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Holographic solar energy systems: The role of optical elements

M. Victoria Collados [a], Daniel Chemisana [b,*], Jesús Atencia [a]

[a] Universidad de Zaragoza, Applied Physics Department, Instituto de Investigación en Ingeniería de Aragón (I3A), Facultad de Ciencias, Pedro Cerbuna 12, 50009 Zaragoza, Spain
[b] Universidad de Lleida, Applied Physics Section of the Environmental Sciences Department, Escuela Politécnica Superior, Jaume II 69, 25001 Lleida, Spain

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ABSTRACT

The use of holographic optical elements for solar energy applications has increased interest in the recent years because of their potential to reduce production cost, their ability to select certain bandwidths of the solar spectrum and their suitability for architectural integration. Among the different typologies of holograms, volume holograms are the most widely utilised devices due to their high efficiency (up to 100%) and also because they have two important characteristics: angular selectivity and chromatic selectivity, which are crucial for the design of systems addressed for lighting, solar shading or solar concentrators. In the present article, an analysis of the main existing holographic solar energy systems is presented, with emphasis on the characteristics of the optical element.

Contents

1. Introduction

The holographic optical elements (HOEs) for solar energy applications can be used in combination with Photovoltaic (PV) cells or solar thermal absorbers, in order to generate electricity or heat respectively. On the other hand, HOEs can be used in applications related to the aesthetics of the building or in applications about temperature or lighting control.

Among the different types of holograms, thin holograms, both amplitude and phase, are not suitable for applications with white light (sun) because the issue of very low efficiency arises, with maximum values (after bleaching process) of 33%. Despite the fact of presenting greater chromatic and angular selectivity than thin

* Corresponding author. Tel.: +34 973003711; fax: +34 973003575.
E-mail address: daniel.chemisana@macs.udl.cat (D. Chemisana).

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holograms, almost all the elements used in holographic solar energy applications are volume and phase holograms. With this type of holograms, efficiencies up to 100% can be reached for certain wavelengths and directions of light incidence.

Over the different solutions using volume holograms, reflection and transmission elements can be found. According to the way that these elements operate, they can be classified into non-concentrator elements (they only modify the direction of the sunlight, but they do not concentrate it) and concentrator elements. The holographic elements can exist alone or combined with other holographic elements, refractive elements and/or reflective, or light-guide systems.

Dichromated gelatines and photopolymers are the most commonly used recording materials for this type of applications. Although designs in silver halide materials are reported in the literature as laboratory studies, these materials are not suitable for use in field conditions because of their blackening tendency.

It should be noted that, in many cases, the holographic element would operate in a range of wavelengths different than the recording wavelength for which the holographic material is sensitive. Therefore, a photosensitive material presenting index modulations sufficient to diffract with high efficiency in a wavelength different to the recording one is required.

In the case of solar applications, it is essential to consider that solar radiation changes direction during the day and over the year. As the distance from the Sun to the Earth is very large, it can be assumed that the Sun is a point source and the sunrays are collimated (source at infinity) for each point of its trajectory.

The solar spectrum varies considerably the energy flux for each of the wavelengths. This fact determines, jointly with the angle of incidence, the performance of the holographic solar energy system.

1.1. Key characteristics of the volume holograms

For the comprehension of the different designs which will be described in the following sections, it is necessary to consider three typical characteristics of volume holograms: angular selectivity, chromatic selectivity and chromatic dispersion. These characteristics strongly depend on the recording geometries and the holographic material [1].

1.1.1. Angular selectivity

Volume holograms only present maximum efficiency (defined as the quotient between diffracted and incident fluxes) for a range of incidence angles near the direction that satisfies the Bragg condition. This range of angles can be higher or lower depending on the material thickness and the spatial period of the recorded interference. In general, this is a disadvantage since the hologram does not work with maximum efficiency for all the incoming light inclinations, requiring a solar tracking system or cascade design elements or multiplexed gratings.

It should be taken into account the fact that the angular selectivity of the volume hologram is not equal for all the directions of incidence, but it shows higher selectivity when the illumination angle is varying in the recording plane direction (Fig. 1(a)). In the perpendicular plane, the efficiency decays softer when incident directions go away from the optimal reconstruction angle; thus, it is possible to design systems that require tracking only in one direction (azimuth tracking or sun height tracking).

The angular selectivity can also be an advantage, so that a hologram can deflect radiation entering a building depending on the season and time of day, blocking or using it for lighting.

In Fig. 1(b), an example of angular selectivity curves for a transmission volume hologram on the major and minor angular selectivity directions is illustrated. When the direction of illumination, in the reconstruction, varies in the plane perpendicular to the recording one (*XZ* plane), the angular selectivity is 20 times lower than when it varies in the plane parallel to the recording plane (*YZ* plane). Therefore, the system is much more tolerant (maintains high efficiency) when the illumination direction varies in the *XZ* plane than when it varies in the *YZ* plane.

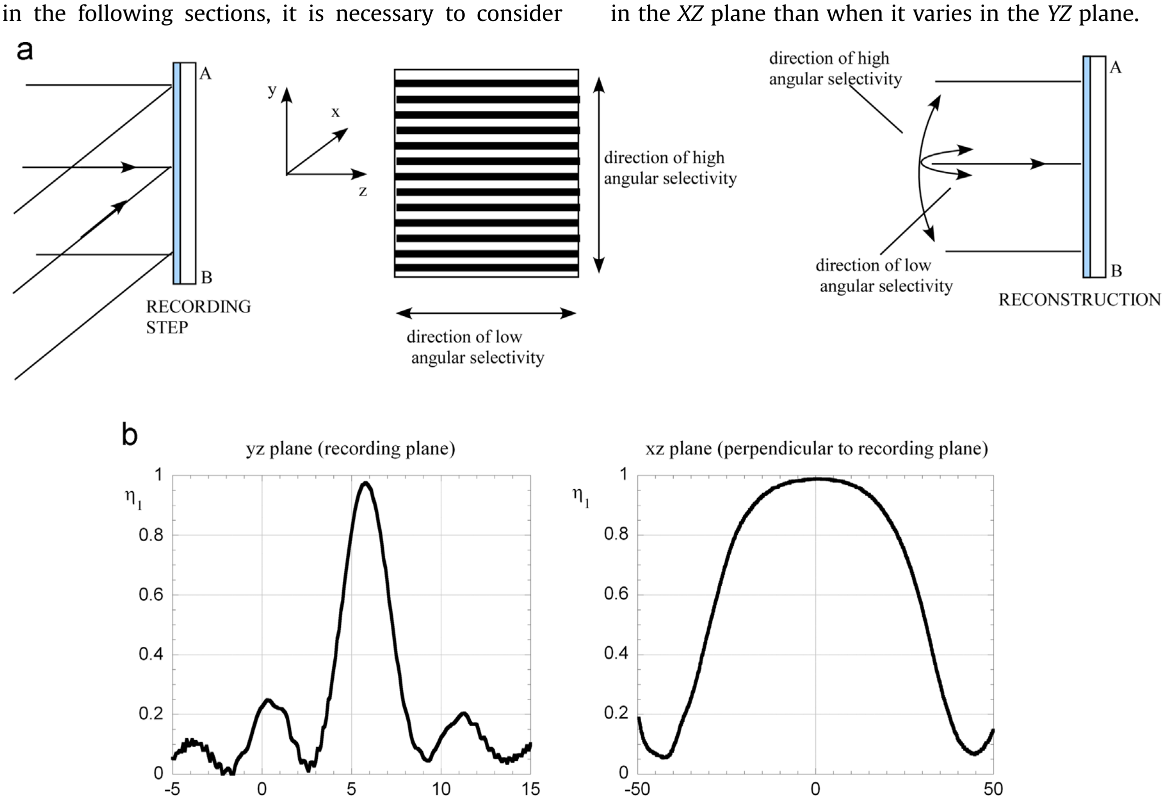

Fig. 1. (a) Diagram of recording and reconstruction of a volume holographic grating. The *YZ* plane is the recording one, (b) monochromatic diffracted efficiency (η_1) curves vs. angle of incidence when it varies at the *YZ* plane or at the *XZ* plane.