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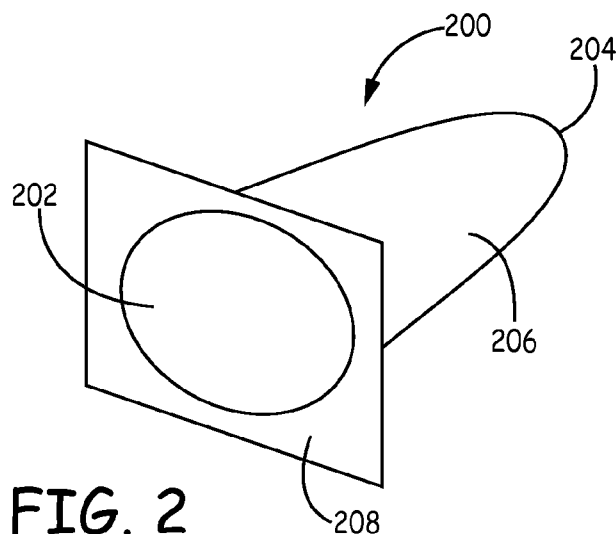
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(54) Title: RECIRCULATION FILTER FOR AN ELECTRONIC ENCLOSURE



**FIG. 2**

(57) Abstract: A filter assembly for use in an electronic enclosure is provided. The filter assembly includes a highly permeable scrim that defines an elongate enclosure with an inlet at a first end and a closed second end, wherein an electrostatic filtration media is dis-

## **RECIRCULATION FILTER FOR AN ELECTRONIC ENCLOSURE**

This application is being filed as a PCT International Patent application on August 10, 2013 in the name of Donaldson Company, Inc., a U.S. national corporation, applicant for the designation of all countries and Stanley B. Miller, III, a U.S. Citizen; Allen N. Nicklay, a U.S. Citizen; Christopher J. Fischer, a U.S. Citizen; and Daniel L. Tuma, a U.S. Citizen, are applicants and inventors for all designated states, and claim priority to U.S. Provisional Patent Application No. 61/681,618, filed August 10, 2012, and to U.S. Patent Application No. 13/831,458, filed March 14, 2013, the contents of which are herein incorporated by reference in its entirety.

### **FIELD OF THE INVENTION**

The present invention is directed to filters for use in electronic enclosures. In particular, the invention is directed to filters for removing contaminants circulating within the interior of an electronic enclosure.

### **BACKGROUND**

Contaminants within an electronic enclosure, such as a hard disk drive enclosure, can reduce the efficiency and longevity of the components within the enclosure. Contaminants can include chemicals and particulates, and can enter the hard drive enclosure from external sources, or be generated within the enclosure during manufacture or use. The contaminants can gradually damage the drive, resulting in deterioration of drive performance and even complete failure of the drive. Consequently, data storage systems such as hard disk drives typically include one or more filters capable of removing or preventing entry of particulate and/or chemical contaminants in the air within the disk drive enclosure. One type of such filter is a recirculation filter, which is generally placed such that it can filter out contaminants from the path of airflow caused by rotation of one or more disks within the disk drive. Although existing recirculation filters can remove many contaminants, a need exists for improved performance at removing certain contaminants, in particular, large particulate contaminants.

## **SUMMARY OF THE INVENTION**

The present application is directed, in part, to filter assemblies for use in an electronic enclosure. The filter assemblies are designed to remove particulate contaminants circulating within the electronic enclosure. In particular, the filter assemblies are constructed and arranged so as to effectively reduce the particulate contaminant levels by capturing the particles and preventing their release back into the electronic enclosure. Typically the filter assemblies are constructed with a media geometry that aids in the capture of particles, and which avoids reflection of particles out of the filter assemblies.

The filter assemblies further include, in various embodiments, media configurations that are further designed to promote the capture of particulate contaminants. These media configurations include, for example, constructions with an electrostatic media overlaying all or part of a scrim material on the interior of the filter assembly. Without intending to be bound by a specific mechanism of operation, it is believed that the electrostatic helps prevent particles from striking the media and then bouncing off (often referred to as reflection), which can otherwise occur with exposed scrim materials. The electrostatic may also further help in capturing the particles to prevent their continued circulation through the electronic enclosure.

In an example embodiment, the filter assembly includes a media structure that includes an open front end, a closed rear end, and an internal recess between the open front end and closed rear end. Permeable filter media forms at least a portion of the recess. The recess is typically relatively deep, in some cases as deep or deeper than the width of the filter assembly. Thus, the recess can be conical or column shaped (for example) in some embodiments. This recirculation filter structure with an internal recess promotes the capture and retention of particulate contaminants by having a large open front surface area while having an even larger interior surface area comprising filter media. The interior media surface is generally angled relative to the air flow direction so that particles hit the media at an acute angle such that they can either be retained by the media at the point of initial contact or slowed down sufficiently to be retained deeper inside the filter assembly.

In some implementations at least 50 percent of the surface area of the internal recess has an angle to the opening that is less than or equal to 45 degrees. At least 75 percent of the surface area of the internal recess has an angle to the opening that is less than or equal to 45 degrees in some example implementations. Optionally at least 50 percent of the surface area of the internal recess has an angle to the opening that is less than or equal to 30 degrees. In some example embodiments at least 75 percent of the surface area of the internal recess has

an angle to the opening that is less than or equal to 30 degrees.

In certain implementations the internal recess of the filter assembly has a ratio of maximum depth to maximum diameter of the open front face of at least 1.0, but this maximum depth to maximum diameter ratio can vary, and is often higher than 1.0, such as higher than 1.25, 1.5, 1.75; or 2.0, for example. The internal recess of the filter assembly can have an internal surface area that is at least 2 times the area at the open front face, in other implementations at least 3 times the area at the open front face, and in other implementations at least 4 times the area at the open front face, at least 4 times the area of the open face in some implementations, or at least 5 or 6 times the area at the open front face in certain embodiments.

In some embodiments, the permeable scrim material comprises woven or non-woven material, such as polypropylene fibers. The scrim material can have, for example, a permeability of between about 100 ft./min. at 0.5 inches of water and about 800 ft./min. at 0.5 inches of water in some embodiments. In certain embodiments the scrim material has a permeability of between about 250 ft./min. at 0.5 inches of water and about 600 ft./min. at 0.5 inches of water. The scrim material has a permeability of between about 300 ft./min. at 0.5 inches of water and about 500 ft./min. at 0.5 inches of water in some example implementations. It will be understood that suitable scrim material can have, for example, a permeability of more than 100 ft./min. at 0.5 inches of water; more than 250 ft./min. at 0.5 inches of water; or more than 300 ft./min. at 0.5 inches of water. Suitable scrim material can have, for example, a permeability of less than about 800 ft./min. at 0.5 inches of water in some embodiments; less than 600 ft./min. at 0.5 inches of water in some embodiments; or less than 500 ft./min. at 0.5 inches of water in some embodiments.

The electrostatic material can contain various fibers, and is optionally a mixed fiber media comprising polypropylene and acrylic fibers. The electrostatic material has, for example, a permeability of between about 250 ft./min. at 0.5 inches of water and about 750 ft./min. at 0.5 inches of water. The electrostatic material can have a filtering efficiency of about 20 % to about 99.99 % for 20 to 30 micron particulate contaminants in some embodiments. Suitable electrostatic can, for example, have a filtering efficiency of greater than 20 % for 20 to 30 micron particulate contaminants; greater than 40 % for 20 to 30 micron particulate contaminants; or greater than 60 % for 20 to 30 micron particulate contaminants. The electrostatic material can have in some example implementations a filtering efficiency of less than 99.99 % for 20 to 30 micron particulate contaminants; less than 80 % for 20 to 30 micron particulate contaminants; or less than 60 % for 20 to 30 micron

particulate contaminants.

The above summary of the present invention is not intended to describe each discussed embodiment of the present invention. This is the purpose of the figures and the detailed description that follows.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

The invention will be more fully explained with reference to the following drawings.

FIG. 1 is a simplified perspective view of a disk drive assembly, showing the top of the disk drive assembly removed.

FIG. 2 is a perspective view of a filter assembly constructed and arranged in accordance with an implementation of the invention.

FIG. 3 is a side elevation view of a filter assembly constructed and arranged in accordance with the implementation of the invention shown in FIG. 2.

FIG. 4 is a front elevational view of a filter assembly constructed and arranged in accordance with the implementation of the invention shown in FIG. 2.

FIG. 5A is a cross-sectional view of the filter assembly of FIG. 3 taken along line 3-3'.

FIG. 5B is a detail of a portion of the filter assembly shown in cross section in FIG. 5A, showing the media layers.

FIG. 6 is a partial top plan view of disk drive assembly containing a filter assembly constructed and arranged in accordance with an example implementation of the present invention.

FIGs. 7A-7D are schematic depictions showing a method of making a filter assembly as described herein.

FIG. 8 is a cross sectional view of a filter assembly made in accordance with an implementation of the invention, the filter assembly having an inclined opening.

FIG. 9 is a perspective view of a filter assembly made in accordance with an implementation of the invention, the filter assembly having a plurality of filtration recesses.

FIG. 10 is a cross sectional view of the filter assembly of FIG. 9 taken along lines 9-9'.

FIGs. 11A-11I are schematic depictions showing a method of making a filter assembly as described herein.

FIG. 11J is chart depicting a method of making a filter assembly as described herein

FIGs. 12A-12G are schematic depictions showing a method of making a filter

assembly as described herein.

FIG. 12H is chart depicting a method of making a filter assembly as described herein

FIG. 13A is a cross sectional view of a filter assembly.

FIG. 13B is a cross sectional view of a filter assembly.

FIG. 14A is a cross sectional view of a filter assembly as described herein

FIG. 14B is a cross sectional view of a filter assembly as described herein

FIGs. 15A-15E are schematic depictions showing a method of making a filter assembly as described herein.

While principles of the invention are amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the disclosure and claims.

### **DETAILED DESCRIPTION**

Various filtering systems are known that are used to reduce or remove contaminants from disk drive assemblies, as well as other electronic enclosures. In particular, recirculation filters are often used to reduce or remove particulate and/or chemical contaminants that have entered a disk drive enclosure or been generated during use of the disk drive. A typical recirculation filter includes a filter element that is positioned in the path of air currents induced by disk rotation such that contaminants present in the air current are subject to filtration.

However, not all particles that come into contact with the filter are successfully captured. The face velocity of many available filter assemblies is very high, which can increase particle momentum. The high momentum can result in particulate contaminants “reflecting” or “bouncing” off the filter surface, rather than being entrapped by the filter. This phenomenon can be referred to as “particle bounce.” Exposed scrim material, which makes up the surface of many existing recirculation filters, can be a particular problem because particles bounce off the scrim fibers at relatively high rates. Thus, a need exists for an improved recirculation filter that can capture even particulate contaminants having relatively high momentum.

A filter assembly for use in an electronic enclosure is described herein to provide improved particulate contaminant removal. In an example embodiment, the filter assembly includes a media structure having an open front face, a closed rear face, and an internal recess between the open front face and closed rear face. A permeable scrim material can form at least a portion of the media structure. An electrostatic material is disposed within the internal recess of the filter assembly, the electrostatic material at least partially covering the permeable scrim. In an example embodiment the electrostatic material will overlay all or most of the permeable scrim. In some embodiments the electrostatic material and scrim are combined together before production of the filter assembly (such as, for example, by lamination, heat bonding, or light calendaring) and subsequently formed into a media structure that creates at least a portion of the filter assembly.

In certain implementations the internal recess of the filter assembly has a ratio of maximum depth to maximum diameter of the open front face of at least 1.0, but this maximum depth to maximum diameter ratio can vary, and is often higher than 1.0, such as 1.25, 1.5, 1.75; or 2.0, for example. The internal recess of the filter assembly can have an internal surface area that is at least 2 times the area at the open front face, in other implementations at least 3 times the area at the open front face, and in other implementations

at least 4 times the area at the open front face, or at least 5 or 6 times the area at the open front face.

In some embodiments, the permeable scrim material comprises woven or non-woven material, such as polypropylene fibers. The scrim material can have, for example, a permeability of between about 100 ft./min. at 0.5 inches of water and about 800 ft./min. at 0.5 inches of water in some embodiments. In some embodiments the scrim material has a permeability of about 250 ft./min. at 0.5 inches of water and about 600 ft./min. at 0.5 inches of water. In yet other implementations the scrim material has a permeability of about 300 ft./min. at 0.5 inches of water and about 500 ft./min at 0.5 inches of water, It will be understood that suitable scrim material can have, for example, a permeability of more than 100 ft./min. at 0.5 inches of water; more than 250 ft./min. at 0.5 inches of water; or more than 300 ft./min. at 0.5 inches of water. Suitable scrim material can have, for example, a permeability of less than about 800 ft./min. at 0.5 inches of water in some embodiments; less than 600 ft./min. at 0.5 inches of water in some embodiments; or less than 500 ft./min. at 0.5 inches of water in some embodiments.

The electrostatic material can contain various fibers, and is optionally a mixed fiber media comprising polypropylene and acrylic fibers. The electrostatic material has, for example, a permeability of between about 250 ft./min. at 0.5 inches of water and about 750 ft./min. at 0.5 inches of water. The electrostatic can have a filtering efficiency of about 20 % to about 99.99 % for 20 to 30 micron particulate contaminants in some embodiments. Suitable electrostatic can, for example, have a filtering efficiency of greater than 20 % for 20 to 30 micron particulate contaminants; greater than 40 % for 20 to 30 micron particulate contaminants; or greater than 60 % for 20 to 30 micron particulate contaminants. The electrostatic can have in some example implementations a filtering efficiency of less than 99.99 % for 20 to 30 micron particulate contaminants; less than 80 % for 20 to 30 micron particulate contaminants; or less than 60 % for 20 to 30 micron particulate contaminants.

Now, in reference to the drawings, Figure 1 is a simplified perspective representation of a disk drive 100. The disk drive 100 includes body 102 that forms an enclosure 104. In an example embodiment, one or more rotatable magnetic disks 106 are positioned within the enclosure 104. The rotation of the drive is shown by arrows (although opposite rotation is alternatively possible). Other disk drive components, such as a read-write head and wiring can be incorporated into an armature 108.

An example embodiment of a filter assembly 200 is shown in Figures 2, 3 and 4. As shown in Figure 2, the filter assembly comprises an open front end 202, and a closed rear end



204. The filter assembly 200 includes an elongate media structure 206 between the front end 202 and rear end 204, the elongate media structure 206 being primarily made of filter media, such as in an example embodiment, a scrim on one side with an electrostatic material on the other side. Preferably the electrostatic media is located on the interior side of the elongate media structure 206. Sidewalls forming the elongate media structure extend from the open front end 202 to the closed rear end 204. In the implementation shown, the elongate media structure 206 is secured to a frame 208. The frame 208 can be, for example, a metal or plastic support that secures the media structure 206 and may aid in installation into an electronic enclosure.

This example filter assembly 200 is also shown in Figure 3, in side elevational view, and in Figure 4 in front view (taken from the front end 202). Measurement of the diameter “D” of the filter assembly 200 is taken along the open interior of the filter assembly 200 at the front end 202. The opening can be generally circular as shown in Figure 2. In the alternative, the opening can be oval shaped, otherwise non-circular, and rectangular or otherwise the approximate shape of a polygon, for example. In many embodiments, however, the opening will be circular, semi-circular, ovular, semi-ovular, or otherwise have a generally rounded front opening. This generally rounded front opening allows for ease of manufacture of the filter assembly 200.

In Figure 4, two diameters are shown:  $D_x$  and  $D_y$ .  $D_x$  refers to the longest diameter across the open front end 202, and  $D_y$  refers to a diameter at the open front end 202 that is perpendicular to  $D_x$ . Diameter of non-circular openings can be measured by taking an average diameter (such as by averaging the  $D_x$  and  $D_y$  diameters), or by measuring a maximum diameter, such as  $D_x$ . In general, at least one of  $D_x$  and  $D_y$  is between about 0.25 and about 1 inches. Generally the length “L”, shown in Figure 2, of the filter assembly 200 is greater than the diameter of the filter assembly 200. Specifically, the length L is typically longer than the longer of  $D_x$  and  $D_y$ . In some implementations length L is longer than the average of  $D_x$  and  $D_y$ . In one embodiment, the length “L” of the filter assembly 200 can be at least 1.5, 2, or 3 times the longer of the diameters  $D_x$  and  $D_y$  of the filter assembly. The length L can be, for example, between about 0.25 and about 2 inches.

The open front end 202 is generally positioned upstream from the closed rear end 204 with respect to airflow within the electronic enclosure. The elongate shape of the filter assembly 200, in particular the elongate media structure 206, increases the surface area of filtration media to which the airflow is exposed, thereby increasing the amount of particles that are captured by the filter assembly 200 during filtration, as well as entrapping particles with higher mass or momentum. Furthermore, the construction of the filter assembly, with a large front opening, and an even larger media surface area in the elongate media structure 206, reduces pressure restriction of the filter assembly 200.

In an example embodiment, the filter assembly 200 has a substantially cylindrical configuration. As used herein, the term “substantially cylindrical” means that the front end 202 and rear end 204 of the filter assembly are substantially circular and the sidewalls 212 (Figure 3) of the filter assembly 200 are parallel or substantially parallel. In another embodiment, the filter assembly 200 has a substantially conical or parabolic configuration. As used herein, the term “substantially conical” or “substantially parabolic” means that the open front end 202 converges towards the closed rear 204 end of the filter assembly 200. Other filter assembly configurations are also possible, in particular other elongate configurations having an ovoid, square, rectangular or other cross-sectional shape either with or without converging sidewalls, and would fall within the scope of the invention.

While not wishing to be bound by theory, it is believed that the use of an open filtration construction with large media surface area reduces surface velocity of the particulate contaminants and can thereby increase particle capture. In an example embodiment, the filtration media has a 20 micron to 30 micron filtering efficiency of about 20 % to about 99.99 %. The permeability of the filtration media is generally between about

250 ft./min. at 0.5 inches of water and about 750 ft./min. at 0.5 inches of water. The basis weight is generally between about 45gm/m<sup>2</sup> and about 165 gm/m<sup>2</sup>.

Figure 5A shows a cross section of the filter assembly 200 of FIGs. 2 to 4. Figure 5A shows the angle alpha between the side wall 212 and a line 214 perpendicular to the front end 202 of the filter assembly 200, corresponding to the path of a particle flowing perpendicular to the front end 202 of the filter assembly. This angle alpha is typically less than 45 degrees over the majority of the sidewall forming the elongate member 206, and alternatively less than 30 degrees or less than 15 degrees over the majority of the media. Figure 5B shows a simplified enlarged view of a cross section of the filter assembly, showing an electrostatic layer 220 and a support layer 222 (such as a scrim layer). The line 214 at angle alpha is also shown, depicting the relatively acute angle (e.g. preferably less than 45 degrees) at which particles that are travelling perpendicular to the opening will strike the media. In the alternative, the media forming the filter assembly 200 can be formed of a single layer, or more than two layers. Also, in certain embodiments a portion of the media is single layer, and a portion of the media has more than one layer.

In one embodiment, the filtration media forming the elongate portion 206 includes electrostatic fibers. The term “electrostatic fibers,” as used herein, refers to fibers that contain an electric charge. One advantage of including electrostatic fibers in the filter assembly 200 is that the filter is not only able to mechanically trap contaminants, but is also able to exert an electrostatic force on contaminants that contain electric charges, thereby increasing the amount of contaminants that are removed from the airstream. The electrostatic media can be triboelectric media, electret media, or any other media that can be charged, or that depends on charging as the main mechanism for particle removal. In example embodiments, the electrostatic media include triboelectric fibers. Triboelectric fibers are known and can be formed, for example, using a mixture of (1) polyolefin fibers such as polyethylene, polypropylene or ethylene and propylene copolymers, with (2) fibers of another polymer, for example, fibers containing hydrocarbon functions substituted by halogen atoms, such as chlorine or polyacrylonitrile fibers. In general, the polyolefin fibers and the other polymer fibers are included in the electrostatic media at a weight ratio between about 60:40 or about 20:80 or about 30:70.

Figure 6 shows a filter assembly 200 installed within an electronic enclosure 100 (only a corner of the enclosure 100 is depicted). The filter assembly 200 is oriented so that the open front end 202 is directed toward the air stream generated by the rotating disk 106 (depicted directionally by arrows). In the embodiment shown, a baffle 114 is present to aid in

the direction of air into the open front end 202 of the filter assembly 200. The filter assembly 200 can be placed within the electronic enclosure such that the baffle 114 directs air into and through the open front end 202. In certain implementations the baffle 114, along with any mounting elements (such as a frame 208 shown in Figure 2) or other portions of the housing form a channel that directs air into the open front end 202. In other implementations the filter assembly 200 is positioned in a flowing air stream without a channel directing air into it, or only an open sided channel that only partially directs air into the filter assembly 200.

One method for making a filter assembly as described herein is shown schematically in Figure 7A to 7D. In this method, a sheet of scrim material 302 having a length " $L_m$ " and a width " $W_m$ " is provided (FIG. 7A). The scrim material 302 is rolled along an axis substantially parallel to the length  $L_m$  of the scrim to form a cylindrical or conical article 306 (FIG. 7B). The scrim 302 is sealed along the length  $L_m$  of the article, for example, using an adhesive or by welding. An end 304 of the article is then sealed to form a closed article that defines a chamber having a length " $L_A$ " (FIG. 7C). The opposite end 302 is then adhered to a frame 308, for example, using an adhesive, or by welding (FIG. 7D) and a filtration media, for example, an electrostatic filtration media is introduced into the interior of the elongate member formed by the process.

FIG. 8 is a cross sectional view of a filter assembly 400 made in accordance with an alternative implementation of the invention, the filter assembly having an inclined opening 402 secured to a frame 408. Media is configured in an elongate member 406. The filter assembly 400 has a length " $L$ " measured from the middle of the opening, and diameter " $D$ ". The overall configuration and performance is similar to that of assembly 200 discussed above, only the open end 402 and frame 408 are angled relative to the elongate media member 406. Also, the filter assembly 400 has sidewalls 410 and 412 of different lengths from one another.

FIG. 9 is a perspective view of a filter assembly 500 made in accordance with an implementation of the invention, the filter assembly 500 having a plurality of filtration recesses 520. FIG. 10 is a cross sectional view of the filter assembly of FIG. 9 taken along lines 9-9', showing the filter assembly 500 with recesses 520. The cross section shows the relative length " $L$ " and diameter " $D$ " of the filter assembly 500. Typically the length  $L$  is at least 1.5 times the diameter  $D$ , more commonly the length  $L$  is at least 2.0 times the diameter  $D$ . In some implementations the length  $L$  is at least 3.0 times the diameter  $D$ . The filter assembly 500 will typically have a sealed back end 522 covered by media, such as a scrim material or an electrostatic material covering a scrim material.

A method for making a filter assembly as described herein is shown schematically in Figures 11A to 11I. In the example method, a sheet of filter material 1102 is provided (FIG. 11A). The sheet of filter material 1102 can comprise an electrostatic layer 1120 and a support layer 1122 (such as a scrim layer). The sheet of filter material 1102 can be pressed into a desired configuration. The method can comprise the use of a nest 1104. The nest 1104 can comprise a recess 1106 (FIG. 11B). The recess 1106 can be shaped similarly to the desired final shape of the filter assembly. The method can comprise the use of a horn 1108 (FIG. 11C). The horn 1108 can have a similar shape as the desired final shape of the filter assembly. The sheet of filter material 1102 can be positioned between the horn 1108 and a nest 1104 (FIG. 11D).

The horn 1108 can be moved into a position where the horn 1108 is at least partially disposed within the recess 1106 of the nest 1104. The filter material 1102 can conform to the outer shape of the horn 1108 and the shape of the recess 1106. In an embodiment, sufficient force is applied to the filter material 1102 to permanently deform the filter material 1102. A small amount of heat or sonic energy is applied to melt some of the media to form a border 1103 that helps retain the shape.

The horn 1108 can be removed from a position where the horn 1108 is at least partially disposed within the recess 1106 (FIG. 11E) and the filter material 1102 can remain in a configuration closely resembling the configuration the filter material 1102 was in when the horn 1108 was at least partially disposed within the recess 1106.

A screen layer 1110 can be placed on top of the filter material 1102, such as to sandwich the filter material 1102 between the nest 1104 and the screen layer 1110 (FIG. 11F). The screen layer 1110 can be welded, fused or otherwise bonded to the filter material 1102. In an embodiment, the filter material 1102 comprises an electrostatic layer 1120 and a support layer 1122 and when the screen layer 1110 is welded to the filter material 1102, the electrostatic layer 1120 can be welded to the support layer 1122. The filter assembly can be welded such as along line 1114. The filter assembly can be welded on a plurality of lines 1114. Any excess material beyond the weld line (FIG. 11H) can be removed from the filter assembly, such as by trimming, resulting in a filter assembly 1100 (FIG. 11I).

The screen layer 1110 can partially cover the open end of the filter assembly. The screen layer 1110 can allow air to pass through the screen layer and into the recess 1106 of the filter assembly. The screen layer 1110 can provide support, such as to aid the filter assembly in keeping a desired configuration.

Figure 11J shows a flow chart depicting a method of making a filter assembly. A filter material can comprise an electrostatic layer and a support layer. The filter material can be sandwiched between a horn and a nest. The horn can be lowered or otherwise moved into a recess in the nest, thereby configuring the filter material to a shape that substantially resembles the shape of the outer surface of the horn and the shape of the recess in the nest. The horn can be removed from the recess. The filter material can be configured to substantially retain its shape once the horn is removed from the recess. A screen layer can be placed on top of the filter material. The screen layer can cover a portion of the open side of the filter material. The layers can be bonded, such as by welding, together. The filter assembly can be removed from the nest. Excess material can be removed from the filter assembly.

A method for making a filter assembly as described herein is shown schematically in Figures 12A to 12G. In this method a sheet of filter material 1202 is provided (FIG. 12A). The sheet of filter material 1202 can comprise an electrostatic layer 1220 and one or more support layer 1222 (such as a scrim layer). The sheet of filter material 1202 can be welded in one or more locations, such as along weld line 1214 (FIG. 12B). The distance between two weld lines 1214 can differ from a first sheet of filter material 1202 to a second sheet of filter material 1202.

The method can also include the use of a nest 1204. The nest 1204 can comprise a recess 1206 (FIG. 12C). The recess 1206 can be shaped similarly to the desired final shape of the filter assembly. A first sheet of filter material 1202 can be placed on the nest 1204. The weld lines 1214 can be perpendicular to the nest 1204. The first sheet of filter material 1202 can be placed on the nest 1204, such that a portion of the recess 1206 is still exposed. In an embodiment an edge of the first filter sheet (such as a welded line 1214) is aligned with an edge of the nest 1204.

The method can comprise the use of a horn 1208 (FIG. 12D). The horn 1208 can have a similar shape as desired final shape of the filter assembly. The sheet of filter material 1202 can be positioned between the horn 1208 and a nest 1204. The horn 1208 can be pressed into the recess 1206, such as to configure the filter material 1202 into a shape that closely resembles the recess 1206 and the horn 1208 (FIG. 12E).

A second sheet of filter material 1202 can be placed on top of the first sheet of filter material 1202, such as to sandwich the horn 1208 in between (FIG. 12F). The first sheet of filter material 1202 can be bonded to the second sheet of filter material 1202, such as by welding along lines 1214. The horn 1208 can be removed from the recess 1206, such as

through the open end of the filter assembly. Removing the horn 1208 can define the recess in the filter assembly. Excess material 1216 can be removed from the filter assembly, such as by trimming it, resulting in a filter assembly 1200 (FIG. 12G).

Figure 12H shows a flow chart depicting a method of making a filter assembly. A filter material can comprise a layer of electrostatic sandwiched between two support layers (such as two scrim layers). A filter material can include two weld lines, such as one at the front portion of the filter assembly and one at the back portion of the filter assembly. The two weld lines can be parallel. A first sheet of filter material can be disposed on a nest. The nest can comprise a recess. The two weld lines can be positioned perpendicular to the recess. A horn can be inserted into the recess, such as to form the first sheet filter material to closely match the shape of the horn and the recess.

A second sheet of filter material can be disposed on top of the horn and on a portion of the first sheet of filter material. The second sheet of filter material can comprise two weld lines. The weld lines on the second sheet of filter material can be aligned with the weld lines on the first sheet of filter material. The first sheet of filter material can be bonded to the second sheet of filter material, such as by welding.

The horn can be removed from the recess, such as to define a recess in the filter assembly. The filter assembly can be removed from the nest. Excess material can be removed from filter assembly, such as by trimming.

FIGs. 13A and 13B are a cross sectional view of an absorbent recirculation filter 1300, known in the art. A filling element 1302, such as a carbon element can be disposed between an upper sheet 1304 (containing a scrim layer and a media layer) and a lower sheet 1306 (also containing a scrim layer and media layer), and the filling element 1302 can fill a portion of a cavity defined by the layers. The filling element 1302 can help filter the air passing through the filter 1300. In alternative implementations the filter element 1302 can include both a scrim layer

FIGs 14A and 14B are cross sectional views of a filter 1400 comprising a filling element 1402 in accordance with the herein described structure. A filling element 1402 can be disposed within a cavity defined by the filter. The filling element 1402 can include a carbon element or an absorbent element. A carbon element can include a carbon web, carbon beads, or bulk carbon. It is possible for other forms of carbon to be included in the carbon element.

A portion of the scrim layer 1304 can be welded with a portion of the media layer 1306 and a clearance 1308 can result. The clearance 1308 can describe a portion of the filter

between the weld 1310 and the filling element 1302. In the design shown in FIGs 13A and 13B the carbon element can be sized significantly smaller than the media area due to the clearance 1308. The clearance 1308 can ensure that during the welding process a portion of the filling element 1302 does not get welded between the layers. If a portion of the filling element 1302 becomes welded between the layers, the filter could be rejected for having a defect. If the filter is not rejected and is used in a drive, a portion of the filling element 1302 could become particle contamination for the drive. The reduction in the filling element 1302 area can become even greater as the outside dimensions of the filter get smaller. As the filter gets smaller it can become more difficult to get the flat media to flex over the carbon and result in the need to use a thinner filling element 1302.

By forming the filter 1400 as shown in FIGs. 14A and 14B, as previously described, the clearance 1308, 1408 can be reduced and a thicker filling element 1402 can be disposed within the cavity. In an embodiment, the filter 1400 can be 8.5 mm x 20 mm and can be 4 mm thick. In an embodiment, the filling element 1402 can comprise carbon beads. In an embodiment, the mass of the carbon beads can be at least 35mg and no more than 55mg, such as 45mg. In an embodiment, the filter 1400 can be 4 mm x 15.5 mm and comprise carbon beads with a mass of at least 20 mg and no more than 45 mg, such as 33 mg.

Similar to the process shown in FIGs 11A-11I, FIGs. 15A-15E are schematic depictions showing a method of making a filter assembly. The method can comprise the use of a nest 1504 (shown in FIG. 15A). The nest 1504 can define a recess 1506. The recess 1506 can be configured to the desired shape of a finished filter. A sheet of filter material 1502 can be disposed between the nest 1504 and a horn 1508 (shown in FIG. 15B). The horn 1508 can be moved, such that it is at least partially disposed within the recess 1506. The filter material 1502 can substantially take the shape of the recess 1506 and the horn 1508 (shown in FIG. 15C). The horn 1508 can be removed from the recess 1506. The filter material 1502 can substantially retain the same shape as when the horn 1508 was at least partially disposed within the recess 1506. The filter material 1502 can define a cavity 1510. A filling element 1512 can be disposed within the cavity 1510 (shown in FIG. 15D). In an embodiment the filling element occupies at least 50% of the cavity. In alternative embodiments, the filling element can occupy at least 50%, 60%, 70%, 75%, 80%, 85%, 90%, 95%, or 99% of the cavity 1510. A screen layer can be disposed on top of the cavity similar to FIG. 11F. The screen layer can be welded to the filter material, similar to FIG. 11G. Excess material can be trimmed away from the filter, resulting in the filter 1500 (shown in FIG. 11E).



## **Experiments**

In order to evaluate the performance of filters made in accordance with the present invention, comparisons were made between two comparative recirculation filter elements, and two filter elements made in accordance with the present disclosure.

In the first comparative example, the filter element was a substantially planar recirculation filter with a polypropylene scrim overlying an electrostatic media. The polypropylene scrim had a permeability of approximately 300 feet per minute at 0.5 inches of water. The electrostatic media had a permeability of approximately 400 feet per minute at 0.5 inches of water. The filter element did not contain an adsorbent material.

In the second comparative example, the filter element also was a substantially planar recirculation filter with a polypropylene scrim overlying an electrostatic media. The polypropylene scrim had a permeability of approximately 500 feet per minute at 0.5 inches of water. The electrostatic media had a permeability of approximately 400 feet per minute at 0.5 inches of water. The filter element did not contain an adsorbent material.

In the single recess filter, a filter element made in accordance with the present disclosure was produced, the filter element having a substantially conical shape. The filter element included an electrostatic media overlying a polypropylene scrim on the interior of the filter element. The electrostatic media had a permeability of approximately 400 feet per minute at 0.5 inches of water. The polypropylene scrim had a permeability of approximately 500 feet per minute at 0.5 inches of water. The filter element did not contain an adsorbent material.

In the multiple recess filter, a filter element made in accordance with the present disclosure was produced, the filter element had multiple elongate recesses that were substantially parallel to one another. The filter element included an electrostatic media overlying a polypropylene scrim on the interior of the filter element. The electrostatic media had a permeability of approximately 400 feet per minute at 0.5 inches of water. The polypropylene scrim had a permeability of approximately 500 feet per minute at 0.5 inches of water. The filter element did not contain an adsorbent material.

**Table 1**

	<b>Percent of Particles Reflected</b>	<b>Percent of Particles Trapped</b>	<b>Percent of Particles that Fall Out View</b>	<b>Ratio of Trapped to Reflected Particles</b>
Comparative Example 1	38.0	29.0	33.0	.76
Comparative Example 2	35.0	16.0	49.0	.46
Single Recess Filter	34.2	26.7	39.2	.78
Multiple Recess Filter	20.0	48.3	31.7	2.42

As indicated in Table 1, the filter constructions with recesses and exposed electrostatic had lower particle reflection rates, and also had higher ratios of trapped to reflected particles.

Table 1 shows that that the percent of particles reflected from the filter elements was lower for the two elements made in accordance with the present disclosure than the two comparative examples: 20.0 and 34.2 compared to 35.0 and 38.0. In addition, both filter elements made in accordance with the present disclosure showed a higher ratio of trapped to reflected particles: 2.42 and .78 compared to .76 and .46. Thus, the two example elements made in accordance with present disclosure demonstrated improved removal of particulate contaminants compared to the two comparative examples.

The above specification provides a complete description of the manufacture and use of the invention. Since many embodiments of the invention can be made without departing from the spirit and scope of the invention the invention resides in the claims hereinafter appended.

**CLAIMS:**

1. A filter assembly for use in an electronic enclosure, the filter assembly comprising:  
a media structure including an open front face, a closed rear face, and an internal recess between the open front face and closed rear face;  
a scrim material forming at least a portion of the media structure; and  
an electrostatic material disposed within the internal recess of the filter assembly, the electrostatic material at least partially covering the scrim.
2. The filter assembly of any of the previous claims, wherein the scrim material comprises a woven material.
3. The filter assembly of any of the previous claims, wherein the scrim material comprises a non-woven material.
4. The filter assembly of any of the previous claims, wherein the scrim material comprises polypropylene fibers.
5. The filter assembly of any of the previous claims, wherein the scrim material has a permeability of between about 100 ft./min. at 0.5 inches of water and about 800 ft./min. at 0.5 inches of water.
6. The filter assembly of any of the previous claims, wherein the electrostatic material comprises polypropylene fibers.
7. The filter assembly of any of the previous claims, wherein the electrostatic material comprises acrylic fibers.
8. The filter assembly of any of the previous claims, wherein the electrostatic material comprises a mixed fiber medium comprising polypropylene and acrylic.
9. The filter assembly of any of the previous claims, wherein the electrostatic material has a permeability of between about 250 ft./min. at 0.5 inches of water and about 750 ft./min. at 0.5 inches of water.

10. The filter assembly of any of the previous claims, wherein the electrostatic material has a filtering efficiency of about 20 % to about 99.99 % for 20 to 30 micron particulate contaminants.
11. The filter assembly of any of the previous claims, wherein the internal recess of the filter assembly has a ratio of maximum length to maximum diameter of the open front face of at least 1.0.
12. The filter assembly of any of the previous claims, wherein the internal recess of the filter assembly has a ratio of maximum length to maximum diameter of the open front face of at least 1.5.
13. The filter assembly of any of the previous claims, wherein the internal recess of the filter assembly has a ratio of maximum length to maximum diameter of the open front face of at least 2.0.
14. The filter assembly of any of the previous claims, wherein the internal recess of the filter assembly has an internal surface area that is at least 2 times the area at the open front face.
15. The filter assembly of any of the previous claims, wherein the internal recess of the filter assembly has an internal surface area that is at least 3 times the area at the open front face.
16. The filter assembly of any of the previous claims, wherein the internal recess of the filter assembly has an internal surface area that is at least 4 times the area at the open front face.
17. The filter assembly of any of the previous claims, wherein the internal recess of the filter assembly has an internal surface area that is at least 6 times the area at the open front face.

18. The filter assembly of any of the previous claims, wherein at least 50 percent of the surface area of the internal recess has an angle to the opening that is less than or equal to 45 degrees.
19. The filter assembly of any of the previous claims, wherein at least 75 percent of the surface area of the internal recess has an angle to the opening that is less than or equal to 45 degrees.
20. The filter assembly of any of the previous claims, wherein at least 50 percent of the surface area of the internal recess has an angle to the opening that is less than or equal to 30 degrees.
21. The filter assembly of any of the previous claims, wherein at least 75 percent of the surface area of the internal recess has an angle to the opening that is less than or equal to 30 degrees.
22. The filter assembly of any of the previous claims, wherein the filter assembly comprises a recirculation filter disposed within a housing of a disk drive, and the filter assembly is oriented to filter airflow induced by the rotation of one or more disks within the disk drive housing.
23. The filter assembly of any of the previous claims, wherein the filter assembly comprises a plurality of structures including an open front face, a closed rear face, and a plurality of internal recesses between the open front face and closed rear face.
24. A filter assembly for use in an electronic enclosure, the filter assembly comprising:
  - a media construction including an open front end, a closed rear end, and a plurality of internal recesses between the open front face and closed rear face;
  - a scrim material forming at least a portion of the internal recesses; and
  - an electrostatic material disposed within the internal recesses of the filter assembly, the electrostatic material at least partially covering the scrim.
25. The filter assembly of any of the previous claims, wherein the scrim material comprises woven material.

26. The filter assembly of any of the previous claims, wherein the scrim material comprises polypropylene fibers.
27. The filter assembly of any of the previous claims, wherein the scrim enclosure has a permeability of between about 100ft./min. at 0.5 inches of water and about 800ft./min. at 0.5 inches of water.
28. The filter assembly of any of the previous claims, wherein the electrostatic material comprises a mixture of polypropylene fibers and acrylic fibers.
29. The filter assembly of any of the previous claims, wherein the electrostatic material comprises a mixed fiber medium comprising polypropylene and acrylic.
30. The filter assembly of any of the previous claims, wherein the electrostatic material has a permeability of between about 250ft./min. at 0.5 inches of water and about 750ft./min. at 0.5 inches of water.
31. The filter assembly of any of the previous claims, wherein the electrostatic material has a filtering efficiency of about 20 % to about 99.99 % for 20 to 30 micron particulate contaminants.
32. The filter assembly of any of the previous claims, wherein at least one of the plurality of internal recesses has a ratio of maximum length to maximum diameter of the open front face of at least 1.0.
33. The filter assembly of any of the previous claims, wherein at least one of the plurality of internal recesses has a ratio of maximum length to maximum diameter of the open front face of at least 1.5.
34. The filter assembly of any of the previous claims, wherein at least one of the plurality of internal recesses has a ratio of maximum length to maximum diameter of the open front face of at least 2.0.

35. The filter assembly of any of the previous claims, wherein at least one of the plurality of internal recesses has an internal surface area that is at least 2 times the area at the open front face.
36. The filter assembly of any of the previous claims, wherein at least one of the plurality of internal recesses has an internal surface area that is at least 3 times the area at the open front face.
37. The filter assembly of any of the previous claims, wherein at least one of the plurality of internal recesses has an internal surface area that is at least 4 times the area at the open front face.
38. The filter assembly of any of the previous claims, wherein at least one of the plurality of internal recesses has an internal surface area that is at least 6 times the area at the open front face.
39. The filter assembly of any of the previous claims, wherein at least 50 percent of the surface area of at least one internal recess has an angle to the opening that is less than or equal to 45 degrees.
40. The filter assembly of any of the previous claims, wherein at least 75 percent of the surface area of at least one internal recess has an angle to the opening that is less than or equal to 45 degrees.
41. The filter assembly of any of the previous claims, wherein at least 50 percent of the surface area of at least one internal recess has an angle to the opening that is less than or equal to 30 degrees.
42. The filter assembly of any of the previous claims, wherein at least 75 percent of the surface area of at least one internal recess has an angle to the opening that is less than or equal to 30 degrees.
43. The filter assembly of any of the previous claims, wherein the filter assembly comprises a recirculation filter disposed within a housing of a disk drive, and the filter

assembly is oriented to filter airflow induced by the rotation of one or more disks within the disk drive housing.

44. A filter assembly for use in an electronic enclosure, the filter assembly comprising:  
a media structure including an open front face, a closed rear face, and an internal recess between the open front face and closed rear face; and  
a permeable filter media forming at least a portion of the media structure;  
wherein the internal recess of the filter assembly has a ratio of maximum length to maximum diameter of the open front face of at least 1.0.

45. A filter assembly for use in an electronic enclosure, the filter assembly comprising;  
An upper sheet containing a scrim layer and a media layer;  
a lower sheet containing a scrim layer and media layer;  
a cavity defined by the sheets; and  
an adsorbent material positioned within the cavity.

46. The filter assembly of claim 45, wherein the upper sheet is substantially flat and the lower sheet forms the cavity between the sheets.

47. The filter assembly of claim 45, wherein the upper sheet is substantially flat and the lower sheet is substantially concave.



46. The filter assembly for use in an electronic enclosure of any of the previous claims, wherein the permeable filter media has a permeability of between about 100ft./min. at 0.5 inches of water and about 800ft./min. at 0.5 inches of water.
47. The filter assembly for use in an electronic enclosure of any of the previous claims, wherein the electrostatic material comprises a mixture of polypropylene fibers and acrylic fibers.
48. The filter assembly for use in an electronic enclosure of any of the previous claims, wherein the internal recess of the filter assembly has a ratio of maximum length to maximum diameter of the open front face of at least 1.5.
49. The filter assembly for use in an electronic enclosure of any of the previous claims, wherein the internal recess of the filter assembly has a ratio of maximum length to maximum diameter of the open front face of at least 2.0.
50. The filter assembly for use in an electronic enclosure of any of the previous claims, wherein the internal recess of the filter assembly has an internal surface area that is at least 2 times the area at the open front face.
51. The filter assembly for use in an electronic enclosure of any of the previous claims, wherein the internal recess of the filter assembly has an internal surface area that is at least 6 times the area at the open front face.
52. The filter assembly for use in an electronic enclosure of any of the previous claims, wherein at least 50 percent of the surface area of the internal recess has an angle to the opening that is less than or equal to 45 degrees.
53. The filter assembly for use in an electronic enclosure of any of the previous claims, wherein at least 50 percent of the surface area of the internal recess has an angle to the opening that is less than or equal to 30 degrees.
- 54.

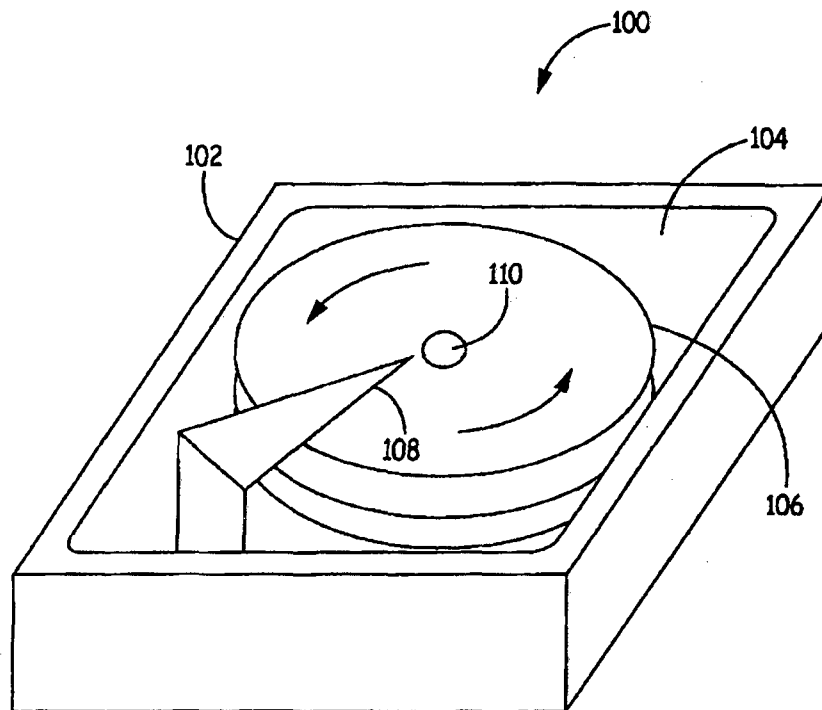


FIG. 1

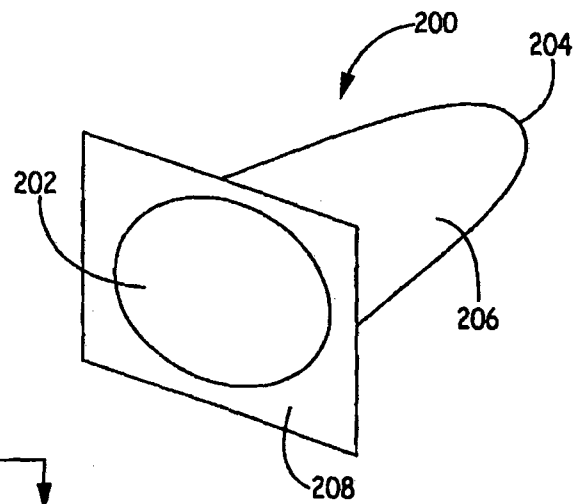


FIG. 2

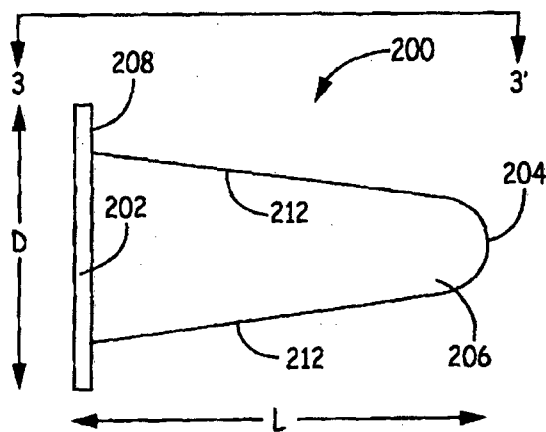


FIG. 3

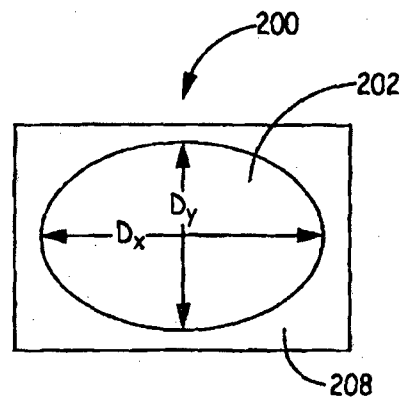


FIG. 4

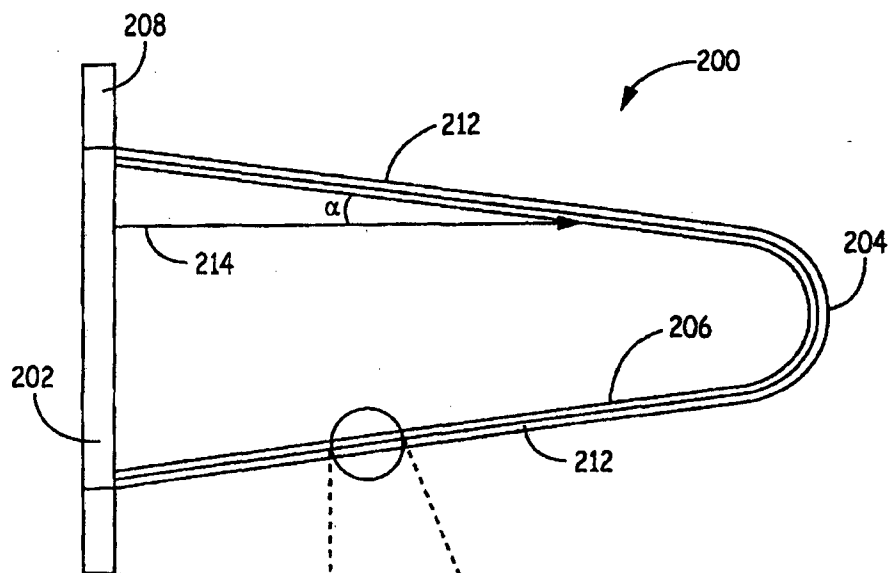


FIG. 5A

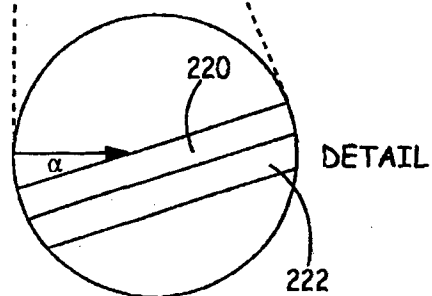


FIG. 5B

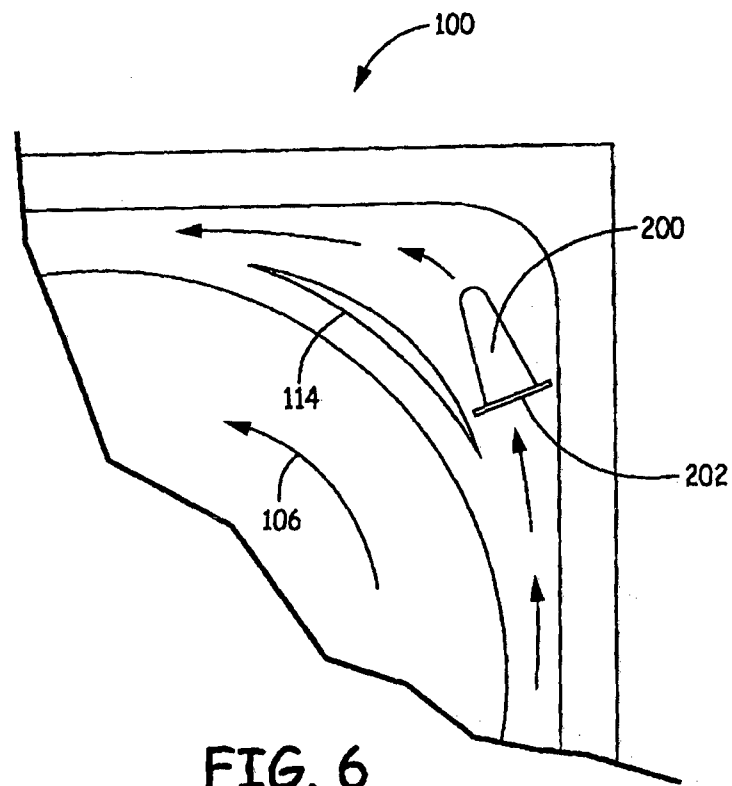


FIG. 6

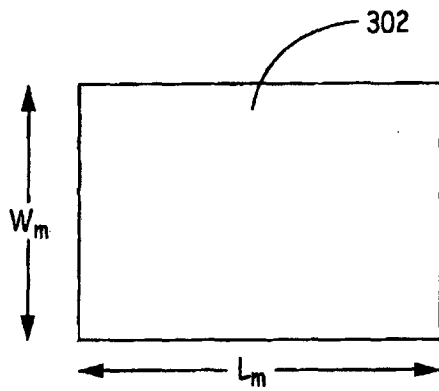


FIG. 7A

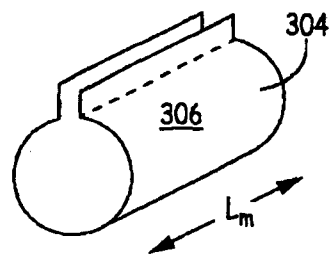


FIG. 7B

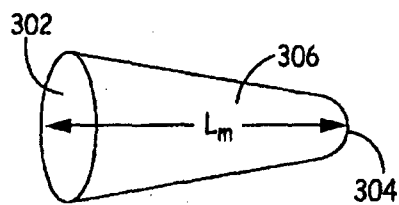


FIG. 7C

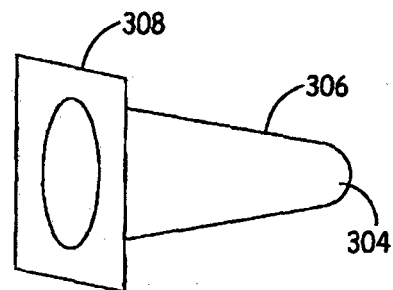


FIG. 7D

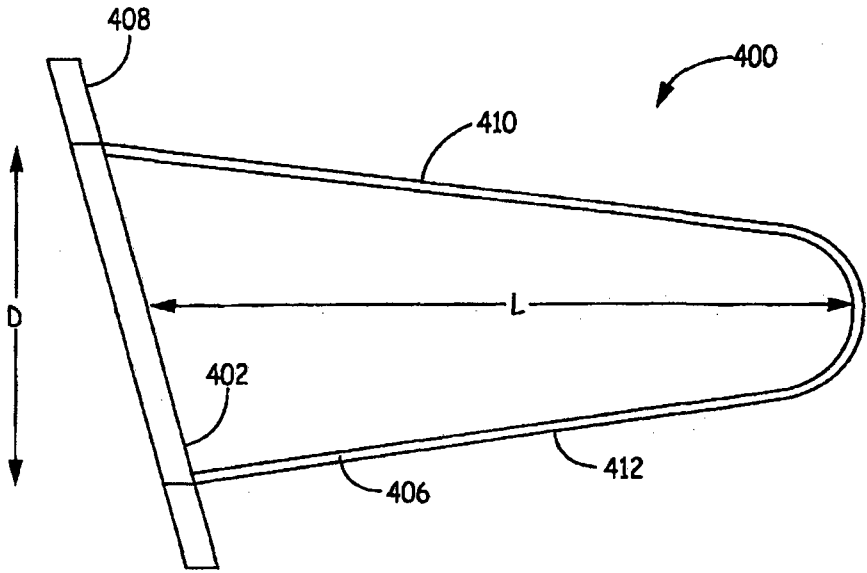


FIG. 8

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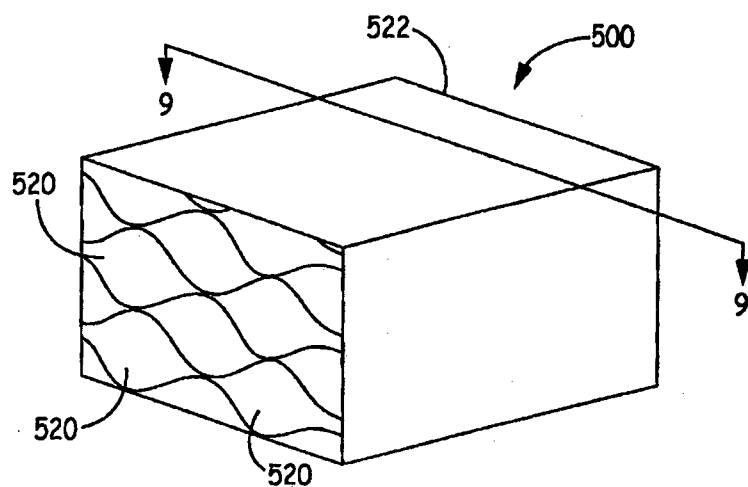


FIG. 9

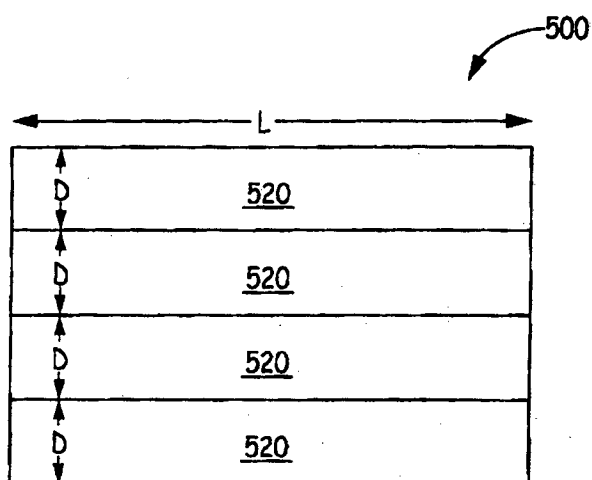


FIG. 10



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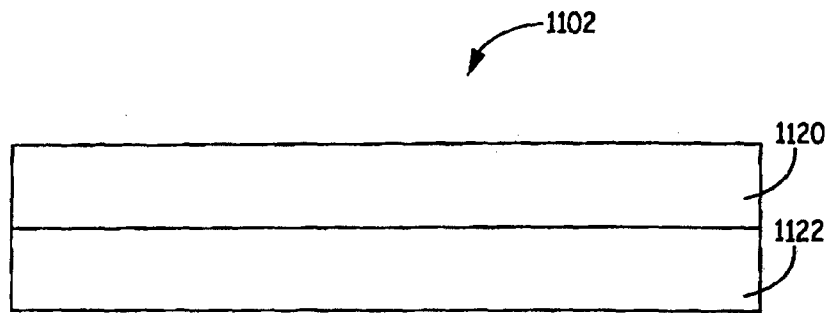


FIG. 11A

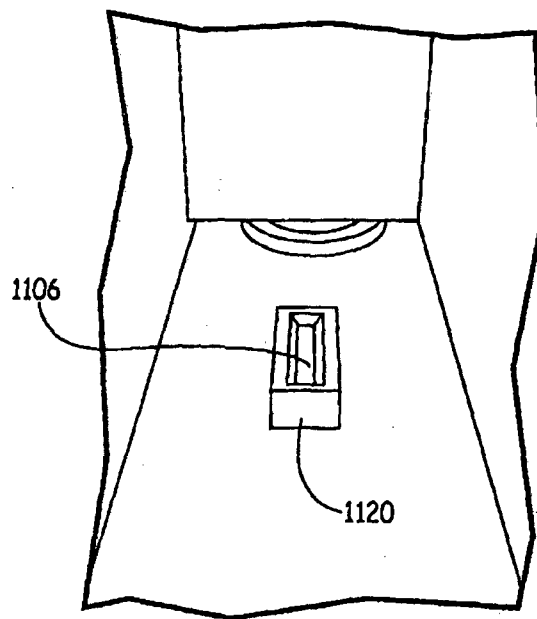


FIG. 11B

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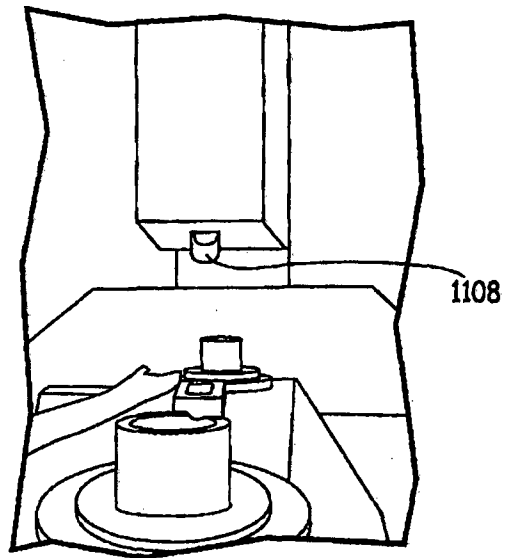


FIG. 11C

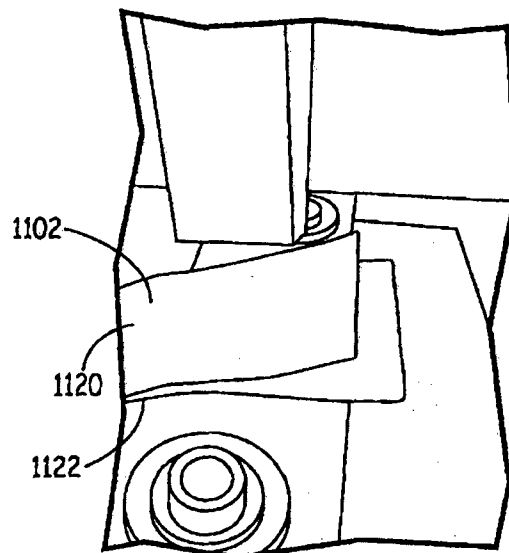


FIG. 11D

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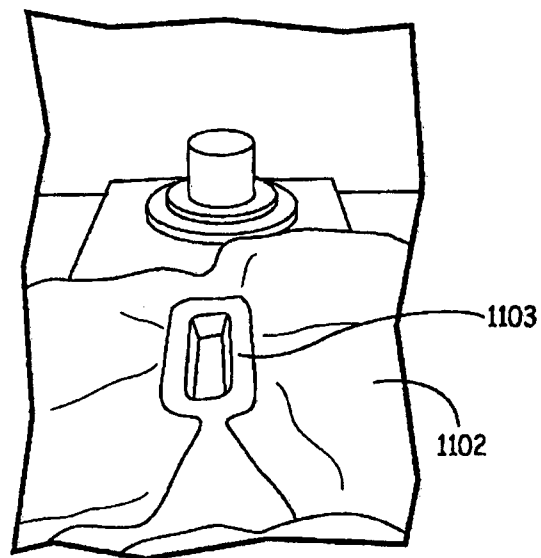


FIG. 11E

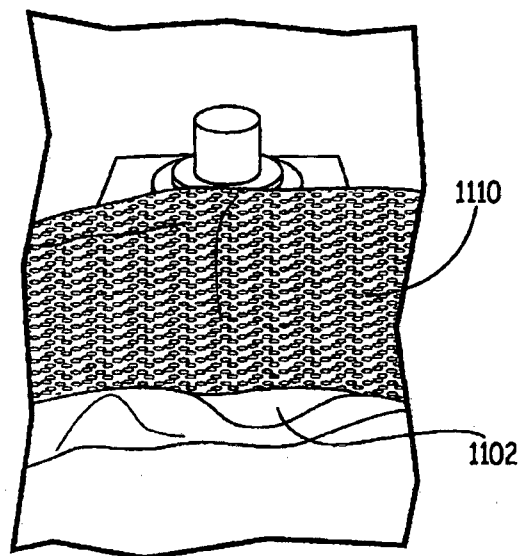


FIG. 11F

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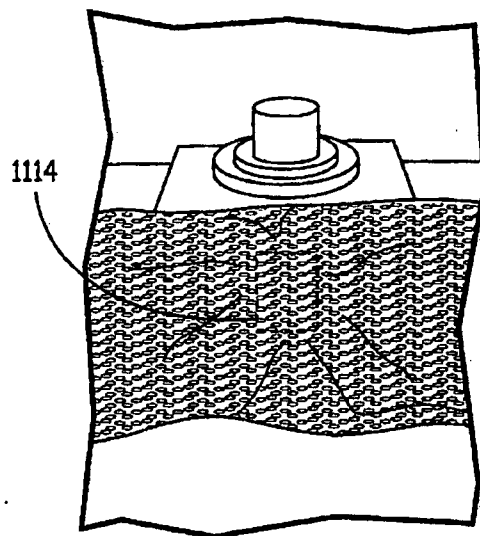


FIG. 11G

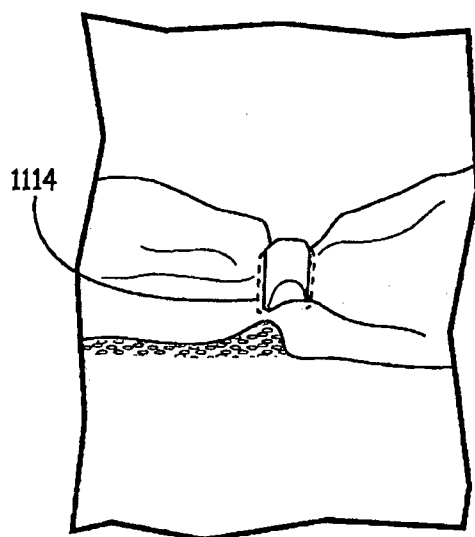


FIG. 11H

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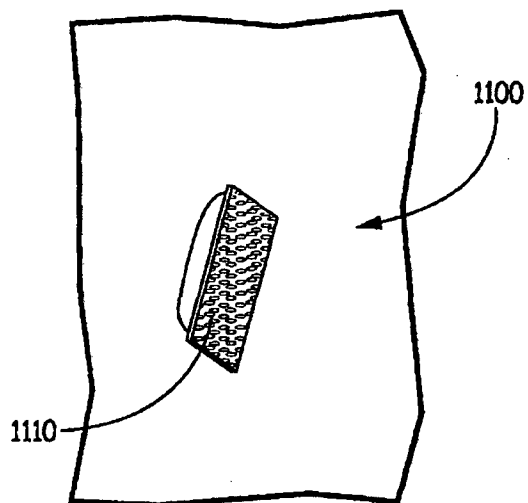


FIG. 11I

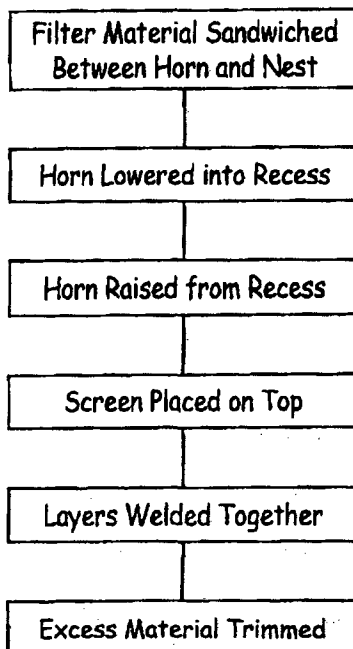


FIG. 11J

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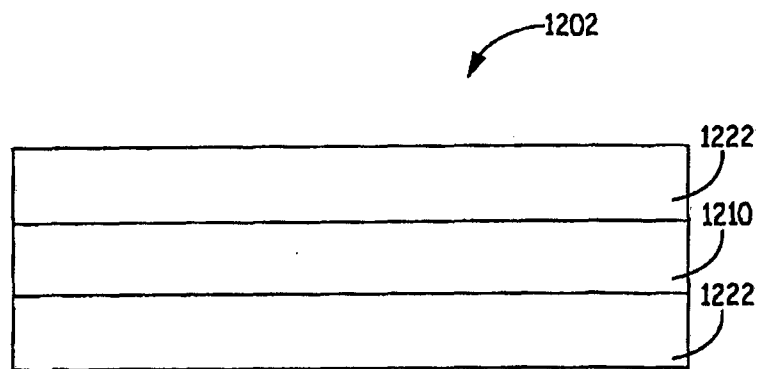


FIG. 12A

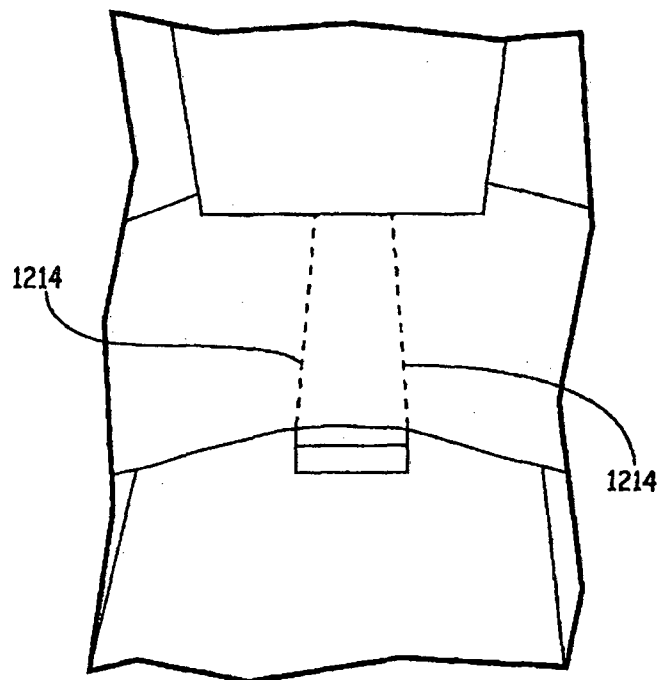


FIG. 12B

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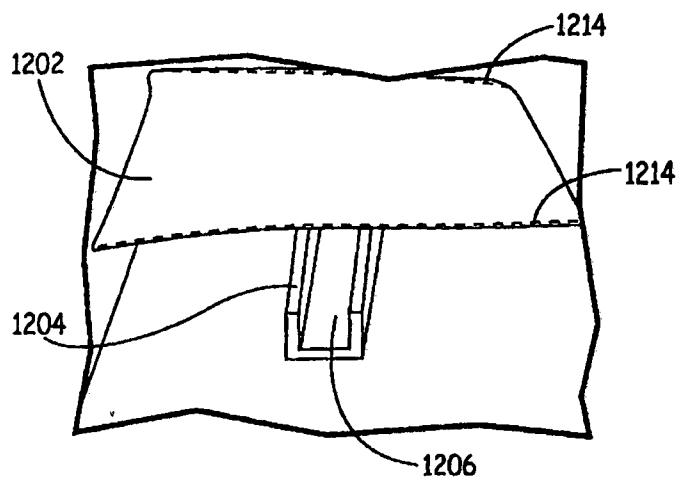


FIG. 12C

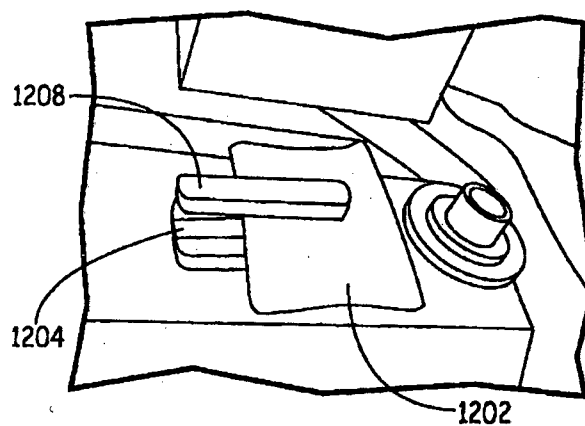


FIG. 12D

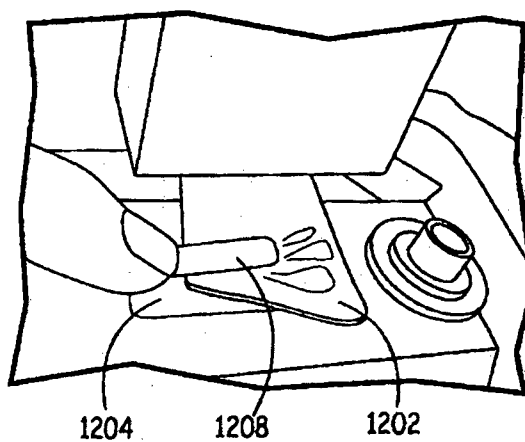


FIG. 12E

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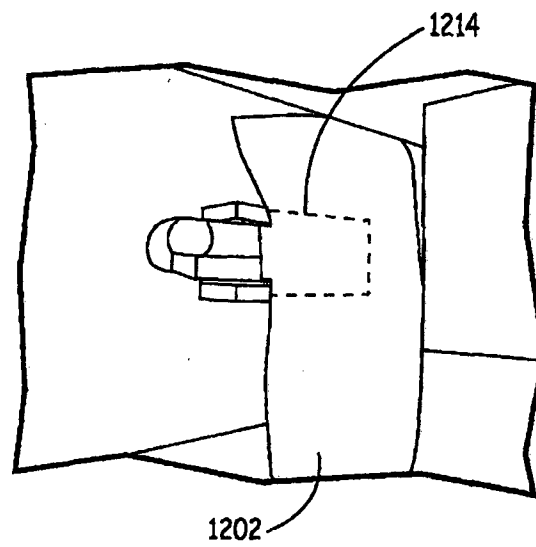


FIG. 12F

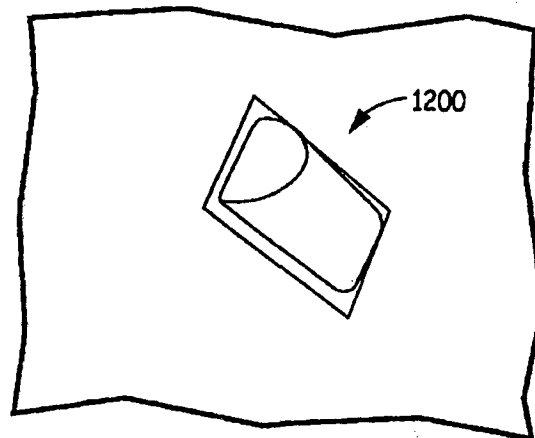


FIG. 12G



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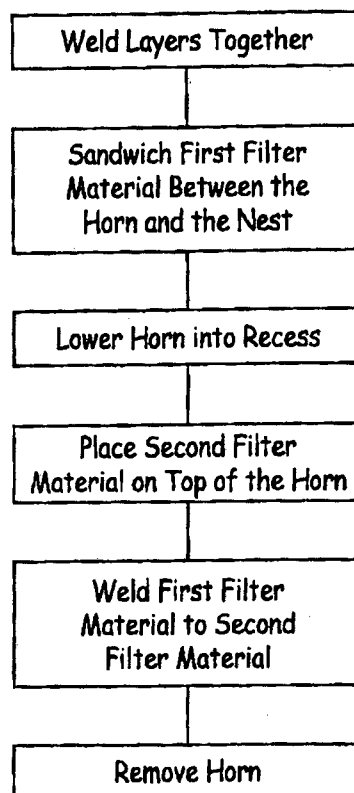


FIG. 12H

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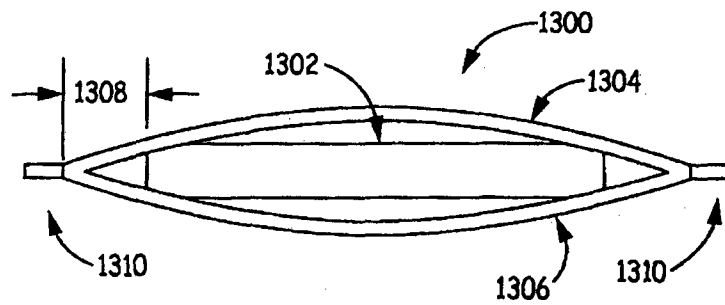


FIG. 13A

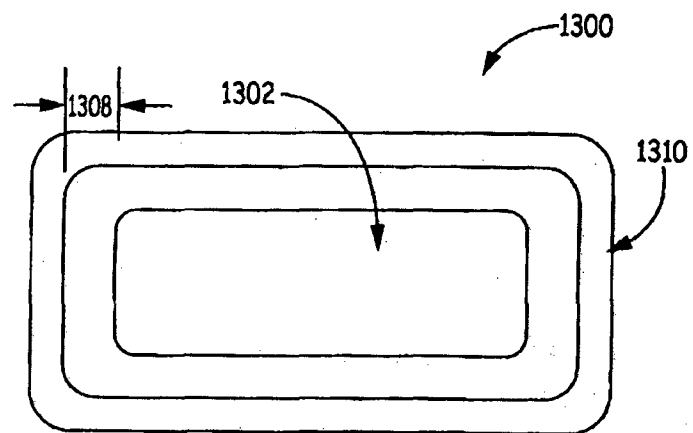


FIG. 13B

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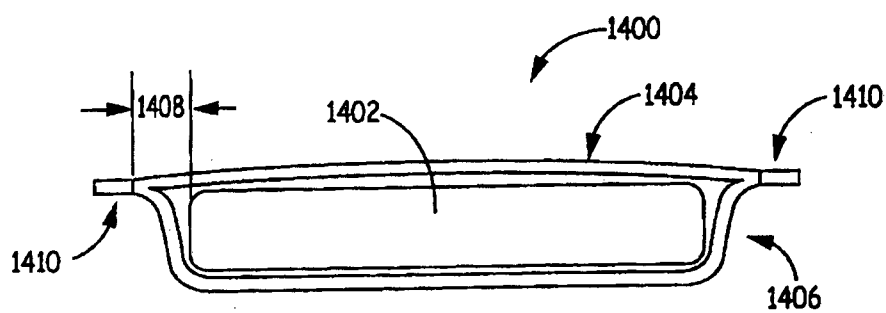


FIG. 14A

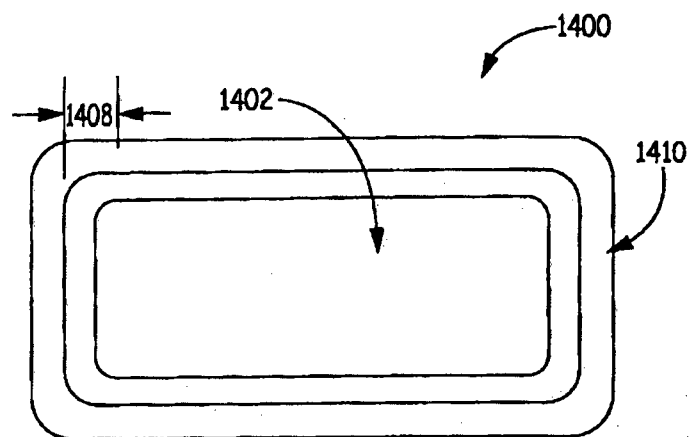


FIG. 14B

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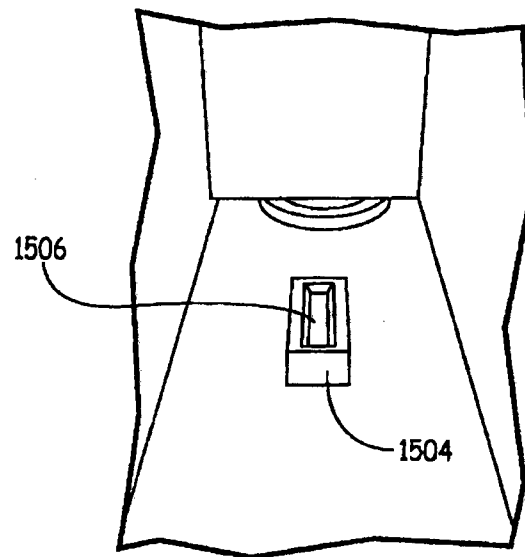


FIG. 15A

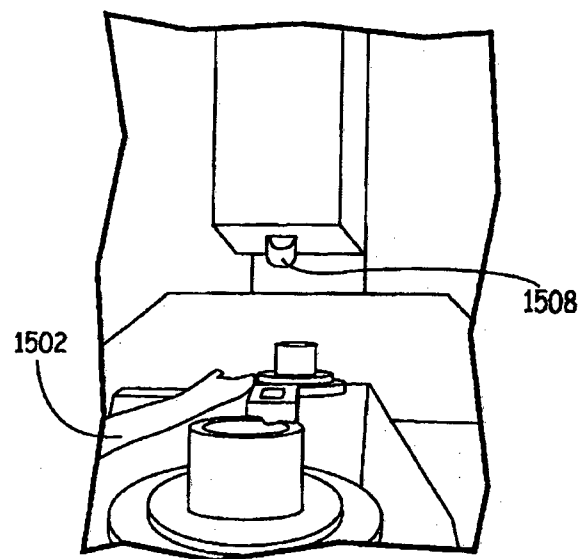


FIG. 15B

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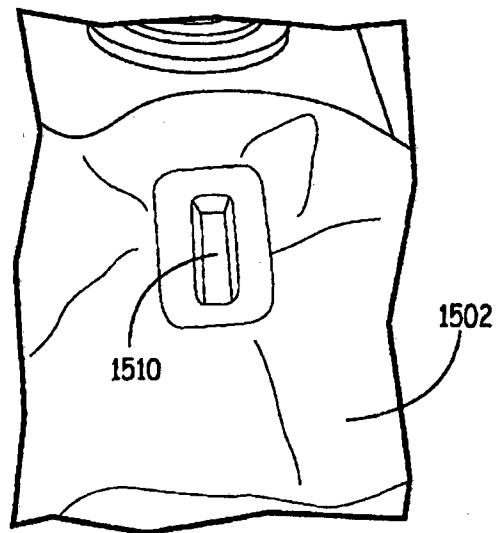


FIG. 15C

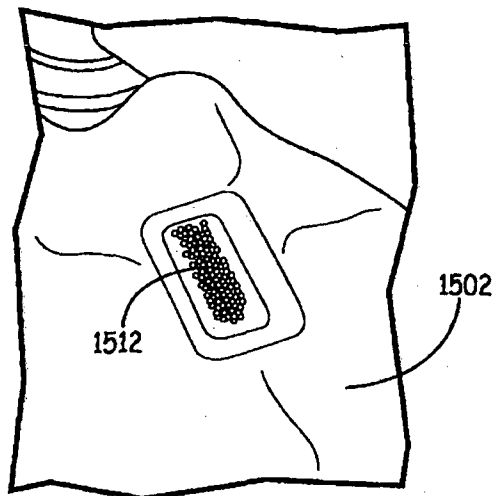


FIG. 15D

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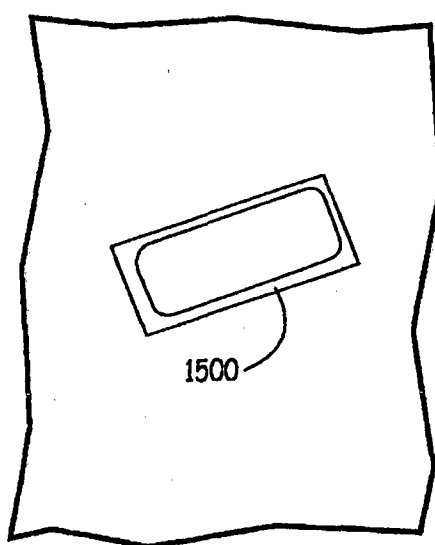


FIG. 15E

## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/US2013/054446****A. CLASSIFICATION OF SUBJECT MATTER****G11B 33/14(2006.01)i, G11B 33/02(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

G11B 33/14; B01D 53/02; B01D 46/52; G11B 17/02; B32B 3/12; B03C 3/155; B01D 53/04; G11B 33/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) &amp; keywords: contaminant, recirculation, filter, scrim, electrostatic, open, closed.

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009-0183475 A1 (EDWIN G. DAUBER et al.) 23 July 2009 See paragraphs [0006], [0012], [0025], [0028], [0033], [0034], [0040], [0056]; and figures 1-4A.	1-10, 22-31, 43, 45-47
A		11-21, 32-42, 44, 46(1), 47(1), 48-53
A	US 7404836 B2 (VIJAY K. GARIKIPATI et al.) 29 July 2008 See column 3, line 37 - column 7, line 10; and figures 1A-3B.	1-53
A	US 6238467 B1 (MICHAEL H. AZARIAN et al.) 29 May 2001 See column 12, line 23 - column 13, line 23; and figures 1-3.	1-53
A	US 2007-0283809 A1 (DANIEL A. BOULAY et al.) 13 December 2007 See paragraphs [0043], [0044]; and figures 7-8.	1-53
A	US 2005-0139078 A1 (DANIEL L. TUMA et al.) 30 June 2005 See paragraphs [0031]-[0043]; and figures 1-4.	1-53

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

06 December 2013 (06.12.2013)

Date of mailing of the international search report

**11 December 2013 (11.12.2013)**

Name and mailing address of the ISA/KR

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## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/US2013/054446**

**Box No. II**    **Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
2. ☒ Claims Nos.: 54  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:  
The claim is contrary to PCT Rule 6.3(a) since the claim does not contain the technical features of the invention.
  
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims: it is covered by claims Nos.:

### Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.



**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2013/054446**

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009-0183475 A1	23/07/2009	CA 2712754 A1 CN 101952008 A EP 2234688 A2 JP 2011-510430 A KR 10-2010-0113584 A WO 2009-094138 A2 WO 2009-094138 A3	30/07/2009 19/01/2011 06/10/2010 31/03/2011 21/10/2010 30/07/2009 08/10/2009
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US 2005-0139078 A1	30/06/2005	US 7166142 B2	23/01/2007