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Some aspects of image processing using foams

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ABSTRACT

We have explored some concepts of chaotic dynamics and wave light transport in foams. Using some experiments, we have obtained the main features of light intensity distribution through foams. We are proposing a model for this phenomenon, based on the combination of two processes: a diffusive process and another one derived from chaotic dynamics. We have presented a short outline of the chaotic dynamics involving light scattering in foams. We also have studied the existence of caustics from scattering of light from foams, with typical patterns observed in the light diffraction in transparent films. The nonlinear geometry of the foam structure was explored in order to create optical elements, such as hyperbolic prisms and filters.

1. Introduction

Foams have the properties of transparency and translucency. While transparent objects let light pass trough without noticeably scattering its rays, a translucent object lets some light through, but it scatters the ray so much that whatever is on the other side cannot be seen clearly. Just like transparency, translucency depends on the geometric properties of the foam. Conceding that point, if a single soap bubble is held up to a lamp, the light will pass through, but the liquid part will scatter and absorb some light. If more and more bubbles are added to make a thicker layer, then the light will eventually disappear turning the foam an opaque object [1].

Despite the fact that the different states are naturally observed in foams such as transparency, translucency and the capacity of blocking the light, the light transport in foams is challenging because it involves multiple chaotic scattering of light through hyperbolic optical elements formed by the interface of bubbles [2,3]. Although the laws of ray reflection and refraction are simple and related to geometrical optics, the boundary conditions for the light scattering in foams are very difficult to be determined precisely, due to the concept of sensitivity to initial conditions. In addition to this, there is the possibility of the occurrence of diffraction and other phenomena for which the ray approximation is not valid, as in the case of thin film interference of a soap bubble. On the other hand, studying the complex physical system of light in foams and other systems can be rewarding, because these systems can give valuable insights to development of new device design in optics [2,4,5], such as hyperbolic prisms, filters and diffusers, along with the improving of the understanding of image formation through translucent objects [6].

The problem of the transport of light in foams has been studied using different techniques, experimentally and theoretically [6–8], and since a lot of excellent papers and reviews from various perspectives have been published, we have decided to examine the light transport in foams using a different approach, by making some slices of foams in transparent boxes, and injecting light in these liquid foams, mimicking a naive tomography of light profile scattered in a liquid foam. This Letter is organized as follows. The next section presents the experimental apparatus. In Section 3, we discuss the existence of diffusive and chaotic behaviors observed in our experiment involving the scattering of light in foams. After that, we have tried to recognize the main features of the light intensity distribution inside the foam, proposing a model for this phenomenon, with a brief discussion of the chaotic scattering of light in Section 4. Furthermore, we have explored some diffraction patterns obtained from the experiment in Section 5, and we have used some of these features of the light transport in foams to implement an optical filter based on foams. Finally, we present the conclusions of our findings in Section 6.

2. Experimental apparatus

This experiment involves the light scattering in three-dimensional foams. We have studied the light scattering in liquid foam confined in a setup of transparent boxes [2,3,9]. Each box consists of two plain parallel Plexiglas plates separated by a gap ($19 \times 19 \times 2.0$ cm^3). Using different ensembles of these boxes

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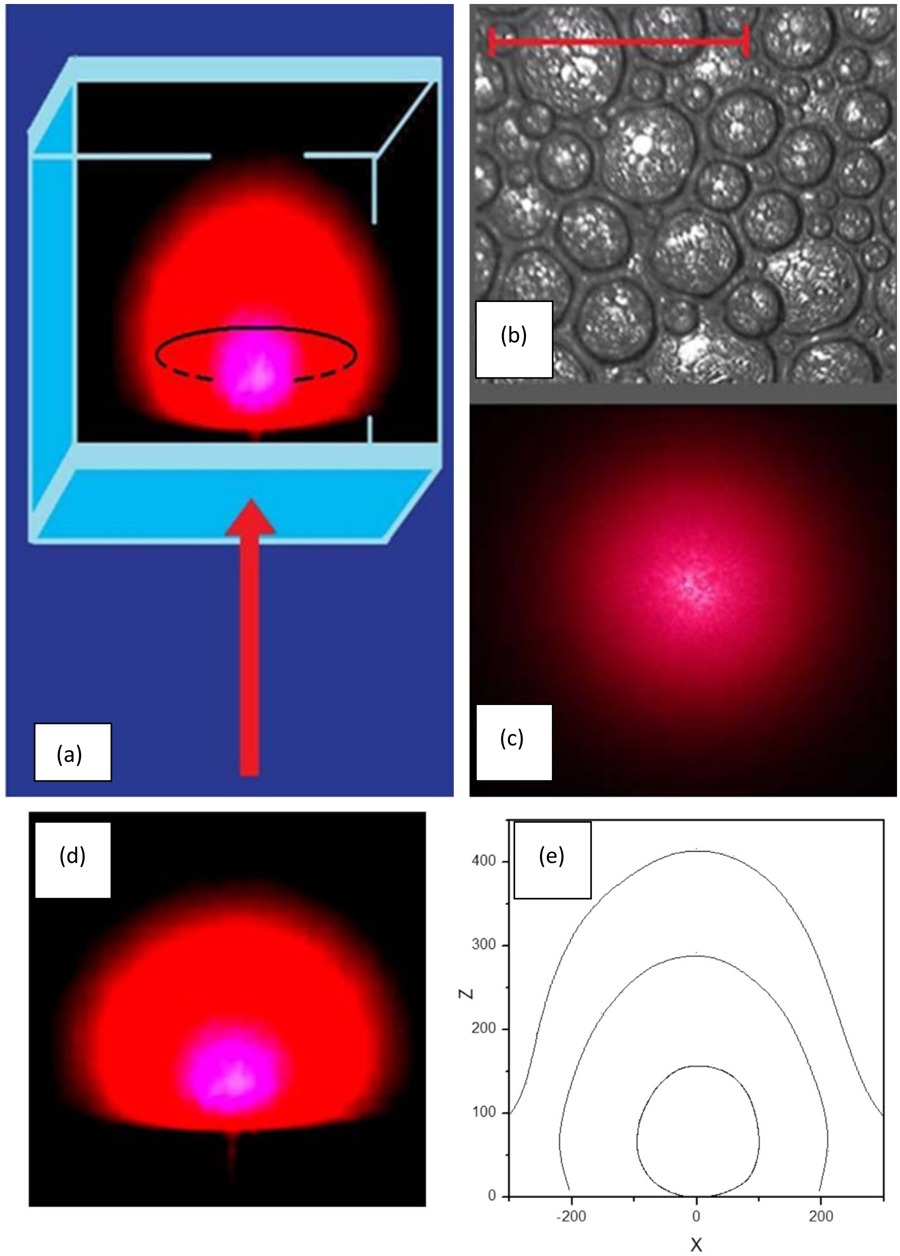

Fig. 1. (a) Diagram of the laser beam scattered by the foam inside a transparent box. The scattering process spreads the light and limits the depth of light penetration, creating a center glow located just above the interface of the box and the foam. (b) Image of the bubbles inside the foam, the bar size is 5.0 mm. (c) Top view of the light scattered by the foam in the region of the circle around the glowing point in (a). (d) Profile of the light scattered in the vertical position, with the laser beam entering at the bottom side. (e) As foams age, the bubbles coarsen, decreasing the number of bubbles, and consequently an amount of light penetrates beyond the initial region, increasing the size of the light profile.

containing this liquid foam, we could inspect different slices of the light scattered inside the foam, as it is shown in Figs. 1(a)–1(e). Initially, a laser beam is injected at the center of the face of the box containing foam. The box contains air and an amount of commercial dishwashing liquid diluted in water ($V = 114$ cm^3). The essential surfactant is Linear Alkylbenzene Sulfonate (LAS). The surface tension is 25 dyne/cm, and the density of this detergent is $\rho = 0.95$ g/cm^3, with refractive indices $n_l = 1.333$ for the liquid, and $n_g = 1.0$ for the air. The foam is obtained by shaking the boxes. A camera was used to detect the resulting light patterns. Once the beam reaches the foam in Fig. 1(a), part is reflected or refracted, and part is transmitted. The scattering process makes the light spread out and limits the depth of light penetration. In Fig. 1(b), there is a typical image of the foam. We can observe two different cross sections of the light scattered in the foam, for example, taking the circle around the blob of light of Fig. 1(a), we can see the horizontal profile of light scattered in Fig. 1(c), and the vertical profile in Fig. 1(d). As foam ages, its structure can vary greatly, changing the profile of the light scattered, as shown in Fig. 1(e), because average bubble size increases, decreasing the number of bubbles, and consequently a larger amount of light penetrates beyond the initial region. We have used this property to find the best condition to make use of the foam as a filter.

In order to explore some properties related to chaotic behavior observed in foams, we have used hyperbolic kaleidoscopes and hyperbolic prisms discussed in a previous paper [9]. The regular hyperbolic kaleidoscopes were constructed using three Christmas ball ornaments with the same size in a plane touching each other as curved mirrors, with a diameter of 5.0 cm. We also have made a hyperbolic prism as a way to obtain images of multiple reflections