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Multiple-layer radiation absorber

Abstract

A structure is discussed for absorbing incident radiation, either electromagnetic (EM) or sound. Such a surface structure is needed, for example, in a highly sensitive high-frequency gravitational wave or HFGW detector such as the Li-Baker. The multi-layer absorber, which is discussed, is constructed with metamaterial [MM] layer or layers on top. This MM is configured for a specific EM or sound radiation frequency band, which absorbs incident EM or sound radiation without reflection. Below these top MM layers is a substrate of conventional EM-radiation absorbing or acoustical absorbing reflective material, such as an array of pyramidal foam absorbers. Incident radiation is partially absorbed by the MM layer or layers, and then it is more absorbed by the lower absorbing and reflecting substrate. The remaining reflected radiation is even further absorbed by the MM layers on its "way out" so that essentially all of the incident radiation is absorbed – a nearly perfect black-body absorber. In a HFGW detector a substrate, such as foam absorbers, may outgas into a high vacuum and reduce the capability of the vacuum-producing equipment, however, the layers above this lowest substrate will seal the absorbing and reflecting substrate from any external vacuum. The layers also serve to seal the absorbing material against air or water flow past the surfaces of aircraft, watercraft or submarines. Other applications for such a multiple-level radiation absorber include stealth aircraft, missiles and submarines.

Keywords

Absorber; Black body; Li-Baker gravitational wave detector; Stealth; Metamaterial.

INTRODUCTION

The purpose of this paper is to present and discuss a novel concept in the absorption of radiation, both electromagnetic and sound, by using a composite absorbing surface structure. There exist a number of applications for a highly efficient absorber of electromagnetic or sound radiation especially in the microwave or ultrasonic frequency bands. The advent of metamaterials [MMs] has prompted the consideration or objective for creating perfectly "black" or totally absorbent material or structure. Such an objective, although not totally achievable, can be closely approximated. Electromagnetic metamaterials are artificially structured materials that are designed to interact with and control electromagnetic waves. Acoustic or sound metamaterials are artificially structured materials that are designed to interact with and control sound waves. One especially significant application of electromagnetic microwave-absorbing technology is for the Li-Baker high-frequency gravitational wave (HFGW) detector[1]. In this detector a small number of microwave photons in the presence of an intense beam of microwave photons need to be detected. Such a beam may also produce scattered or diffracted photons that must be efficiently absorbed. A structure or method of absorption is discussed in Baker[2], and Woods, et al.[3]. This absorption method also relates to the construction of an anechoic chamber having highly absorbent walls. Thus only a negligibly small number of microwave photons or sound waves are reflected from the chamber's walls. The upper layers also prevent evaporation, sublimation or out gassing of any warm (possibly due to radiation absorption heating) material in a substrate adjacent to the chamber walls. Other applications involve stealth aircraft, missiles and submarine craft and various acoustical systems.

GENERAL CONCEPT

The general concept of the absorption method is to utilize a conventional, primarily electromagnetic or sound radiation absorbing, but partially reflecting material substrate. On the surface of such an absorber facing the incident electromagnetic or sound radiation (of any given wavelength to be absorbed) are applied an additional layer or layers of primarily electromagnetic or sound radiation absorbing but partially transmitting but not reflecting material. Since the absorbed radiation may heat the substrate and cause out gassing, possibly into a vacuum, the upper layers also presents a barrier or seal against the evaporation, sublimation or out gassing. In addition these layers would seal the structure against a passing flow of air or water. A preferred design involves the use of an electromagnetic or sound radiation absorbing substrate array such as pyramidal foam absorbers. On the incident radiation-facing side of which is a layer or layers of metamaterial electromagnetic or sound radiation absorbing material. This material is positioned substantially parallel to and at a predetermined distance from the substrate. Such pyramidal foam or other such absorbers may evaporate, sublimate or outgas in a hard-vacuum and/or low-temperature environment. Such a substrate may be sealed from evaporation, sublimation or out gassing by the layers of the metamaterials. Metamaterial layer or layers comprise a periodic pattern or patterns of conducting metallic inclusions deposited on the surface of a solid dielectric material or acoustical tiles similarly patterned. When properly tuned to the frequency of the radiation to be absorbed they do not reflect any incident radiation. In Landy, et al.[4] they state from experimental data "…, our MM structure was optimized to maximize the (absorbance) with the restriction of minimizing the thickness. If

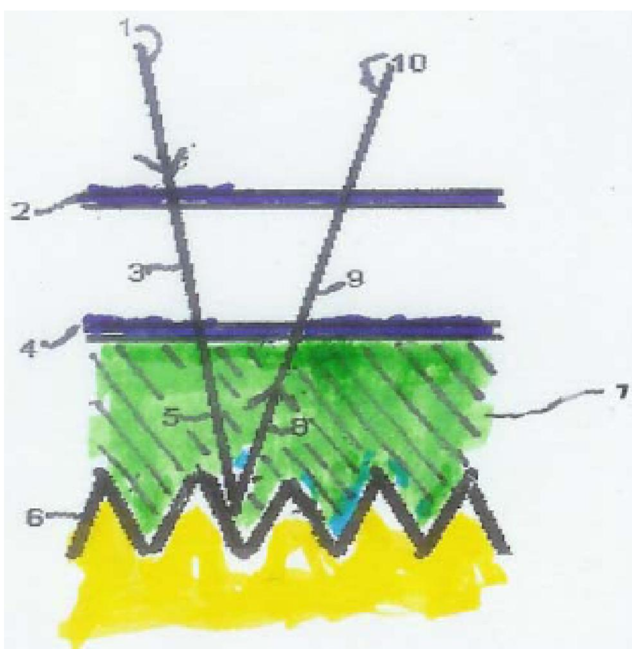

Figure 1 : Schematic of multiple-layer radiation absorber indicating the approximate direction of diffusely reflected radiation from the lower substrate, patent pending[5].

this constraint is relaxed, impedance matching is possible, and with multiple layers, a perfect (absorbance) can be achieved." Therefore there is essentially no reflected radiation from the MM structure. All layers and the substrate are designed for the absorption of the same electromagnetic or sound radiation frequency band or bands of any given wavelength.

In Figure 1, the incident electromagnetic (EM)) - or sound-radiation wave 1 reaches typical layer 2 in blue, partially transmitted electromagnetic- or sound-radiation wave 3 from layer 2 reaches typical layer 4 in blue, typical partially transmitted electromagnetic- or sound-radiation wave 5 from typical layer 4 reaches substrate 6 in yellow and is partially diffusely reflected as typical electromagnetic- or sound-radiation wave 8. Typical partially diffusely reflected as typical electromagnetic- or sound-radiation 8 reaches typical layer 4, typical partially transmitted electromagnetic- or sound-radiation wave 9 from typical layer 4 reaches typical layer 2 and the final partially transmitted remainder electromagnetic or sound wave 10 emerges from the structure. In Figure 1 the multilayers consist two 2 and 4; but any number of such layers are possible. The incident ray 1 can have almost any inclination. As Service[6] writes, "… Sandia Laboratories in Albuquerque, New Mexico are developing a technique to produce metamaterials [MMs] that work with [electromagnetic] radiation coming from virtually any direction." Substrate layers 2 and 4 seal off substrate 6 from evaporating, sublimating or out gassing into the region above MM layer 2. The surface 6 of a substrate of acoustical tiles upon which the MM layers are deposited as well as the voids between one or more MM layers such as 4 and substrate 6 is filled with uniform or variable density solid material such as dielectric material 7, shown in green, in order to resist deformation of layer 4 and substrate 6 and seal the substrate surfaces 6 from evaporation, sublimation or out gassing of the material composing substrate 6 in the presence of a vacuum and also would seal the structure against a passing flow of air or water. Applications include especially the Li-Baker HFGW detector for the detection of relic high-frequency gravitational waves. In the Li-Baker detector are sensitive microwave receivers that sense a very small number of microwave photons produced by the HFGWs. These receivers must operate in the presence of an intense microwave Gaussian beam (GB) whose scattered or diffracted photons must be very efficiently absorbed. Thus the multiple-layer absorber discussed herein is a necessary feature of the Li-Baker detector the bottle-shaped chamber containing a Gaussian-beam transmitter for such an application is shown in Figure 2. The yellow absorbing and reflecting pyramids are separated by a material (green) from the MM absorbing and transmitting material (blue). The multiple-layer radiation absorbing walls permit a pencil-like GB, (exhibiting a relic HFGW frequency of 10 GHz for which the absorbing layers re tuned) to enter the main detection chamber of the detector. Other applications involve surface coatings of the near perfect absorption layers for stealth aircraft, missiles and submarine craft and various acoustical systems. With regard to submarines the concept discussed herein is similar to the fluid-flow cloak discussed by Urzhumov and Smith[7] and Chen and Chan[8].

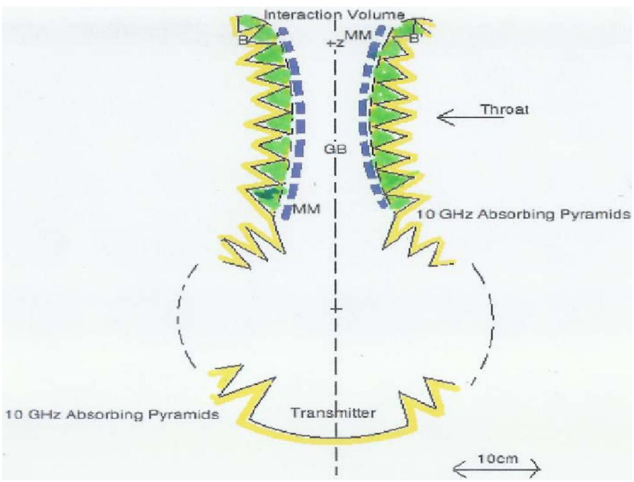

Figure 2 : Schematic of Gaussian-beam chamber for the Li-Baker HFGW detector[3,9].

FABRICATION DETAILS

As is well known, an electromagnetic wave incident on a surface is divided into a reflected and a transmitted wave. With a lossy surface, the incident electromagnetic wave is absorbed as it propagates such that the reflected and the transmitted wave together are less energetic than the incident wave. There exist certain surfaces, which comprise the substrate of the structure of the subject absorption method, that only reflect and do not transmit the incident radiation. There exist layers of other material that only transmit and do not reflect electromagnetic radiation due to their composition. When the inter-layer and substrate void is filled with solid material such as a dielectric plastic, evaporation, sublimation or out gassing of the substrate is inhibited and a vacuum or pressure difference among the layers and substrate will not deform the layers and substrate. Examples of the layers and substrates materials include, but are not limited to, the following:

- Materials that only transmit or absorb and do not reflect electromagnetic or sound radiation have been developed and defined as metamaterials or MMs. In the case of electromagnetic radiation they are constructed with a small, sub-wavelength dimensioned arrangement of conductors and dielectrics to affect various macroscopic optical behaviors. Such behaviors include negative indices of refraction and non-reflectivity in the case of electromagnetic radiation. Examples of such metamaterials are discussed in Landy, et al.[4]. They state: "In this study, we are interested in achieving (absorption) in a single unit cell in the propagation direction. Thus, our MM structure was optimized to maximize the (absorbance) with the restriction of minimizing the thickness. If this constraint is relaxed, impedance matching is possible, and with multiple layers, a perfect (absorbance) can be achieved." Available acoustical metamaterials are described in Chen and Chan[8].
- As to the commercially available substrates or electromagnetic microwave absorbers that do reflect a small amount of radiation, there are several materials available that offer the required low reflectivity. For example, ARC Technologies, Cummings Microwave, the ETS Lindgren Rantec Microwave Absorbers or Anechoic Foam Wedges to mention only a few. The ETS Lindgren microwave pyramid absorbers are a preferred EM or microwave absorber. At normal incidence the typical reflectivity is down -45 db (guarantied -40 db) according to their data sheets. As to the commercially available acoustic or sound absorbers, there are several materials available that offer the required low reflectivity. For example Sound Services, Ltd., Oxford, England, Sonex, USA, Acoustical Panels, Guangzhou Liyin Building Materials Co., Ltd., China to mention only a few. The Liyin sound-absorbing acoustic pyramids are preferred. Note that out gassing in a hard vacuum and the adverse effects of water and/or wind flow passed such substrates would be inhibited by the MM layers.

Although the radiation for sound and electromagnetic effects is entirely different, the application of MM technology is completely analogous as discussed by Chen and Chan[8]. Similarly Microwave absorbers or anechoic foam wedges are exactly analogous to commercially available acoustic or sound absorbers. In fact, they often exhibit precisely the same geometry. As discussed in detail in Woods, et al.[3] the utilization of the absorbing structure discussed herein absorbs essentially all of the diffracted background EM photon noise from the GB and allows for the utilization of very sensitive single EM photon microwave detectors to measure the HFGWs.

CONCLUSIONS

Discussion has been given of the general concept to wit:

(1) To utilize a primarily electromagnetic or sound radiation absorbing, but partially reflecting material substrate and

(2) on the surface of which are applied an additional layer or layers of primarily electromagnetic or sound radiation absorbing partially transmitting, non-reflecting material is an innovative approach[5].

This approach improves upon both the partially reflecting and the partially absorbing conventional EM and acoustic absorbers. The new radiation-absorbing method is appropriately applied to both the Li-Baker HFGW detector and to stealth vehicles. The relevant literature has been cited to provide design details of the new absorbing structure and to facilitate its fabrication.

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