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(54) **HUMIDIFICATION CONTROL DEVICE**

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(57) **ABSTRACT**

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A humidification control device and an apparatus implementing the humidification control device is provided. The device includes a membrane electrode assembly (MEA) for the control of humidity in an enclosed space via electrolysis. The MEA includes an anode, a cathode and a proton exchange membrane (PEM) disposed between the anode and the cathode. The PEM is selected to increase the efficiency of the humidification control device by decreasing the back diffusion of water across the PEM. The PEM may include a functional tetrafluoroethylene (TFE) copolymer having a polymer chain of TFE and at least one comonomer having a proton conducting functional group pendant to said polymer chain. The comonomer may be present in an amount from about 0.01 mol. % to about 7 mol. % of the TFE copolymer. In one embodiment, the comonomer is a fluorovinyl ether such as perfluorosulfonyl vinyl ether (PSVE).

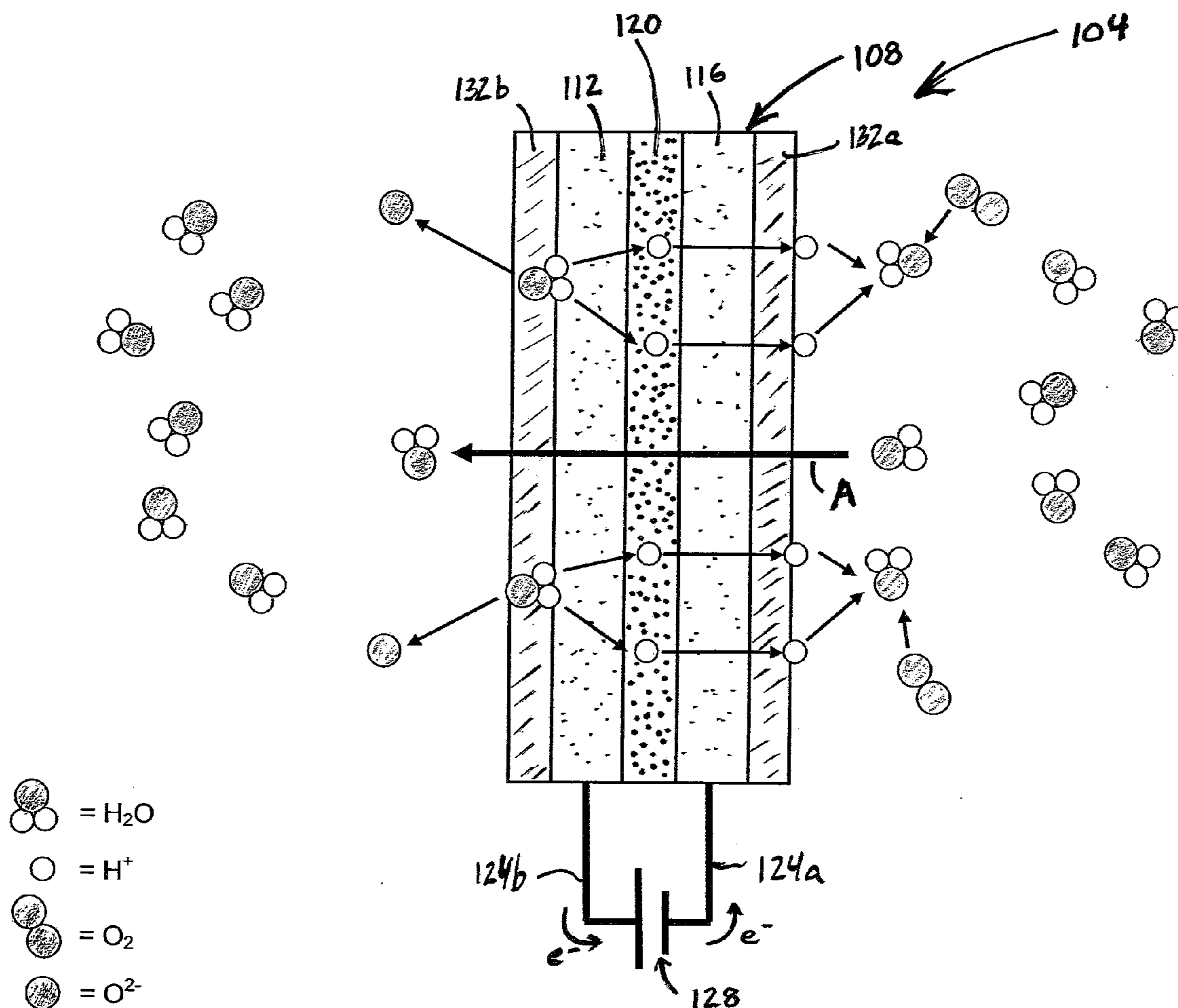
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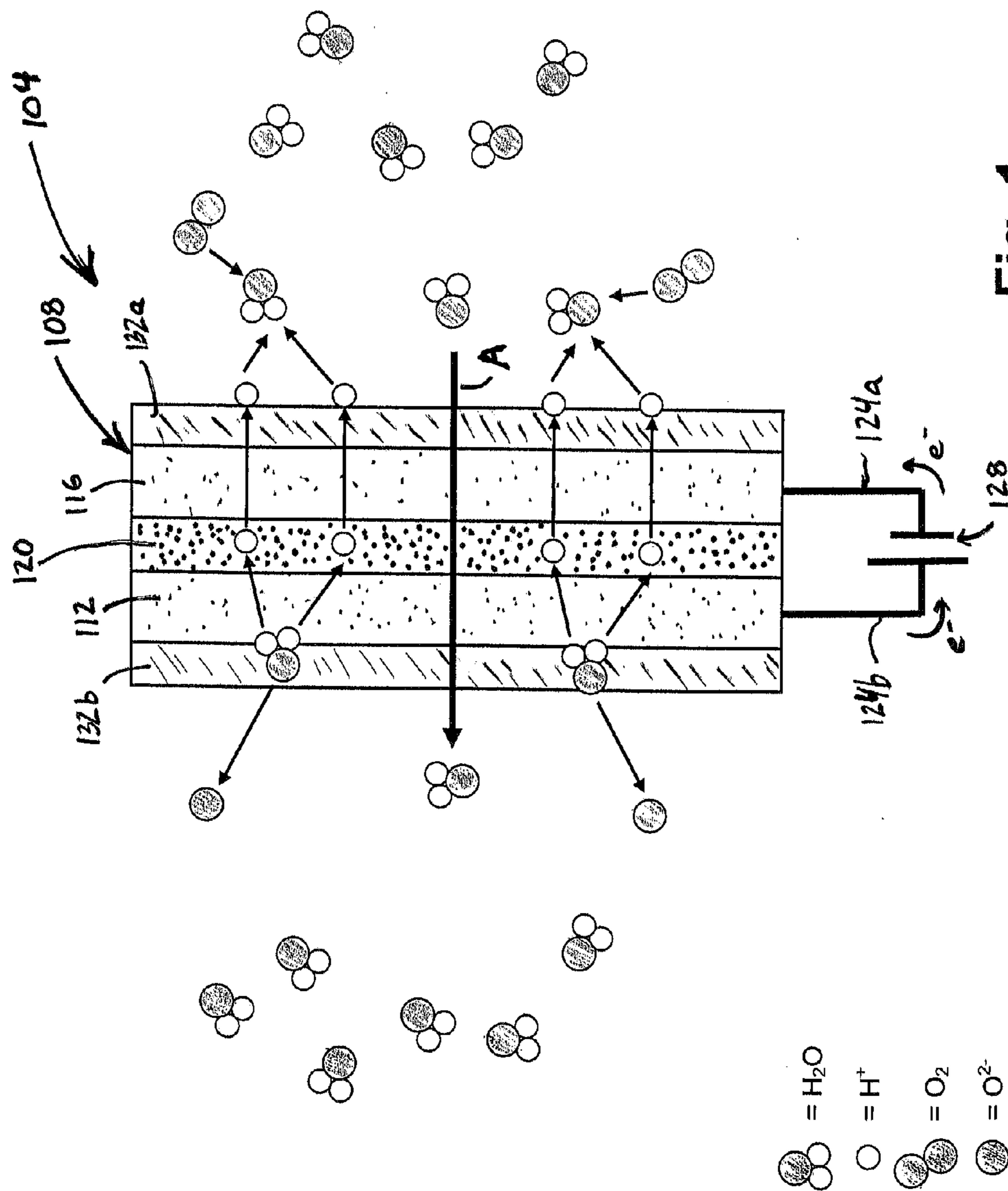


Fig. 1

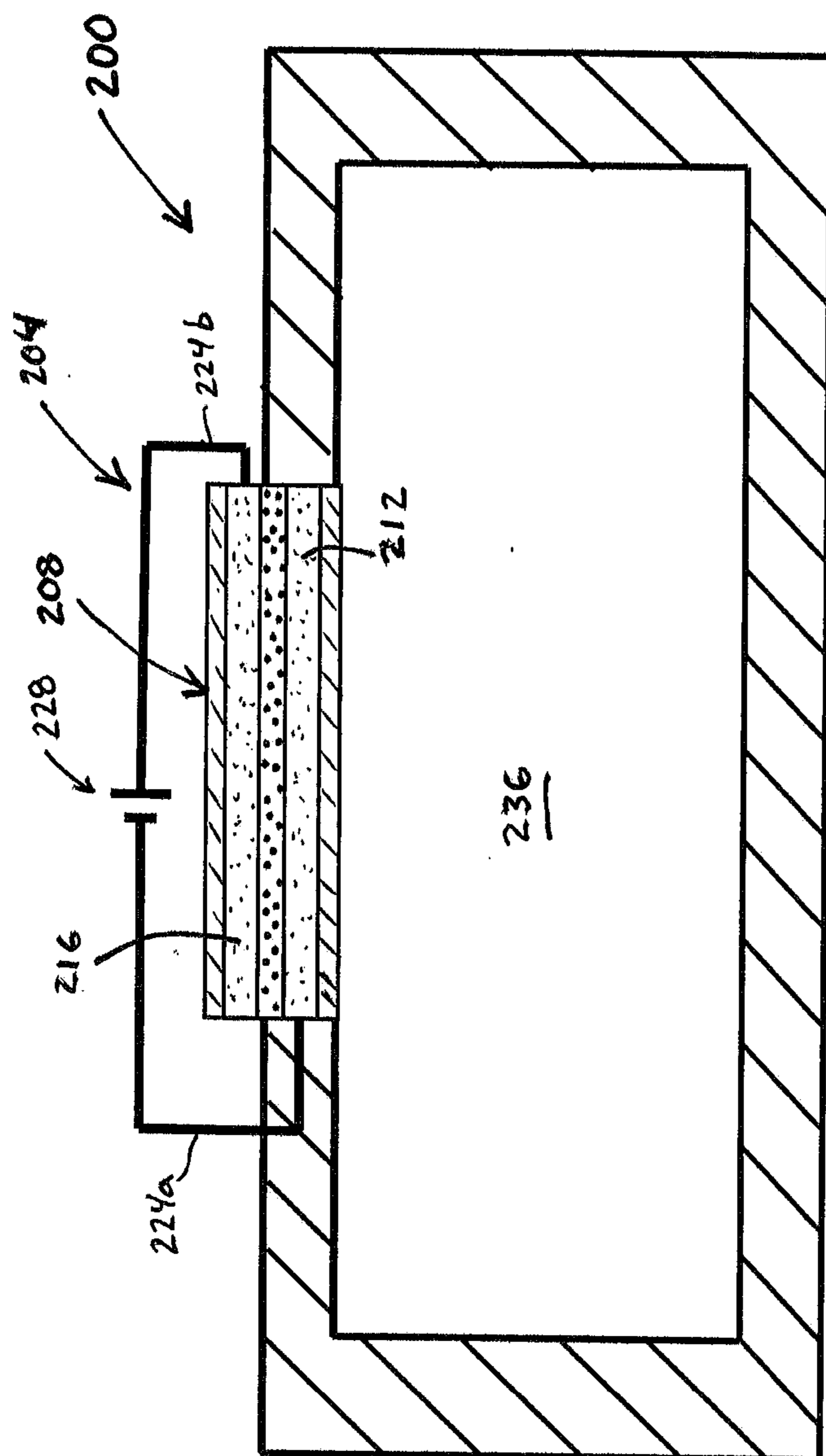


Fig. 2

HUMIDIFICATION CONTROL DEVICE

FIELD

[0001] This disclosure relates to the field of humidification control devices that utilize a membrane electrode assembly (MEA) for humidification control of an enclosure by electrolysis. Such enclosures may include, but are not limited to, lighting enclosures such as automotive head lamps, vehicle electronic control units, compact photovoltaic arrays, cameras such as surveillance cameras, bar code scanners, battery packs, power control units, fluid reservoirs, charging stations, telecommunication devices, transformer units, hard disk drives and the like.

BACKGROUND

[0002] Humidification control devices employing a membrane electrode assembly (MEA) as the dehumidifying element are known. The MEA is configured such that a polymer electrolyte membrane (PEM) is sandwiched between two electrodes, namely an anode and a cathode. When an electric potential is applied across the MEA, water molecules are electrolyzed into hydrogen (H^+) and oxygen (O^{2-}) ions on the anode side, which faces the inside of the enclosure. The PEM serves as the hydrogen ion exchange membrane and moves the hydrogen ions to the cathode side, which may face the ambient environment. On the cathode side, the hydrogen ions react with oxygen in the air to form water molecules. Thus, the enclosure is dehumidified by moving the moisture from the anode side of the MEA into the environment on the cathode side.

[0003] One challenge associated with using an MEA as the dehumidifying element is that the water generated on the cathode side (e.g., outside of the enclosure) tends to diffuse back into the enclosure through the PEM after the enclosure has been dehumidified, a phenomenon referred to as back diffusion. The water diffusing back into the enclosure needs to be removed from the enclosure again, increasing the electric current required to operate the MEA. As a result, back diffusion lowers the overall dehumidifying efficiency of the MEA.

[0004] Dehumidification devices employing MEAs are commercially available. One example is the Rosahl line of dehumidification devices (Westside International, Oxfordshire, UK). These devices typically utilize Nafion® 115 (E.I. DuPont de Nemours and Company, Wilmington, Del.) as the PEM. Nafion® 115 is a sulfonated tetrafluoroethylene based fluoropolymer that includes perfluorovinyl ether groups terminated with sulfonated groups that are incorporated onto a tetrafluoroethylene backbone. However, the overall dehumidifying efficiency of dehumidification elements employing Nafion® 115 as the PEM is limited due to back diffusion. Thicker membrane materials may lower back diffusion to a certain degree. However, the use of thicker membranes increases the material cost of the dehumidifying element significantly.

SUMMARY

[0005] One embodiment is directed to a humidification control device that is configured for controlling the humidity of an enclosure. The humidification control device includes a membrane electrode assembly, the membrane electrode assembly comprising an anode and a cathode, and at least a first proton exchange membrane disposed between the anode

and the cathode. The proton exchange membrane comprises a polymeric material comprising a resin that includes a functional TFE copolymer having a polymer chain of TFE and at least one comonomer having a proton conducting functional group pendant to the polymer chain, where the at least one comonomer having a proton conducting functional group pendant to the polymer chain is present in an amount of at least about 0.01 mol. % and not greater than about 7 mol. % of the functional TFE copolymer. The device also includes first and second electrically conductive terminals interconnected to the anode and cathode, respectively, and configured to apply an electric potential across the membrane electrode assembly.

[0006] In one characterization, the at least one comonomer having a proton conducting functional group pendant to the polymer chain is perfluorosulfonyl vinyl ether (PSVE). In another characterization, the polymeric material has an equivalent weight (EW) of at least about 1500, such as at least about 2400.

[0007] In another characterization, the polymeric material is fabricated by extruding a fine powder resin into a tape, calendaring the tape, and subjecting the calendared tape to heat-treatment to a temperature greater than the crystalline melting temperature of polytetrafluoroethylene (PTFE) to form a non-porous tape. In another characterization, the polymeric material is fabricated by expanding the resin into a porous functional tetrafluoroethylene (TFE) copolymer material having a microstructure characterized by nodes interconnected by fibrils, and further densifying the porous material and subjecting material to a heat treatment above the crystalline melting temperature of PTFE to form a non-porous structure.

[0008] The humidification control device may be configured to be positioned across an aperture of an enclosure to dehumidify a gaseous enclosed volume within an enclosed space defined by the enclosure. In another characterization, a DC voltage source is operatively connected to the first and second electrically conductive terminals. In yet another characterization, the proton exchange membrane has a thickness of not greater than about 200 μm . In yet another characterization, the at least one comonomer having a proton conducting functional group pendant to the polymer chain is present in an amount of not greater than about 7 mol. % of the functional TFE copolymer. In a further characterization, the proton exchange membrane has a Gurley number of at least about 1000 seconds.

[0009] In another embodiment, an apparatus is provided that includes an enclosure defining an enclosed space and a humidification control device operatively affixed to the enclosure. The humidification control device includes an anode and a cathode, and at least a first proton exchange membrane disposed between the anode and the cathode. The proton exchange membrane comprises a polymeric material comprising a resin that includes a functional TFE copolymer having a polymer chain of TFE and at least one comonomer having a proton conducting functional group pendant to the polymer chain, where the at least one comonomer having a proton conducting functional group pendant to the polymer chain is present in an amount of at least about 0.01 mol. % and not greater than about 7 mol. % of the functional TFE copolymer. First and second electrically conductive terminals are interconnected to the anode and cathode, and a DC voltage source operatively connected to the first and second electrically conductive terminals.

[0010] In a further characterization, the humidification control device is affixed to the enclosure such that the anode is in fluid communication with the enclosed space, e.g., to dehumidify the enclosure. In another characterization, the at least one comonomer having a proton conducting functional group pendant to the polymer chain is PSVE.

[0011] In another characterization, the polymeric material has an equivalent weight of at least about 1500, such as at least about 2400. In yet another characterization, the proton exchange membrane has a thickness of not greater than about 200 μm .

[0012] In yet another characterization, the at least one comonomer having a proton conducting functional group pendant to the polymer chain may present in an amount of not greater than about 5 mol. % of the functional TFE copolymer. In another characterization, the proton exchange membrane has a Gurley number at least about 1000 seconds.

DESCRIPTION OF THE DRAWINGS

[0013] FIG. 1 illustrates a schematic view of a humidification control device.

[0014] FIG. 2 illustrates a schematic view of an apparatus that includes a dehumidification device that is operatively affixed to an enclosure for dehumidification of an enclosed space.

DETAILED DESCRIPTION

[0015] High relative humidity within an enclosure can affect the working characteristics and/or the useful lifetime of component(s) sealed within the enclosure. Such enclosures may therefore be equipped with a humidity control device (e.g., a dehumidification device) that employs a membrane electrode assembly (MEA) as the dehumidifying element. Such enclosures may include, for example, lighting and electronic enclosures that contain sensitive components that may be affected by inadequate humidity control within the enclosure.

[0016] FIG. 1 illustrates a schematic cross-sectional view of a humidity control device 104 in accordance with one embodiment of this disclosure. The humidity control device 104 utilizes a membrane electrode assembly (MEA) 108 as the humidity control element. The MEA 108 includes an anode 112 and a cathode 116, which are separated by a proton exchange membrane (PEM) 120. The humidity control device 104 further includes conductive terminals 124a and 124b that are operatively connected to the anode 112 and to the cathode 116. A voltage source 128 (e.g., a DC voltage source) is operatively attached to the conductive terminals 124a and 124b and is configured to apply a voltage across the anode 112 and the cathode 116.

[0017] When a voltage is applied across the anode 112 and the cathode 116, water that is adjacent to the anode 112 is reduced to protons and oxygen in accordance with Equation 1:



[0018] The protons (H^+) are selectively transported through the PEM 120 to the cathode 116 where they react with O_2 (e.g., in the ambient air) to form water in accordance with Equation 2:



[0019] Thus, water is removed from the anode side of the device 104 and water is formed on the cathode side of the

device 104. As a result, the relative humidity on the anode side decreases (i.e., dehumidification) and the relative humidity on the cathode side increases (i.e., humidification).

[0020] The electrodes (i.e., anode 112 and cathode 116) may comprise an electrically conductive material such as particulate carbon and a polymeric binder. The conductive material often includes a catalytic material dispersed thereon that is selected to catalyze the desired reaction at the electrode. For example, the cathode 116 may include a platinum (Pt) catalyst dispersed on particulate carbon to catalyze the oxidation of protons (H^+) to form water. The anode 112 may include a catalyst for the reduction of water, such as a mixture of Pt metal and an iridium compound (e.g., iridium oxide). Other metals or metal compounds that are useful as catalysts for the electrodes will be apparent to those of skill in the art. The electrodes may be prepared using known methods in the art, such as those described in U.S. Pat. No. 6,054,230 by Kato and U.S. Pat. No. 6,723,464 by Tabata et al.

[0021] The phenomenon of back diffusion of the water formed at the cathode 116 across the PEM 120 and the anode 112 is illustrated in FIG. 1 by arrow A. Such back diffusion may be present when the external conditions (e.g., adjacent the cathode 116) are ambient with no forced convection to move moisture away from the cathode 116. Such back diffusion lowers the overall efficiency of the MEA 108 by requiring more energy to drive Equation 1 at the anode. The PEM materials of the present disclosure advantageously utilize functional tetrafluoroethylene (TFE) copolymers that improve the overall efficiency of the device (e.g., dehumidification efficiency) when compared to commercial PEM materials such as Nafion® 115.

[0022] In one embodiment, the PEM 120 comprises a functional TFE copolymer. The functional TFE copolymer includes functional groups that are pendant to the polymer chain. The functional TFE copolymer may be formed by copolymerizing TFE with at least one functional comonomer, i.e., a comonomer having at least one functional group. The functional comonomer may advantageously include proton conducting groups, such as, for example, phosphonic acid groups and sulfonic acid groups. In one particular embodiment, the functional comonomer comprises a fluorovinyl ether, such as perfluorosulfonyl vinyl ether (PSVE).

[0023] According to the embodiments disclosed herein, the comonomer may be present in the copolymer in a relatively low amount as compared to conventional devices. In one particular characterization, comonomer may be present in the copolymer in an amount of at least about 0.01 mol. %, such as at least about 0.1 mol. %. However, the amount of comonomer present in the copolymer should not be greater than about 7 mol. %, or even not greater than about 6 mol. %, such as not greater than about 5 mol. %. It is also desirable that the PEM 120 have a relatively high equivalent weight (EW). The equivalent weight is a characteristic of an ionomer that is equal to the weight of the polymer in acid form that is required to neutralize one equivalent of NaOH. A higher equivalent weight indicates that there are fewer active ionic species (e.g., H^+) present. If it takes more of the polymer to neutralize one equivalent of hydroxyl ions from NaOH, there must be fewer active ionic species within the polymer. The ionic conductivity of the membrane is generally proportional to the number of active ionic species in the polymer.

[0024] In accordance with the present disclosure, the PEM may have an equivalent weight of at least about 1500, at least

about 2000 or at least about 2400. In exemplary embodiments, the equivalent weight of the PEM will not be greater than about 9000.

[0025] It is also desirable that the PEM 120 be relatively thin for efficient operation of the humidification control device 104. In this regard, it has been found that back diffusion of water in the device 104 can be decreased even when utilizing a relatively thin PEM 120. In this regard, the PEM may have a thickness of not greater than about 200 μm , such as not greater than about 150 μm or not greater than about 125 μm . In exemplary embodiments, the PEM will have a thickness of at least about 10 μm .

[0026] U.S. Patent Publication No. 2010/0248324 by Xu et al. describes a method for the manufacture of a porous functional TFE copolymer material that may be utilized in part to produce the PEM according to the present disclosure. Xu et al. describes a method for the manufacture of a functional TFE copolymer fine powder resin. The fine powder resin is then extruded and expanded to form a microporous expanded TFE copolymer film. For the formation of a PEM 120 for use in a humidification control device, the functional TFE copolymer should be densified and treated at a temperature above the crystalline melting temperature of PTFE to be substantially non-porous. Accordingly, in one embodiment, the functional TFE copolymer material may be extruded to produce a tape, which may further be heat-treated to a temperature greater than crystalline melting temperature of TFE to form a non-porous structure.

[0027] In another embodiment, the functional TFE copolymer material may be expanded into a microstructure characterized by nodes and fibrils. Dense (non-porous) articles may then be formed from the expanded TFE copolymer materials by densification and heating above the crystalline melting temperature of PTFE according to the methods described in U.S. Pat. No. 3,953,566 by Gore and/or U.S. Pat. No. 7,521,010 by Kennedy et al.

[0028] To function efficiently in an MEA, the PEM should be resistant to the flow of fluids through the membrane, i.e., the membrane should have a relatively low porosity. Thus, the PEM according to the invention may be characterized as having a relatively high Gurley number. The Gurley number is a unit describing the number of seconds required for 100 cm^3 of air to pass through one square inch (in^2) of the material. The measurement of a Gurley number is described, for example, in U.S. Pat. No. 5,547,551 by Bahar et al. Thus, in one embodiment, the PEM may have a Gurley number of at least about 1000 seconds, such as at least about 5000 seconds and even at least about 10,000 seconds.

[0029] As will be appreciated, other components of the MEA 108 may include gas diffusion layers 132a and 132b which may be disposed on opposite sides of the anode 112 and cathode 116 from the PEM 120. The gas diffusion layers 132a/132b may comprise porous carbon cloth, for example. As is noted above, the device 104 further includes conductive terminals 124a and 124b that are operatively connected to the anode 112 and to the cathode 116 to supply an electric potential from a voltage source 128.

[0030] FIG. 2 schematically illustrates an apparatus in accordance with the present disclosure that includes a humidity control device 204 (e.g., a dehumidification device) that is operatively affixed to an enclosure 200 to control the humidity within the enclosure by dehumidifying an enclosed space 236 defined by the enclosure 200. The device 204 includes an MEA 208 that may be configured in the manner described

with respect to MEA 104 (FIG. 1). As is illustrated in FIG. 2, the anode 212 faces (e.g., is in fluid communication with) the enclosed space 236. The cathode 216 faces (e.g., is in fluid communication with) an environment that is separated from the enclosed space 236, such as the ambient environment surrounding the enclosure 200. In this manner, moisture may be removed from the enclosed space 236 and vented to the ambient environment. The enclosed space 236 may contain components (e.g., lighting components or electrical components) that require a low relative humidity for optimum operation and/or extended lifetime of the components.

[0031] Although illustrated and described as a dehumidification device that is configured to remove moisture from an enclosed space to lower the relative humidity within the enclosed space, it will be appreciated that the device can be utilized in other configurations. For example, the device may be configured such that the cathode faces an enclosed space and the anode faces an ambient environment, such as to increase the humidity in the enclosed space, e.g., to maintain a desired minimum humidity within the enclosed space.

EXAMPLES

Example 1

[0032] A fine powder of TFE-PSVE copolymer containing 3.2 mol. % PSVE was blended with Isopar® K (Exxon Mobile Corp., Fairfax, Va.) in the proportion of 0.25 g/g of fine powder. The lubricated powder was compressed in a cylinder to form a pellet and placed into an oven set at about 49° C. for about 12 hours. The compressed and heated pellets were extruded to produce a tape that was about 16 cm wide and about 0.78 mm thick. The tape was calendered in a first calendering step to a thickness of about 0.381 mm and was further calendered in a second calendering step to a thickness of about 0.125 mm. This calendered tape was then allowed to dry at room temperature while unrestrained. The calendered and dried tape was then restrained and heated in an oven at about 365° C. for about 90 seconds to form a substantially non-porous tape.

[0033] The resultant non-porous tape was then immersed in isopropyl alcohol (IPA) at about 85° C. for about 19 hours followed by immersion in a 20 wt. % KOH aqueous solution at about 125° C. for about 72 hours. The tape was then rinsed with deionized water and immersed in 15 wt. % nitric acid at about 125° C. for about 48 hours, followed by a deionized water rinse. The tape was then air dried at room temperature. This reacted, non-porous tape comprised a functional TFE copolymer having 3.2 mol. % sulfonic acid functional groups and was used as the PEM material. The equivalent weight (EW) of the PEM material was about 4510.

[0034] The cathode layer was formed by casting a dispersion of platinum on carbon black (Pt/C) and a TFE/PSVE copolymer (EW=800) in ethanol and water on an expanded PTFE substrate having a thickness of about 0.16 mm and a density of about 0.59 g/cm^3 . After casting the dispersion onto the substrate, the dispersion was dried at about 140° C. The resulting cathode layer had a Pt loading of about 0.4 mg/cm^2 .

[0035] The anode layer was formed by casting a dispersion of Pt black, iridium oxide and TFE/PSVE copolymer (EW=800) in ethanol and water on an expanded PTFE substrate having a thickness of about 0.16 mm and density of about 0.59 g/cm^3 . The resulting anode had a Pt loading of about 0.35 mg/cm^2 and an iridium loading of about 0.35 mg/cm^2 .

[0036] The PEM material was placed between the anode and the cathode layer. To ensure good bonding of the PEM and the electrodes, the PEM layer was painted with a dispersion containing 4 wt. % TFE/PSVE copolymer (EW=800), 4 wt. % water and balance ethanol, and was then dried using a hair drier.

[0037] All three layers (cathode, PEM, anode) were nominally 63.5 mm in diameter, but the anode and cathode were about 4 mm smaller in diameter as compared to the PEM to avoid shorting across the PEM.

[0038] The three layers were then pressed at about 173° C. for about five minutes under a pressure of about 115 psi. The ePTFE substrate layers in the anode and the cathode were then removed, resulting in a three layered stack. Gas diffusion layers (Carbel® CL, W. L. Gore & Associates, Newark, Del.) were then attached on either side of the three layered stack, one at a time, by heating to about 173° C. and contacting with the electrode for about 180 seconds under a pressure of about 115 psi.

[0039] Circular stainless steel current collectors in the form of a screen with attachment tabs were placed on either side of the five-layered MEA construction. The thickness and the overall dehumidifying efficiency of the MEA was measured and reported in Table 1.

Example 2

[0040] A fine powder of TFE-PSVE copolymer, containing 4.7 mol. % PSVE was blended with Isopar® K (Exxon Mobile Corp., Fairfax, Va.) in the proportion of 0.243 g/g of fine powder. The lubricated powder was compressed in a cylinder to form a pellet and was placed into an oven set at about 49° C. for about 12 hours. The compressed and heated pellets were ram extruded to produce a tape that was about 15.87 cm wide and about 0.81 mm thick. The tape was calendered in a first calendering step to a thickness of about 0.254 mm. This calendered tape was further calendered in a second calendering step to a thickness of about 0.122 mm. This calendering tape was then restrained and dried at about 250° C. The dried tape was then heated in an oven at about 365° C. for about 90 seconds, while restrained, to form a substantially non-porous tape.

[0041] The resultant non-porous tape was then immersed in IPA at 85° C. for about 19 hours followed by immersion in a 20 wt. % KOH aqueous solution at 125° C. for about 72 hours. The tape was then rinsed with deionized water and was immersed in 15 wt. % nitric acid at about 125° C. for about 48 hours followed by a deionized water rinse. The tape was then air dried at room temperature. This reacted non-porous tape comprised a functional TFE copolymer having 4.7 mol. % sulfonic acid functional groups and was used as the PEM material. The equivalent weight (EW) of the PEM material was 2800.

[0042] A five layered MEA as described in Example 1 was constructed using the PEM material. The thickness and the overall dehumidifying efficiency of the MEA were measured and reported in Table 1.

Comparative Example 1

[0043] An MEA as described in Example 1 was constructed using one layer, two layers and five layers of Nafion® 115 (E.I. DuPont de Nemours and Company, Wilmington, Del.) as the PEM material. The equivalent weight of the PEM was

1100. The thickness and the overall dehumidifying efficiency of these MEAs were measured and reported in Table 1.

Comparative Example 2

[0044] An MEA as described in Example 1 was constructed using a commercially available PEM material (GORE-SELECT® Part No: GSM650.35) used for fuel cells and comprising 14.8 mol. % PSVE. The equivalent weight of the PEM was 1020. The thickness and the overall dehumidifying efficiency of these MEAs were measured and reported in Table 1.

[0045] As illustrated in Table 1, for a comparable thickness, the MEAs employing the functional TFE copolymers described herein for the PEM provide an overall dehumidification efficiency that is at least 5 times greater than that of an MEA using a single layer of Nafion® 115. Even when the thickness of the Nafion® 115 was increased by a factor of 4×, the dehumidifying efficiency of the MEA disclosed herein was still at least 2× greater.

TABLE 1

	Thickness (μm)	Overall Dehumidification Efficiency (mg H ₂ O/coulomb)
EXAMPLE 1	125	0.132
EXAMPLE 2	125	0.104
COMPARATIVE	125 (1 layer)	0.018
EXAMPLE 1	250 (2 layers)	0.030
	500 (4 layers)	0.050
COMPARATIVE	35	0.0034
EXAMPLE 2		

Test Methods

[0046] Overall Dehumidifying Efficiency Test

[0047] The overall dehumidifying efficiency test reported in Table 1 is a steady state measurement that measures water pumping rate and current draw of an energized MEA with a fixed relative humidity (RH) and temperature on the cathode and anode side.

[0048] The cathode side temperature and RH are controlled with a dedicated room ventilation system and maintained at about 22° C. and about 50% RH respectively. There is no forced air convection over the cathode side of the MEA.

[0049] The anode side temperature is maintained at about 22° C. A RH of about 22% at this temperature is established by placing the MEA over a Petri dish with a two phase mixture of 6.6 g potassium acetate in 2.2 g of water. The distance between the solution and surface of the anode is minimal, at about 3 mm.

[0050] The five layer MEA construction is screwed on to a sample holder. The holder/Petri dish assembly is placed on a tared microbalance (Mettler Toledo AG204) and the initial weight (W_0) of the holder/Petri dish assembly is measured. The doors of the microbalance are opened slightly and a DC power supply (Instek PS-3225D) unit is attached to the electrical leads of the current collector tabs on the MEA. The power supply is connected to an ammeter (Ahlborn ZA9901-AB3) to measure the current. The output from the ammeter is transmitted to a data logger (Ahlborn Almemo 2890-9).

[0051] The DC power supply is turned on to produce 1.5 volts for 30 minutes and the current is measured during this time period. After 30 minutes, the power supply is turned off by removing the electrical leads attached to the current col-

lector tabs on the MEA. The doors of the balance are closed and the housing/Petri dish assembly is weighed (W_1).

[0052] The power supply is re-attached to the MEA and turned on again and the above cycle is repeated three times to measure W_2 , W_3 , W_4 over a period of 1.5 hours. The difference in weight between W_1 and W_0 , W_2 and W_1 , W_3 and W_2 and W_4 and W_3 over time is plotted.

[0053] The dehumidification efficiency (mg water pumped per Coulomb) is calculated as:

$$\frac{\text{asymptotic value of water pumping rate (mg/sec)}}{\text{asymptotic value of the current density (coulomb/sec, or amp)}}$$

Determination of Equivalent Weight

[0054] The method used to determine equivalent weight takes a measured weight of the solid sample and calculates an acid equivalent weight based on the first inflection point of the titration curve near pH 7. Specifically, for each sample, approximately 5 g of the solid sample weighing no more than 0.05 g each are dried in an oven for at least two hours at 80° C. under full vacuum (~2 in. Hg). The dried pieces are removed from the oven and placed in a capped container to minimize moisture pickup. After allowing the dried sample to cool to room temperature in the capped container, approximately 0.15 g is quickly weighed into a 100 ml titration cup. The sample of known dry weight is then allowed to soak in the titration cup for 15 minutes in 5 ml of deionized water and 5 ml of ethanol. To the soaked sample, 55 ml of 2.0N NaCl solution is then added. A back titration method using a TIM900 Titration Manager (Radiometer Analytical S.A., Lyon, France) is then started beginning with the addition of 5 ml of 0.05N NaOH solution. The entire blend is then stirred for 15 minutes under a nitrogen blanket prior to the acid titration with 0.01 N HCl solution. The end point near pH 7 is used to calculate both the ion exchange capacity (IEC) and the acid equivalent weight (EW) of the sample according to:

$$IEC \text{ (meq/g)} = \frac{[5 \text{ ml NaOH} \times 0.05 \text{ N}] - [\text{Volume HCl (ml)} \times 0.01 \text{ N}]}{\text{Dried Ionomer Solid Weight (g)}}$$

$$EW \text{ (g/eq)} = 1000 / IEC \text{ (meq/g)}$$

[0055] The dried ionomer solid weight (e.g., in the denominator) is equal to the sample weight. The arithmetic mean of the measured results from two different samples of each membrane is reported as the Equivalent Weight.

[0056] While various embodiments of the present invention have been described in detail, it is apparent that modifications and adaptations of those embodiments will occur to those skilled in the art. However, it is to be expressly understood that such modifications and adaptations are within the spirit and scope of the present invention.

What is claimed is:

1. A humidification control device configured for controlling the humidity of an enclosure, said humidification control device comprising:

a membrane electrode assembly, said membrane electrode assembly comprising:

an anode and a cathode;

at least a first proton exchange membrane disposed between said anode and said cathode, said proton exchange membrane comprising a polymeric material comprising a resin that includes a functional TFE copolymer having a polymer chain of TFE and at least one comonomer having a proton conducting functional group pendant to said polymer chain, wherein said at least one comonomer having a proton conducting functional group pendant to said polymer chain is present in an amount of at least about 0.01 mol. % and not greater than about 7 mol. % of said functional TFE copolymer; and

first and second electrically conductive terminals interconnected to said anode and cathode, respectively, and configured to apply an electric potential across said membrane electrode assembly.

2. The humidification control device of claim 1, wherein said at least one comonomer having a proton conducting functional group pendant to said polymer chain is PSVE.

3. The humidification control device of claim 1, wherein said polymeric material has an equivalent weight of at least about 1500.

4. The humidification control device of claim 1, wherein said polymeric material has an equivalent weight of at least about 2400.

5. The humidification control device of claim 1, wherein said polymeric material is fabricated by extruding a fine powder resin into a tape, calendering said tape, and subjecting said calendered tape to heat-treatment to a temperature greater than the crystalline melting temperature of PTFE to form a non-porous tape.

6. The humidification control device of claim 1, wherein said polymeric material is fabricated by expanding said resin into a porous functional TFE copolymer material having a micro structure characterized by nodes interconnected by fibrils, and further densifying said porous material to form a non-porous structure.

7. The humidification control device of claim 1, wherein said membrane electrode assembly is configured to be positioned across an aperture of an enclosure to dehumidify a gaseous enclosed volume within an enclosed space defined by said enclosure.

8. The humidification control device of claim 1, further comprising a DC voltage source operatively connected to said first and second electrically conductive terminals.

9. The humidification control device of claim 1, wherein said proton exchange membrane has a thickness of not greater than about 200 μm .

10. The humidification control device of claim 1, wherein said at least one comonomer having a proton conducting functional group pendant to said polymer chain is present in an amount of not greater than about 5 mol. % of said functional TFE copolymer.

11. The humidification control device of claim 1, wherein said proton exchange membrane has a Gurley number of at least about 1000 seconds.

12. An apparatus, comprising:

an enclosure defining an enclosed space; and

a humidification control device operatively affixed to said enclosure, said humidification control device comprising

an anode and a cathode;
at least a first proton exchange membrane disposed between said anode and said cathode, said proton exchange membrane comprising a polymeric material comprising a resin that includes a functional TFE copolymer having a polymer chain of TFE and at least one comonomer having a proton conducting functional group pendant to said polymer chain, wherein said at least one comonomer having a proton conducting functional group pendant to said polymer chain is present in an amount of at least about 0.01 mol. % and not greater than about 7 mol. % of said functional TFE copolymer; and
first and second electrically conductive terminals interconnected to said anode and cathode; and
a DC voltage source operatively connected to said first and second electrically conductive terminals.

13. The apparatus of claim **12**, wherein said humidification control device is affixed to said enclosure such that said anode is in fluid communication with said enclosed space.

14. The apparatus of claim **12**, wherein said at least one comonomer having a proton conducting functional group pendant to said polymer chain is PSVE.

15. The apparatus of claim **12**, wherein said polymeric material has an equivalent weight of at least about 1500.

16. The apparatus of claim **12**, wherein said polymeric material has an equivalent weight of at least about 2400.

17. The apparatus of claim **12**, wherein said proton exchange membrane has a thickness of not greater than about 200 μm .

18. The apparatus of claim **12**, wherein said at least one comonomer having a proton conducting functional group pendant to said polymer chain is present in an amount of not greater than about 5 mol. % of said functional TFE copolymer.

19. The apparatus of claim **12**, wherein said proton exchange membrane has a Gurley number of at least about 1000 seconds.

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