chemical bonds on borders between crystallites. When the used material with high dielectric permittivity possesses polycrystalline structure, a percolation may occur along the borders of crystal grains. Another drawback of the known device is an expensive manufacturing procedure which is vacuum deposition of all layers.

[0011] Capacitors as energy storage device have well-known advantages versus electrochemical energy storage, e.g. a battery. Compared to batteries, capacitors are able to store energy with very high power density, i.e. charge/recharge rates, have long shelf life with little degradation, and can be charged and discharged (cycled) hundreds of thousands or millions of times. However, capacitors often do not store energy in small volume or weight as in case of a battery, or at low energy storage cost, which makes capacitors impractical for some applications, for example electric vehicles. Accordingly, it may be an advance in energy storage technology to provide capacitors of higher volumetric and mass energy storage density and lower cost.

SUMMARY

[0012] The present disclosure provides energy storage devices (e.g., capacitors) and methods of production thereof. Energy storage devices of the present disclosure may solve a problem of the further increase of volumetric and mass density of reserved energy associated with some energy storage devices, and at the same time reduce cost of materials and manufacturing process.

[0013] In an embodiment, a capacitor comprises a first electrode, a second electrode, and a solid multilayer structure disposed between said first and second electrodes. Said electrodes are planar and positioned parallel to each other, and said solid multilayer structure comprises layers disposed parallel to said electrodes and has following sequence: $(A\text{-}B)_m\text{-}A$, where A is an insulating layer; B is a polarization layer comprising a micro-dispersion of electro-conductive nano-particles in an insulator matrix, and number $m \geq 1$. In some situations, m can be greater than or equal to 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, 50, 100, 200, 300, 400, 500, or 1000. In some examples, m is from 1 to 1000, 1 to 100, or 1 to 50. The electrodes can be nearly or substantially parallel to each other. The electrodes can be off-set from a parallel configuration.

[0013a] In one aspect, there is provided a capacitor comprising

a first electrode;

a second electrode; and

a solid multilayer structure disposed between said first and second electrodes,

wherein the solid multilayer structure is in contact with said first and second electrodes and comprises layers disposed parallel to said electrodes, wherein the solid multilayer structure has a sequence of layers $(A\text{-}B)_m\text{-}A$, wherein A is an insulating layer and B is a polarization layer comprising a colloidal composite with a micro-dispersion of electro-conductive nano-particles in an insulator matrix, and m is a number greater than or equal to 1,

wherein A has a breakdown voltage of at least about 0.05 volts (V) per nanometer (nm), and

wherein B has dielectric permittivity of at least about 100.

[0014] In another embodiment, a method of producing a capacitor comprises (a) preparation of a conducting substrate serving as one of the electrodes, (b) formation of a solid multilayer structure, and (c) formation of the second electrode on the multilayer structure, wherein formation of the multilayer structure comprises alternating steps of the application of insulating and polarization layers or a step of coextrusion of the layers.

[0014a] In another aspect, there is provided a method of producing a capacitor, comprising:

a) preparing a conducting substrate serving as a first electrode;

b) forming a solid multilayer structure adjacent to the first electrode; and

c) forming a second electrode adjacent to the multilayer structure, wherein formation of the multilayer structure comprises alternating operations of the application of insulating and polarization layers or an operation of coextrusion of the insulating and polarization layers, wherein the polarization layer is a colloidal composite with a micro-dispersion of electro-conductive nano-particles in an insulator matrix, wherein an individual insulating layer has a breakdown voltage of at least about 0.05 volts per nanometer (nm) and an individual polarization layer has dielectric permittivity of at least about 100.

[0015] In another embodiment, a method of producing a capacitor comprises coating of insulating layers on both electrodes, and coating of a multilayer structure on one of electrodes with lamination of second electrode to multilayer structure.

[0015a] In another aspect, there is provided method of producing a capacitor, which comprises:

a) coating insulating layers on first and second electrodes; and

b) coating a multilayer structure on an insulating layer on one of the first and second electrodes with the lamination of the other of the first and second electrodes to the multilayer structure,

wherein an individual insulating layer has a breakdown voltage of at least about 0.05 volts per nanometer (nm) and the multilayer structure comprises a polarization layer having a dielectric permittivity of at least about 100, wherein the polarization layer is a colloidal composite with a micro-dispersion of electro-conductive nano-particles in an insulator matrix.

[0016] Additional aspects and advantages of the present disclosure will become readily apparent to those skilled in this art from the following detailed description, wherein only illustrative embodiments of the present disclosure are shown and described. As will be realized, the present disclosure is capable of other and different embodiments, and its several details are capable of modifications in various obvious respects, all without departing from the disclosure. Accordingly, the drawings and description are to be regarded as illustrative in nature, and not as restrictive.

INCORPORATION BY REFERENCE

[0017] All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

[0019] **Figure 1** schematically shows an energy storage device, in accordance with some embodiments of the present disclosure; and

[0020] **Figure 2** schematically shows another energy storage device, in accordance with some embodiments of the present disclosure.

DETAILED DESCRIPTION

[0021] While various embodiments of the invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions may occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to the embodiments of the invention described herein may be employed.

[0022] The present disclosure provides energy storage devices, such as capacitors. In one embodiment of the present invention, the insulating layers are crystalline. The insulating layers can

polyoxypropylene glycol alkyl ethers, polyoxyethylene glycol octylphenol ethers, polyoxyethylene glycol sorbitan alkyl esters, sorbitan alkyl esters, and dobecyldimethylamine oxide.

26. A method of producing a capacitor, comprising:

a) preparing a conducting substrate serving as a first electrode;

b) forming a solid multilayer structure adjacent to the first electrode; and

c) forming a second electrode adjacent to the multilayer structure, wherein formation of the multilayer structure comprises alternating operations of the application of insulating and polarization layers or an operation of coextrusion of the insulating and polarization layers, wherein the polarization layer is a colloidal composite with a micro-dispersion of electro-conductive nano-particles in an insulator matrix, wherein an individual insulating layer has a breakdown voltage of at least about 0.05 volts per nanometer (nm) and an individual polarization layer has dielectric permittivity of at least about 100.

27. A method according to Claim 26, wherein forming the solid multilayer structure comprises alternating operations of the application of a solution of an insulating material and the application of a solution of the polarization material, wherein both application operations are followed with an operation of drying to form a solid insulating and polarization layers, the alternating operations are recurred until a formation of the multilayer structure is completed, and the insulating layer is formed as the first and the last layer being in direct contact with the electrodes.

28. A method according to Claim 26, wherein forming the solid multilayer structure comprises alternating operations of the application of a melt of an insulating material and the application of a melt of the polarization material, wherein both application operations are followed with an operation of cooling down to form a solid insulating and polarization layers, and wherein the alternating operations are recurred until a formation of the multilayer structure is completed, and the insulating layers are formed as the first and the last layers being in direct contact with the electrodes.

29. A method according to Claim 26, wherein forming the solid multilayer structure comprises an operation of coextrusion of at least one set of the layers successively containing alternating polarization materials and insulating dielectric materials onto the substrate, followed by drying to form the solid multilayer structure.

30. A method according to Claim 26, wherein forming the solid multilayer structure comprises an operation of coextrusion of set of the layers successively containing alternating melts of polarization materials and insulating dielectric materials, followed with the step of cooling down to form the solid multilayer structure.

31. A method of producing a capacitor, which comprises:

a) coating insulating layers on first and second electrodes; and

b) coating a multilayer structure on an insulating layer on one of the first and second electrodes with the lamination of the other of the first and second electrodes to the multilayer structure,

wherein an individual insulating layer has a breakdown voltage of at least about 0.05 volts per nanometer (nm) and the multilayer structure comprises a polarization layer having a dielectric permittivity of at least about 100, wherein the polarization layer is a colloidal composite with a micro-dispersion of electro-conductive nano-particles in an insulator matrix.