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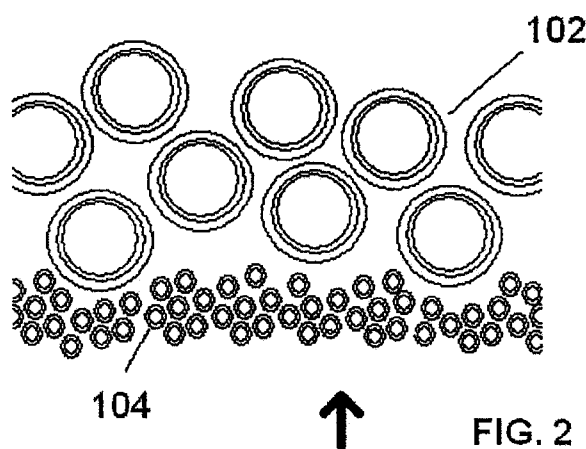
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(54) Title: FABRICS SUITABLE FOR ELECTROMAGNETIC INTERFERENCE SHIELDING APPLICATIONS



(57) Abstract: Exemplary embodiments are provided of an electrically-conductive fabric suitable for electromagnetic interference (EMI) shielding applications. In one exemplary embodiment, the electrically-conductive fabric generally includes a non-woven substrate, nanofibers coupled to the non-woven substrate, and an electrically-conductive plating disposed on at least a portion of the nanofibers.

FABRICS SUITABLE FOR ELECTROMAGNETIC INTERFERENCE SHIELDING APPLICATIONS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a PCT International Application of (and claims priority to) United States Provisional Application No. 61/158,141 filed March 6, 2009. The entire disclosure of the above application is incorporated herein by reference.

FIELD

[0002] The present disclosure generally relates to fabrics suitable for electromagnetic interference (EMI) shielding applications.

BACKGROUND

[0003] This section provides background information related to the present disclosure which is not necessarily prior art.

[0004] The operation of electronic equipment generates electromagnetic radiation within the electronic circuitry of the equipment. Such radiation results in electromagnetic interference (EMI), which can interfere with the operation of other electronic equipment within a certain proximity. A common solution to ameliorate the effects of EMI has been the development of shields capable of absorbing and/or reflecting EMI energy.

[0005] As used herein, the term "EMI" should be considered to generally include and refer to EMI emissions and RFI emissions, and the term "electromagnetic" should be considered to generally include and refer to electromagnetic and radio frequency from external sources and internal sources. Accordingly, the term shielding (as used herein) generally includes and refers to EMI shielding and RFI shielding, for example, to prevent (or at least reduce) ingress and egress of EMI and RFI relative to a housing or other enclosure in which electronic equipment is disposed.

SUMMARY

[0006] This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

[0007] According to various aspects, exemplary embodiments are provided of fabrics suitable for electromagnetic interference (EMI) shielding applications. In one exemplary embodiment, a fabric includes a non-woven fabric substrate, nanofibers coupled to the non-woven substrate, and an electrically-conductive plating disposed on at least a portion of the nanofibers. In another exemplary embodiment, an electrically-conductive fabric includes a non-woven fabric substrate and electrospun nanofibers deposited along at least a surface portion of the non-woven fabric substrate.

[0008] Other exemplary embodiments provide electromagnetic interference shielding gaskets. In one exemplary embodiment, a gasket includes an electrically-

conductive fabric. The electrically-conductive fabric includes a non-woven fabric substrate and a nanofiber layer including between about 0.5 grams per square meter to about 1 gram per square meter of nanofibers deposited along at least a surface portion of the non-woven fabric substrate. Still other exemplary embodiments provide methods of making an electrically-conductive fabric suitable for electromagnetic interference (EMI) shielding application. In one exemplary embodiment, a method includes depositing nanofibers onto at least a portion of a non-woven substrate and metalizing at least one of the non-woven substrate and the nanofibers.

[0009] Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

DRAWINGS

[0010] The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

[0011] FIG. 1 is a elevational view of a fabric according to an exemplary embodiment of the present disclosure;

[0012] FIG. 2 is a magnified elevational view of the fabric of FIG. 1;

[0013] FIG. 3 is an elevational view of a fabric including a non-woven fabric substrate with nanofibers on opposing surfaces according to an exemplary embodiment of the present disclosure;

[0014] FIG. 4 is an elevational view of a fabric including two non-woven fabric substrates according to an exemplary embodiment of the present disclosure;

[0015] FIG. 5 is an elevational view of an electromagnetic interference gasket according to an exemplary embodiment of the present disclosure;

[0016] FIG. 6 is a schematic view of an electrospinning process for depositing nanofibers onto at least a portion of a non-woven substrate according to an exemplary embodiment of the present disclosure;

[0017] FIG. 7 is a cross-section view of a nanofiber included in the fabric of FIG. 2; and

[0018] FIG. 8 is a block diagram of a method of plating a fabric according to an exemplary embodiment of the present disclosure.

DETAILED DESCRIPTION

[0019] Example embodiments will now be described more fully with reference to the accompanying drawings.

[0020] In accordance with various exemplary embodiments, the present disclosure generally relates to fabrics suitable for electromagnetic interference (EMI) shielding applications. The fabrics may be used, for example, in application for reducing electromagnetic radiation from and/or into electronic equipment. Other aspects of the present disclosure relate to methods of making and/or using fabrics suitable for EMI shielding applications. In various examples, the fabric may be a laminate having several layers.

[0021] Referring to the drawings, FIG. 1 illustrates a fabric 100 according to an exemplary embodiment of the present disclosure. As shown, the fabric 100 includes a non-woven fabric substrate 102, nanofibers 104, and an electrically-conductive plating (not visible in FIG. 1) disposed on at least a portion of the nanofibers 104. The nanofibers 104 are coupled to at least a portion of the non-woven fiber substrate 102. By coupling the nanofibers 104 to the non-woven fabric substrate 102, as shown, nanofibers 104 are disposed over a number of voids defined by the non-woven fabric substrate 102 such that a surface area of the combination is increased, as compared to a surface area of the non-woven fabric substrate alone.

[0022] A magnification of the fabric 100 is illustrated in FIG. 2. As shown, the non-woven fabric substrate 102 defines a number of voids. The nanofibers 104 coupled to the non-woven fabric substrate 102 are composed at least partially of filaments having smaller diameters relative to the diameters and/or cross-sectional area of the fibers of the non-woven fabric substrate 102. When the nanofibers 104 are deposited, *e.g.*, via an electrospinning process, etc., onto the non-woven fabric substrate 102, the nanofibers 104 are deposited into and/or onto the voids of the non-woven fabric substrate 102. Accordingly, a surface which comes into contact with the fabric 100 (as represented by the upwardly pointing arrow in FIG. 2) will contact the nanofibers 104, rather than the non-woven fabric substrate 102. In this exemplary manner, surface contact between the surface and the fabric 100 is increased because of the small diameters of the nanofibers 104 deposited onto the non-woven fabric substrate 102 that fills voids in the non-woven fabric substrate 102. Indeed, the fabric 100 provides a highly homogeneous surface with a small pore structure, potentially eliminating (or at least reducing) issues caused by adhesive penetration.

[0023] When the nanofibers 104 are deposited onto at least a portion of the non-woven fabric substrate 102, the thickness, coverage, coating or basis weight, etc. of the nanofibers 104 deposited can be different depending on the particular application. In some example applications, electrospun nanofibers are coupled to a non-woven substrate such that between about 0.2 g/m² (grams per square meter) and about 1.0 g/m² of nanofibers covers at least a portion of the non-woven substrate. In other applications that may require different EMI performance, electrospun nanofibers are coupled to a non-woven substrate

such that between about 0.5 g/m^2 and about 1.0 g/m^2 of nanofibers covers at least a portion of the non-woven substrate. In one example, a layer of nanofibers may be about 1.0 g/m^2 , which the inventor hereof believes will improve EMI filtration by about 30 percent over known cellulose filtration paper. In another example, a layer of nanofibers may be about 1.5 g/m^2 . In yet another example, a layer of nanofibers may be about 0.2 g/m^2 . In a further example, a layer of nanofibers may be about 0.5 g/m^2 . While nanofibers are generally uniformly distributed across the at least one portion of the non-woven substrate so as provide a homogeneous surface, it should be understood that a non-uniform distribution of nanofibers may be employed in other embodiments.

[0024] The non-woven fabric substrate 102 illustrated in FIG. 1 includes spunbond polyester. In other embodiments of the present disclosure, a non-woven fabric substrate may include a type of polyester, *e.g.*, a spunbound polyester, a wetlaid flat calendered polyester, etc. In still other embodiments, a non-woven fabric substrate may include spunbond polyamid, wetlaid flat calendered polyamid, and/or a different type of polyamid. Notwithstanding the specific exemplary embodiments disclosed herein, alternative embodiments may include a different type of organic non-woven substrate of the present disclosure. Still other embodiments may include an inorganic non-woven substrate.

[0025] With continued reference to the example illustrates in FIGS. 1 and 2, the nanofibers 104 are formed from organic polymer solutions and melts in an electrospinning process, resulting in endless, non-hollow filaments. While the nanofibers illustrated in FIG. 1 are electrospun nanofibers, it should be appreciated that nanofibers can be deposited on a non-woven fabric substrate by different techniques in other embodiments of the present disclosure (*e.g.*, such as the example described below with reference to FIG. 6). For example, nanofibers may be deposited onto at least a portion of a non-woven fabric substrate by drawing out, base synthesis, phase separation, self-organization, etc. A particular technique of depositing nanofibers onto a non-woven fabric substrate may be employed in other embodiments based on cost, performance, manufacturability, environmental constraints, a characteristic of the nanofibers, such as a diameter of a filament of nanofiber or a thickness, coverage, coating or basis weight, etc. of a nanofiber layer, and/or other considerations, etc.

[0026] The fabric 100 is operable for shielding electromagnetic interference across a range of frequencies, such as a frequency range from about 200 Megahertz to about 24 Gigahertz in some embodiments. It should be appreciated that a fiber according to the present disclosure may include a different shape, size, thickness, coverage, coating or basis weight, configuration etc. to shield EMI in various discrete ranges between about 200 Megahertz and about 24 Gigahertz, other frequency ranges below 200 Megahertz or greater than 24 Gigahertz, etc.

[0027] As shown in FIG. 1, the non-woven fabric substrate 102 includes generally opposing first and second surfaces 106, 108. The nanofibers 104 are deposited only on the second surface 108. In other embodiments of the present disclosure, a different number of non-woven fabric substrates may be employed with nanofibers deposited on one or more surfaces depending on the particular implementation of the embodiment. Nanofibers may also be deposited on less than an entire surface of a non-woven fabric substrate. In one exemplary embodiment illustrated in FIG. 3, the fabric 300 includes a non-woven fabric substrate 302. Nanofibers 304, 306 are deposited on first and second opposing surfaces 308, 310, respectively. In another exemplary embodiment illustrated in FIG. 4, the fabric 400 includes a first non-woven fabric substrate 402 and a second non-woven fabric substrate 404. The fabric 400 further includes nanofibers 406 disposed between the first and second non-woven fabric substrates 402, 404.

[0028] In various exemplary embodiments, an electromagnetic interference (EMI) gasket includes an electrically-conductive fabric including a non-woven fabric substrate and nanofibers. The electrically-conductive fabric can be implemented, alone or in combination, in EMI shielding applications. In one example illustrated in FIG. 5, an EMI gasket 500 includes an electrically-conductive fabric 502 coupled to a resilient core member 504 (e.g., foam, etc.). The electrically conductive fabric 502 includes a non-woven fabric 506 and a nanofiber layer 508. The resilient core member permits the EMI gasket 500 to be efficiently disposed within a gap, etc. between two components of electronic equipment. The EMI gasket 500, via the resilient core member 504, is compressible between the two components, thereby minimizing (or at least reducing) gaps between the two components from which electromagnetic energy may be radiated. The resilient core member 504 may include a foam material, thereby providing a fabric-over-foam ("FOF") EMI gasket 500. In other embodiments, different types of resilient core members may be used depending on the particular installation, size demands, etc. for an EMI gasket. In still other embodiments, a resilient core member may be omitted from an EMI gasket including an electrically-conductive fabric according to the present disclosure.

[0029] While the resilient core member 504 is wrapped with the electrically-conductive fabric 502 in FIG.5, it should be appreciated that a fabric may be disposed over a different number of surfaces in other embodiments of the present disclosure. For example, a fabric may be disposed over only a top surface of a resilient core member. In other exemplary embodiments, a fabric may be coupled to one or more portions of a resilient core member, intended to contact electronic equipment when installed. In various examples, a fabric may be coupled to a resilient core member via adhesives, etc.

[0030] The dimensions of the gasket 500 may be varied depending on a particular installation, functionality, space considerations, etc. It should further be

appreciated that gaskets according to the present disclosure may be incorporated into a wide range of electronic equipment.

[0031] FIG. 6 illustrates a schematic view of an electrospinning process for depositing a nanofiber on a non-woven fabric substrate. In this example, the process utilizes a system 600. As shown in FIG. 6, the system includes a capillary 602, a reservoir 604, a collector or conductor plate 606, and a voltage source 608. The reservoir 604 is in fluidic communication with the capillary 602. The capillary 602 is coupled to the positive electrode 610 of the voltage source 608. The conductor plate 606 is coupled to the negative electrode 612 of the voltage source 608, generally earth ground. In use, an organic polymer solution is supplied to the reservoir 604, and a non-woven fabric substrate 614 is coupled to the conductor plate 606. As current flows from the voltage source 608, *e.g.*, a high voltage source, etc., into the capillary 602, the polymer solution becomes charged and follows a current path from the end of the capillary 602 to the conductor plate 606, through the non-woven fabric substrate 614. As the polymer solution passes from the capillary 602, the polymer solution forms a cone-shape as polymer solution approaches the non-woven fabric substrate 614. Also, as polymer solution approaches the non-woven fabric substrate 614, the polymer solution dries, leaving filaments of nanofibers 616 deposited on the non-woven fabric substrate 614. In this exemplary manner, the nanofibers 616 may be continuously, and endlessly, supplied to the non-woven fabric substrate 614. Either one of the capillary 602 and the conductor plate 606 can be rotated, displaced, and/or moved to deposit a uniform thickness of the nanofibers 616 onto at least a portion of the non-woven fabric substrate 614.

[0032] Additionally or alternatively, a distance between the capillary 602 and the conductor plate 606 can be adjusted to change the diameter of the filaments of nanofibers 616. In one exemplary embodiment, the distance between a capillary and a collector/conductor plate may be configured to provide filaments of nanofibers with diameters of less than about 1.0 micrometers. It should further be appreciated from the example electrospinning process illustrated in FIG. 6 that the length of the nanofibers is independent of the electrospinning process. Accordingly, nanofibers may have virtually any length based on a size of a non-woven fabric substrate, a thickness of nanofibers, efficiency of the electrospinning process, etc. as desired for a particular embodiment.

[0033] Referring again to FIG. 2, the fibers of the non-woven fabric 102 and the nanofibers 104 are plated to be electronically-conductive. As generally shown in FIG. 7, one of the nanofibers 702 is illustrated as being plated with copper 704 and nickel 706. It should be understood that different metallic and/or non-metallic plating(s) may be employed in other embodiments of the present disclosure to render a fabric electrically-conductive. For example, a nanofiber may be plated with only one of copper and nickel. In other examples, other materials may be used, such as copper, nickel, nickel copper, palladium, platinum,

silver, tin, tin copper, gold, alloys thereof, etc. While the plating is disposed on the non-woven fabric substrate 102 and the nanofibers 104 of the fabric 100 as shown in FIG. 2, it should be appreciated that only the nanofibers or the non-woven fabric substrate may be plated in other embodiments of the present disclosure.

[0034] By way of example only, the non-woven fabric substrate and nanofibers may be metalized in accordance with the operations or processes 802 and 804 of the exemplary process 800 shown in FIG. 8. In this example, the non-woven fabric substrate and nanofibers are catalyzed at operation 802. Various embodiments may catalyze the porous substrate at operation 802 by using one or more of the processes or methods described in U.S. Patent 6,395,402 entitled “Electrically Conductive Polymeric Foam and Method of Preparation Thereof”, the disclosure of which is incorporated herein by reference.

[0035] With continued reference to FIG. 8, operation 804 includes plating and/or metalizing the catalyzed porous substrate with one or more metals. In one particular embodiment, the catalyzed porous substrate is plated with copper, and then plated with nickel. Alternatively, the porous substrate may be provided with more or less than two metal layers, may be provided with metals using other processes (*e.g.*, batch plating, reel-to-reel metal plating, physical vapor deposition, electroless plating, electrolytic plating, combinations thereof, etc.), and/or may be provided with metals besides nickel and copper. The plating process generally includes partially or wholly immersing the nanofibers into a solution containing the metal or non-metal plating to be disposed on the nanofibers. In one example, plating includes immersing nanofibers in a copper solution and applying an electrical current thereto.

[0036] In the description, numerous specific details are set forth such as examples of specific components, devices, methods, in order to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to a person of ordinary skill in the art that these specific details need not be employed, and should not be construed to limit the scope of the disclosure. In the development of any actual implementation, numerous implementation-specific decisions must be made to achieve the developer's specific goals, such as compliance with system-related and business-related constraints. Such a development effort might be complex and time consuming, but is nevertheless a routine undertaking of design, fabrication and manufacture for those of ordinary skill. Example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be

construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail. Moreover, any one or more aspects of the present disclosure may be implemented individually or in any combination with any one or more of the other aspects of the present disclosure.

[0037] The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items. Also as used herein, the singular forms "a", "an" and "the" may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms "comprises," "comprising," "including," and "having," are inclusive and therefore specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

[0038] When an element or layer is referred to as being "on", "engaged to", "connected to" or "coupled to" another element or layer, it may be directly on, engaged, connected or coupled to the other element or layer, or intervening elements or layers may be present. In contrast, when an element is referred to as being "directly on," "directly engaged to", "directly connected to" or "directly coupled to" another element or layer, there may be no intervening elements or layers present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., "between" versus "directly between," "adjacent" versus "directly adjacent," etc.). As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0039] Although the terms first, second, third, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another region, layer or section. Terms such as "first," "second," and other numerical terms, "next," etc., when used herein, do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the example embodiments.

[0040] Spatially relative terms, such as "inner," "outer," "beneath", "below", "lower", "above", "upper" and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the example term "below" can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

[0041] The disclosure herein of particular values and particular ranges of values for given parameters are not exclusive of other values and ranges of values that may be useful in one or more of the examples disclosed herein. Moreover, it is envisioned that any two particular values for a specific parameter stated herein may define the endpoints of a range of values that may be suitable for the given parameter (*i.e.*, the disclosure of a first value and a second value for a given parameter can be interpreted as disclosing that any value between the first and second values could also be employed for the given parameter). Similarly, it is envisioned that disclosure of two or more ranges of values for a parameter (whether such ranges are nested, overlapping or distinct) subsume all possible combination of ranges for the value that might be claimed using endpoints of the disclosed ranges.

[0042] The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the invention, and all such modifications are intended to be included within the scope of the invention.

CLAIMS

What is claimed is:

1. A fabric suitable for electromagnetic interference (EMI) shielding applications, the fabric comprising a non-woven fabric substrate, nanofibers coupled to the non-woven fabric substrate, and an electrically-conductive plating disposed on at least a portion of the nanofibers.
2. The fabric of claim 1, wherein the non-woven fabric substrate includes an organic material.
3. The fabric of claim 1 or 2, wherein the non-woven fabric substrate includes at least one or more of spunbond polyester, spunbond polyamide, wetlaid flat calendared polyester, or wetlaid flat calendared polyamid.
4. The fabric of any one of claims 1-3, wherein the nanofibers comprise electrospun filaments having a diameter of less than about 1.0 micron.
5. The fabric of any one of claims 1-4, wherein between about 0.2 grams per square meter to about 1.5 grams per square of the nanofibers are on the non-woven fabric substrate.
6. The fabric of any one of claims 1-5, wherein between about 0.5 grams per square meter to about 1 gram per square of the nanofibers are on the non-woven fabric substrate.
7. The fabric of any one of claims 1-6, wherein the non-woven fabric substrate comprises a sheet having generally opposing first and second surfaces and the electrospun nanofibers are substantially uniformly deposited on at least one of the first and second surfaces of the sheet.
8. The fabric of any one of claims 1-7, wherein the fabric is operable at shielding electromagnetic interference in a frequency range from about 200 Megahertz to about 24 Gigahertz.
9. An electromagnetic interference (EMI) gasket comprising the fabric of any one of claims 1-8.
10. The EMI gasket of claim 9, further comprising a resilient core coupled to said fabric.
11. An electromagnetic interference (EMI) shielding gasket comprising an electrically-conductive fabric including a non-woven fabric substrate and a nanofiber layer including between about 0.5 grams per square meter to about 1 gram per square meter of nanofibers deposited along at least one portion of at least one surface of the non-woven fabric substrate.
12. The gasket of claim 11, wherein the nanofibers are formed from an organic polymer and generally include thicknesses of less than about 1.0 micrometer.

13. The gasket of claim 11 or 12, wherein the electrically-conductive fabric includes metal plating disposed on one or the non-woven fabric substrate and nanofiber layer.

14. An electrically-conductive fabric suitable for electromagnetic interference (EMI) shielding applications, the electrically-conductive fabric comprising a non-woven fabric substrate and electrospun nanofibers deposited along at least a surface portion of the non-woven fabric substrate.

15. The fabric of claim 14, wherein the nanofibers form a layer on the non-woven fabric substrate between about 0.2 grams per square meter to about 1.5 grams per square meter.

16. The fabric of claim 14 or 15, wherein the electrospun nanofibers include a pore structure and specific surface area such that the fabric is operable for shielding electromagnetic interference in a frequency between about 200 Megahertz to about 24 Gigahertz.

17. The fabric of any one of claims 14-16, wherein the electrospun nanofibers comprise electrospun nanofibers metalized with at least one of copper and nickel.

18. A fabric-over-foam electromagnetic interference (EMI) gasket comprising a foam core about which is wrapped the fabric of any one of claims 1-7 or 14-17.

19. A method of making an electrically-conductive fabric suitable for electromagnetic interference (EMI) shielding applications, the method comprising depositing nanofibers onto at least a portion of a non-woven substrate and metalizing and/or plating at least one of the non-woven substrate and the nanofibers.

20. The method of claim 19, wherein depositing nanofibers includes electrospinning nanofibers onto at least a portion of a non-woven substrate.

21. The method of claim 19 or 20, wherein depositing nanofibers includes depositing between about 0.5 grams per square meter to about 1.0 gram per square meter of nanofibers onto at least a portion of a non-woven substrate.

22. The method of any one of claims 19-21, wherein metalizing includes applying one or more of a nickel solution and a copper solution to the nanofibers.

23. The method of claim 22, wherein applying one or more of a nickel solution and a copper solution includes immersing at least a portion of the nanofibers in the one or more of a nickel solution and a copper solution.

24. The method of any one of claims 19-23, wherein the non-woven substrate include one of polyester and a polyamid.

25. The method of any one of claims 19-24, wherein the method includes making the non-woven substrate by one or more of spunbond polyester, spunbond polyamide, calendaring wetlaid flat polyester, or calendaring wetlaid flat polyamid.

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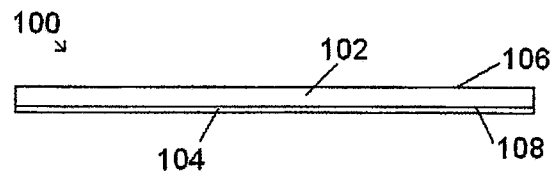


FIG. 1

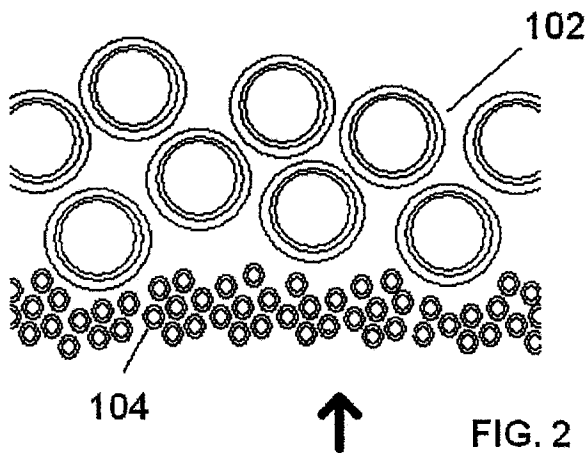


FIG. 2

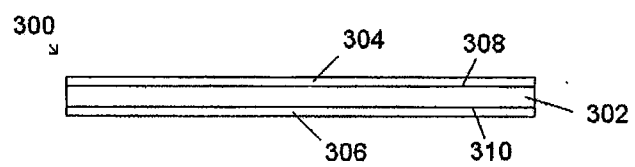


FIG. 3

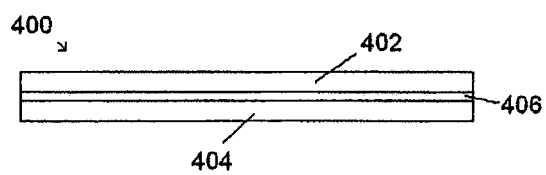


FIG. 4

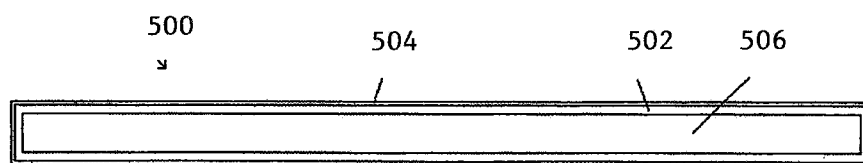


FIG. 5

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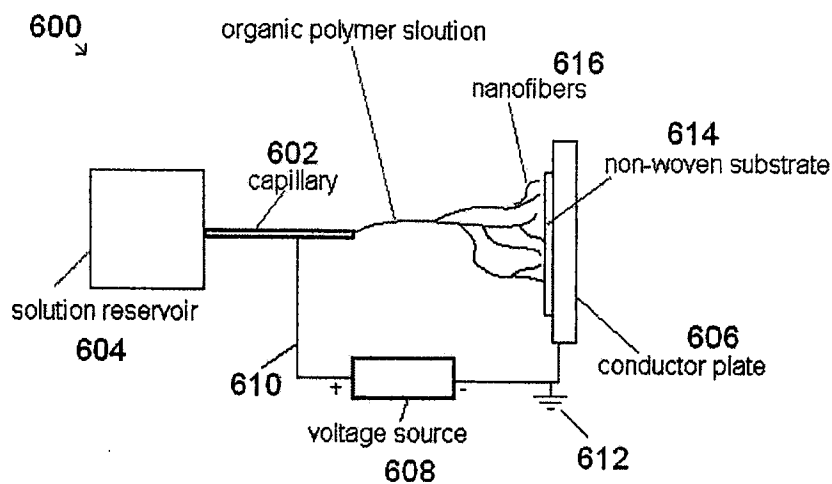


FIG. 6

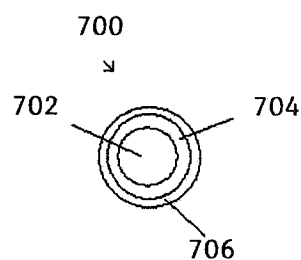


FIG. 7

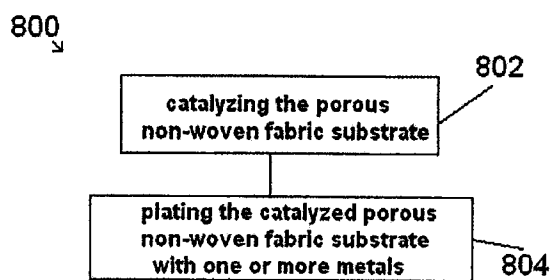


FIG. 8