least 2 hours, at least 24 hours, 1 second to 12 months, 5 seconds to 24 hours, 10 seconds to 24 hours, 10 seconds to 12 months, 60 seconds to 24 hours, 1 hour to 24 hours; and 1 hour to 24 months), an energy density of 1 W·h/kg to 500 W·h/kg (e.g., 2 W·h/kg to 300 W·h/kg, 5 W·h/kg to 100 W·h/kg, and 5 W·h/kg to 50 W·h/kg), and a power density of 10 W/kg to 5000 W/kg (e.g., 100 W/kg to 4000 w/kg, 200 W/kg to 2000 w/kg). The above-described material can be charged to 50% of its capacitance within 0.1 second to 6 hours (e.g., 0.5 second to 1 hour, 1 second to 10 minutes, and 1 second to 30 seconds).

The polarization retention time is the length of time during which 50% of the polarized charges remain in a polarizable ion-conducting material in the absence of an electrical field, an electromagnetic field, a magnetic field, or an external load.

The polarizable ion-conducting material can be a membrane having a thickness of 1 nm to 1 cm (e.g., 1 nm to 1000 nm, 2 nm to 500 nm, 3 nm to 100 nm, 1 μm to 1 cm, 10 μm to 1 cm, and 50 μm to ~~500~~ 5 mm~~, and 100 μm to 100 mm~~). Furthermore, the membrane typically has a polarization of 1 mC/cm^2 to 10 C/cm^2 (e.g., 5 mC/cm^2 to 10 C/cm^2, 10 mC/cm^2 to 10 C/cm^2, 0.05 C/cm^2 to 5 C/cm^2, and 0.1 C/cm^2 to 2 C/cm^2), a capacitance of 0.01 F/cm^2 to 10 F/cm^2 (e.g., 0.05 F/cm^2 to 5 F/cm^2 and 0.1 F/cm^2 to 1 F/cm^2), an ion conductivity of 1×10^{-6} to 1000 S/cm (e.g., 1×10^{-4} to 100 S/cm, 1×10^{-5} S/cm to 10 S/cm, 1×10^{-4} S/cm to 1 S/cm, and 1×10^{-4} S/cm to 0.1 S/cm). For a membrane having a size of 1 cm x 1 cm x 0.1 mm, its open-circuit voltage typically ranges from 0.5 V to 5 V.

Also within the scope of this invention is a device for storing electric charges.

The device, which contains the polarizable ion-conducting material, can be used as a single unit for energy storage and other applications. If necessary, multiple units can be connected either in series or in parallel.

The device disclosed herein possesses several advantages over a double-layer capacitor. First, it can be securely assembled by sandwiching the solid polarizable ion-conducting membrane between two charge collectors. By contrast, a double-layer capacitor requires a nanomaterial having a large surface area and a liquid electrolyte, thus is prone to leaking. Second, the device of this invention invariably has a high capacitance. By contrast, the capacitance of a double-layer capacitor depends on a number of factors, e.g., nanomaterials and

WHAT IS CLAIMED IS:

1. A polarizable ion-conducting material, the material comprising mobile ions and a matrix formed of a polymer having ionic groups of a charge opposite to that of the mobile ions, wherein the material is a membrane having a thickness of 10 μm to 1 cm and has a polarization of at least 0.2 mC/g, a capacitance of at least 0.1 mF/g, an open-circuit voltage of 1.3 to 5 V, and a polarization retention time of at least 5 seconds.

2. The polarizable ion-conducting material of claim 1, wherein the material has a polarization of 2 mC/g to 25 C/g, a capacitance of 1 mF/g to 80 F/g, a polarization retention time of at least 10 seconds, an energy density of 1 W·h/kg to 30 W·h/kg, ~~and~~ a power density of 100 W/kg to 5000 W/kg, and an ion conductivity of 0.0001 S/cm to 100 S/cm.

3. The polarizable ion-conducting material of claim 2, wherein the material has a polarization of 0.1 C/g to 25 C/g, a capacitance of 0.5 F/g to 80 F/g, a polarization retention time of at least 60 seconds, an energy density of 5 W·h/kg to 30 W·h/kg, ~~and~~ a power density of 500 W/kg to 5000 W/kg, and an ion conductivity of 0.001 S/cm to 100 S/cm.

4. The polarizable ion-conducting material of claim 1, wherein the mobile ions are cations and the ionic groups are negatively charged.

5. The polarizable ion-conducting material of claim 4, wherein the material has a polarization of 2 mC/g to 25 C/g, a capacitance of 1mF/g to 80 F/g, a polarization retention time of at least 10 seconds, an energy density of 1 W·h/kg to 30 W·h/kg, ~~and~~ a power density of 100 W/kg to 5000 W/kg, and an ion conductivity of 0.0001 S/cm to 100 S/cm.

6. The polarizable ion-conducting material of claim 5, wherein the material has a polarization of 0.1 C/g to 25 C/g, a capacitance of 0.5 F/g to 80 F/g, a polarization retention time of at least 60 seconds, an energy density of 5 W·h/kg to

30 W·h/kg, ~~and~~ a power density of 500 W/kg to 5000 W/kg, and an ion conductivity of 0.001 S/cm to 100 S/cm.

7. The polarizable ion-conducting material of claim 4, wherein the mobile ions are H^+, Li^+, Na^+, K^+, NH_4^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Fe^{3+}, Sn^{2+}, Co^{2+}, Cu^{2+},Ag^+, Au^{2+}, or a combination thereof; and the polymer is a polymer having sulfonic groups, a polymer having carboxylic groups, a polymer having phosphonic groups, a polymer having enolate groups, a polymer having thiolate groups, a polymer having phenoxide groups, or a combination thereof.

8. The polarizable ion-conducting material of claim 7, wherein the material has a polarization of 2 mC/g to 25 C/g, a capacitance of 1 mF/g to 80 F/g, a polarization retention time of at least 10 seconds, an energy density of 1 W·h/kg to 30 W·h/kg, ~~and~~ a power density of 100 W/kg to 5000 W/kg, and an ion-conductivity of 0.0001 S/cm to 100 S/cm.

9. The polarizable ion-conducting material of claim 8, wherein the material has a polarization of 0.1 C/g to 25 C/g, a capacitance of 0.5 F/g to 80 F/g, a polarization retention time of at least 60 seconds, an energy density of 5 W·h/kg to 30 W·h/kg, ~~and~~ a power density of 500 W/kg to 5000 W/kg, and an ion conductivity of 0.001 S/cm to 100 S/cm.

10. The polarizable ion-conducting material of claim 1, wherein the mobile ions are anions and the ionic groups are positively charged.

11. The polarizable ion-conducting material of claim 10, ~~The polarizable ion-conducting material of claim 1,~~ wherein the material has a polarization of 2 mC/g to 25 C/g, a capacitance of 1 mF/g to 80 F/g, a polarization retention time of at least 10 seconds, an energy density of 1 W·h/kg to 30 W·h/kg, ~~and~~ a power density of 100 W/kg to 5000 W/kg, and an ion conductivity of 0.0001 S/cm to 100 S/cm.

12. The polarizable ion-conducting material of claim 11, wherein the material has a polarization of 0.1 C/g to 25 C/g, a capacitance of 0.5 F/g to 80 F/g, a

polarization retention time of at least 60 seconds, an energy density of 5 W·h/kg to 30 W·h/kg, ~~and~~ a power density of 500 W/kg to 5000 W/kg, and an ion conductivity of 0.001 S/cm to 100 S/cm.

13. The polarizable ion-conducting material of claim 10, wherein the mobile ions are F^-, Cl^-, Br^-, I^-, OH^-, or a combination thereof; and the polymer is poly(allylamine hydrochloride), poly(diallyldimethylammonium chloride), poly(acrylamide-*co*-diallyldimethylammonium chloride), or a combination thereof.

14. The polarizable ion-conducting material of claim 13, ~~The polarizable ion-conducting material of claim 1,~~ wherein the material has a polarization of 2 mC/g to 25 C/g, a capacitance of 1 mF/g to 80 F/g, a polarization retention time of at least 10 seconds, an energy density of 1 W·h/kg to 30 W·h/kg, ~~and~~ a power density of 100 W/kg to 5000 W/kg, and an ion conductivity of 0.0001 S/cm to 100 S/cm.

15. The polarizable ion-conducting material of claim 14, wherein the material has a polarization of 0.1 C/g to 25 C/g, a capacitance of 0.5 F/g to 80 F/g, a polarization retention time of at least 60 seconds, an energy density of 5 W·h/kg to 30 W·h/kg, ~~and~~ a power density of 500 W/kg to 5000 W/kg, and an ion conductivity of 0.001 S/cm to 100 S/cm.

~~16. The polarizable ion-conducting material of claim 1, wherein the material is a membrane.~~

~~17. The polarizable ion-conducting material of claim 16, wherein the mobile ions are cations and the ionic groups are negatively charged.~~

~~18. The polarizable ion-conducting material of claim 17, wherein the material has a polarization of 2 mC/g to 25 C/g, a capacitance of 1 mF/g to 80 F/g, a polarization retention time of at least 10 seconds, an energy density of 1 W·h/kg to 30 W·h/kg, a power density of 100 W/kg to 5000 W/kg, and an ion conductivity of 0.0001 S/cm to 100 S/cm.~~

~~19. The polarizable ion-conducting material of claim 18, wherein the material has a polarization of 0.1 C/g to 25 C/g, a capacitance of 0.5 F/g to 80 F/g, a polarization retention time of at least 60 seconds, an energy density of 5 W·h/kg to 30 W·h/kg, a power density of 500 W/kg to 5000 W/kg, and an ion conductivity of 0.001 S/cm to 100 S/cm.~~

~~20. The polarizable ion-conducting material of claim 17, wherein the mobile ions are H^+, Li^+, Na^+, K^+, NH_4^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Fe^{3+}, Sn^{2+}, Co^{2+}, Cu^{2+}, Ag^+, Au^{2+}, or a combination thereof.~~

~~21. The polarizable ion-conducting material of claim 20, wherein the material has a polarization of 2 mC/g to 25 C/g, a capacitance of 1 mF/g to 80 F/g, a polarization retention time of at least 10 seconds, an energy density of 1 W·h/kg to 30 W·h/kg, a power density of 100 W/kg to 5000 W/kg, and an ion conductivity of 0.0001 S/cm to 100 S/cm.~~

~~22. The polarizable ion-conducting material of claim 21, wherein the material has a polarization of 0.1 C/g to 25 C/g, a capacitance of 0.5 F/g to 80 F/g, a polarization retention time of at least 60 seconds, an energy density of 5 W·h/kg to 30 W·h/kg, a power density of 500 W/kg to 5000 W/kg, and an ion conductivity of 0.001 S/cm to 100 S/cm.~~

~~23. The polarizable ion-conducting material of claim 20, wherein the polymer is a polymer having sulfonic groups, a polymer having carboxylic groups, a polymer having phosphonic groups, a polymer having enolate groups, a polymer having thiolate groups, a polymer having phenoxide groups, or a combination thereof.~~

~~24. The polarizable ion-conducting material of claim 23, wherein the material has a polarization of 1.5 mC/g to 25 C/g, a capacitance of 1 mF/g to 80 F/g, a polarization retention time of at least 10 seconds, an energy density of 1 W·h/kg to 30 W·h/kg, a power density of 100 W/kg to 5000 W/kg, and an ion conductivity of 0.0001 S/cm to 100 S/cm.~~

~~25. The polarizable ion-conducting material of claim 24, wherein the material has a polarization of 0.1 C/g to 25 C/g, a capacitance of 0.5 F/g to 0 F/g, a polarization retention time of at least 60 seconds, an energy density of 5 W·h/kg to 30 W·h/kg, a power density of 500 W/kg to 5000 W/kg, and an ion conductivity of 0.001 S/cm to 100 S/cm.~~

~~26.~~16. The polarizable ion-conducting material of claim ~~25~~ 9, wherein the mobile ions are H^+, Li^+, Na^+, or a combination thereof; and the polymer is a poly(4-styrenesulfonate).

~~27.~~17. A device for storing electric charge, the device comprising the polarizable ion-conducting material of claim 1, a first conducting layer, and a second conducting layer, the polarizable ion-conducting material being disposed between the first conducting layer and the second conducting layer, whereby, upon charging, the mobile ions migrate toward the first conducting layer thereby polarizing the polarizable ion-conducting material; and, upon discharging, the mobile ions migrate toward the second conducting layer thereby depolarizing the polarizable ion-conducting material.

~~28.~~18. The device of claim ~~27~~ 17, wherein the first conducting layer and the second conducting layer are, independently, made of a graphite sheet, a carbon-based conductive material, copper, iron, steel, aluminum, silver, gold, or platinum.

19. The polarizable ion-conducting material of claim 1, wherein the membrane has a thickness of 50 μm to 5 mm.

20. The polarizable ion-conducting material of claim 19, wherein the material has a polarization of 2 mC/g to 25 C/g, a capacitance of 1 mF/g to 80 F/g, a polarization retention time of at least 10 seconds, an energy density of 1 W·h/kg to 30 W·h/kg, a power density of 100 W/kg to 5000 W/kg, and an ion conductivity of 0.0001 S/cm to 100 S/cm.

21. The polarizable ion-conducting material of claim 20, wherein the material has a polarization of 0.1 C/g to 25 C/g, a capacitance of 0.5 F/g to 80 F/g, a polarization retention time of at least 60 seconds, an energy density of 5 W·h/kg to 30 W·h/kg, a power density of 500 W/kg to 5000 W/kg, and an ion conductivity of 0.001 S/cm to 100 S/cm.

22. The polarizable ion-conducting material of claim 19, wherein the mobile ions are cations and the ionic groups are negatively charged.

23. The polarizable ion-conducting material of claim 22, wherein the material has a polarization of 2 mC/g to 25 C/g, a capacitance of 1 mF/g to 80 F/g, a polarization retention time of at least 10 seconds, an energy density of 1 W·h/kg to 30 W·h/kg, a power density of 100 W/kg to 5000 W/kg, and an ion conductivity of 0.0001 S/cm to 100 S/cm.

24. The polarizable ion-conducting material of claim 23, wherein the material has a polarization of 0.1 C/g to 25 C/g, a capacitance of 0.5 F/g to 80 F/g, a polarization retention time of at least 60 seconds, an energy density of 5 W·h/kg to 30 W·h/kg, a power density of 500 W/kg to 5000 W/kg, and an ion conductivity of 0.001 S/cm to 100 S/cm.

25. The polarizable ion-conducting material of claim 19, wherein the mobile ions are anions and the ionic groups are positively charged.

26. The polarizable ion-conducting material of claim 25, wherein the material has a polarization of 2 mC/g to 25 C/g, a capacitance of 1 mF/g to 80 F/g, a polarization retention time of at least 10 seconds, an energy density of 1 W·h/kg to 30 W·h/kg, a power density of 100 W/kg to 5000 W/kg, and an ion conductivity of 0.0001 S/cm to 100 S/cm.

27. The polarizable ion-conducting material of claim 26, wherein the material has a polarization of 0.1 C/g to 25 C/g, a capacitance of 0.5 F/g to 80 F/g, a polarization retention time of at least 60 seconds, an energy density of 5 W·h/kg to

30 W·h/kg, a power density of 500 W/kg to 5000 W/kg, and an ion conductivity of 0.001 S/cm to 100 S/cm.

28. The polarizable ion-conducting material of claim 22, wherein the mobile ions are H^+, Li^+, Na^+, or a combination thereof; the polymer is a poly(4-styrenesulfonate); and the material has a polarization of 0.1 C/g to 25 C/g, a capacitance of 0.5 F/g to 80 F/g, a polarization retention time of at least 60 seconds, an energy density of 5 W·h/kg to 30 W·h/kg, a power density of 500 W/kg to 5000 W/kg, and an ion conductivity of 0.001 S/cm to 100 S/cm.