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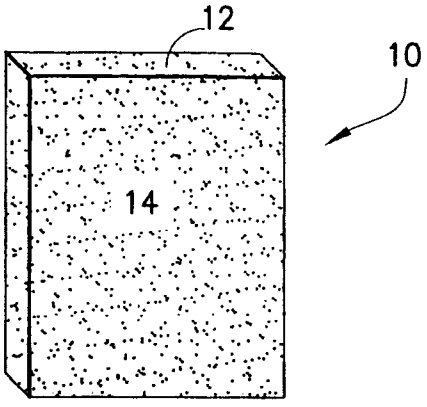
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(54) Title: NANOPOROUS CARBON MATERIALS, AND SYSTEMS AND METHODS UTILIZING SAME



(57) Abstract: A porous carbon composite having porosity that is at least partially filled with material imparting to the composite an enhanced character with respect to characteristics selected from the group consisting of hardness, wear-resistance and toughness, as compared with the nanoporous carbon alone. Porous carbon material is also described as a storage medium for chlorine gas, or as a hydrogen storage medium, e.g., for hydrogen fuel cells.

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INTERNATIONAL PATENT APPLICATION

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NANOPOROUS CARBON MATERIALS, AND SYSTEMS AND METHODS UTILIZING SAME

CERTIFICATE OF EFS FILING

I hereby certify that this patent application is being filed via EFS in the United States Patent and Trademark Office on January 29, 2007.

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NANOPOROUS CARBON MATERIALS, AND SYSTEMS AND METHODS UTILIZING SAME

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The priority of U.S. provisional patent application 60/763,258 filed January 30, 2006 in the names of Frank Dimeo, Jr., et al. for "CARBONACEOUS MATERIALS USEFUL FOR FLUID STORAGE/DISPENSING, DESULFURIZATION, AND INFRARED RADIATION EMISSION, AND APPARATUS AND METHODS UTILIZING SAME," is hereby claimed under the provisions of 35 USC 119. The disclosure of such U.S. provisional patent application is hereby incorporated herein by reference in its entirety, for all purposes.

FIELD OF THE INVENTION

[0002] The present invention relates to nanoporous carbon materials having utility for fluid storage/dispensing applications, and to systems and methods utilizing same, as well as impregnated nanoporous carbon materials useful in tribological applications and as ultra-tough structural materials.

DESCRIPTION OF THE RELATED ART

[0003] Carbonaceous materials are used as fluid adsorbent media in many applications, including fluid purification, fluid storage and dispensing, and fluid filtration.

[0004] One specific application of commercial significance is fluid storage and dispensing systems, wherein a carbonaceous adsorbent material is deployed to sorptively retain a fluid in an adsorbed state, and to release such fluid for dispensing under appropriate dispensing conditions, such as application of heat to effect thermal desorption of the fluid, application of reduced pressure conditions to effect desorption of the fluid, and/or application of a concentration gradient such as by flowing a carrier gas in contact with the adsorbent having the fluid adsorbed thereon to cause the desorption of the fluid and entrainment thereof in the carrier fluid.

[0005] A fluid storage and dispensing system is disclosed in U.S. Patent 6,743,278 issued June 1, 2004 in the name of J. Donald Carruthers for "Gas storage and dispensing system with monolithic carbon adsorbent," the disclosure of which is hereby incorporated herein by reference in its entirety, for all purposes. This patent describes a monolithic carbon physical adsorbent that is characterized by at least one of the following characteristics: (a) a fill density measured for

arsine gas at 25°C and pressure of 650 torr that is greater than 400 grams arsine per liter of adsorbent; (b) at least 30% of overall porosity of the adsorbent including slit-shaped pores having a size in a range of from about 0.3 to about 0.72 nanometer, and at least 20% of the overall porosity including micropores of diameter <2 nanometers; and (c) having been formed by pyrolysis and optional activation, at temperature(s) below 1000°C, and having a bulk density of from about 0.80 to about 2.0 grams per cubic centimeter.

[0006] Apart from fluid storage and dispensing systems, carbon is conventionally used as a component in high-strength composites, as a reinforcing medium. In addition, carbon is used in composite materials applications as a continuous medium in vitreous carbon composites, which are useful in a variety of tribological applications, but suffer the inherent disadvantage of being highly brittle and therefore subject to cracking and loss of physical integrity.

SUMMARY OF THE INVENTION

[0007] The present invention relates to nanoporous carbon materials having utility for fluid storage/dispensing applications, and to systems and methods utilizing same, as well as impregnated nanoporous carbon materials useful in tribological applications and as ultra-tough structural materials.

[0008] In one aspect, the invention relates to a nanoporous carbon composite including nanoporous carbon having porosity that is at least partially filled with material imparting to the composite an enhanced character with respect to characteristics selected from the group consisting of hardness, wear-resistance and toughness, as compared with the nanoporous carbon alone.

[0009] In another aspect, the invention relates to a hydrogen storage system comprising such nanoporous carbon composite.

[0010] In a further aspect, the invention relates to a hydrogen fuel energy-producing system comprising the nanoporous carbon composite.

[0011] A further aspect of the invention relates to a chlorine gas storage system comprising porous carbon.

[0012] Another aspect of the invention relates to a method of fabricating a composite material, comprising at least partially filling porosity of a nanoporous carbon with material imparting to the composite an enhanced character with respect to characteristics selected from the group consisting of hardness, wear-resistance and toughness, as compared with the nanoporous carbon alone.

[0013] In a further aspect, the invention relates to a method of storing hydrogen for dispensing thereof, comprising use of a hydrogen storage medium including a nanoporous carbon containing boron.

[0014] Yet another aspect the invention relates to a method of generating energy, comprising use of a hydrogen storage medium including a nanoporous carbon containing boron.

[0015] A further aspect of the invention relates to a method of storing chlorine gas, comprising holding the chlorine gas in an adsorbed state on porous carbon.

[0016] Other aspects, features and embodiments of the invention will be more fully apparent from the ensuing disclosure and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. 1 is a perspective view of an impregnated carbon structural member according to one embodiment of the invention.

[0018] FIG. 2 is a schematic elevation view of a fluid storage and dispensing apparatus according to one embodiment of the invention, as arranged for supplying fluid to a fluid-utilizing facility.

DETAILED DESCRIPTION OF THE INVENTION, AND PREFERRED EMBODIMENTS THEREOF

[0019] The present invention relates to nanoporous carbon materials suitable for tribological and ultra-tough structural materials applications, as well having utility in fluid storage/dispensing applications. The invention also relates to systems and methods utilizing such nanoporous carbon materials.

[0020] The invention in one aspect relates to nanoimpregnated carbon composite materials that are impregnated with complimentary materials to yield composites that are useful for a variety of purposes, e.g., as tribological materials of high wear-resistant character, as ballistically tough materials, and as armor and armor-piercing materials.

[0021] The impregnant can be of any suitable type, as introduced into the porosity of the carbon material to yield a composite having desired properties for a given use application. For such purpose, the carbon material suitably has a porosity comprising pores that are sufficiently deep and extensive throughout the material to enable impregnation to be effected in a simple and efficient manner. For example, the carbon may have nanoporosity including pores having an average pore diameter of less than 10 nm, it being recognized that the specific pore size, pore size

distribution, pore tortuosity, etc., may be varied widely in the general practice of the present invention.

[0022] Illustrative techniques that may be employed to impregnate the porosity of the carbon material include, without limitation, solution deposition, vapor deposition, ion implantation, etc.

[0023] In one embodiment, the impregnant material includes polymers. As an example of an application of such polymer impregnation, a nanoporous carbon material may be impregnated with a polymer such as high molecular weight silicone or polyethylene glycol to produce a super-tough ballistic armor. In the use of such impregnated material, increasing impact of the material will result in the polymer forming long-range linkages between graphitic plates, so that a high degree of fracture toughness is achieved.

[0024] Alternatively, polymeric fibers such as long chain aramid fibers, or fibers commercially available under the trademarks Kevlar, PBO, Zorlon and Spectra can be employed as the impregnant. The objective in such impregnation is to attain polymeric penetration of the nanopores to provide multiple anchor points and a three-dimensional array of high-strength fibers, yielding a high fracture toughness material. Such impregnated materials afford the advantages of decreased weight, increased strength, and the ability to form molded structures in a green state that permits uniquely shaped ballistically tough materials to be obtained.

[0025] In another embodiment, the impregnant material is selected from among hard materials, the term "hard" denoting materials that have intrinsic hardness and toughness characteristics that distinguish them from "soft" materials such as the polymers and fibers described above.

[0026] The impregnant in such applications can be a precursor material that reacts in situ with the carbon to form carbides and/or other reaction products providing the desired properties. As an example, tungsten can be impregnated into nanoporosity of the carbon material by suitable vapor phase deposition techniques, such as by volatilization of an organotungsten precursor so that tungsten vapor permeates the pores of the carbon material, and is converted during the deposition and/or by subsequent heat treating of the material to tungsten carbide.

[0027] Tungsten carbide is a highly dense material, and one of the hardest materials known. Its use has heretofore been limited due to its difficult-to-machine character. Such difficulty can be surmounted by a provision of a shaped porous carbon article of the ultimate desired conformation, which subsequent to formation of tungsten carbide in porosity thereof provides the finished article having the desired dimensions and configuration. The carbon porosity could for example be penetrated using chemical vapor deposition techniques employing tungsten carbonyl

or tungsten hexafluoride to provide tungsten deposits in the pores that then react under elevated temperature conditions to form tungsten carbide in situ.

[0028] Such carbon/tungsten carbide composites can be manufactured to provide a replacement material for depleted uranium, e.g., in projectiles for use as armor piercing weapons. Currently, depleted uranium is used for such armor piercing applications, but depleted uranium is a toxic material that is the focus of international efforts to eliminate same from use in weaponry.

[0029] More generally, such carbon porosity impregnation can be employed to form structurally graded materials, in which porosity is impregnated to a certain depth or dimension of the porous carbon, or in which diffusional characteristics are employed to provide a concentration gradient of the impregnant over a depth or dimension of the porous carbon material.

[0030] Other hard impregnants that may be useful in specific embodiments of the invention include, without limitation, lead, titanium, aluminum, aluminum oxide, silicon, silicon oxide and the like.

[0031] The use of an impregnant to at least partially fill porosity of porous carbon material enables the creation of new composite materials, with the ability to create a wide variety of conformations and structural forms in a green state that then can be converted to materials of a desired shape and/or functional character, e.g., ultra-hard and/or densified materials useful in armor piercing bullets and the corresponding dense armor.

[0032] In other embodiments of the invention, porous carbon is incorporated with boron to provide a hydrogen storage medium of high hydrogen loading capacity. The boronated porous carbon then can be loaded with hydrogen, so that hydrogen is stored by the porous carbon and released therefrom under dispensing conditions to provide hydrogen, e.g., for a hydrogen fuel cell or other hydrogen-utilizing apparatus or process. In this way, the boron-containing porous carbon provides a hydrogen storage medium having high loading capacity as useful for applications such as hydrogen-powered vehicles.

[0033] The boron can be incorporated in the porous carbon material in any suitable manner and by any suitable technique. In one preferred embodiment, boron is at least partially introduced into the porous carbon material by ion implantation, and combinations of ion implantation of boron and vapor deposition or solution deposition techniques can be employed to create boron-containing carbon materials of desired properties.

[0034] Another aspect of the invention relates to the use of porous carbon as a chlorine storage medium at subatmospheric storage conditions. Although porous carbon has heretofore been employed as a storage medium for a wide variety of fluids and gases that are adsorbable on such material, chlorine has not been considered for such storage applications, since liquids

typically occupy many orders of magnitude less volume than gases, and since chlorine is normally stored and transported in pressurized liquid form.

[0035] Such pressurized liquid form of chlorine, however, presents issues of safety and toxicity, particularly when the amount of chlorine involved is large. For example, on January 6, 2005, a Norfolk Southern Corp. freight train carrying chemicals hit a parked train near the Avondale Mills Plant in Graniteville, South Carolina, USA. The chemicals being transported by the freight train included pressurized liquid-form chlorine. As a result of the collision, toxic chlorine gas was released into the air surrounding the crash site, which caused the deaths of 10 individuals and required the evacuation of 5000 people from nearby residences.

[0036] The storage of chlorine in gaseous form as an adsorbate on porous carbon would on initial consideration not appear to be economically viable or practical as a mode of packaging chlorine, but it has surprisingly been found that when comparing the loading capacity of a confined volume holding pressurized liquid chlorine, with the capacity of an equal volume of porous carbon having chlorine gas adsorbed thereon at subatmospheric pressure, the actual capacity of the porous carbon exceeds the capacity of the high-pressure liquid containment volume by approximately 30%.

[0037] As applied to the catastrophic release of chlorine at the Graniteville, South Carolina, USA crash site, the transport of the same amount of chlorine gas (as carried by the Norfolk Southern Corp. freight train) in tube-trailer type rail cars containing porous carbon adsorbent at less than atmospheric pressure, would have resulted in the rate of the release of chlorine being reduced by approximately 1/100,000th compared to the high pressure release that caused the death and damage that occurred.

[0038] The surprising capacity improvement in chlorine storage that is achievable by gaseous chlorine storage on porous carbon, as compared to capacity of a corresponding confinement volume of pressurized chlorine liquid, is due to the fact that the confinement volume is limited in the amount of pressurized chlorine liquid that can be stored, since changes in ambient temperature of the confinement volume can cause evaporation, gas expansion and rupture of the containment structure. Accordingly, the confinement volume holding pressurized chlorine liquid must be designed and employed to accommodate increases in temperature of the environment in which the confinement volume resides, as well as evaporation and gas expansion deriving from the liquid chlorine.

[0039] In the storage of gaseous chlorine on porous carbon at subatmospheric pressure, however, the chlorine gas is held on the porous carbon adsorbent by physical adsorption forces, enabling the volume containing the porous carbon adsorbent to be much more effectively used at

subatmospheric pressure than is achievable by the corresponding volume in which pressurized chlorine liquid is held. As a result, a surprising and unexpected improvement in chlorine storage capacity is achieved, with an accompanying high level of safety improvement, as a result of the subatmospheric gas storage condition of the chlorine gas adsorbed on the porous carbon.

[0040] Thus, chlorine gas can be efficiently stored in an adsorbed state at subatmospheric pressure, to obviate the hazards associated with prior art storage and transport of pressurized liquid chlorine, with markedly improved capacity of chlorine per unit of storage volume. At the point of use, the chlorine gas is readily dispensed from the porous carbon adsorbent, by any of suitable thermally-mediated desorption, pressure gradient-mediated desorption, and/or concentration gradient-mediated desorption techniques. For example, a vacuum pump may be employed to effect desorption of chlorine from the porous carbon in the dispensing operation.

[0041] In addition to chlorine, such sorbent-based storage and dispensing approach may be applied to ammonia, or to phosgene, or to other industrial gases.

[0042] Referring now to the drawings, FIG. 1 is a perspective view of an impregnated carbon structural member 10 according to one embodiment of the invention. The impregnated carbon structural member 10 is constituted by a main body portion 12 having a front surface 14 in the view shown.

[0043] The impregnated carbon structural member 10 can be a constituent portion of an article of widely varying type. Such member can for example be fabricated from a porous carbon that is impregnated with long chain aramid fibers, or fibers commercially available under the trademarks Kevlar, PBO, Zorlon and Spectra, or with long chain silicone or polyethylene glycol polymers, or with tungsten carbide or other metal carbide. The porous carbon for such application can be formed or provided with porosity of any suitable pore size and pore size distribution, as appropriate to the end use of the structural member.

[0044] The structural member itself can be employed for any of a variety of applications, such as ultra-tough composite body armor, vehicular armor, bumper member or impact element, or as a densified material for construction or coating of munitions articles, as a casing material for rugged notebook computers, personal digital assistants, extreme sport watches, and deep sea sensor assemblies, etc.

[0045] The impregnant component may be deposited in the porosity of the porous carbon material in any suitable manner, such as vapor deposition (chemical vapor deposition, plasma contacting, etc.), solution deposition, vacuum evacuaton and high pressure impregnation of the pores, or any other technique or methodology that is effective to introduce the reinforcement component or a precursor thereof into the porosity of the porous carbon.

[0046] FIG. 2 is a schematic elevation view of a fluid storage and dispensing apparatus 42 according to one embodiment of the invention, as arranged for supplying fluid to a fluid-utilizing facility 56 in a process system 40.

[0047] The fluid storage and dispensing apparatus 42 as shown includes a fluid storage and dispensing vessel 44 containing a sorbent medium 48, which may be formed of a porous carbon material, in a discontinuous (e.g., bead or pellet) form, or alternatively in a monolithic bulk form, such as one or more porous carbon sorbent articles, each of which may be in the form of a brick, block, disc, sheet or other conformation for use in storing and dispensing fluids such as gases for fluid-utilizing applications.

[0048] The vessel 44 is joined at its upper neck region to a valve head assembly 46 including a flow control valve element (not shown) in the valve body that is translatable between fully open and fully closed positions under the controlling action of the handwheel 50, to effect discharge of the fluid from the vessel 44. By opening the valve, to expose the interior volume of the vessel 44 to the lower pressure in the line 52 coupled to the discharge port of the valve head assembly, fluid adsorbed on the porous carbon sorbent medium in the vessel is caused to desorb and to flow through the valve in the valve head and through the discharge port to the fluid discharge line 52 for dispensing.

[0049] The fluid can be dispensed from the vessel 44 in any suitable manner, e.g., in which the dispensing comprises at least one dispensing modality selected from the group consisting of thermally-mediated desorption, pressure gradient-mediated desorption, and concentration gradient-mediated desorption

[0050] The dispensed fluid in line 52 flows through flow control unit 54 to the fluid-utilizing facility 56. The flow control unit may include any suitable flow control devices or flow modulating elements, such as for example, regulators, mass flow controllers, restricted flow orifices, flow control valves, pumps, compressors, venturis, eductors, flow-smoothing surge vessels, etc. The flow control unit may for example include a vacuum pump for extraction of the fluid from the vessel.

[0051] The fluid-utilizing facility 56 may be of any suitable type, as appropriate to the specific fluid that is being delivered. The facility may for example be a manufacturing process facility, a chemical reactor, distribution or blending facility, or the like.

[0052] In one embodiment of the invention, the porous carbon 48 in the vessel 44 has boron impregnated in the porosity of the carbon medium, e.g., by ion implantation of boron in the porosity from a precursor such as diborane, borohydride or other boron source material, and functions as a hydrogen gas storage medium. Under dispensing conditions, hydrogen is desorbed

from the sorbent medium and flows into the dispensing line 52 to the hydrogen-utilizing facility 56, which may be constituted by a hydrogen fuel cell unit wherein the hydrogen fuel is used to generate a power output, e.g., for vehicular propulsion.

[0053] In another embodiment of the invention, the porous carbon 48 in the vessel 44 has chlorine gas adsorbed thereon, for storage of chlorine and selective dispensing thereof from the vessel. The vessel in lieu of the gas supply cylinder shown, may be configured as a tube trailer vessel, or a railcar vessel, for motive transport of chlorine. By such sorptive holding of the chlorine in an adsorbed state on the porous carbon adsorbent medium, the chlorine is maintained in an inherently safer state than high pressure gas vessels of the prior art.

[0054] As indicated earlier herein, such sorbent-based storage and dispensing arrangement may be applied to phosgene, ammonia or other industrial gases, to store and transport such gases in an inherently safer form that the high pressure containment structures of the prior art.

[0055] While the invention has been has been described herein in reference to specific aspects, features and illustrative embodiments of the invention, it will be appreciated that the utility of the invention is not thus limited, but rather extends to and encompasses numerous other variations, modifications and alternative embodiments, as will suggest themselves to those of ordinary skill in the field of the present invention, based on the disclosure herein. Correspondingly, the invention as hereinafter claimed is intended to be broadly construed and interpreted, as including all such variations, modifications and alternative embodiments, within its spirit and scope.

THE CLAIMS

What is claimed is:

1. A nanoporous carbon composite including nanoporous carbon having porosity that is at least partially filled with material imparting to the composite an enhanced character with respect to characteristics selected from the group consisting of hardness, wear-resistance and toughness, as compared with the nanoporous carbon alone.

2. The nanoporous carbon composite of claim 1, wherein said enhanced character comprises ballistic toughness.

3. The nanoporous carbon composite of claim 1, wherein said porosity has an average pore diameter of less than 10 nanometers.

4. The nanoporous carbon composite of claim 1, wherein said material comprises polymeric material.

5. The nanoporous carbon composite of claim 1, wherein said polymeric material includes a viscoelastic material.

6. The nanoporous carbon composite of claim 1, wherein said viscoelastic material is selected from the group consisting of silicones and polyethylene glycols.

7. The nanoporous carbon composite of claim 1, wherein said nanoporous carbon comprises a PVDC char material having at least 30% of overall porosity constituted by slit-shaped pores having a size in a range of from about 0.3 to about 0.72 nanometers, and at least 20% of the overall porosity comprising pores of diameter < 2 nanometers, with a bulk density of from about 0.80 to about 2.0 grams per cubic centimeter.

8. The nanoporous carbon composite of claim 1, wherein said material comprises polymeric fibers.

9. The nanoporous carbon composite of claim 8, wherein said polymeric fibers comprise aramid fibers.

10. The nanoporous carbon composite of claim 1, wherein said enhanced character comprises fracture toughness.

11. The nanoporous carbon composite of claim 1, wherein said material is a reaction product formed in situ in said porosity.

12. The nanoporous carbon composite of claim 1, wherein said material comprises a carbide material.

13. The nanoporous carbon composite of claim 12, wherein said carbide material comprises tungsten carbide.

14. The nanoporous carbon composite of claim 1, wherein said composite is graded.

15. The nanoporous carbon composite of claim 14, wherein said composite is graded in the presence of said material to a depth or dimension within the porous carbon.

16. The nanoporous carbon composite of claim 1, wherein the material comprises at least one of materials selected from the group consisting of lead, titanium, aluminum, aluminum oxide, silicon, and silicon oxide.

17. The nanoporous carbon composite of claim 1, wherein the composite has a molded or machined predetermined shape.

18. The nanoporous carbon composite of claim 1, wherein the material comprises an ion implanted material.

19. The nanoporous carbon carbon composite of claim 18, wherein the ion implanted material comprises a material that is reversibly interactive with hydrogen.

20. The nanoporous carbon carbon composite of claim 18, wherein the ion implanted material comprises boron.

21. A hydrogen storage system comprising the nanoporous carbon composite of claim 20.

22. A hydrogen fuel energy-producing system comprising the nanoporous carbon composite of claim 20.

23. The nanoporous carbon composite of claim 1, wherein the material comprises boron.

24. A chlorine gas storage system comprising porous carbon.

25. The chlorine gas storage system of claim 24, comprising a container having an interior volume holding said porous carbon therein.

26. The chlorine gas storage system of claim 25, wherein the container is a portable container.

27. The chlorine gas storage system of claim 25, wherein said container comprises a motive vehicular container.

28. The chlorine gas storage system of claim 27, wherein the motive vehicular container comprises a railroad container car.

29. The chlorine gas storage system of claim 27, wherein the motive vehicular container comprises a tube trailer container.

30. The chlorine gas storage system of claim 24, wherein chlorine gas is adsorptively held on said porous carbon.

31. The chlorine gas storage system of claim 30, wherein the chlorine gas is held at subatmospheric pressure.

32. The chlorine gas storage system of claim 24, as adapted for dispensing of chlorine gas.

33. The chlorine gas storage system of claim 32, wherein said dispensing comprises at least one dispensing modality selected from the group consisting of thermally-mediated desorption, pressure gradient-mediated desorption, and concentration gradient-mediated desorption.

34. The chlorine gas storage system of claim 32, further comprising a vacuum pump to effect desorption from the porous carbon in said dispensing.

35. A method of fabricating a composite, comprising at least partially filling porosity of a nanoporous carbon with material imparting to the composite an enhanced character with respect to characteristics selected from the group consisting of hardness, wear-resistance and toughness, as compared with the nanoporous carbon alone.

36. The method of claim 35, wherein said enhanced character comprises ballistic toughness.

37. The method of claim 35, wherein said porosity has an average pore diameter of less than 10 nanometers.

38. The method of claim 35, wherein said material comprises polymeric material.

39. The method of claim 35, wherein said polymeric material includes a viscoelastic material.

40. The method of claim 35, wherein said viscoelastic material is selected from the group consisting of silicones and polyethylene glycols.

41. The method of claim 35, wherein said nanoporous carbon comprises a PVDC char material having at least 30% of overall porosity constituted by slit-shaped pores having a size in a range of from about 0.3 to about 0.72 nanometer, and at least 20% of the overall porosity comprising pores of diameter < 2 nanometers, with a bulk density of from about 0.80 to about 2.0 grams per cubic centimeter.

42. The method of claim 35, wherein said material comprises polymeric fibers.

43. The method of claim 42, wherein said polymeric fibers comprise aramid fibers.

44. The method of claim 35, wherein said enhanced character comprises fracture toughness.

45. The method of claim 35, comprising reacting the filled material in situ in said porosity to form a reaction product therein.

46. The method of claim 35, wherein said material comprises a carbide.

47. The method of claim 45, wherein said reaction product comprises a carbide.

48. The method of claim 46, wherein said reaction product comprises tungsten carbide.

49. The method of claim 48, wherein said at least partially filling comprises chemical vapor deposition of tungsten in said porosity.

50. The method of claim 35, comprising forming a graded composite.

51. The method of claim 50, wherein said composite is graded to a depth or dimension within the porous carbon.

52. The method of claim 35, wherein the material comprises at least one of materials selected from the group consisting of lead, titanium, aluminum, aluminum oxide, silicon, and silicon oxide.

53. The method of claim 35, further comprising molding or machining the composite to impart a predetermined shape thereto.

54. The method of claim 35, comprising ion implantation of said material.

55. The method of claim 54, wherein the ion implanted material comprises a material that is reversibly interactive with hydrogen.

56. The method of claim 54, wherein the ion implanted material comprises boron.

57. A method of storing hydrogen for dispensing thereof, comprising use of a hydrogen storage medium including a nanoporous carbon containing boron.

58. The method of claim 57, wherein said boron is ion implanted in said nanoporous carbon.

59. A method of generating energy, comprising use of a hydrogen storage medium including a nanoporous carbon containing boron.

60. A method of storing chlorine gas, comprising holding said chlorine gas in an adsorbed state on porous carbon.

61. The method of claim 60, comprising disposing said porous carbon in an interior volume of a container for said holding of said chlorine gas.

62. The method of claim 61, wherein said container comprises a portable container.

63. The method of claim 61, wherein said container comprises a motive vehicular container.

64. The method of claim 63, wherein said motive vehicular container comprises a railroad container car.

65. The method of claim 63, wherein said motive vehicular container comprises a tube trailer container.

66. The method of claim 60, wherein the chlorine gas is held at subatmospheric pressure.

67. The method of claim 61, further comprising dispensing of said chlorine gas from said container.

68. The method of claim 67, wherein said dispensing comprises at least one dispensing modality selected from the group consisting of thermally-mediated desorption, pressure gradient-mediated desorption, and concentration gradient-mediated desorption.

69. The method of claim 67, further comprising vacuum pumping said chlorine gas in said dispensing.

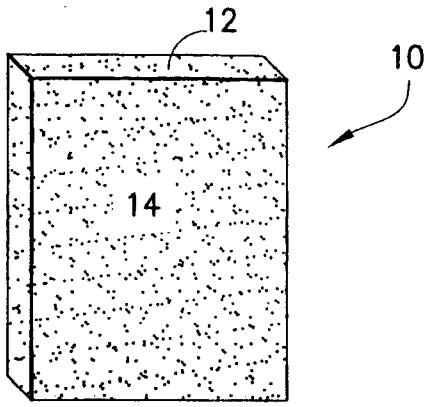


FIG.1

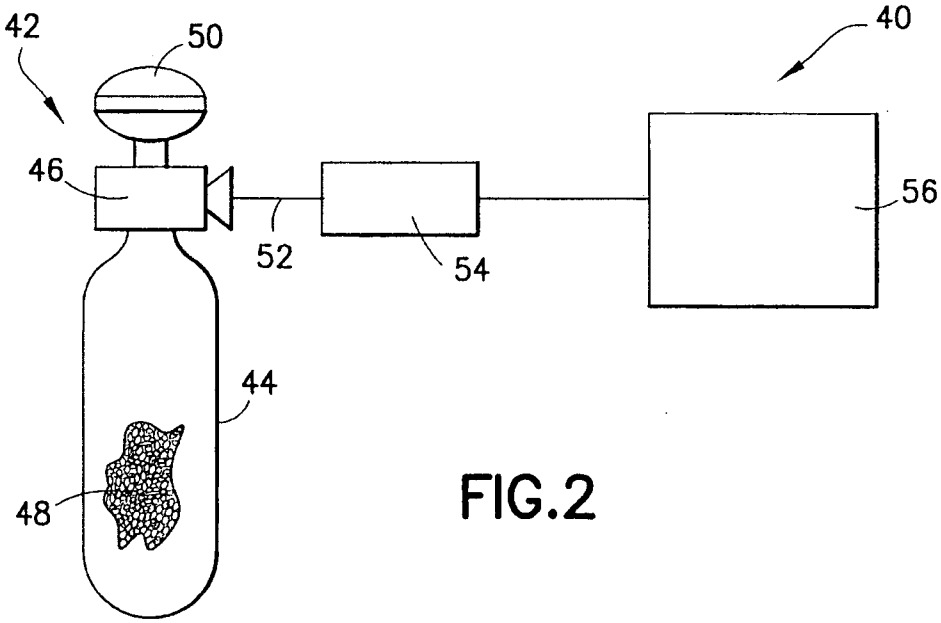


FIG.2