequency of 400lines/mm at 14o incoming angle. And the high spatial frequency of 2000lines/mm at 54o of incoming angle was studied. The low frequency was able to concentrate a large part of the visible spectrum. High frequency has used a rotation of the element was necessary in order to observe the different light at different wavelength. Finally saying the physical thickness of the photopolymer led to higher angular and spectral selectivity of the optical element.

Ren Xuechang et al. fabricated the holographic Fresnel lens in 2007 [18]. Three Holographic Fresnel Lenses with the different fringe pattern were achieved and using by cascade method. They operate in the morning, at noon and in the afternoon, respectively shown in fig 3. Primary experimental results, which effectively concentrates the visible spectrum over a 60o daily angular variation. For fabrication MELLES GRIOT laser (458nm), with 45mW output power and the holographic recording material used was CHP-C positive Photo resist. Then fabricated another two HFLs with the same focus length, but the parallel beam has the incidence of 60o angle to the holographic plate respectively, rather than vertically. Finally, in the conclusion, they will accept the three-layer structure results in great loss of light energy by glass absorption. To avoid this have to record several holograms in one photographic layer.

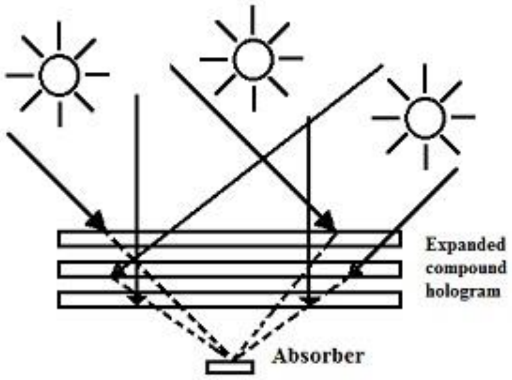

Fig-3

Raymond et al. in 2009 present the details of the Holographic Low Concentration Ratio Solar Concentrators [19]. Here they experimentally verified a model for holographic low concentration ratio concentrators for solar energy applications. One of the main problems confronting photovoltaic energy systems is cost. However, this approach is possible that uses low concentration (2-10X) optical collectors in combination with moderately priced PV devices. Holographic optical elements have long been considered for use as solar concentrators. In this paper, they illustrate methodology and apply it to holographic planar concentrator geometry. The holographic collector must efficiently diffract solar illumination to the surface of the PV device. The basic analysis is performed in a two-step process with the first step consisting of a ray trace through the optical system and the second step a diffraction efficiency calculation. Problem is complicated by the fact that solar collection requires the analysis with a source that changes position in two angulars. As a result of reconstruction geometry, the diffraction efficiency must be computed for both in-plane and cross-plane reconstruction conditions with a spectrum derived from the product of the solar illumination and PV material response characteristic. In order to compute the energy collection properties of holographic collectors, it is necessary to evaluate specific collection geometry. In this paper, a holographic planar concentrator is considered. In this method, expensive PV material (DPVC) is replaced with a low-cost holographic material (DH). The light illuminating the holographic collectors are directed to the PV device with a resulting concentration ratio of $C = (2DH + DPVC)/DPVC$ for the element. The in-plane solar power collected by the HPC module relative to a module with the same area covered completely with PV cells. In the presentation different holographic collector geometries with and without tracking will be evaluated.

The year of 2012 S.N.Singh et al. discussing holographic film as a static solar tracker for a PV module [20]. The technical viability of using holographic film over the solar plate and its benefits over motor driven conventional tracking system has been investigated. The lower cost of the energy produced, coupled with the fact that the HPC solar 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 technology. The HPC panels can be used vertically as well as horizontally. If this will happens, 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 fuels they use to generate electricity. The prototype design modules are tested in two different layouts. In the first test, the module was kept normal to the sun where as in the second test, the module is to be mounted in a standard configuration for a fixed solar module on a flat roof facing north-south at an angle 45o. The type of PV cell is equally important from an efficiency point of view. The bandwidth is the range of wavelengths that are concentrated onto the cell by the hologram. The diffraction efficiency is the average efficiency over the bandwidth. Then it will be taken to the performance analysis of plant size, power generation, and performance test, the concentration of power, cost-effectiveness, flexibility, temperature compatibility, and power and energy tastings. From the result of this paper, it has also been revealed that HPC increases solar cell efficiency by 40-50%, reduces the size by 50%. The green electricity generated by the proposed system can be used in the remote areas where grid availability is either very poor or not available. As discussed in this study, the implementation of the system will reduce the level of hazarder's gases i.e. CO_2, SO_2 etc, emitted from fossil fuel in the conventional system and thus keep the environment clean and green. The intelligent system will reduce the electricity bill of home and create employment opportunity for potential youth, especially in villages. The literacy rate is expected to increase by a factor of 40% - 50% and the economic status of villagers in India will certainly increase.

Izabela Naydenova et al. investigated Photopolymer Holographic Optical Elements for Application in Solar Energy Concentrators at 2013 [21]. First, they prepare their own photopolymer themselves by varying the thickness of the layer. And then record the focusing HOE as well as recording the multiplexed gratings. To obtain high efficiency they can change the intensity of the beam and then vary exposure energy. Finally, this experiment can be demonstrated that high diffraction efficiency HOE consisting of a single spherical lens can be recorded in a relatively thin photopolymer layer of 50 µm thickness. The advantage of using thin layers and lower spatial frequency of recording in this application is the larger acceptance angle of the optical component. It was possible to equalize the diffraction efficiencies of three multiplexed gratings at 51.9 ± 3.5 %. A study of the influence of the exposure schedule keeping the intensity constant and changing the time or keeping the exposure time constant and varying the intensity revealed that the first schedule delivered better equalization of the diffraction efficiency. Three HOEs - containing five gratings with a range of spatial frequencies from 450 to 1700 l/mm, five cylindrical lenses and four cylindrical lenses, were successfully recorded in the same photopolymer layer.

Hoda Akbari et al. In 2014 fabricated holographic optical elements using acrylamide based photopolymers [22]. The three gratings are combined to make a device that has a working range of 24o (-3o to + 21o) showed in fig 4. If the light is incident along or near the normal (0o angular deviation will pass through the three gratings A, B, C and be focused by the focusing element D. This element will efficiently focus light over a 6o range or 3o either side of normal incidence. For light that is incident at angles between 3o and 9o deviation from normal, the light will be transmitted by A and B but will be on-Bragg for grating C, which will then bend the light though 6o ensuring its correct alignment for focusing by D. For light incident with a deviation of 9o-15o from normal, the direction is corrected by B and then by C before being focused by D. Similarly for light incident at 15o-21o all three gratings will correct the path of the incident light in sequence before it is focused by D. Gratings A,B and C are all identical in terms of grating spatial frequency and efficiency but the grating slant angle increases moving towards the top of the stack. The challenge here is to increase the angular and wavelength range of the gratings so that a reasonable number may be multiplexed and/or combined to provide a device that can concentrate light incident from a large range of angles. Ultimately, a combination of gratings will be used so that a broad range of angles of incidence are accepted. This paper reports results on the efficiency of holograms recorded in an acrylamide-based photopolymer at low spatial frequencies (100, 200 and 300 l/mm). A diffraction efficiency of over 80% was achieved at a spatial frequency of 200 l/mm. The optimum intensity of recording at this spatial frequency was found to be 1 mW/cm2. Modeling confirmed that lower spatial frequencies are more suitable for capturing light over a wide range of angles. At the thicknesses most commonly used in acrylamide based photopolymers, spatial frequencies as low as a few hundred lines per millimeter are necessary in order to keep the number of multiplexed or stacked gratings used in a solar collector low. Experimental work to optimize the holographic recording characteristics of the photopolymer material at these low spatial frequencies was presented. It showed that low intensity of recording produces higher efficiency gratings and focusing elements. Maximum diffraction efficiencies observed in photopolymer layers of 50 µm and 75 µm thickness at these spatial frequencies. The advantage of using thinner layers and lower spatial frequency of recording in this application is the larger angular and wavelength range of the optical component.

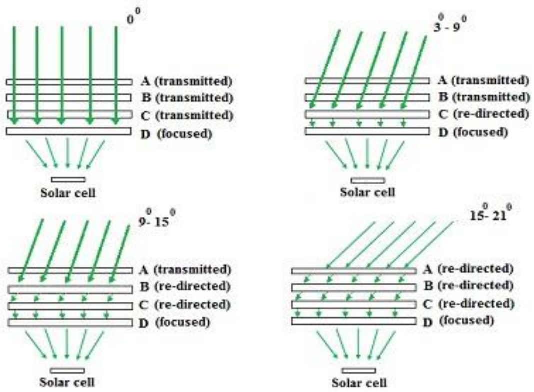

Fig-4

Jeong-Hyeon Lee et al. In 2014 optimized a detail about Holographic Optical Element for Solar Concentrators using Photopolymer [23]. In this paper, the holographic optical element for solar concentrators using photopolymer was proposed. For this, they fabricated the holographic solar condensing lens which has maximum efficiency. To add sun-tracking function, we performed the angular multiplexing. Effective concentrate rate (ECR) is conception from Han’s paper has been taken here [24]. First, they record transmission holograms and lenses. As a record object convex lens was used and 532nm green laser as the recording source. The multiplexed concentrator has been recorded at secondary; for they use three mirrors for the record the different three angles. The difference of angle is 10o of each for actualizing the sun altitude from 10 am to 2 pm. The middle angle would be the altitude of noon which is based on perpendicular of photopolymer. Through experiment of property records of the lens, condition of maximum efficiency was founded. The conditions of the experiment are a change of laser power, exposure time, beam ratio and recording angle. As a result, 95 mW of laser power, 1 second of exposure time, 0.66 of beam ratio, and 35o of recording angle generated high efficiency. At the angular multiplexing, the sun altitude was considered for design the angles of incident. Based on a perpendicular of photopolymer, each 10o was recorded side to side for actualizing the sun altitude from 10 is to 2 pm. The results are non-uniform and low. Therefore, another recording method was needed for the better efficiency. The record efficiency was equalized after changing exposure. However, efficiency was extremely low. Accordingly, another recording method was needed to be considered. Finally, they come to the iterative recording method. The iterative record method repeatedly records the image information by short times. The exposure time was 0.125s and repetition number was from 2 to 6. Through, this method they found the equalized and enhanced recording efficiency.

At the beginning of 2015 V. Vadivelan et al. Have been fabricated and explained about the Recording of Holographic Solar Concentrators [25]. Using ultra-fine grain visible wavelength spectral sensitive silver halide holographic emulsion as a recording material. The first time of three different laser sources of 442nm, 532nm and 633nm was used for multiplex holographic transmission lens in the same emulsion. Exposure sensitivity is optimized by trial and error method for all three laser sources separately as well as combined. The recorded interference patterns under a safe light condition with optimized laser exposures are processed by developer and bleach combination. The high diffraction efficiency of over 50% was recorded and also high visible transmission was achieved by using Ultimate developer and modified re-halogenating bleach combination. Modifying R10 bleach from the standard bleach by only chemical concentration used Potassium Dichromate (1g), Potassium Bromide (35g) and Sulphuric Acid (1ml). The main advantage of the holographic solar concentrator is spectrum splitting and concentration, but here they split the spectrum of specific wavelengths on visible wavelength dependable solar cells. Fig 5 shows the recorded holographic solar concentrator by three different wavelengths.

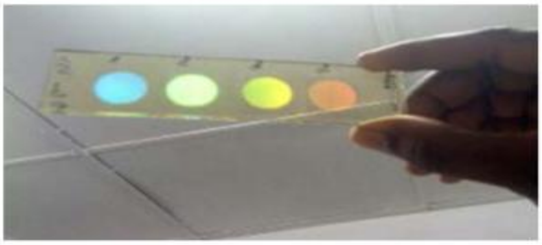

Fig-5

Paula Benares-Palacios et al. establish the Broadband behavior of transmission volume holographic optical elements for solar concentration at 2015 [26]. The ray tracing algorithm has been developed in order to analyze the energy performance of volume and transmission holographic lenses as solar concentrators. The algorithm is a powerful simulation tool that allows analyzing different designs of holographic concentrators, conducting a local analysis of angular and chromatic selectivity in different points of the lens, and performing a global analysis, by means of spots diagrams and energy integration onto the cell, taking into account the whole aperture of the lens. The comparison demonstrated very good agreement for both, chromatic and angular selectivity. Two lens configurations with on-axis (lens 1) and off-axis (lens 2) cylindrical wave reconstructions were analyzed. Lens 2 has a better performance when the incident light goes out of the Bragg condition, as it can be seen this lens presents a higher chromatic dispersion. An integration process of ray energy along the cell is conducted in order to obtain the optical concentration ratio when the incident beam fulfills the Bragg condition for 800 nm. Lens 1 shows an average concentration ratio 1.94, which is 16.1% higher than in lens 2. A comparison of total concentration ratio when incident beam varies along the day will be necessary to determine the best configuration.

Abhijit Ghosh et al. 2015 investigated the Wavelength selective holographic concentrator: application to solar cells [27]. In this paper dependence of wavelength selectivity of holographic solar concentrators on the depth of refractive index, modulation have been reported. Typically recorded two holographic concentrators on silver halide plate of different depth of refractive index modulations (n1= 0.018 & 0.024) at available wavelength sources (λ = 0.488 μm, 0.514μm, 0.532μm & 0.6328 μm) and are found to be in good agreement. In addition intensity distribution of different regions of the spectrum (colors) is also measured and the voltage generated due to an incident of different colors of the spectrum on the solar cell is being reported. For present work, holocons have been recorded on high-resolution silver halide plate PFG-01 (film thickness d = 7 μm and average refractive index n = 1.61) using a He-Ne Laser of power 2 mW. The exposed film was processed using standard procedure [29, 30]. In order to study the feasibility of spectral characteristics and performance analysis of chromatic characteristics of holocons, two typical holocons were recorded with different depth of refractive index modulations (n1= 0.018 & 0.024). For spectral responses, they were illuminated with available wavelength sources (λ = 0.488 μm, 0.514μm, 0.532μm & 0.6328 μm) at the optimum Bragg position for maximum efficiency operation and for chromatic dispersion they were played back by a white light coming from a LED source. By properly optimizing depth of refractive index modulation of holocons, their spectral characteristics can be controlled in the desired wavelength range and chromatic characteristics over the desired intensity ratio. From the characterization result of holocons it is concluded that low depth of refractive index modulation of holocons exhibits maximum efficiency in lower wavelength (ultraviolet) region whereas its high depth of refractive index modulation exhibits maximum efficiency in higher wavelength region (near infrared) at a particular film thickness and at the same time the intermediate depth of refractive index modulation is quite suitable for visible range of the spectrum.

G. Bianco et al. at the end of 2015 they describe Photopolymer based Volume Holographic Optical Elements (V-HOEs) and its design with possible applications [28]. In this paper, they describe the recording process to obtain V- HOEs presented. In particular, two different types of optical elements were carried out and characterized: Volume Holographic Grating (VHG) and Volume Holographic Lens (VHL). Finally, a multiplexed volume holographic lenses configuration is proposed to implement a passive solar tracking. As optical elements, they have recorded both VHG and VHL. The diffraction efficiency η was of about 94% and it has been calculated as:

$$\eta = P1/ (Pinc - Prefl)$$

Where P1 is the power of the 1st diffraction order, Pinc and Prefl are the incidents and the reflected respectively. An Atomic Force Microscopy (AFM) characterization on the VHG surface, at the result the holographic grating is considered to be a surface hologram when $Q \leq 1$, a volume hologram when $Q \geq 10$. In this case, obtained $Q \approx 17$, therefore the hologram is a VHG and the surface grating. With the aim to implement a passive solar tracking, a set of three lenses (0o, ±30o) has been recorded on the same glass to focus the light on the same PV cell positioned close to the focus of the lenses system shown in fig 6. Holographic lenses at ±30o were recorded by tilting of ±30o the photosensitive substrate. A preliminary result shows a degree of concentration for the proposed system on an average of 5.85suns over the angular range of ±30o. And a degree of concentration of about 5.5suns was obtained for an angular incidence inside the lens angular selectivity range (±8o), therefore the multiplexing systems enhance the angular acceptance.

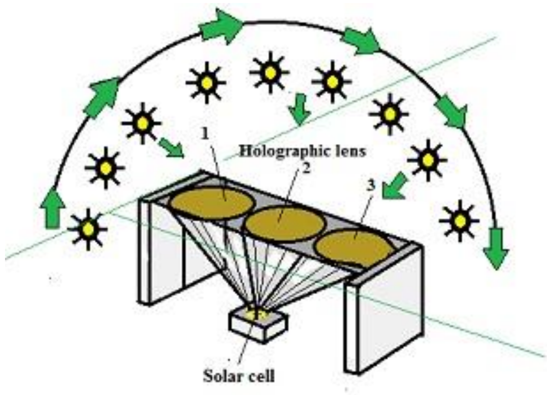

Fig-6

At the year of 2016, Nam Kim et al. proposed a method of Holographic Solar Energy Concentrator using Angular Multiplexed and Iterative Recording [29]. Here they suggested a new efficiency calculation method of concentrated diffraction efficiency (CDE) for the holographic solar concentrator. The exposure-response of a monochromatic hologram recorded in photopolymer film is presented. The iterative exposure schedules at three different angles are chosen to optimize the uniformity of the CDE using the angular multiplexed technique. The experimental results confirm that the angular multiplexing method and newly proposed iterative recording scheduling are appropriate for fabricating the holographic solar concentrator. Effective concentration rate (ECR) is a metric measure that is already proposed for measuring the concentration rate of the solar concentrator [30]. This concept is usually applied in solar concentrators in case of Fresnel lenses.

$$ECR = \eta\, opt \times Rc \qquad (1)$$

Were opt is the optical efficiency which is the ratio of condensed light intensity to incident light intensity, and c R is the geometric concentration rate which is the ratio of the area of incident beam and condensed beam. Therefore, we newly suggest the concentrated diffraction efficiency (CDE) calculation method that uses an ECR. The CDE, nc , is defined by ECRh of HOE and ECRl of the convex lens as follows:

$$\eta\, c = ECRh / ECRl \times 100\ (\%) \qquad (2)$$

Equation (2) shows the actual performance of the recorded HOE as a solar concentrator. Here, it can be seen that the CDE is more effective than ECR to demonstrate the concentration efficiency of solar energy. In order to fabricate a holographic solar concentrator, an angular multiplexed HOE is produced using a photopolymer. A convex lens is considered as a recording object to condense the lights. The new efficiency calculation method, CDE, could express similar performance for the actual optical element as a solar concentrator. Through the characteristic analysis of the photopolymer, the optimized recording conditions for the HOE lens are carried out. Also, the most suitable recording method for an angular multiplexed HOE solar concentrator is showed. Using the iterative recording method, the low efficiency of multiplexed holograms is compensated. Furthermore, they suggest a new recording schedule calculation with a modified iterative recording method. As a result, the fabricated holographic solar concentrator that uses the proposed method from this paper has ideal results. The performance of the fabricated holographic solar concentrator has CDEs of 26.73%, 35.31%, and 22.78%, respectively, from incidence angles. The fabricated HOE has a more appropriate concentration rate and CDE than the previous method. Therefore, we can conclude that the fabricated HOE that uses the modified iterative recording method is suitable for applications of angular multiplexed solar concentrators.

In 2017 Hoda Akbari et al. fabricate the off-axis focusing lenses in photopolymer material for concentrating elements [31]. Recorded both cylindrical and spherical lenses with combining of 532nm Nd: YVo4 laser and 633nm He-Ne sources, experimental setup shown in fig 7. The focusing elements with the low spatial frequency of 300 ± 30 line pairs/ mm can be achieved for broad working range, inter-beam angle was set at 9.14o for low spatial frequency. The result shows 95% diffraction efficiency laser illumination and 85% diffraction efficiency with unpolarised source were observed. The relative increase of output current of c-Si solar cells for cylindrical DOEs to be 16%, 32%, and 40% respectively for a cell with an area of around 60 mm2. Results of DOEs design focus on the same position in the place there is just over 100% increase in the short circuit current. Further, they have needed to work for increasing the number of DOEs in an array.

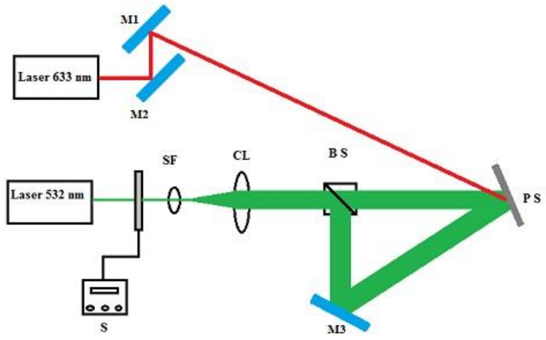

Fig-7

Finally 2018 G. Aswathy, et al. describe the nickel ion doped photopolymer material for holographic lens [32]. They achieved more than 85% diffraction efficiency were recorded in nickel ion doped photopolymer material in the blue, red and green regions at the low spatial frequency. Angular selectivity and wavelength selectivity of the material in low spatial frequency optical elements were more suitable for solar applications. At a low spatial frequency of good angular working range and they could achieve good diffraction efficiency over the entire visible region. Photocurrent measurements result solar cell with the holographic lens using white light source increased the current density by 27%. The I-V measurements of the solar cell, combined with a holographic lens, were proved for checking the suitability of using the holographic lens as solar concentrators.

5. CONCLUSION

An overview of reported work on the holographic solar concentrator is presented, important key factors and several types of holographic solar concentrators are discussed. The recording angle and reconstruction angle are very important for high-efficiency enhancement concentrators. The thickness of the material, refractive index has been discussed for broad angular acceptance. Angular selectivity of volume hologram having much higher efficiency when the incident angles same as recording angle and dropping the efficiency when the angle of incident varies. Angular selectivity, Dispersion, and Diffraction of holograms are strongly depending upon the recording geometrics and the recording materials. In particular the dichromate gelatin, photopolymer and silver halides are used in holographic solar concentrator applications. The dichromate gelatins excellent holographic properties including low scattering and high refractive index modulation can be used for creating any type of holographic optical elements. The photopolymers have undesirable features like excellent optical quality lead to a bright image, the material has maximum diffraction efficiency, and also this material sensitive to react at low exposure energy, self-processing without any post-exposure treatment or wet chemical process, long-term stability of the recorded image. The silver halides having high resolving power, cleared image quality, this material should be sensitive to react to low exposure energies and easily availability. The volume phase holograms recorded by using these materials can achieve 100% diffraction efficiency. Reflection and transmission type of holograms likely mirrors, lenses, gratings, multiplexed, array models are mostly used for solar concentration application. They can track the sun’s angle day by day and yearly variations, like self-tracking mechanism. Solar cells must be identified that band gap energy and need to coincidence with the exact matching holographic solar concentrator should give us maximum output efficiency. Over all the review shows that holography is the best way to convert the solar energy into electric energy. Because of Low cost for mass production, low installation, and high efficiency with self-tracking, high self life and low maintenance are the main advantages.

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