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Electromagnetic radiation absorbing material employing doubly layered particles
Elektromagnetische Strahlung absorbierendes Material mit doppelt umhüllten Partikeln
Matériaux absorbant les ondes électromagnétiques à particules à double enrobage

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Description

Technical Field

This invention relates to electromagnetic radiation absorbing materials which comprise dissipative particles dispersed in dielectric binders.

Background

Electromagnetic radiation absorbing materials typically comprise one or more kinds of dissipative particles dispersed through a dielectric binder material. For example, U.S. Patent 4,173,018 (Dawson et al.) discloses a material comprising an insulating resin and solid iron spheres of 3 microns diameter, or solid glass spheres of 0.4 micron diameter having a single 1.3 micron thick iron coating, for a total diameter of 3 microns. The particles comprise up to 90% of the weight of the composite material.

Substantially spherical solid particles of such sizes are often called "microspheres." A variation on the microsphere is the "microbubble," a hollow microsphere made of a material such as glass. Single thin film layers of nonmagnetic metal may be deposited on glass microbubbles, and the product dispersed through polymeric binders, as taught in U. S. Patent 4,618,525 (Chamberlain et al.)

Singly layered microbubbles dispersed through polymeric binders have been used in electromagnetic shielding applications. For example, U.S. Patent 4,624,798 (Gindrup et al.) describes a composite material in which the microbubbles form a network of contacting particles, giving the bulk material sufficient electrical conductivity to act as a radiation shield, i.e., like a sheet of conductive material.

US-A-3,721,982 discloses a body designed to absorb electromagnetic radiation in the UHF, SHF and EHF including a multiplicity of closely juxtaposed spheres, whose diameters lie between about 0.1 to 5 times the wavelength of that radiation, imbedded in a polymeric matrix. Each sphere has a nonconductive, preferably highly porous spherical core coated with one or more layers of radiation-responsive (electrically conductive and/or magnetically permeable) material each advantageously overlain by a protective dielectric coating.

The radiation responsive layers of the reference are disclosed as being composed of a mass of carbonaceous or ferromagnetic particles embedded in a non-conductive binder; and as having a thickness of 0.01 mm to 0.05 mm

Summary of Invention

The invention a non-electrically-conductive electromagnetic radiation absorbing material (12), comprising a plurality of dissipative particles (11) and a dielectric binder (14) through which the dissipative particles (11) are dispersed in which any of the dissipative particles (11) comprises:

(a) a core particle (13);
(b) a dissipative layer (15) made of metal material, located on the surface of the core particle (13), wherein said dissipative layer (15) has a thickness between 0.05 and 10 nanometers, and wherein said dissipative layer continuously overlays the core particle (13); and
(c) an insulating layer (17) overlaying the dissipative layer.

Brief Description of the Drawing

Figure 1 is a cross sectional view of one embodiment of the invention. Figure 2 is a graph of the calculated reflection magnitude of radiation normally incident upon a surface of two embodiments of the invention, as a function of incident radiation frequency.

Detailed Description

One preferred embodiment of the invention is a radiation absorbing tile. Figure 1 is a cross sectional view of this embodiment, in which such a tile 10 comprises a radiation absorbing material 12. This absorbing material 12 is applied to the radiation-incident side (in the figure, the upper side) of an optional second component, an electrically conductive material 18. The electrically conductive material 18 is preferred because it reflects radiation which is not fully absorbed back into the absorbing material 12 for further absorption. Also shown is an optional impedance matching material 16. The impedance matching material 16 is preferred because it reduces reflection of the incident radiation from the radiation-incident side of the absorbing material 12.

The absorbing material 12 comprises a plurality of doubly layered dissipative particles 11, dispersed in a dielectric...
The electromagnetic radiation absorption properties of the invention may be attributed to the polarization of the dissipative layer 15. As the electric field component of the incident radiation is oriented in one direction, the electrons...
in the dissipative layer 15 tend to flow in the opposite direction, producing an electric current and resistive heating. The energy required to support this heating is removed from the electric field, and therefore the incident radiation is absorbed.

However, if the amount of material in the dissipative layer 15 is too great, depolarization effects occur to reduce the effectiveness of the resistive heating process. The dipole interaction induced by the electric field polarizes the excess material in the direction opposite to the induced field (i.e., in the same direction as the incident electric field), thus reducing the amount of induced electric current.

A way to identify a suitable range of thicknesses is to consider a parameter "B." For spherically shaped dissipative particles 11, B is known as the "bubble parameter," and is the ratio of the product of the frequency of incident radiation and the core particle radius, divided by the product of the thickness of the dissipative layer and the conductivity of the dissipative layer. Generally, the radiation frequency for the intended application and the core particle radius are known, and the process conditions varied to adjust the dissipative layer thickness and conductivity.

The conductivity of the ultrathin layer is not the same as the bulk conductivity of the material from which the layer is made. This is because the electronic behavior of ultrathin films is inherently different from that of bulk materials, and because impurities entrapped in the ultrathin layer have a great effect due to their proportionately greater presence in the material. For metals, the ultrathin film conductivity is held approximately constant and the thickness is controlled. Generally, thicker layers are desirable for higher incident frequencies, and vice versa. For tungsten layered microbubbles, the optimum values of B for the 1-20 GHz range follow from a 1 nm thick tungsten layer on a microbubble of about 50 micron outer diameter.

The insulating layer 17 is preferably made of aluminum oxide, silicon dioxide, zirconium oxide, or titanium dioxide. The choice of material for the dissipative layer 15 influences the choice of material for the insulating layer 17. For example, when zirconium is used in the dissipative layer 15, zirconium oxide is the preferred material for the insulating layer 17, because it may be formed by thermal oxidation of the outer surface of the zirconium without direct deposition of a second layer. A similar situation applies to titanium dioxide layered on titanium. Of course, in all these examples the insulating layer 17 could be separately deposited on the layer 15. Thus, in practice, the insulating layer 17 may be a reaction product of the dissipative layer 15, but it need not be.

However formed, the insulating layer 17 preferably overlays the inorganic layer 15 at a thickness of 1 to 10 nm, more preferably about 2 nm. The insulating layer 17 allows the dissipative particles 11 to be present in the absorbing material 12 at fairly high volume loading ratios, despite possible contact between the particles. Such contact can cause the absorbing material 12 to become effectively a conductive sheet which reflects, rather than absorbs, radiation. The insulating layer 17 also helps prevent degradation of the dissipative layer 15 due to oxidation or other processes. Ultrathin metal films are expected to oxidize over time, which will result in a change to the composite material permittivity. With ultrathin tungsten films, measurable changes in powder resistivity occur in a period of hours in some cases. The addition of the aluminum suboxide layer results in a material with permittivity which is constant over a period of months or more. As with the dissipative layer 15, the insulating layer 17 is an ultrathin layer which may be contiguous, but in preferred embodiments it is continuous, and uniform in thickness.

The dielectric binder 14 may be made from a ceramic, polymeric, or elastomeric material. Ceramic binders are preferred for applications requiring exposure to high temperatures, while polymeric binders are preferred for their flexibility and lightness. Many polymeric binders are suitable, including polyethylenes, polypropylenes, polymethacrylates, urethanes, cellulose acetates, epoxies, and polytetrafluoroethylene (PTFE). Suitable elastomeric binders are natural rubbers and synthetic rubbers, such as the polychloroprene rubbers known by the trademark name "NEOPRENE" and those based on ethylene propylene diene monomers (EPDM). Other preferred binders are silicone compounds available from General Electric Company under the designations RTV-11 and RTV-615.

The dielectric binder could be made from thermosetting or thermoplastic material. Thermosetting materials, once heated, irreversibly cure and cannot be remelted to be reformed. Thermoplastic materials can be repeatedly heated and reformed. In either case, the materials may be heated and set into a form by one or more forces external to the binder. Typically the force is due to heat conduction, or pressure, but it may be the influence of gravity or a vacuum. In this respect the binders suitable for the present invention differ from the "conformable" materials taught in U.S. Patent 4,814,546 (Whitney et al.), which require molecular forces internal to the binder (such as a mechanical stress in a stretchable material) to be responsible for the change in shape of the absorber.

Many types of adhesives have the required thermoplastic or thermosetting properties. An adhesive is a material which forms intimate contact with a surface such that mechanical force can be transferred across the contact interface. Suitable thermoplastic and thermosetting adhesives include (but are not limited to) polyamides, polyethylenes, polypropylenes, polymethacrylates, urethanes, cellulose acetates, vinyl acetates, epoxies, and silicones.

Alternatively, the conformable materials mentioned above are also suitable for other embodiments of the invention. For example, a thermoplastic heat-shrinkable binder may be formed from cross-linked or oriented crystallizable materials such as polyethylene, polypropylene, and polyvinyl chloride; or from amorphous materials such as silicones, polyacrylates, and polystyrenes. Solvent-shrinkable or mechanically stretchable binders may be elastomers such as natural
rubbers or synthetic rubbers such as reactive diene polymers; suitable solvents are aromatic and aliphatic hydrocarbons. Specific examples of such materials are taught in U.S. Patent 4,814,546 (Whitney et al.).

The binder may be homogenous, or a matrix of interentangled fibrils, such as the PTFE matrix taught in U.S. Patent 4,153,661 (Ree et al.). In general, an absorber of this embodiment is formed in a fibrillation process involving the formation of a water-logged paste of doubly layered particles and PTFE particles, intensive mixing at 50° to 100°C, biaxial calendering at 50° to 100°C, and drying at 20° to 100°C. The composite of PTFE fibrils and particles has the high tensile strength of the PTFE matrix.

To be effective, the absorbing material 12 should have a thickness in the direction of radiation propagation greater than about one-fourth (2.5 percent) of the wavelength absorbed. The invention is suitable for absorbing radiation over as broad an incident frequency range as possible in the region of approximately 2 to 40 GHz. This implies a thickness greater than the order of about 0.2 mm. Thicker layers generally provide greater absorption, but the increased weight and reduced flexibility are not desired in many applications. Thus, while layers having thicknesses up to one-fourth (25 percent) of the absorbed wavelength are possible, they are not preferred. For example, in the same frequency region this upper thickness limit is on the order of about 37.5 mm, but sufficient absorption can be obtained with layers on the order of 2.0 mm or less in thickness.

The absorbing material 12 has a reduced specific gravity, which will produce a reduction in weight of the tile 10. Volume loading factors for composites based on carbonyl iron microspheres typically range from forty to sixty-five percent, and the specific density of iron is 7.9 g/cm³. In the present invention the volume loading factor is in the range of thirty to sixty-five percent, but the specific density of the doubly layered particles is far less, in the range of 0.10 to 0.60 g/cm³. For example, consider an absorber with sixty percent volume loading of particles and a binder of specific gravity 1.0. If the absorber is constructed according to the present invention, the specific gravity of the inventive absorber will be from 0.40 to 0.46. For a similar but non-inventive absorber comprising iron spheres, the specific gravity will be 5.1, or about eleven to thirteen times as much as the inventive absorber. This shows that the metal on the particles of the present invention is used very efficiently, i.e., it is only about 0.01% (by weight) of the non-inventive absorber, but about 92% (by weight) of the non-inventive absorber comprising iron spheres.

The absorbing material 12 is non-electrically conductive, i.e., it has a high DC resistivity. If the resistivity is too low, the absorber 12 effectively becomes a conductive sheet, which reflects radiation instead of absorbing it. The resistivity of iron, for example, is about 10⁻⁵ ohm-cm at room temperature. Insulators typically have resistivities of 10¹² ohm-cm or more. Samples of the absorbing material 12 having 60 percent volume loading of layered microbubbles had measured resistivites of greater than 2x10⁶ ohm-cm at room temperature, indicating that they were non-conductive.

Any electrically conductive material is suitable for the optional electrically conductive material 18. The absorbing material 15 may be bound to the electrically conductive material 18 by extruding the former onto the latter and allowing the former to cure. Many thermoplastic binders are suitable for extrusion, especially polyvinylchlorides, polyamides, and polyletheranes. The electrically conductive material 18 may be a wire or cable in lieu of the flat sheet shown in Figure 1. Alternatives to extrusion include the use of adhesives, and processes involving in-place thermal casting.

In any embodiment of the invention, impedance matching of the absorbing material to the incident medium (usually air) is preferred, but not required. Impedance matching is done by a material which maximizes transmission of incident radiation to the absorbing layer. In the embodiment of Figure 1, an optional impedance matching material 16 is shown as a component of the tile 10. The impedance matching material 16 is bound to the radiation incident side of the absorbing material 12. Co-extrusion and the use adhesives are suitable processes for binding the materials together. The dimensions, weight, and other properties of the impedance matching material 16 are considered in the design of a complete tile 10.

A suitable impedance matching layer 16 is a layer of polymeric material having high volumes of trapped air, such as air-filled, bare, glass microbubbles embedded in the polymeric binder materials described above. For example, a suitable impedance matching comprises 5 to 25 volume percent type S60/10000 SCOTCHLITE® brand glass microbubbles, dispersed in a synthetic rubber such as that made from the EPDM resin identified by E.I duPont de Nemours Company as NORDEL® brand type 1440.

Furthermore, a laminated structure, each lamina individually constructed according to the description above, is possible. For example, one lamina may be an absorber comprising doubly layered glass microbubbles, a second lamina may be an absorber comprising double layered ceramic fibers, and a third lamina may be an absorber comprising double layered inorganic flakes. Preferably two to five layers are used. The total thickness of the laminated structure may be as great as 40 centimeters, although generally each lamina will meet the thickness limitations described above. Use of a laminated structure allows the absorption profile of the composite structure to be "tuned" to a particular frequency range and bandwidth of interest.

The invention need not be in the form of a flat sheet as shown in Figure 1. For a cylindrical conductor, for example, a pre-sized flexible cylindrical shell absorber is preferred to minimize possible stretching, cracking, or delamination of a flat laminated sheet. The pre-formed cylindrical shell could be slit along its length, wrapped around the conductor (or slid along the long axis of the conductor) with little distortion, and then adhered into place. The seam formed by the
edges of the slit should be sealed.

The exact choices of materials depend on the final absorption versus frequency characteristics desired, and the physical application required. The choices of materials also dictate the procedure and equipment required to assemble the absorber, as illustrated by the following examples.

**Examples 1 to 8: Aluminum Suboxide and Tungsten Layered Glass Bubbles**

In each example batch, two hundred cubic centimeters of type S60/10000 "SCOTCHLITE" brand glass microbubbles were screened through a 325 mesh (44 micron) sieve. The microbubbles which did not pass the sieve were floated in methanol, and those that did not float were discarded, the remainder then allowed to dry in air. The microbubbles retained had an average diameter of 70 microns, with 90% of the microbubbles being between 50 and 88 microns, and an average surface area (determined by the BET method) of 0.33 m²/g.

The microbubbles were prepared using essentially the same method as taught in U.S. Patent 4,618,525 (Chamberlain, et al.). They were tumbled in a vacuum chamber while being sputter coated with a vapor of tungsten for 120 minutes. The sputtering cathode was a water-cooled rectangular target, 12.7 x 20.3 cm in size. The direct current planar magnetron method was used. The argon sputtering gas pressure was 0.53 Pascal, and the background pressure was about 1.33x10⁻³ Pascal. Table 1 lists various parameters and results for the example batches.

<table>
<thead>
<tr>
<th>Example</th>
<th>Applied Power</th>
<th>Weight Percentage</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5</td>
<td>0.19 kW</td>
<td>0.80</td>
<td>1.3</td>
</tr>
<tr>
<td>6</td>
<td>0.16 kW</td>
<td>0.55</td>
<td>0.9</td>
</tr>
<tr>
<td>7</td>
<td>0.26 kW</td>
<td>0.98</td>
<td>1.6</td>
</tr>
<tr>
<td>8</td>
<td>0.18 kW</td>
<td>0.67</td>
<td>1.1</td>
</tr>
</tbody>
</table>

The weight percentage of the dissipative tungsten layer was determined by dissolving portions of the batches in dilute hydrofloric acid in combination with nitric, hydrochloric, or sulfuric acid as appropriate. The resulting solutions were analyzed by Inductively Coupled Argon Plasma Atomic Emission Spectroscopy.

The average thickness of each tungsten layer was calculated from the weight percentage of metal and the specific surface area of the uncoated microbubbles as:

\[
t = \frac{(10^W)}{(D*S)}
\]

Where:
- \( t \) = average layer thickness, nm
- \( W \) = weight percentage of layer
- \( D \) = density of layer material
  (for tungsten, 19.3 g/cm³)
- \( S \) = surface area of microbubbles (m²/g)

Each batch was then sputtered by the same process with an aluminum target, while admitting oxygen into the chamber in the vicinity of the particles at a rate of 4.0 cc/min. This produced an insulative layer of non-stoichiometric aluminum oxide of approximately 2.0 nm thickness.

The doubly layered particles were hand mixed into an epoxy binder using a lab spatula and a 30 ml beaker. The binder material was type 5 "SCOTCHCAST" Electrical Resin supplied by the Minnesota Mining and Manufacturing Company. This product is a two-part room temperature cure epoxy consisting of two parts (by weight) of a diglycidal ether of bisphenol A to one part (by weight) of a 20 weight percent solution of diethylene triamine in an aromatic oil. The mixtures were placed under vacuum for about 10 minutes to removed air entrapped while mixing.

The volume loadings of the particles in the resin were 60% for Examples 1 and 6-8, and 50.0%, 53.5%, 57.0%, and 60.5% for Examples 2-5 respectively.

The mixtures were spread and pressed between two 75x25 mm glass microscope slides, using 1 mm spacers, and allowed to cure at room temperature for 12 hours, after which the slides were removed. This produced eight samples of hardened radiation absorbing materials.

The hardened composites were removed from the slides and machined into a flat annular rings. Each ring had an outside diameter of 7.0mm±0.0076mm, an inside diameter of 3.5mm±0.0076mm, and a known thickness of approxi-
mately 1 mm. They were placed, at a position known to ± 0.1 mm, in a 6 cm long coaxial airline connected to a Hewlett-Packard Model 8510A precision microwave measurement system. The annular plastic substrates used to hold the rings in place had a relative permittivity of 2.58 and a relative permeability of 1.00.

Two hundred one step mode measurements from 0.1 to 20.1 GHz were made on each ring. Measurements of the transmission and reflection of the radiation by the sample were used to calculate the real and imaginary parts of the permittivities and permeabilities of the samples as a function of incident frequency.

The calculated permittivity and permeability values for Example 1 were used to generate Figure 2, which shows (at "A") the predicted reflection magnitude of radiation incident normal to a 2.18 mm thick layer of the composite material over a conductive ground plane. The results predict the desired broad and strong absorption response, at least 5 dB over a range from about 7.5 to 20 GHz, and at least 10 dB over a range from about 9.5 to about 11.5 GHz.

Also shown (at "B") is the beneficial effect of adding an impedance matching layer to the composite material, specifically a 2.66 mm thick layer of homogeneous material having a dielectric constant of 2.6. Absorption response is both broadened and deepened, to least 5 dB over a range from about 6.5 to over 20 GHz, and at least 10 dB over a range from about 7.5 to over 20 GHz. Two ranges of at least 15 dB absorption are predicted: the first from 8 to 12 GHz, with a maximum of nearly 30 dB at about 9 GHz, and the second from 13 to 19 GHz, with a local maximum of over 20 dB at about 17 GHz.

Example 9: Aluminum Suboxide and Tungsten Layered Mica Flakes

The procedures of Examples 1 to 8 were followed, except as noted below, with the following results:

(1) Mica flakes obtained from Suzorite Mica Products, Inc., and designated 200HK, were used. This product contains particles which are no larger than 75 microns, have a density of 2.9 g/cm³, and have an average surface area of 2.8 m²/g.

(2) The mica flakes (460 g) were sputter coated with a vapor of tungsten for 180 minutes at an applied power of 1.1 kW.

(3) The weight percentage of the dissipative tungsten layer was 1.7%.

(4) The average thickness of each tungsten layer was calculated to be 0.3 nm.

(5) The tungsten coated mica flakes were then sputter coated with aluminum suboxide to a thickness of about 2 nm.

(6) The volume loadings of the particles in the resin was 15%.

Qualitative inspection of the calculated permeability vs. frequency curves indicated acceptable absorption performance.

Example 10: Aluminum Suboxide and Tungsten Layered Milled Glass Fibers

The procedures of Examples 1 to 8 were followed, except as noted below, with the following results:

(1) Milled glass fibers obtained from Owens Corning Company, and designated "FIBERGLAS," were used. This product contained glass fibers with a diameter of 16 microns, and lengths from about 1 to 300 microns. They had a density of 2.56 g/cm³, and an average surface area of 0.17 m²/g.

(2) The glass fibers (202 g) were sputter coated with a vapor of tungsten for 135 minutes at an applied power of 0.5 kW.

(3) The weight percentage of the dissipative tungsten layer was 0.45%.

(4) The average thickness of each tungsten layer was calculated to be 1.2 nm.

(5) The tungsten coated glass fibers were then sputter coated with aluminum suboxide to a thickness of about 2 nm.

(6) The volume loadings of the particles in the resin was 33%.

Qualitative inspection of the calculated permeability vs. frequency curves indicated acceptable absorption performance.

Claims

1. A non-electrically-conductive electromagnetic radiation absorbing material (12), comprising a plurality of dissipative particles (11) and a dielectric binder (14) through which the dissipative particles (11) are dispersed in which any of the dissipative particles (11) comprises:
(a) a core particle (13);
(b) a dissipative layer (15) made of metal material, located on the surface of the core particle (13), wherein said dissipative layer (15) has a thickness between 0.05 and 10 nanometers, and wherein said dissipative layer continuously overlays the core particle (13); and
(c) an insulating layer (17) overlaying the dissipative layer.

2. The absorbing material (12) of claim 1 in which the core particle (13) is chosen from the group consisting of microsphere, microbubble, fiber, and flake.

3. The absorbing material (12) of any preceding claims in which the core particle (13) is a glass microbubble having an average outer diameter between 10 and 500 microns.

4. The absorbing material (12) of claim 3 in which the core particle (13) is a glass microbubble having an average outer diameter between 20 and 80 microns.

5. The absorbing material (12) of any preceding claim in which the metal material of the dissipative layer (15) is chosen from the group consisting of tungsten, chromium, aluminum, copper, titanium, iron, zirconium, and stainless steel.

6. The absorbing material (12) of any preceding claim in which the dissipative layer (13) averages approximately 0.4 to 2 nanometers in thickness.

7. The absorbing material (12) of any preceding claim in which the thickness of the dissipative layer (15) is uniform to within ten percent.

8. The absorbing material (12) of any preceding claim in which the insulating layer (17) comprises a material chosen from the group consisting of aluminum suboxide, silicon dioxide, zirconium oxide, and titanium dioxide.

9. The absorbing material (12) of any preceding claim in which the insulating layer (17) is approximately about 2 nanometers thick.

10. The absorbing material (12) of any preceding claim in which the insulating layer (17) contiguously overlays the dissipative layer (15).

11. The absorbing material (12) of any preceding claim in which the insulating layer (17) continuously overlays the dissipative layer (15).

12. The absorbing material (12) of any preceding claim in which the insulating layer (17) comprises a material which is a reaction product of the material of the dissipative layer (15).

13. The absorbing material (12) of any preceding claim in which the dielectric binder (14) is ceramic.

14. The absorbing material (12) of any one of preceding claims 1-12 in which the dielectric binder (14) is polymeric.

15. The absorbing material (12) of claim 14 in which the polymeric binder comprises a polymer chosen from the group consisting of polyethylenes, polypropylenes, polymethylmethacrylates, urethanes, cellulose acetates, and polytetrafluoroethylene.

16. The absorbing material (12) of claim 14 in which the polymeric binder comprises a polymer chosen from the group consisting of thermosetting polymeric adhesives and thermoplastic polymeric adhesives.

17. The absorbing material (12) of claim 14 in which the polymeric binder comprises a polymer chosen from the group consisting of heat-shrinkable polymers, solvent-shrinkable polymers, and mechanically-stretchable polymers.

18. The absorbing material (12) of any preceding claim in which the dielectric binder (14) is elastomeric.

19. The absorbing material (12) of any preceding claim in which the plurality of dissipative particles (11) are dispersed in the dielectric binder (14) at a volume loading between 65 and 15 percent.
20. The absorbing material (12) of any preceding claim in which the core particles (13) are glass microbubbles and the plurality of dissipative particles (11) are dispersed in the dielectric binder (14) at a volume loading between 60 and 30 percent.

21. The combination of the absorbing material (12) of any preceding claim and an electrically conductive material (18) bound directly adjacent to the absorbing material.

22. The combination of the absorbing material (12) of any one of preceding claims 1-20 and an impedance matching material (16) bound to a radiation incident side of the absorbing material (12).

23. A laminated construction comprising two or more laminae of an electromagnetic radiation absorbing material (12), each lamina independently meeting the limitations of any one of preceding claims 1-20.

24. A method of making an electromagnetic radiation absorbing material (12) comprising the steps of:

(a) providing an electrically conductive particle comprising a core particle (13) which has an ultrathin layer (15) of a metal dissipative material, wherein said layer (15) has a thickness between 0.05 and 10 nanometers and wherein said layer (15) is located on the surface of the core particle (13) and continuously overlays the core particle (13);

(b) producing a stable, ultrathin layer of insulating material (17) overlaying the dissipative material (15), wherein the insulating layer is 1 to 10 nm thick;

(c) embedding the result of (b) into a dielectric binder material.

25. The method of claim 24 in which the insulating material of step (b) comprises a reaction product of the dissipative material of step (a).

26. The method of claim 24 in which step (b) comprises introducing oxygen to the dissipative material.

Patentansprüche

1. Elektrisch nichtleitendes, elektromagnetische Strahlung absorbierendes Material (12), umfassend eine Vielzahl von ableitenden Teilchen (11) und einen dielektrischen Binder (14), durch den die ableitenden Teilchen (11) dispersiert werden, wobei jedes der ableitenden Teilchen (11) folgendes umfaßt:

(a) ein Kernteilchen (13);

(b) eine ableitende Schicht (15) aus Metall, die auf der Oberfläche des Kernteilchens (13) liegt, wobei die ableitende Schicht (15) eine Dicke zwischen 0.05 und 10 Nanometer besitzt, und wobei die ableitende Schicht ständig über dem Kernteilchen (13) liegt; und

(c) eine Isolierschicht (17) über der ableitenden Schicht.

2. Absorbierendes Material (12) nach Anspruch 1, bei dem das Kernteilchen (13) ausgewählt ist aus der Gruppe umfassend Mikrokugelchen, Mikroperlen, Fasern und Flocken.

3. Absorbierendes Material (12) nach einem der vorhergehenden Ansprüche, bei dem das Kernteilchen (13) eine Mikroperle aus Glas ist mit einem durchschnittlichen Außendurchmesser zwischen 10 und 500 Mikrometer.


6. Absorbierendes Material (12) nach einem der vorhergehenden Ansprüche, bei dem die ableitende Schicht (13) eine durchschnittliche Dicke von ungefähr 0.4 bis 2 Nanometer besitzt.
7. Absorbierendes Material (12) nach einem der vorhergehenden Ansprüche, bei dem die Dicke der ableitenden Schicht (15) in einem Bereich von bis zu 10 Prozent gleichmäßig ist.


10. Absorbierendes Material (12) nach einem der vorhergehenden Ansprüche, bei dem die Isolierschicht (17) enganliegend auf der ableitenden Schicht (15) angeordnet ist.

11. Absorbierendes Material (12) nach einem der vorhergehenden Ansprüche, bei dem die Isolierschicht (17) ständig über der ableitenden Schicht (15) liegt.


15. Absorbierendes Material (12) nach Anspruch 14, bei dem der polymere Binder ein Polymer umfaßt, das ausgewählt ist aus der Gruppe umfassend Polyethylene, Polypropylene, Polymethylmethacrylate, Urethane, Celluloseacetate und Polytetrafluorethylen.


18. Absorbierendes Material (12) nach einem der vorhergehenden Ansprüche, bei dem der dielektrische Binder (14) elastomer ist.


24. Verfahren zur Herstellung eines elektromagnetische Strahlung absorbierenden Materials (12), umfassend die folgenden Schritte:

(a) Bereitstellen eines elektrisch leitenden Teilchens mit einem Kernteilchen (13), das eine ultradiinne Schicht (15) aus einem ableitenden Metall aufweist, wobei die Schicht (15) eine Dicke zwischen 0,05 und 10 Nanometer besitzt, und wobei die Schicht (15) auf der Oberfläche des Kernteilchens (13) liegt und ständig über dem Kernteilchen (13) liegt;

(b) Herstellen einer stabilen, ultradiinnen Schicht Isoliermaterial (17) über dem ableitenden Material (15), wobei die Isolierschicht eine Dicke von 1 bis 10 nm besitzt;

(c) Einbetten des Resultats von Schritt (b) in ein dielektrisches Bindemittel.

25. Verfahren nach Anspruch 24, bei dem das Isoliermaterial von Schritt (b) ein Reaktionsprodukt des ableitenden Materials von Schritt (a) umfaßt.

26. Verfahren nach Anspruch 24, bei dem Schritt (b) das Einleiten von Sauerstoff auf das ableitende Material umfaßt.

Revendications

1. Matériau absorbant les rayonnements électromagnétiques non conducteur de l'électricité (12), comprenant plusieurs particules dissipatives (11) et un liant diélectrique (14) dans lequel les particules dissipatives (11) sont dispersées, dans lequel toutes les particules dissipatives (11) comprennent:

(a) une particule de noyau (13);
(b) une couche dissipative (15) faite d'un matériau métallique placé à la surface de la particule de noyau (13) où ladite couche dissipative (15) possède une épaisseur comprise entre 0,05 et 10 nanomètres, et où ladite couche dissipative recouvre uniformément la particule de noyau (13); et
(c) une couche isolante (17) recouvrant la couche dissipative.

2. Matériau absorbant (12) de la revendication 1, dans lequel la particule de noyau (13) est choisie dans le groupe constitué par une microsphère, une microbulle, une fibre et une écaille.

3. Matériau absorbant (12) selon l'une quelconque des revendications précédentes, dans lequel la particule de noyau (13) est une microbulle en verre ayant un diamètre extérieur moyen compris entre 10 et 500 microns.

4. Matériau absorbant (12) selon la revendication 3, dans lequel la particule de noyau (13) est une microbulle en verre ayant un diamètre extérieur moyen compris entre 20 et 80 microns.

5. Matériau absorbant (12) selon l'une quelconque des revendications précédentes, dans lequel le matériau métallique de la couche dissipative (15) est choisi dans le groupe constitué par le tungstène, le chrome, l'aluminium, le cuivre, le titane, le fer, le zirconium et l'acier inoxydable.

6. Matériau absorbant (12) selon l'une quelconque des revendications précédentes, dans lequel la couche dissipative (13) a une épaisseur moyenne d'environ 0,4 à 2 nanomètres.

7. Matériau absorbant (12) selon l'une quelconque des revendications précédentes, dans lequel l'épaisseur de la couche dissipative (15) est uniforme à dix pour-cent près.

8. Matériau absorbant (12) selon l'une quelconque des revendications précédentes, dans lequel la couche isolante (17) comprend un matériau choisi dans le groupe constitué par un sous-oxyde d'aluminium, le dioxyde de silicium, l'oxyde de zirconium et le dioxyde de titane.

9. Matériau absorbant (12) selon l'une quelconque des revendications précédentes, dans lequel la couche isolante (17) a une épaisseur d'environ 2 nanomètres.

10. Matériau absorbant (12) selon l'une quelconque des revendications précédentes, dans lequel la couche isolante
11. Matériau absorbant (12) selon l'une quelconque des revendications précédentes, dans lequel la couche isolante (17) recouvre uniformément la couche dissipative (15).

12. Matériau absorbant (12) selon l'une quelconque des revendications précédentes, dans lequel la couche isolante (17) comprend un matériau qui est un produit de réaction du matériau de la couche dissipative (15).

13. Matériau absorbant (12) selon l'une quelconque des revendications précédentes, dans lequel le liant diélectrique (14) est une céramique.

14. Matériau absorbant (12) selon l'une quelconque des revendications précédentes, dans lequel le liant diélectrique (14) est un polymère.

15. Matériau absorbant (12) de la revendication 14, dans lequel le liant polymère comprend un polymère choisi dans le groupe constitué par les polyéthylènes, les polypropylènes, les poly(méthacrylates de méthyle), les uréthanes, les acétates de cellulose, et le poly(tétrafluoroéthylène).

16. Matériau absorbant (12) de la revendication 14, dans lequel le liant polymère comprend un polymère choisi dans le groupe constitué par les adhésifs polymères thermocurcissables et les adhésifs polymères thermoplastiques.

17. Matériau absorbant (12) de la revendication 14, dans lequel le liant polymère comprend un polymère choisi dans le groupe constitué par les polymères pouvant rétrécir sous l'action de la chaleur, les polymères pouvant rétrécir sous l'action de solvants, et les polymères pouvant être étirés mécaniquement.

18. Matériau absorbant (12) selon l'une quelconque des revendications précédentes, dans lequel le liant diélectrique (14) est un élastomère.

19. Matériau absorbant (12) selon l'une quelconque des revendications précédentes, dans lequel les nombreuses particules dissipatives (11) sont dispersées dans le liant diélectrique (14) à une charge volumique comprise entre 65 et 15%.

20. Matériau absorbant (12) selon l'une quelconque des revendications précédentes, dans lequel les particules de noyau (13) sont des microbulles en verre, et les nombreuses particules dissipatives (11) sont dispersées dans le liant diélectrique (14) à une charge volumique comprise entre 60 et 30%.

21. Combinaison du matériau absorbant (12) selon l'une quelconque des revendications précédentes et d'un matériau conducteur de l'électricité (18) lié, directement adjacent au matériau absorbant.


23. Construction stratifiée comprenant deux feuillets d'un matériau absorbant les rayonnements électromagnétiques (12) ou plus, chaque feuillet satisfaisant indépendamment aux exigences de l'une quelconque des revendications 1-20 précédentes.

24. Procédé de fabrication d'un matériau absorbant les rayonnements électromagnétiques (12) comprenant les étapes consistant à:

(a) se munir d'une particule conductrice de l'électricité comprenant une particule de noyau (13) qui contient une couche ultrimince (15) d'un matériau dissipatif métallique, dans laquelle ladite couche (15) possède une épaisseur comprise entre 0,05 et 10 nanomètres, et dans laquelle ladite couche (15) est placée à la surface de la particule de noyau (13) et recouvre uniformément la particule de noyau (13);
(b) produire une couche stable, ultrimince, de matériau isolant (17) recouvrant le matériau dissipatif (15), où la couche isolante à une épaisseur de 1 à 10 nm;
(c) enrober le résultat de (b) dans un matériau liant diélectrique.

25. Procédé de la revendication 24, dans lequel le matériau isolant de l'étape (b) comprend un produit de réaction du
matériau dissipatif de l'étape (a).

26. Procédé de la revendication 24, dans lequel l'étape (b) comprend l'introduction d'oxygène dans le matériau dissipatif.