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(54) **CAPACITOR AND METHOD OF PRODUCTION THEREOF**

(71) Applicant: **CAPACITOR SCIENCES INCORPORATED**, Palo Alto, CA (US)

(72) Inventors: **Pavel Ivan Lazarev**, Menlo Park, CA (US); **Barry K. Sharp**, San Francisco, CA (US); **Paul Furuta**, Sunnyvale, CA (US); **Yan Li**, Fremont, CA (US); **Ian SG Kelly-Morgan**, San Francisco, CA (US); **Matthew R. Robinson**, San Francisco, CA (US); **Daniel Membreno**, Fremont, CA (US)

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H01G 4/01	(2006.01)
H01G 4/008	(2006.01)
H01G 4/002	(2006.01)
H01G 4/18	(2006.01)
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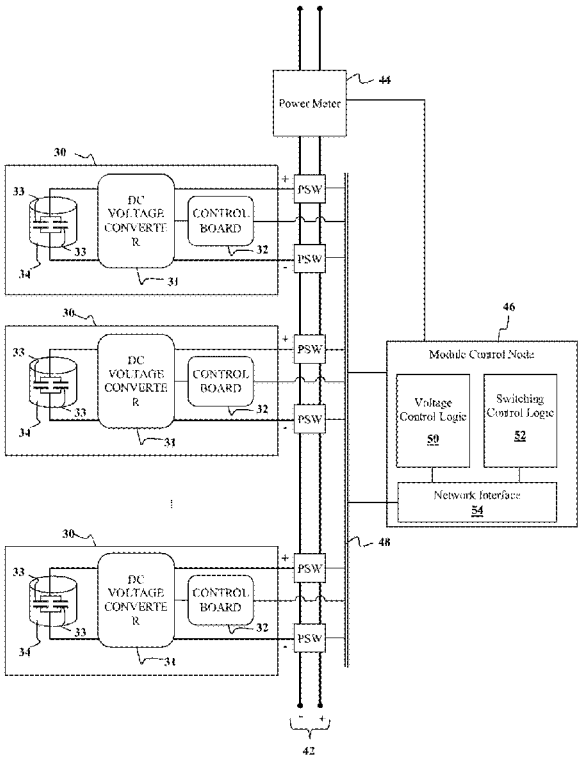
(57) **ABSTRACT**

A capacitor includes a first electrode, a second electrode, and a dielectric layer of molecular material disposed between said first and second electrodes. The molecular material is described by the general formula:

$$D_p\text{-(Core)-}\ H_q,$$

where Core is a polarizable conductive anisometric core, having conjugated π-systems, and characterized by a longitudinal axis, D and H are insulating substituents, and p and q are numbers of the D and H substituents accordingly. And Core possesses at least one dopant group that enhances polarizability.



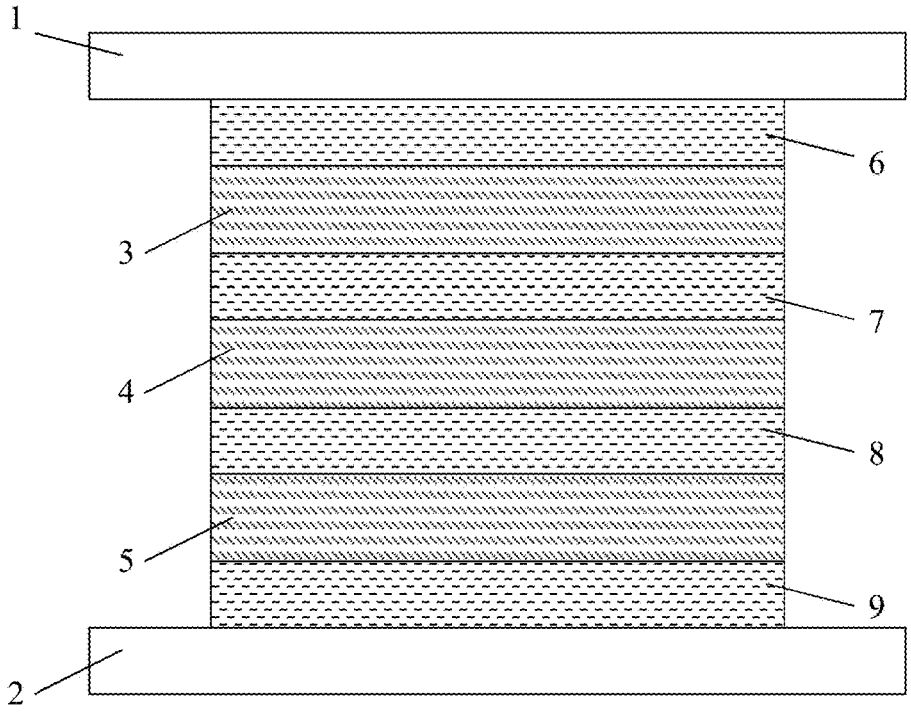


Figure 1 (Prior Art)

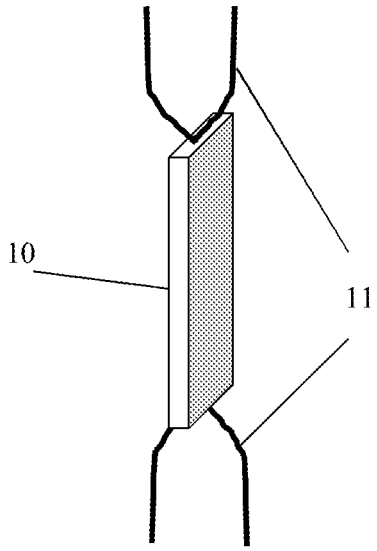
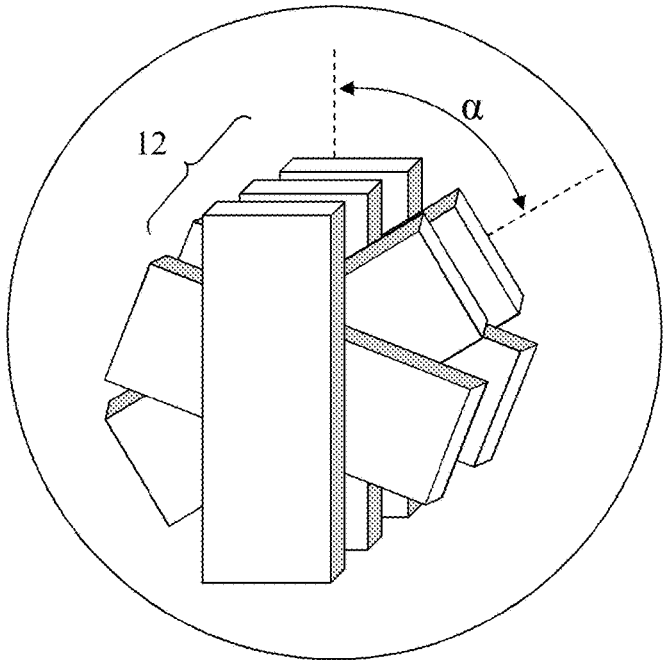


Figure 2



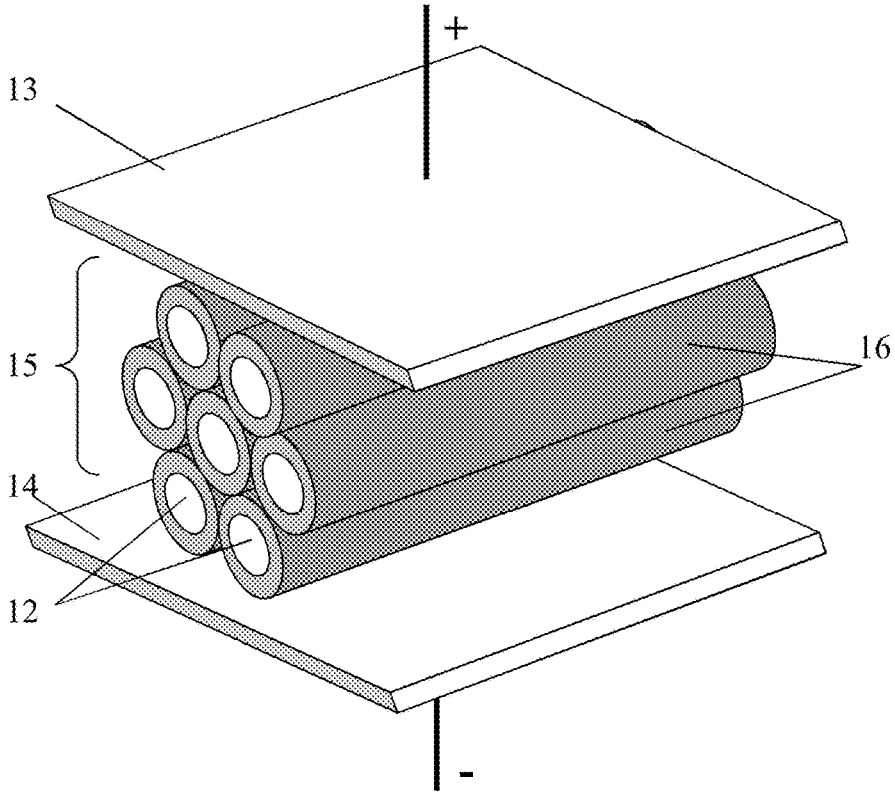


Figure 3

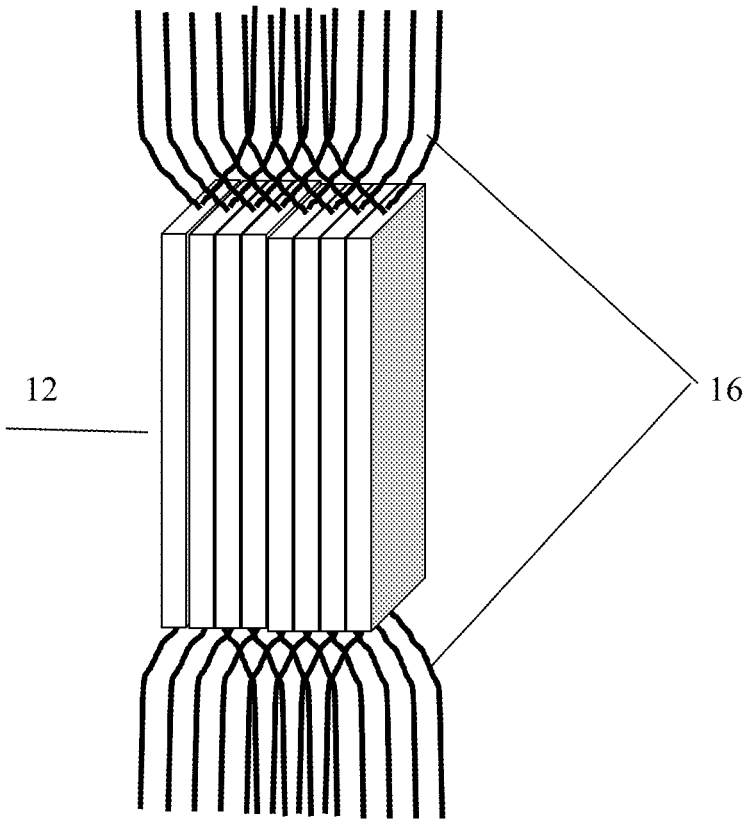


Figure 4

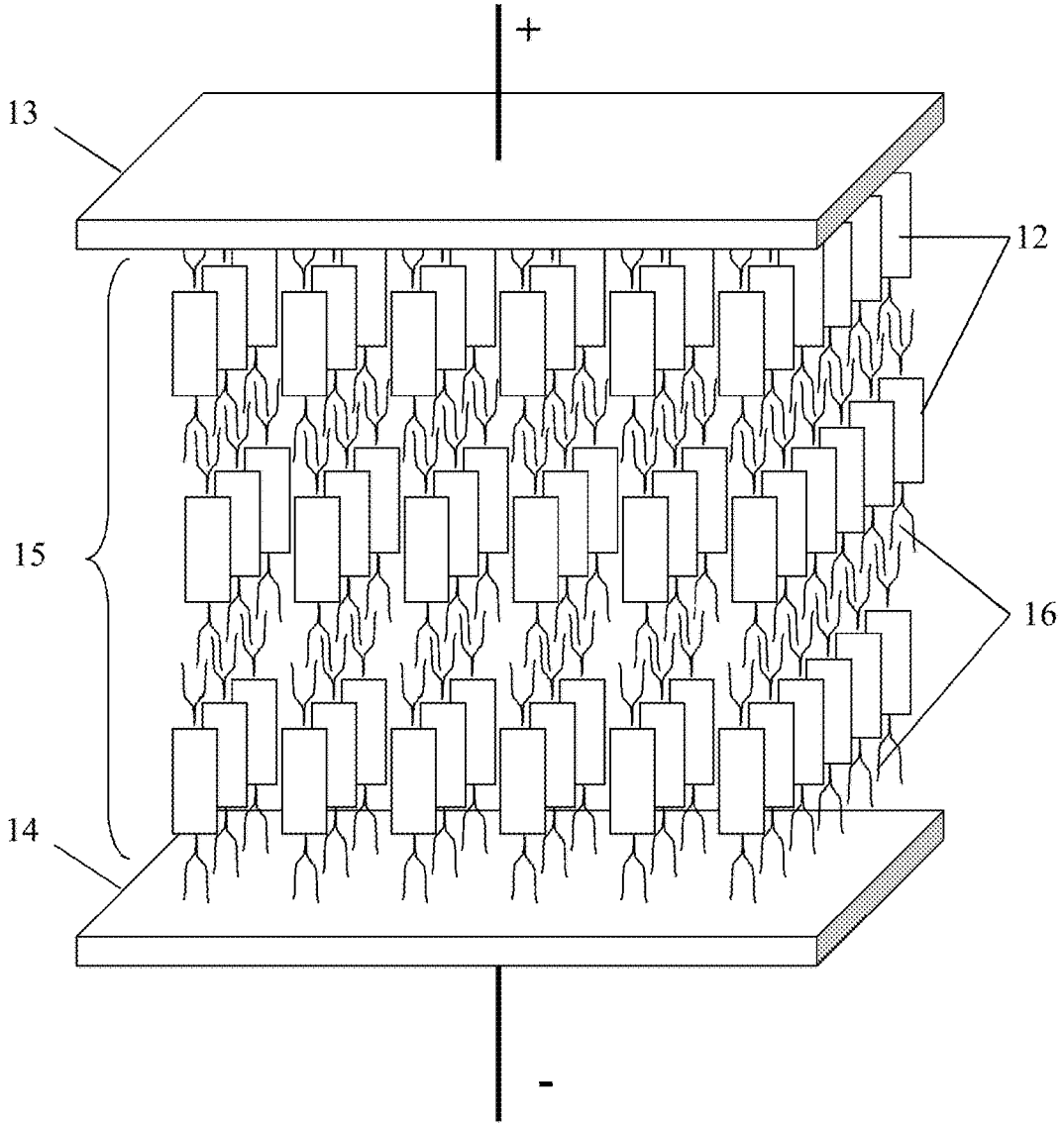


Figure 5

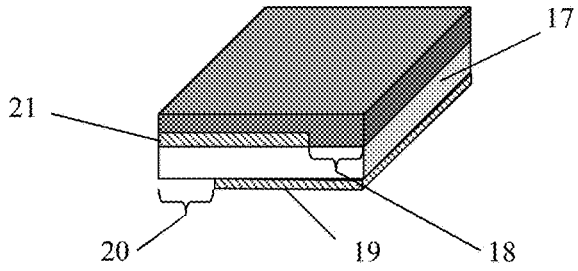


Figure 6

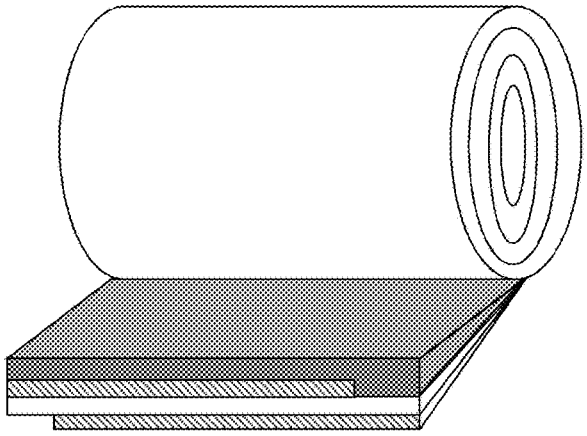
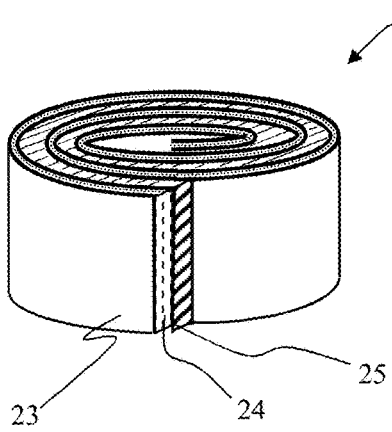


Figure 7



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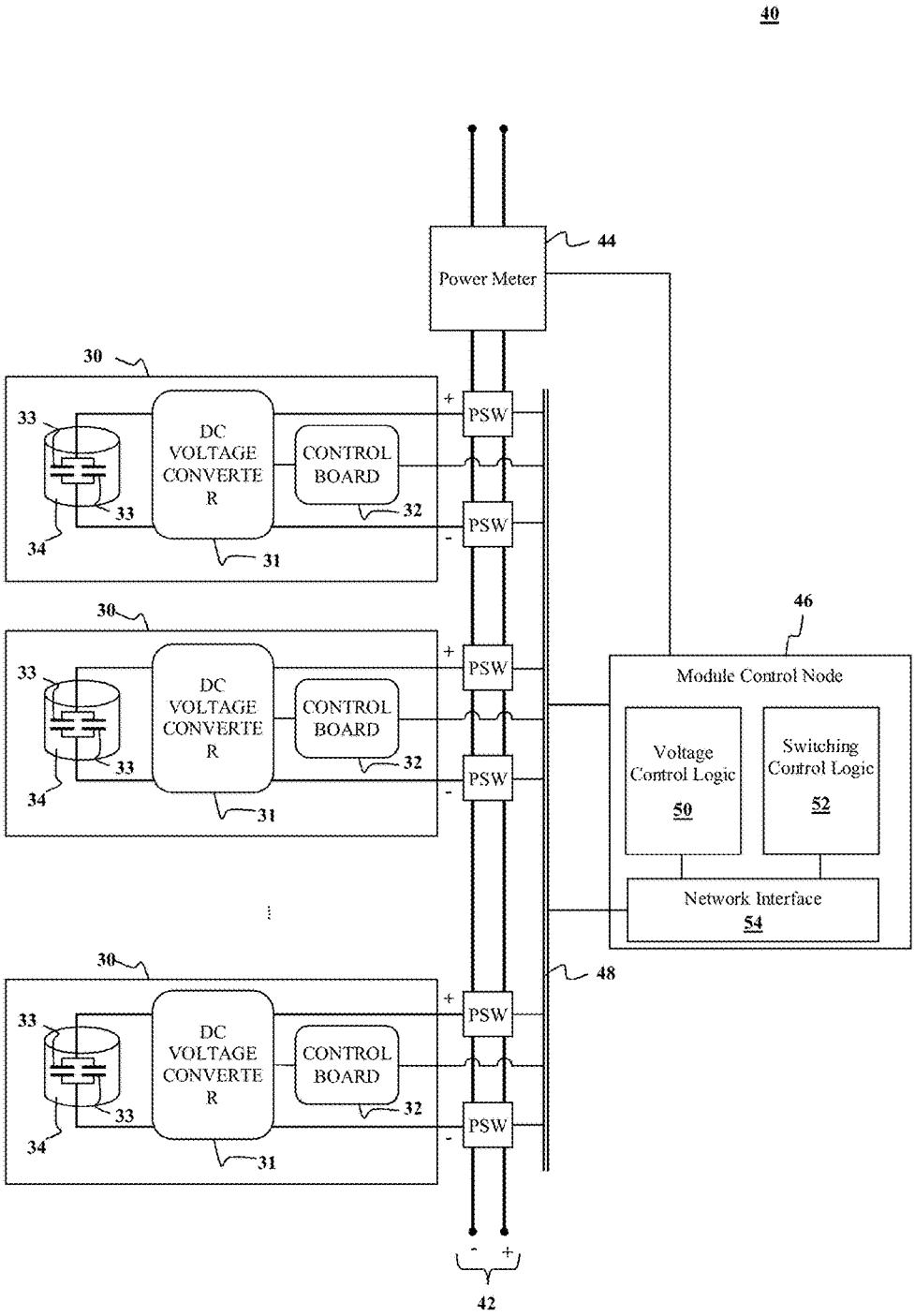
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Power Meter
44
30
33
DC VOLTAGE CONVERTER
CONTROL BOARD
32
31
34
PSW
+
-
46
Module Control Node
Voltage Control Logic
50
Switching Control Logic
52
Network Interface
54
48
42

Figure 9

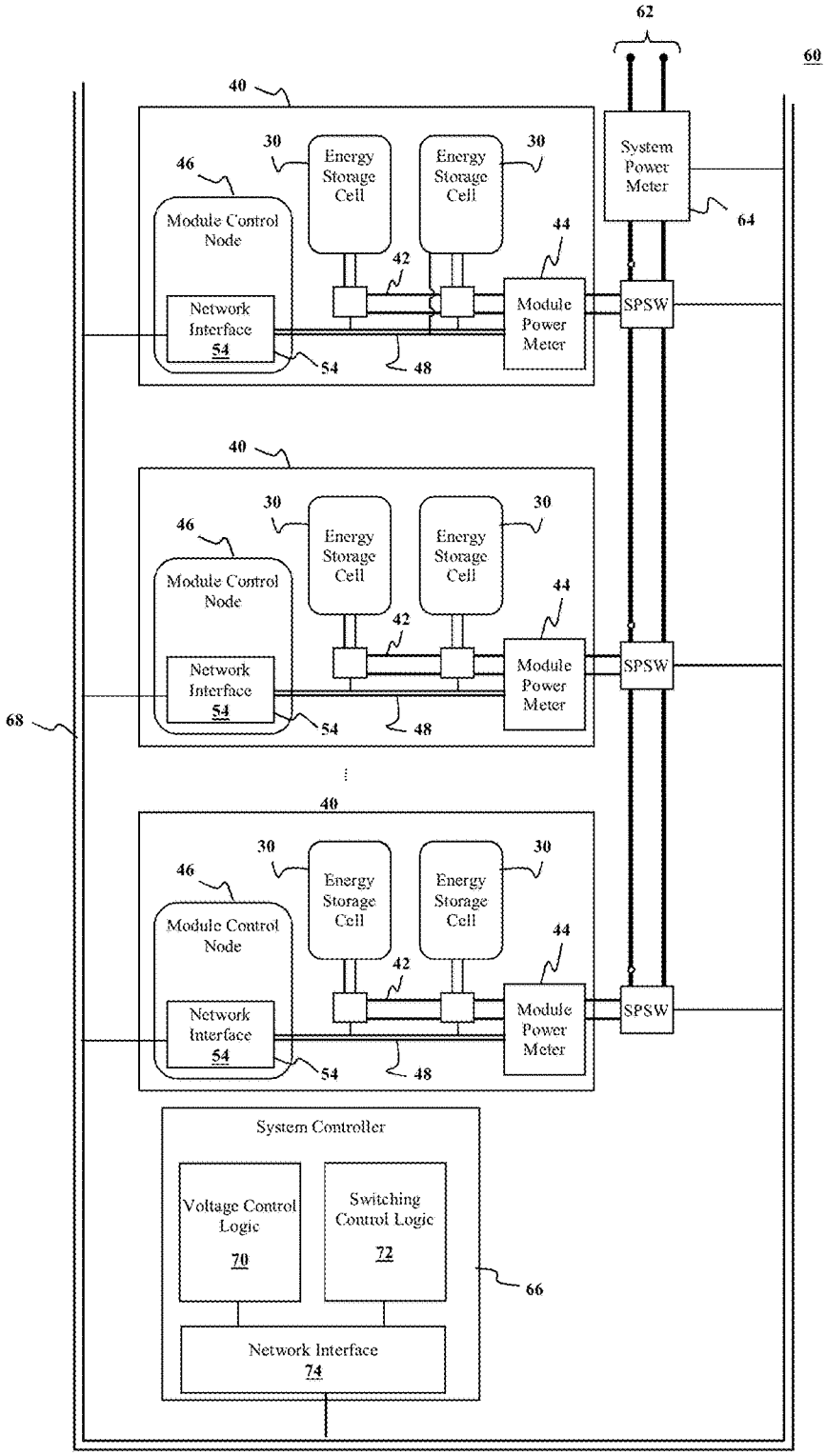

62
60
40
30
Energy Storage Cell
Energy Storage Cell
30
46
Module Control Node
Network Interface 54
54
42
44
48
Module Power Meter
SPSW
System Power Meter
64
68
System Controller
Voltage Control Logic 70
Switching Control Logic 72
Network Interface 74
66

Figure 10

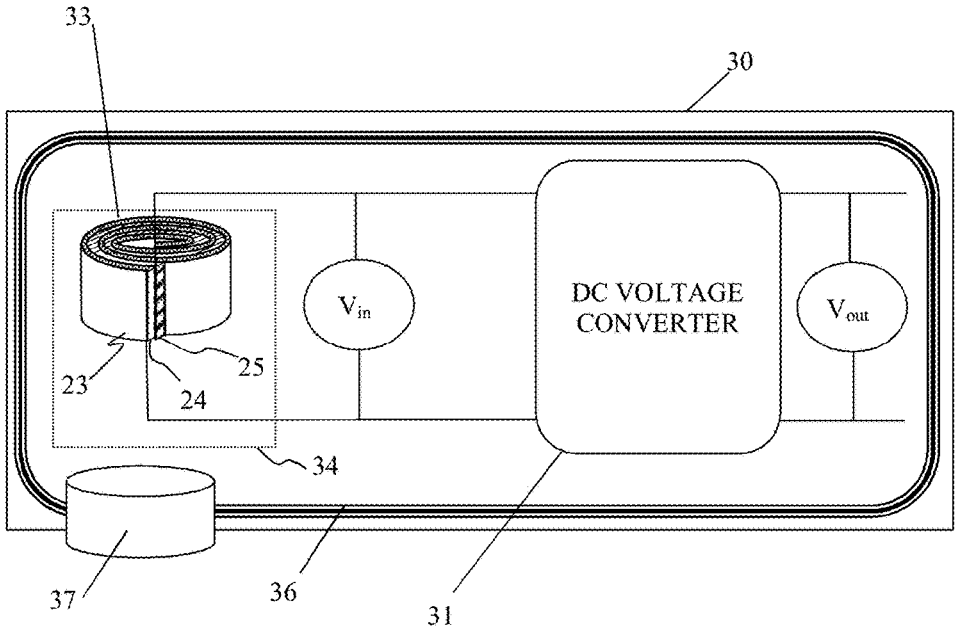


Figure 11

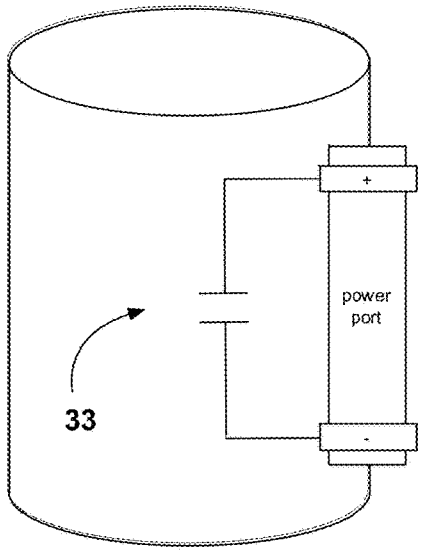


Figure 12

CAPACITOR AND METHOD OF PRODUCTION THEREOF

CLAIM OF PRIORITY

[0001] The present application is a continuation-in-part of U.S. patent application Ser. No. 14/710,491, filed May 12, 2016, the entire contents of which are incorporated herein by reference. U.S. patent application Ser. No. 14/710,491 claims the priority benefit of U.S. Provisional Patent Application No. 61/991,871 filed May 12, 2015, the entire contents of which are incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates generally to passive components of electrical circuit and more particularly to a capacitor intended for energy storage and method of production thereof.

BACKGROUND OF THE INVENTION

[0003] A capacitor is a passive electronic component that is used to store energy in the form of an electrostatic field, and comprises a pair of electrodes separated by a dielectric layer. When a potential difference exists between two electrodes, an electric field is present in the dielectric layer. This field stores energy, and an ideal capacitor is characterized by a single constant value of capacitance which is a ratio of the electric charge on each electrode to the potential difference between them. In practice, the dielectric layer between electrodes passes a small amount of leakage current. Electrodes and leads introduce an equivalent series resistance, and dielectric layer has limitation to an electric field strength which results in a breakdown voltage. The simplest energy storage device consists of two parallel electrodes separated by a dielectric layer of permittivity ϵ, each of the electrodes has an area S and is placed on a distance d from each other. Electrodes are considered to extend uniformly over an area S, and a surface charge density can be expressed by the equation: $\pm\rho=\pm Q/S$. As the width of the electrodes is much greater than the separation (distance) d, an electrical field near the center of the capacitor will be uniform with the magnitude $E=\rho/\epsilon$. Voltage is defined as a line integral of the electric field between electrodes. An ideal capacitor is characterized by a constant capacitance C defined by the formula:

$$C=Q/V, \tag{1}$$

which shows that capacitance increases with area and decreases with distance. Therefore the capacitance is largest in devices made of materials of high permittivity.

[0004] A characteristic electric field known as the breakdown strength E_{bd}, is an electric field in which the dielectric layer in a capacitor becomes conductive. Voltage at which this occurs is called the breakdown voltage of the device, and is given by the product of dielectric strength and separation between the electrodes:

$$V_{bd}=E_{bd}d \tag{2}$$

[0005] The maximal volumetric energy density stored in the capacitor is limited by the value proportional to $\sim\epsilon\cdot E^2_{bd}$, where ϵ is dielectric permittivity and E_{bd} is breakdown strength. Thus, in order to increase the stored energy of the capacitor it is necessary to increase dielectric permeability c and breakdown strength E_{bd} of the dielectric.

[0006] For high voltage applications much larger capacitors have to be used. There are a number of factors that can dramatically reduce the breakdown voltage. Geometry of the conductive electrodes is important for these applications. In particular, sharp edges or points hugely increase the electric field strength locally and can lead to a local breakdown. Once a local breakdown starts at any point, the breakdown will quickly "trace" through the dielectric layer till it reaches the opposite electrode and causes a short circuit.

[0007] Breakdown of the dielectric layer usually occurs as follows. The intensity of the electric field becomes high enough to free electrons from atoms of the dielectric material and the dielectric material begins to conduct an electric current from one electrode to another. Presence of impurities in the dielectric or imperfections of the crystal structure can result in an avalanche breakdown as observed in semiconductor devices, such as avalanche diodes and avalanche transistors.

[0008] Another important characteristic of a dielectric material is its dielectric permittivity. Different types of dielectric materials are used for capacitors and include ceramics, polymer film, paper, and electrolytic capacitors of different kinds. The most widely used polymer film materials are polypropylene and polyester. An important aspect of dielectric permittivity is that an increase of dielectric permittivity increases the maximum volumetric energy density that can be stored in a capacitor.

[0009] A material with an ultra-high dielectric constant was found to be the composite polyaniline, PANI-DBSA/PAA. PANI-DBSA/PAA is synthesized using in situ polymerization of aniline in an aqueous dispersion of poly-acrylic acid (PAA) in the presence of dodecylbenzene sulfonate (DBSA) (Chao-Hsien Hoa et al., "High dielectric constant polyaniline/poly(acrylic acid) composites prepared by in situ polymerization", Synthetic Metals 158 (2008), pp. 630-637). The water-soluble PAA serves as a polymeric stabilizer, protecting the PANI particles from macroscopic aggregation. A very high dielectric constant of ca. $2.0*10^5$ (at 1 kHz) is obtained for the composite containing 30% PANI by weight. SEM micrograph reveals that composites with high PANI content (i.e., 20 wt. %) consisted of numerous nano-scale PANI particles that are evenly distributed within the PAA matrix. The individual nano-scale PANI particles may be thought of as small capacitors. (Hoa et al.) attribute high dielectric constants to the sum of the small capacitors corresponding to the PANI particles. A major drawback of this material is a possible occurrence of percolation and formation of at least one continuous conductive path under electric field with probability of such an event increasing with an increase of the electric field. When at least one continuous path (track) through the neighboring conducting PANI particles is formed between electrodes of the capacitor, it decreases a breakdown voltage of the capacitor.

[0010] Single crystals of doped aniline oligomers are produced via a simple solution-based self-assembly method (see, Yue Wang, et. al., "Morphological and Dimensional Control via Hierarchical Assembly of Doped Oligoaniline Single Crystals", J. Am. Chem. Soc. 2012, 134, pp. 9251-9262). Detailed mechanistic studies have revealed that crystals of different morphologies and dimensions can be produced by a "bottom-up" hierarchical assembly where structures such as one-dimensional (1-D) nanofibers can be aggregated into higher order architectures. A large variety of crystalline nanostructures, including 1-D nanofibers and

nanowires, 2-D nanoribbons and nanosheets, 3-D nanoplates, stacked sheets, nanoflowers, porous networks, hollow spheres, and twisted coils, can be obtained by controlling the nucleation of the crystals and the non-covalent interactions between the doped oligomers. These nanoscale crystals exhibit enhanced conductivity compared to their bulk counterparts as well as interesting structure-property relationships such as shape-dependent crystallinity. Furthermore, the morphology and dimension of these structures can be largely rationalized and predicted by monitoring molecule-solvent interactions via absorption studies.

[0011] There is a known energy storage device based on a multilayer structure. The energy storage device includes first and second electrodes, and a multilayer structure comprising blocking and dielectric layers. The first blocking layer is disposed between the first electrode and a dielectric layer, and the second blocking layer is disposed between the second electrode and a dielectric layer. Dielectric constants of the first and second blocking layers are both independently greater than the dielectric constant of the dielectric layer. FIG. **1** shows one exemplary design that includes electrodes **1** and **2**, and multilayer structure comprising layers made of dielectric material (**3**, **4**, **5**) which are separated by layers of blocking material (**6**, **7**, **8**, **9**). The blocking layers **6** and **9** are disposed in the neighborhood of the electrodes **1** and **2** accordingly and characterized by higher dielectric constant than dielectric constant of the dielectric material. A drawback of this device is that blocking layers of high dielectric permittivity located directly in contact with electrodes can lead to destruction of the energy storage device. Materials with high dielectric permittivity which are based on composite materials and contain polarized particles (such as PANI particles) might demonstrate a percolation phenomenon. The formed polycrystalline structure of layers has multiple tangling chemical bonds on borders between crystallites. When a material with a high dielectric permittivity possesses a polycrystalline structure is used a percolation might occur along the borders of crystal grains. Another drawback of current devices is that they require the expensive manufacturing procedure of vacuum deposition of all layers.

[0012] Capacitors as energy storage devices have well-known advantages versus electrochemical energy storage, e.g. a battery. Compared to batteries, capacitors can 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 a small volume or weight as in a case of batteries, or at low energy storage cost, which makes capacitors impractical for some applications, for example electric vehicles. Accordingly, it would be an advance in energy storage technology to provide capacitors of higher volumetric and mass energy storage density and lower cost.

[0013] The present invention solves a problem of the further increase of volumetric and mass density of reserved energy of the capacitor, and at the same time reduces cost of materials and manufacturing process.

SUMMARY OF THE INVENTION

[0014] Embodiments of the present invention provides a capacitor comprising a first electrode, a second electrode, and a dielectric layer of molecular material disposed between said first and second electrodes. Said electrodes are flat and planar and positioned parallel to each other. The molecular material is described by the general formula:

$$D_p\text{-(Core)-}H_q, \quad (I)$$

where Core is a polarizable conductive anisometric core, having conjugated π-systems, and characterized by a longitudinal axis, D and H are insulating substituents, and p and q are numbers of the D and H substituents accordingly. The insulating substituents are selectively attached to any available positions on the polarizable anisometric core including on apex positions and lateral positions as related the longitudinal axis of the Core, and p and q are independently selected from values 1, 2, 3, 4, and 5. And Core possesses one or more dopant groups that enhance polarizability.

[0015] A method of producing a capacitor, which comprises the steps of a) preparation of a conducting substrate serving as one of the electrodes, b) application of a molecular material on the substrate, c) formation of the solid layer molecular material layer on the substrate, and d) formation of the second electrode on the solid molecular material layer, wherein the molecular material is described by the general formula:

$$D_p\text{-(Core)-}H_q \quad (I)$$

where Core is a conductive and polarizable anisometric core, having conjugated π-systems, and characterized by a longitudinal axis, D and H are insulating substituents, and p and q are numbers of the D and H substituents accordingly. The insulating substituents are selectively attached to any available positions on the polarizable anisometric core including apex positions and lateral positions as related the longitudinal axis of the Core, and p and q are independently selected from values 1, 2, 3, 4, and 5. And Core possesses one or more dopant groups that enhance polarizability.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. **1** is a schematic illustration that shows a typical design of an energy storage device according to the Prior Art.

[0017] FIG. **2** is a schematic illustration that shows a single molecule of a molecular material, according to an embodiment of the invention.

[0018] FIG. **3** is a schematic illustration that shows a disclosed capacitor with a hexagonal crystal structure in the dielectric layer of the molecular material, according to an embodiment of the invention. The insert is a schematic illustration that shows a formation of twisted conductive stacks.

[0019] FIG. **4** is a schematic illustration that shows a dielectric layer of the molecular material, wherein the conductive stacks are formed with a twist angle equal to zero, according to an embodiment of the invention.

[0020] FIG. **5** is a schematic illustration that shows a disclosed capacitor with a lamellar structure of the dielectric layer of the molecular material, according to an embodiment of the invention.

[0021] FIG. **6** shows a cross-section of a multilayered tapes structure of metalized substrate electrode, an energy storage material, and a second electrode.

[0022] FIG. **7** shows an example of winding of a multilayered tape capacitor.

[0023] FIG. **8** shows an alternative embodiment of a wound capacitor.

[0024] FIG. **9** shows an example of a capacitive energy storage module having two or more networked energy storage cells according to an alternative aspect of the present disclosure.

[0025] FIG. **10** shows an example of a capacitive energy storage system having two or more energy storage networked modules according to an alternative aspect of the present disclosure.

[0026] FIG. **11** schematically shows an energy storage cell.

[0027] FIG. **12** shows a capacitive energy storage device containing a single capacitive element connected to a two terminal port.

DETAILED DESCRIPTION OF THE INVENTION

[0028] The general description of the present invention having been made, a further understanding can be obtained by reference to the specific preferred embodiments, which are given herein only for the purpose of illustration and are not intended to limit the scope of the appended claims.

[0029] The present invention provides a capacitor as disclosed hereinabove. The disclosed capacitor comprises a first electrode, a second electrode, and a dielectric layer of molecular material disposed between said first and second electrodes. Said electrodes are flat and planar and positioned parallel to each other. A molecule of the molecular material (schematically shown in FIG. **2**) described by general formula:

$$D_p\text{-(Core)-}H_q, \quad (I)$$

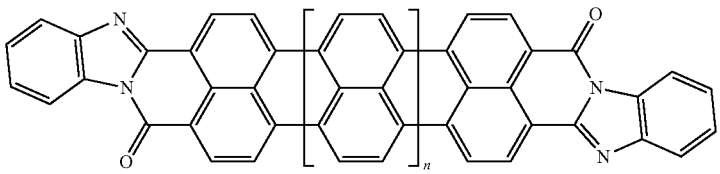
where Core **10** is a polarizable conductive anisometric core, having conjugated π-systems, and characterized by a longitudinal axis, and insulating substituents D and H **11**, and p and q are numbers of substituents D and H accordingly. The insulating substituents are selectively attached to the polarizable anisometric core including on apex positions and lateral positions as related the longitudinal axis of the Core, and p and q are independently selected from values 1, 2, 3, 4, and 5. And Core possesses one or more dopant groups that enhance polarizability.

[0030] The conductive anisometric core may be made further polarizable by adding a variety of dopant groups to various positions of the structure. Incorporating electron donors and electron acceptors is one way to enhance the polarizability. The electrophilic groups (acceptors) are selected from $-NO_2$, $-NH_3^+$ and $—NR_3^+$ (quaternary nitrogen salts), counterion Cl^- or Br^-, —CHO (aldehyde), —CRO (keto group), $—SO_3H$ (sulfonic acids), $—SO_3R$ (sulfonates), SO_2NH_2 (sulfonamides), —COOH (carboxylic acid), —COOR (esters, from carboxylic acid side), —COCl (carboxylic acid chlorides), $—CONH_2$ (amides, from carboxylic acid side), $—CF_3$, CN, wherein R is radical selected from the list comprising alkyl (methyl, ethyl, isopropyl, tert-butyl, neopentyl, cyclohexyl etc.), allyl ($—CH_2—CH═CH_2$), benzyl ($—CH_2C_6H_5$) groups, phenyl (+substituted phenyl) and other aryl (aromatic) groups. The nucleophilic groups (donors) are selected from $—O^-$ (phenoxides, like —ONa or —OK), $—NH_2$, —NHR, $—NR_2$, —OH, —OR (ethers), —NHCOR (amides, from amine side), —OCOR (esters, from alcohol side), alkyls, $—C_6H_5$, vinyls, wherein R is radical selected from the list comprising alkyl (methyl, ethyl, isopropyl, tent-butyl, neopentyl, cyclohexyl etc.), allyl (—CH2-CH═CH2), benzyl (—CH2C6H5) groups, phenyl (+substituted phenyl) and other aryl (aromatic) groups. The existence of electrophilic groups (acceptors) and nucleophilic groups (donors) in the aromatic polycyclic conjugated molecule promotes the electronic polarizability of these molecules. Under the influence of an external electric field, electrons are displaced from the nucleophilic groups (donors) to the electrophilic groups (acceptors) this leads to increases in the electronic polarizability of such molecules. Thus the distribution of electronic density in these molecules is non-uniform. The presence of electro-conductive oligomers leads to a further increase of the polarization ability of the disclosed electro-polarizable compound because of electronic super conductivity of the electro-conductive oligomers. Ionic groups increase an ionic component of polarization of the disclosed electro-polarizable compound. Non-limiting examples of modified cores include rylene and fused rylene fragments where dopants may be placed on any ring in the system. The insulating tails may be attached to the ring structure or may be attached to the dopant groups. Herein we define the term "rylene fragment" to include any polyaromatic system with the rylene motif and may or may not be fused with other ring systems.

TABLE 1

Examples of the polycyclic organic compound comprising the rylene motif, where n is an integer greater than or equal to 0 and preferentially ranges between 0 and 8.

1



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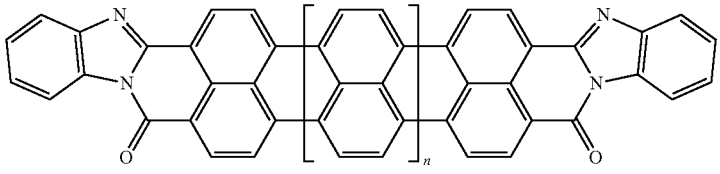

TABLE 1-continued

Examples of the polycyclic organic compound comprising the rylene motif, where n is an integer greater than or equal to 0 and preferentially ranges between 0 and 8.

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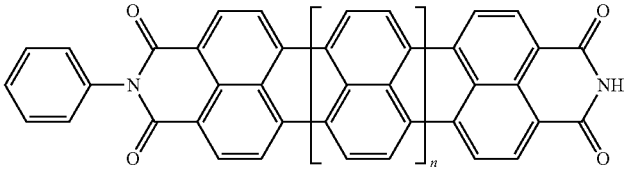

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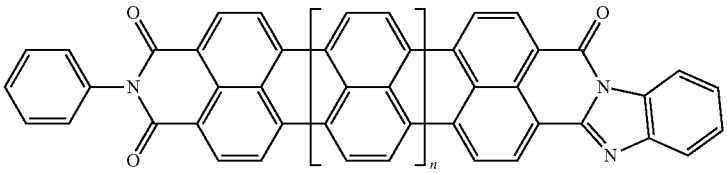

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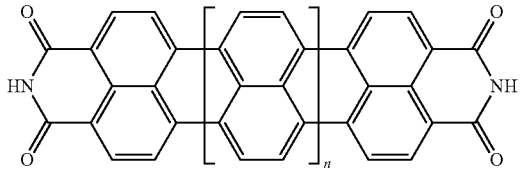

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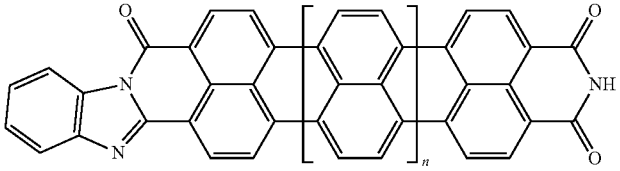

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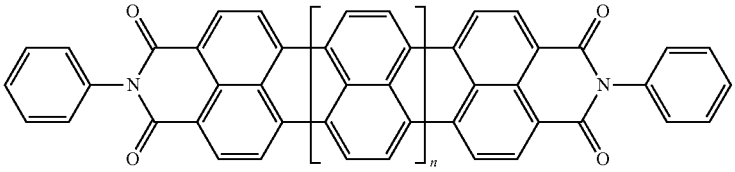

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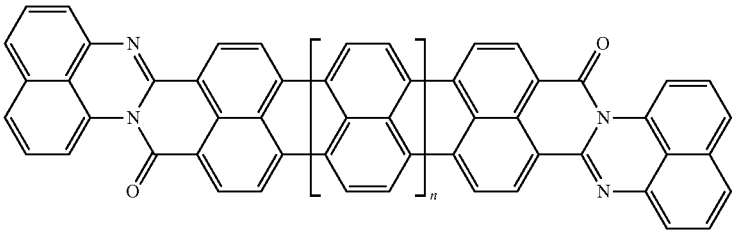

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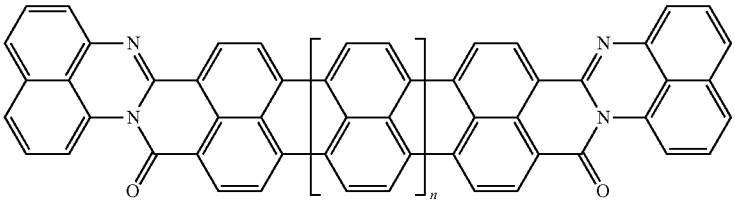
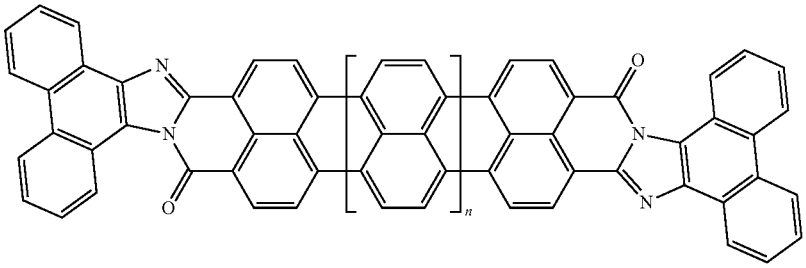


TABLE 1-continued

Examples of the polycyclic organic compound comprising the rylene motif, where n is an integer greater than or equal to 0 and preferentially ranges between 0 and 8.

10



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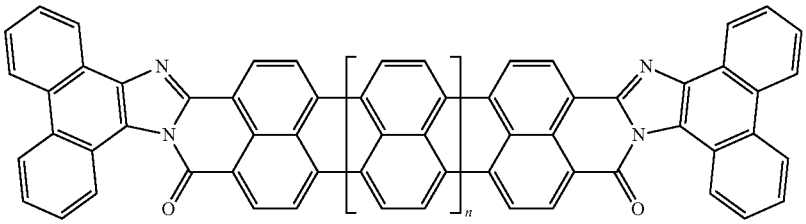

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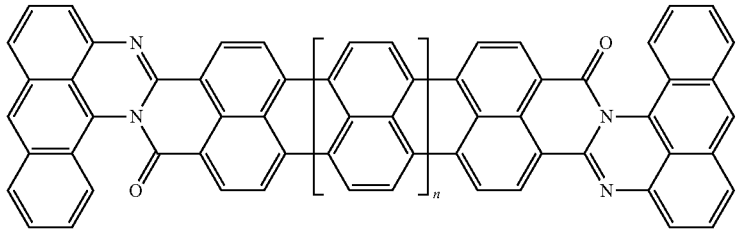
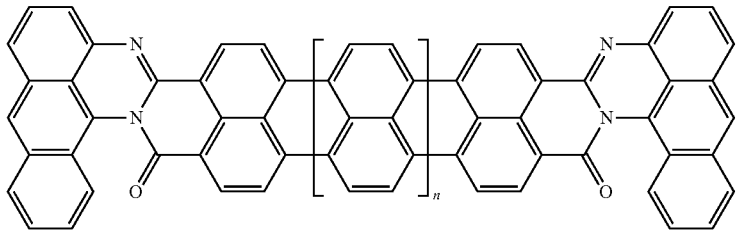


13



[0031] A method of producing a capacitor, which comprises the steps of a) preparation of a conducting substrate serving as one of the electrodes, b) application of a molecular material on the substrate, c) formation of the solid layer molecular material layer on the substrate, and d) formation of the second electrode on the solid molecular material layer, wherein the molecular material is described by the general formula:

$$D_p\text{-(Core)-}H_q \quad (I)$$

where Core is a conductive and polarizable anisometric core, having conjugated π-systems, and characterized by a longitudinal axis, D and H are insulating substituents, and p and q are numbers of the D and H substituents accordingly. The insulating substituents are selectively attached to any available positions on the polarizable anisometric core including at apex positions and lateral positions as related to the longitudinal axis, and p and q are independently selected from values 1, 2, 3, 4, and 5. And, Core possesses one or more dopant groups that enhance polarizability. Wherein, the one or more dopant groups are selectively attached to the anisometric core to enhance both linear and nonlinear polarizability of the compound.

[0032] The anisometric core is a flat molecular system having thickness not exceeding 0.34±0.03 nm and unequal dimensions. It can be characterized by a longitudinal axis which is an axis along the lengthwise direction of the core.

[0033] In one embodiment of the disclosed capacitor at least one of the insulating groups D and at least one of the insulating groups H are independently selected from the list comprising alkyl, fluorinated alkyl, chlorinated alkyl, branched and complex alkyl, branched and complex fluorinated alkyl, branched and complex chlorinated alkyl groups, and any combination thereof.

[0034] In one embodiment of the disclosed capacitor the anisometric cores form conductive stacks due to π-π-interaction, and the insulating substituents form the insulating sublayers surrounding said stacks. The longitudinal axes of the adjacent anisometric cores form a twist angle α, said

twist angle is in the range of $0° \leq \alpha \leq 90°$, and distance between the cores in the stacks is 0.34±0.03 nm.

[0035] Depending on the application of the device, a dielectric permittivity of the insulating sublayer material formed with the insulating substitutes ϵ_{ins} can be in the broad range; for most embodiments it is in the range between about 2 and 25. The insulating sublayer material is characterized by a band gap of greater than 4 eV. The insulating sublayer is characterized by a breakdown field strength being in the range between about of 0.01 V/nm and 10 V/nm. Due to high polarizability of the anisometric cores, the conductive molecular stacks possess relatively high dielectric permittivity ϵ_{cor} in comparison with dielectric permittivity of the insulating sublayer ϵ_{ins}. Thus, the conductive polarizable stacks possess dielectric permittivity ϵ_{cor}, which is ten to one hundred thousand times higher than dielectric permittivity ϵ_{ins} of the insulating sublayer. Therefore, electric field intensity in the insulating sublayer E_{ins} and electric field intensity in the conductive polarizable molecular stacks E_{cor} satisfy:

$$E_{cor}=(\epsilon_{ins}/\epsilon_{cor})\cdot E_{ins}. \quad (1)$$

[0036] Electric field intensity E_{cor} is much less than electric field intensity E_{ins} and the voltage enclosed to the energy storage device is distributed over the insulating sublayers. In order to increase a working voltage of the energy storage device it is necessary to increase number of the insulating sublayers.

[0037] In one embodiment of the present invention the anisometric cores form twisted conductive stacks, wherein the longitudinal axes (indicated by dashed lines in the insert in FIG. **3**) of the adjacent anisometric cores are twisted with respect to each other at a twist angle α. In yet another embodiment the dielectric layer has a hexagonal crystal structure.

[0038] In the schematic view in FIG. **3** the capacitor comprises two electrodes **13** and **14** and dielectric layer **15** which comprises the anisotropic twisted stacks **12** surrounded with insulating sublayers **16**. The term "hexagonal structure" is referred to the molecular material structure of the dielectric layer comprising the twisted conductive stacks. The dielectric layer is characterized by a dense packing of the twisted stacks located parallel to each other. The projections of these stacks onto a plane normal to them form the two-dimensional structure possessing hexagonal symmetry.

[0039] In one embodiment of the disclosed capacitor the anisometric cores form conductive stacks with the twist angle equal to zero. The longitudinal axes of the anisometric cores in one stack are parallel to each other and perpendicular to the surface of said electrodes. FIG. **4** schematically shows the stack **12** formed with the anisometric cores and the insulating sublayers **16** formed with the insulating substituents. The insulating substituents form the insulating sublayers between the conductive stacks and also between the conductive stacks and electrodes. The additional role of the insulating substitutes is increasing of the work function in the molecular material. Work function is the minimum amount of energy required to remove an electron from the surface of the conductive stack.

[0040] In yet another embodiment the molecular material has a lamellar crystal structure. Lamellar structures or microstructures are composed of the alternating fine layers (sublayers) of different materials and/or regions of different structure and/or properties, as for example in a lamellar polyethylene. In the present invention the fine layers of the conductive stacks are alternating with the amorphous sublayers of the insulating substituents. FIG. **5** shows a capacitor with the lamellar structure of the dielectric layer, according to an embodiment of the invention. The capacitor comprises two electrodes **13** and **14**, the dielectric layer **15** which comprises the fine layers of the conductive stacks **12** formed with the polarizable anisometric cores, and isotropic insulating sublayers **16**.

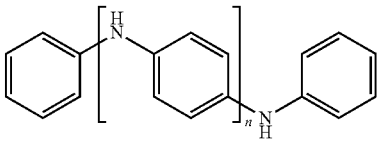
[0041] The polarizable anisometric cores of the molecular material of the disclosed capacitor may possess translation periodicity and symmetry in at least one direction. The properties of a system with translational symmetry do not change when the material shifts on a certain vector which is called a translation vector. In some instances, crystals of the disclosed molecular material may possess a translational symmetry in all three directions.

[0042] In one embodiment of the present invention, the polarizable anisometric core is electroconductive oligomer comprising monomers having conjugated π-systems and the electroconductive oligomers form molecular stacks due to π-π-interaction and stacks are positioned parallel to surface of the planar electrode. In one embodiment of the present invention, the electroconductive oligomers are selected from the list comprising following structural formulas corresponding to one of structures 14 to 33 as given in Tables 2A, 2B, and 2C.

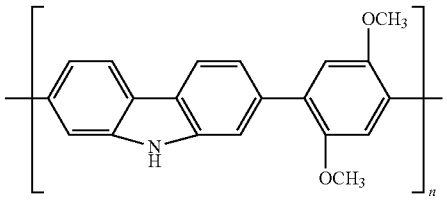
TABLE 2A

Examples of the electroconductive oligomers

14



15



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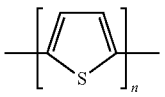

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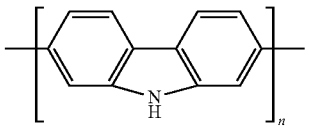

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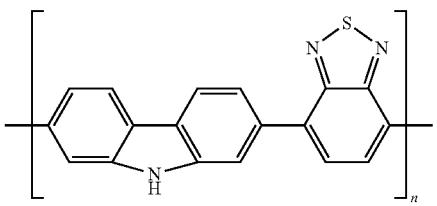


TABLE 2A-continued

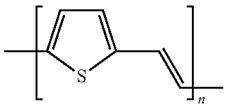
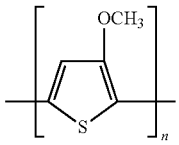
Examples of the electroconductive oligomers	
	19

TABLE 2A-continued

Examples of the electroconductive oligomers	
	20

where n equals to 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12.

TABLE 2B

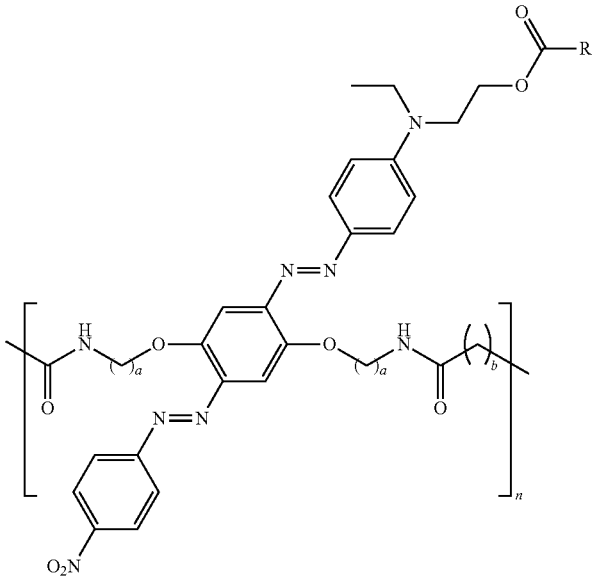
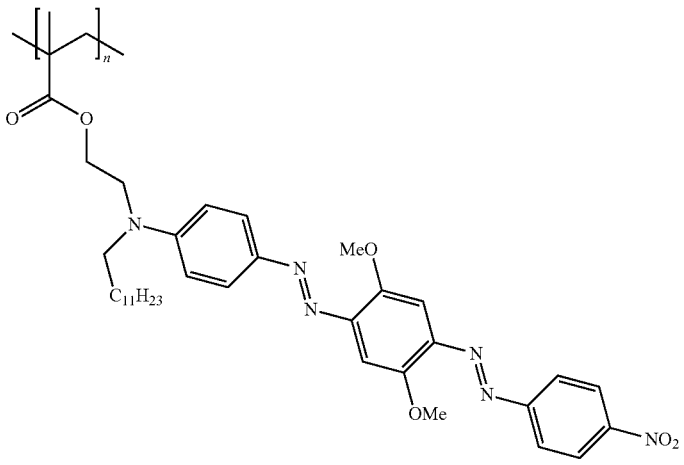
Examples of the electroconductive oligomers	
	21
	22

TABLE 2B-continued

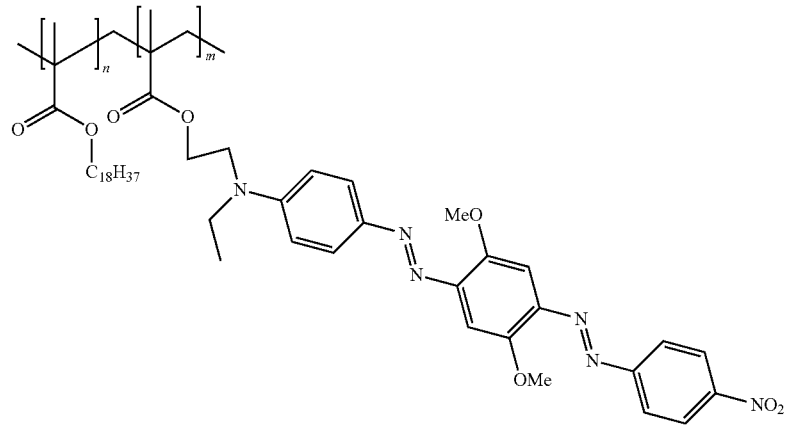
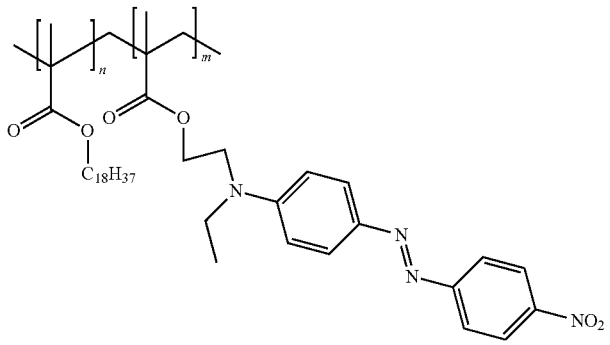
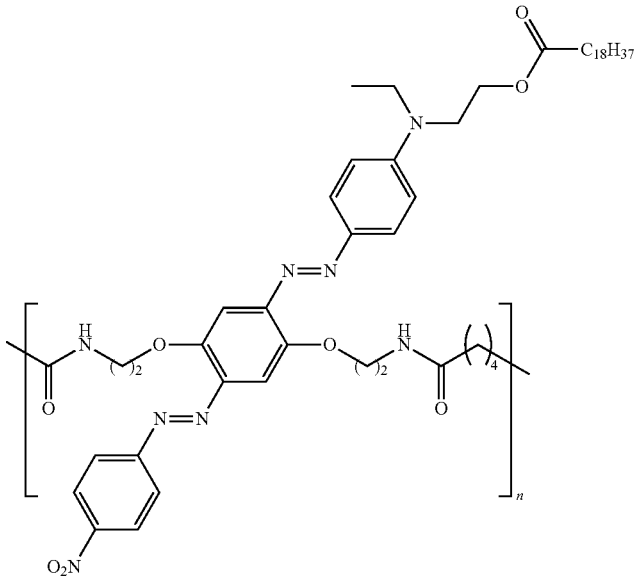
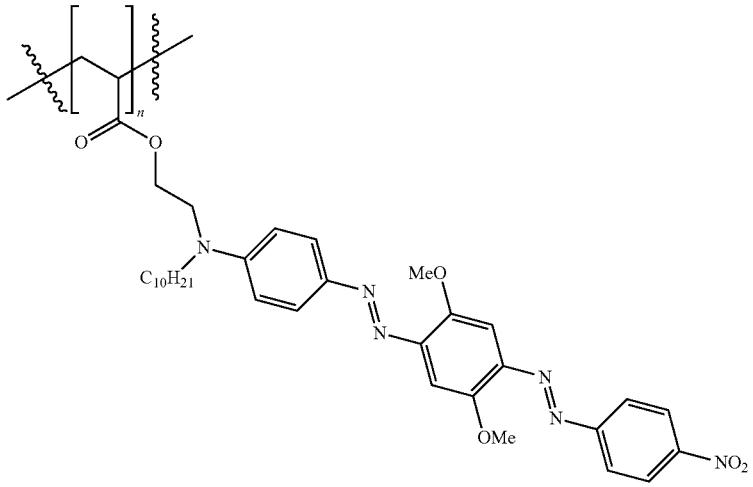
Examples of the electroconductive oligomers	
	23
	24
	25

TABLE 2B-continued

Examples of the electroconductive oligomers

26

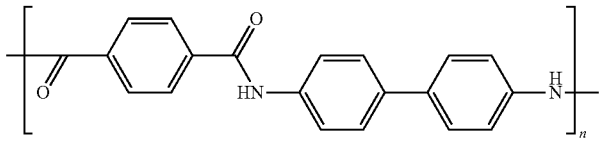


where n and m are independently an integer between 1 and 100, and phenyl groups conjugated by azo-bridges in the above examples can be extended to 3, 4, 5, 6, 7, 8, 9, 10, etc.

TABLE 2C

Examples of the electroconductive oligomers

27



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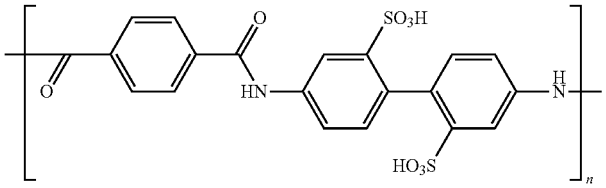

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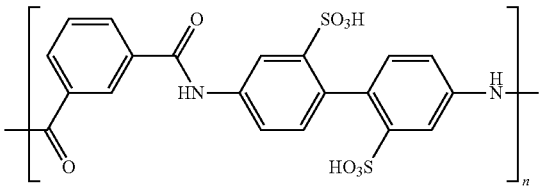

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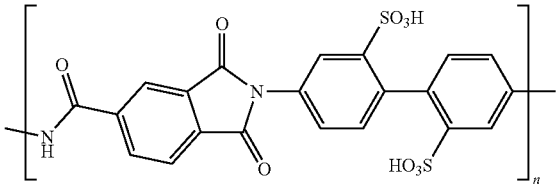
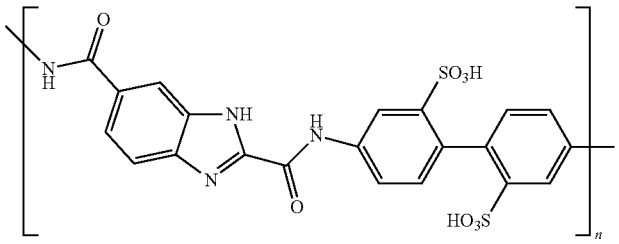


TABLE 2C-continued

Examples of the electroconductive oligomers

31



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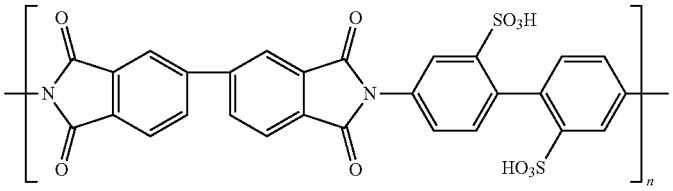
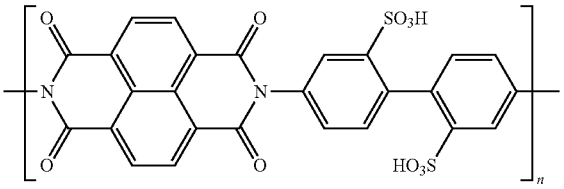


33



where n is an integer between 1 and 100.

[0043] In another implementation of the organic compound, the Core in the above general structural formula comprises an electro-conductive oligomer of azo-dye chromophores. The repeating backbone may contain a portion of the chromophore or possess a handle allowing the chromophore to be present as sidechains. Sidechains may be added to the final backbone product or incorporated into individual monomers that are then polymerized. If incorporated into the backbone the chromophores may be modified such that they react with the other segments of the backbone to form the final product or they may be incorporated into monomers that are then polymerized.

[0044] These chromophores impart high polarizability due to delocalization of electrons. This polarizability may be enhanced by dopant groups. The composite oligomer may further include resistive tails that will provide insulation within the material. In some embodiments, the resistive tails may be rigid in order to limit the motion of the sidechains, potentially stabilizing pi-pi stacking interactions between sidechains while simultaneously making the material more stable by eliminating voids. In some embodiments, the resistive tails may be rigid in order to limit voids within the material. Non-limiting examples of repeating backbones include, but is not limited to, (meth)acrylates, polyvinyls, peptides, peptoids, and polyimides.

[0045] Examples of suitable chromophores are, but are not limited to, Disperse Red-1, Black Hole Quencher-1, and Black Hole Quencher-2. In many of the embodiments it may not be necessary for all monomer units to bear a chromophore, and in some it may be desirable to possess other side chains or sites within the repeating backbone that impart other qualities to the material such as stability, ease of purification, flexibility of finished film, etc.

[0046] For embodiments where the chromophores are incorporated as side chains, the resistive tails may be added before the sidechains are attached to a finished oligomer, after sidechains have been chemically added to a finished oligomer, or incorporated into the oligomer during synthesis by incorporation into monomer units.

[0047] For embodiments where the chromophore is part of the backbone the tails may be attached to the finished composite oligomer or incorporated into monomer units and added during composite synthesis.

[0048] Non-limiting examples of suitable tails are alkyl, haloalkyl, cycloakyl, cyclohaloalkyl, and polyether. Such compounds and their synthesis are described in U.S. patent application Ser. No. 15/090,509 (Attorney Docket No. CSI-051) and U.S. patent application Ser. No. 15/163,595 (Attorney Docket No. CSI-51B) which are herein incorporated by reference in their entirety.

[0049] Electrodes of the disclosed capacitor may be made of any suitable material, including but not limited to metals such as Pt, Cu, Al, Ag or Au; metal alloys, graphene, graphite, or ribtan. The electrodes may be substantially planar (substantially not rough) and in parallel. Further still, the electrodes optionally consist of multiple molecular layers on substrates of said metal or graphite. The molecular layers being described in U.S. patent application Ser. No. 15/368,171 (Attorney docket number CSI-078) filed Dec. 2, 2016 and fully incorporated by reference herein.

[0050] Alternatively, the first electrode may be of a metalized tape consisting of a substrate film and one metalized face-side. Wherein the metalized face-side consisting of any metal or combination thereof. The substrate film may consist of polycarbonate, polyethylene terephthalate (PET, also known as polyester), polypropylene, polystyrene, and poly-

sulfone. In an alternative embodiment, said substrate film may consist of the energy storage material described hereinabove.

[0051] In some embodiments, the capacitor can be coiled as in FIG. **7**. Further schema and methods of production are taught in U.S. patent application Ser. No. 14/752,600 filed on Jun. 26, 2015 (Attorney Docket No. CSI-017) which is fully incorporated by reference herein.

[0052] In some embodiments, the capacitor can be produced by a variety of manufacturing methods, which in general comprise the steps of a) preparation of a conducting substrate serving as one of the electrodes, b) application of a molecular material on the substrate, c) formation of the solid layer molecular material layer on the substrate, and d) formation of the second electrode on the solid molecular material layer, wherein the molecular material is described by the general formula:

$$D_p\text{-(Core)-}H_q \quad (I)$$

where Core **10** is a polarizable conductive anisometric core, having conjugated π-systems and characterized by a longitudinal axis, D and H are insulating substituents, and p and q are numbers of substituents D and H accordingly. The insulating substituents are selectively attached to the polarizable anisometric core including at apex positions and lateral positions as related to the longitudinal axis, and p and q are independently selected from values 1, 2, 3, 4, and 5. And, Core possesses one or more dopant groups that enhance polarizability. Wherein, the one or more dopant groups are selectively attached to the anisometric core to enhance both linear and nonlinear polarizability of the compound.

[0053] In one embodiment of the disclosed method at least one of the insulating groups D and at least one of the insulating groups H are independently selected from the list comprising alkyl, fluorinated alkyl, chlorinated alkyl, branched and complex alkyl, branched and complex fluorinated alkyl, branched and complex chlorinated alkyl groups, and any combination thereof.

[0054] In one embodiment of the disclosed method the application step b) comprises application of a solution of the molecular material, and the solid layer formation step c) comprises drying to form a solid molecular material layer.

[0055] In yet another embodiment of the disclosed method the application step b) comprises application of a melt of the molecular material, and the solid layer formation step c) comprises cooling down to form a solid molecular material layer.

[0056] In order that the embodiments of the invention may be more readily understood, reference is made to the following example, which is intended to be illustrative of the invention, but is not intended to be limiting in scope.

[0057] In an aspect, the present disclosure provides a crystal dielectric layer comprising the disclosed organic compound. The crystal dielectric layers are produced from the disclosed organic compound by Cascade Crystallization. The arrangement of electrophilic groups (acceptors) and nucleophilic groups (donors) on the aromatic polycyclic conjugated core promote formation of supramolecules.

[0058] The Cascade Crystallization process involves a chemical modification step and four steps of ordering during the crystal dielectric layer formation. The chemical modification step introduces hydrophilic groups on the periphery of the molecule of the disclosed organic compound in order to impart amphiphilic properties to the molecule. Amphiphilic molecules stack together into supramolecules, which is the first step of ordering. The supramolecules are then converted into a liquid-crystalline state to form a liquid crystal such a lyotropic liquid crystal or thermotropic liquid crystal, which is the second step of ordering. The liquid crystal ordering can be manipulated via solvent concentration (which may be determined by the supramolecules' critical micelle concentration), temperature as related to the transition phases of the liquid crystal, an applied external electric or magnetic field to orient dipoles of liquid crystal molecules, or any combination thereof. The lyotropic liquid crystal or thermotropic liquid crystal is then, for example, deposited under the action of a shear force (or meniscus force) onto a substrate using the Mayer Rod shearing technique, so that shear force (or the meniscus) direction determines the crystal axis direction in the resulting solid crystal layer. The external alignment upon the liquid crystal, can be produced using any other means, for example by applying an external electric field at normal or elevated temperature, with or without additional illumination, electric field, magnetic field, or optical field (e.g., coherent photovoltaic effect); the degree of the external alignment should be sufficient to impart necessary orientation to the supramolecules of the lyotropic liquid crystal and form a structure, which serves as a base of the crystal lattice of the crystal dielectric layer. This directional deposition is third step of ordering, representing the global ordering of the crystalline or polycrystalline structure on the substrate surface. The last step of the Cascade Crystallization process is drying/crystallization, which converts the liquid crystal into a solid crystal dielectric layer. The term Cascade Crystallization process is used to refer to the chemical modification and four ordering steps as a combination process.

[0059] The Cascade Crystallization process is used for production of thin crystalline dielectric layers. The dielectric layer produced by the Cascade Crystallization process has a global order which means that a direction of the crystallographic axis of the layer over the entire substrate surface is controlled by the deposition process. Molecules of the deposited material are packed into supramolecules with a limited freedom of diffusion or motion. The thin crystalline dielectric layer is characterized by an interplanar spacing of 0.34±0.03 nm—in the direction of one of the optical axes.

EXAMPLE 1

[0060] Example 1 describes a capacitor comprising a dielectric layer formed with the solid molecular material of lamellar structure as shown in FIG. **5**.

[0061] The capacitor comprises two electrodes **13** and **14**, the dielectric layer **15** which comprises the conductive anisometric stacks **12** formed with the polarizable anisometric cores, and isotropic insulating sublayers **16**. Polyaniline (PANI) is used as the polarizable anisometric core, and fluorinated alkyl substituents are used as the insulating substituents. The conductive anisometric stacks formed with polyaniline (PANI) have the dielectric permittivity ϵ_{cor} equal to 10,000. Thickness of each insulating sublayers formed by the substituents is approximately d_{ins}=2 nm, and number of the insulating sublayers n_{ins} is equal to 500. Electrodes **13** and **14** are made of copper. Dielectric permittivity of the insulating sublayers is equal to 2.2 (i.e. ϵ_{ins}=2.2) and its breakdown voltage is equal to 1 V/nm. The working voltage

of the capacitor does not exceed the breakdown voltage Vbd which is approximately equal to 1000 V.

[0062] In some embodiments, the capacitor may be incorporated into energy storage elements called energy storage devices, energy storage cells, energy storage modules, and energy storage systems. These energy storage elements are further described in U.S. patent application 15/043,315 filed on Feb. 12, 2016.

[0063] As an aspect of the present disclosure, a capacitive energy storage module **40**, e.g., as illustrated in FIG. **9**. In the illustrated example, the energy storage module **40** includes two or more energy storage cells **30** of the type described above. Each energy storage cell includes a capacitive energy storage device **34** having one or more capacitors **33** and a DC-voltage converter **31**, which may be a buck converter, boost converter, or buck/boost converter. In addition, each module may include a control board **32** of the type described below with respect to FIG. **11** and an (optional) cooling mechanism (not shown). The module **40** may further include an interconnection system that connects the anodes and cathodes of the individual energy storage cells to create a common anode and common cathode of the capacitive energy storage module.

[0064] In yet another aspect, some implementations, the interconnection system includes a parameter bus **42** and power switches PSW. Each energy storage cell **30** in the module **40** may be coupled to the parameter bus **42** via the power switches PSW. These switches allow two or more modules to be selectively coupled in parallel or in series via two or more rails that can serve as the common anode and common cathode. The power switches can also allow one or more energy storage cells to be disconnected from the module, e.g., to allow for redundancy and/or maintenance of cells without interrupting operation of the module. The power switches PSW may be based on solid state power switching technology or may be implemented by electromechanical switches (e.g., relays) or some combination of the two.

[0065] In some implementations, the energy storage module further comprises a power meter **44** to monitor power input or output to the module. In some implementations, the energy storage module further comprises a networked control node **46** configured to control power output from and power input to the module. The networked control node **46** allows each module to talk with a system control computer over a high speed network. The networked control node **46** includes voltage control logic circuitry **50** configured to selectively control the operation of each of voltage controller **31** in each of the energy storage cells **34**, e.g., via their respective control boards **32**. The control node **46** may also include switch control logic circuitry **52** configured to control operation of the power switches PSW. The control boards **32** and power switches PSW may be connected to the control node **46** via a data bus **48**. The voltage control and switching logic circuitry in the networked control node **46** may be implemented by one or more microprocessors, microcontrollers, application specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), or complex programmable logic devices (CPLDs). The control node **46** may include a network interface **54** to facilitate transfer of signals between the voltage control logic circuitry **50** and the control boards **32** on the individual energy storage cells **34** and also to transfer signals between the switching logic circuitry **52** and the power switches PSW, e.g., via the data bus **48**.

[0066] According to yet another aspect of the present disclosure a capacitive energy storage system may include two or more networked capacitive energy storage modules, e.g., of the type shown in FIG. **9**. One embodiment of such a capacitive energy storage system **60** is shown in FIG. **10**. The system **60** includes two or more energy storage modules **40** of the type shown in FIG. **9**. Each capacitive energy storage module **40** includes two or more capacitive energy storage cells **30**, e.g., of the type shown in FIG. **11** connected by an interconnection system **42** and controlled by a control node **46**. Each capacitive energy storage module may also include a module power meter **44**. Although it is not shown in FIG. **9**, each control node **46** may include voltage control logic circuitry **50** to control voltage controllers within the individual capacitive energy storage cells **30** and switching logic circuitry **52** to control internal power switches with the module, as described above. In addition, each control node **46** includes an internal data bus **48** and a network interface **54**, which may be connected as described above. Power to and from capacitive energy storage modules **40** is coupled to a system power bus **62** via system power switches SPSW, which may be based on solid state power switching technology or may be implemented by electromechanical switches (e.g., relays) or some combination of the two. In some implementations, there may be an inverter (not shown) coupled between each capacitive energy storage module **40** and the system power bus **62** to convert DC power from the module to AC power or vice versa.

[0067] The system **60** includes a system controller **66** connected to a system data bus **68**. The system controller may include switching control logic **72**, voltage control logic **70**, and system network interface **74**. The voltage control logic **70** may be configured to control the operation of individual DC-voltage controllers within individual cells **30** of individual modules **40**. The switching control logic **72** may be configured to control operation of the system power switches SPSW and also the power switches PSW within individual capacitive energy storage modules **40**. Voltage control signals may be sent from the voltage control logic **72** to a specific DC-voltage control device **31** within a specific capacitive energy storage cell **30** of a specific capacitive energy storage module through the network interface **74**, the system data bus **68**, the module network interface **54** of the control node **46** for the specific module, the module data bus **48**, and the control board **4** of the individual cell **1**.

[0068] By way of example, and not by way of limitation, the system controller **66** may be a deterministic controller, an asynchronous controller, or a controller having distributed clock. In one particular embodiment of the capacitive energy storage system **60**, the system controller **66** may include a distributed clock configured to synchronize several independent voltage conversion devices in one or more capacitive energy storage cells of one or more of the capacitive energy storage modules **40**.

[0069] Aspects of the present disclosure allow for electrical energy storage on a much larger scale than possible with conventional electrical energy storage systems. A wide range of energy storage needs can be met by selectively combining one or more capacitors with a DC-voltage conversion devices into a cell, combining two or more cells into a module, or combining two or more modules into systems.

[0070] As depicted in FIG. **11**, in one embodiment of the energy storage cell **30**, each of the one or more capacitors **33** comprises a first electrode **23**, a second electrode **25**, and a dielectric material layer of the type described in the current disclosure **24** disposed between said first and second electrodes. The electrodes **23**, **25** may be made of a metal, such as copper, zinc, or aluminum or other conductive material and are generally planar in shape. In one implementation, the electrodes and dielectric material layer **24** are in the form of long strips of material that are sandwiched together and wound into a coil along with an insulating material, e.g., a plastic film such as polypropylene or polyester to prevent electrical shorting between the electrodes **23**, **25**. Although a single capacitor **33** is shown for convenience in FIG. **11**, aspects of the present disclosure are not limited to such implementations. Those skilled in the art will recognize that the capacitive energy storage device **34** may include multiple capacitors **33** connected in parallel to provide a desired amount of energy storage capacity that scales roughly with the number of capacitors in parallel. Alternatively, the capacitive energy storage device **34** may include two or more capacitors connected in series to accommodate a desired voltage level. In addition, the capacitive energy storage device **34** may include combinations of three or more capacitors in a capacitor network involving various series and parallel combination.

[0071] In yet another implementation, the capacitive energy storage devices may comprise more than one of the capacitors connected in series or parallel. In still another implementation, the capacitive energy storage device may further comprise a cooling mechanism **36**. In some implementations, the cooling can be passive, e.g., using radiative cooling fins on the capacitive energy storage device **34** and DC-voltage conversion device **31**. Alternatively, a fluid such as air, water or ethylene glycol can be used as a coolant in an active cooling system. By way of example, and not by way of limitation, the cooling system **36** may include conduits in thermal contact with the capacitive energy storage device **34** and DC-voltage conversion device **31**. The conduits are filled with a heat exchange medium, which may be a solid, liquid or gas. In some implementations, the cooling mechanism may include a heat exchanger configured to extract heat from the heat exchange medium. In other implementations, the cooling mechanism **36** may include conduits in the form of cooling fins on the capacitive energy storage device **34** and DC-voltage conversion device **31** and the heat exchange medium is air that is blown over the cooling fins, e.g., by a fan. In another embodiment of the present invention, the heat exchanger **37** may include a phase-change heat pipe configured to carry out cooling. The cooling carried out by the phase-change heat pipe may involve a solid to liquid phase change (e.g., using melting of ice or other solid) or liquid to gas phase change (e.g., by evaporation of water or alcohol) of a phase change material. In yet another implementation, the conduits or heat exchanger **37** may include a reservoir containing a solid to liquid phase change material, such as paraffin wax.

[0072] Referring again to FIG. **11** the DC-voltage conversion device **31** may include a buck converter for applications in which $V_{out}<V_{in}$, a boost converter for applications in which $V_{out}>V_{in}$, or a bidirectional buck/boost converter for applications in which $V_{out}<V_{in}$ in certain situations and $V_{out}>V_{in}$ in other situations.

[0073] FIG. **12** depicts a capacitive energy storage device with a single capacitor **33**. Without limitation such devices may have multiple capacitors coupled in series to accommodate a higher voltage level or in parallel to increase the overall capacitance of the system.

[0074] Although the present invention has been described in detail with reference to a particular preferred embodiment, persons possessing ordinary skill in the art to which this invention pertains will appreciate that various modifications and enhancements may be made without departing from the spirit and scope of the claims that follow.

What is claimed is:

1. A capacitor comprising:

a first electrode,

a second electrode, and

a dielectric layer of molecular material disposed between said first and second electrodes,

wherein said electrodes are substantially planar surface and positioned parallel to each other, and

the molecular material is described by the general formula

$$D_p\text{-(Core)-}H_q \quad (I)$$

where Core is a polarizable conductive anisometric core, having conjugated π-systems, and characterized by a longitudinal axis,

D and H are insulating substituents, and

p and q are numbers of the D and H substituents accordingly,

wherein said substituents are selectively attached to any available positions on the polarizable anisometric core including apex positions and lateral positions as related to the longitudinal axis, p and q are independently selected from values 1, 2, 3, 4, and 5, and Core possesses one or more selectively attached dopant groups that enhance polarizability.

2. A capacitor, according to claim **1**, wherein the conductive anisometric core conjugated π-systems form supramolecular structures by means of π-π-interactions.

3. A capacitor, according to claim **1**, wherein the insulating substituents D and H are selected independently from the group consisting of alkyl, fluorinated alkyl, chlorinated alkyl, branched and complex alkyl, branched and complex fluorinated alkyl, branched and complex chlorinated alkyl groups, and any combination thereof.

4. A capacitor, according to claim **1**, wherein one or more of the insulating groups D and one or more of the insulating groups H are each selected independently from the group consisting of alkyl, fluorinated alkyl, chlorinated alkyl, branched and complex alkyl, branched and complex fluorinated alkyl, branched and complex chlorinated alkyl groups, and any combination thereof.

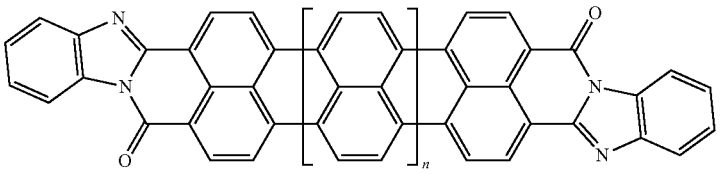
5. A capacitor, according to claim **1**, wherein the one or more dopant groups are selected from the group consisting of —NO_2, —$NH_3^+$and —NR_3^+ (quaternary nitrogen salts), counterion Cl^-, counterion Br^-, —CHO (aldehyde), —CRO (keto group), —SO_3H (sulfonic acids), —SO_3R (sulfonates), SO_2NH_2 (sulfonamides), —COOH (carboxylic acid), —COOR (esters, from carboxylic acid side), —COCl (carboxylic acid chlorides), —$CONH_2$ (amides, from carboxylic acid side), —CF_3, —CCl_3, —CN, wherein R is radical selected from the list comprising alkyl (methyl, ethyl, isopropyl, tert-butyl, neopentyl, cyclohexyl etc.), allyl (—CH_2—CH=CH_2), benzyl (—$CH_2C_6H_5$) groups, phenyl

(+substituted phenyl) and other aryl (aromatic) groups. The nucleophilic groups (donors) are selected from —O^- (phenoxides, like —ONa or —OK), —NH_2, —NHR, —NR_2, —OH, —OR (ethers), —NHCOR (amides, from amine side), —OCOR (esters, from alcohol side), alkyls, —C_6H_5, vinyls, wherein R is radical selected from the list comprising alkyl (methyl, ethyl, isopropyl, tent-butyl, neopentyl, cyclohexyl etc.), allyl (—CH2-CH═CH2), benzyl (-CH2C6H5) groups, phenyl (+substituted phenyl) and other aryl (aromatic) groups.

6. A capacitor according to claim **1**, wherein Core includes one or more rylene fragments.

7. A capacitor according to claim **1**, wherein Core includes one or more rylene fragments selected from the list:

1



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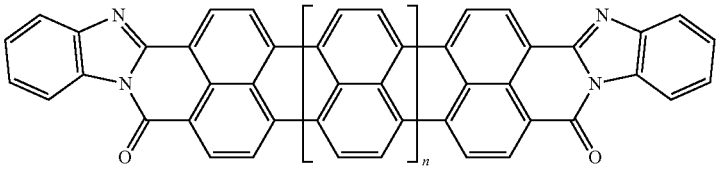

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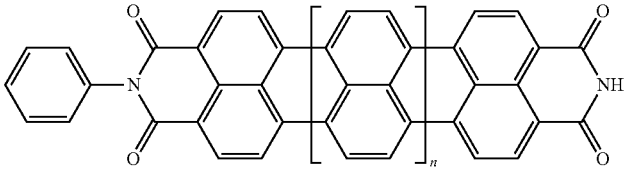

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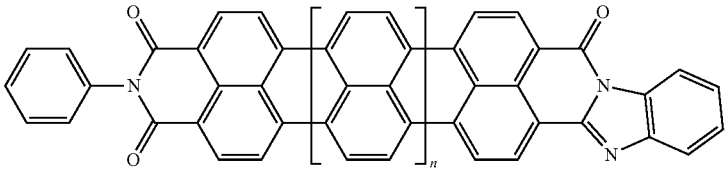

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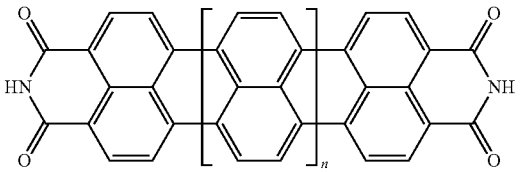

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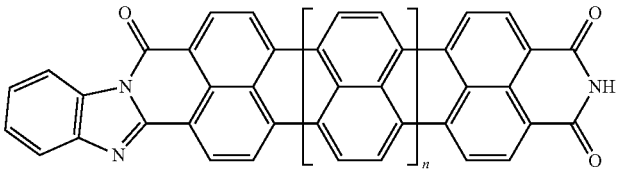

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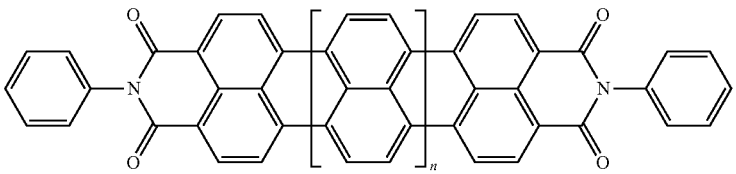

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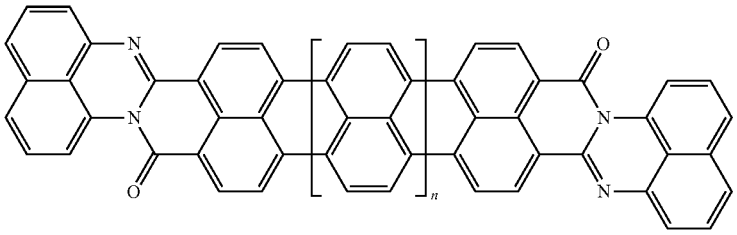

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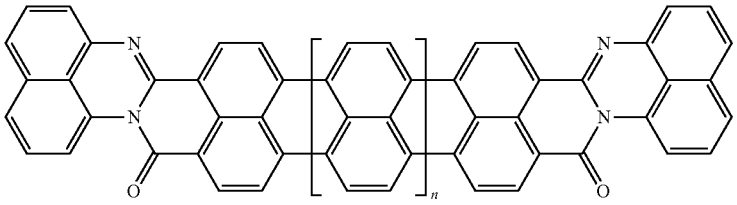

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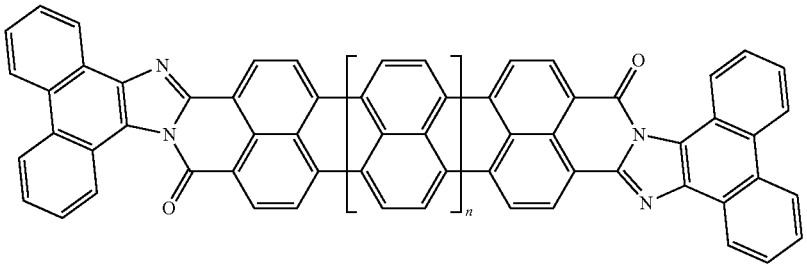

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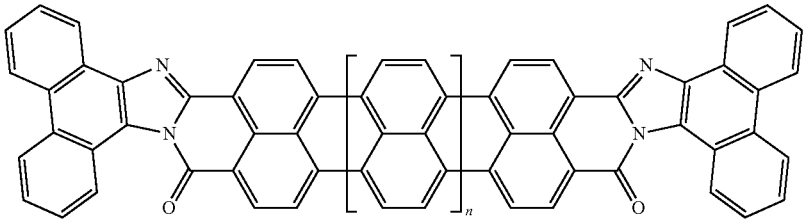

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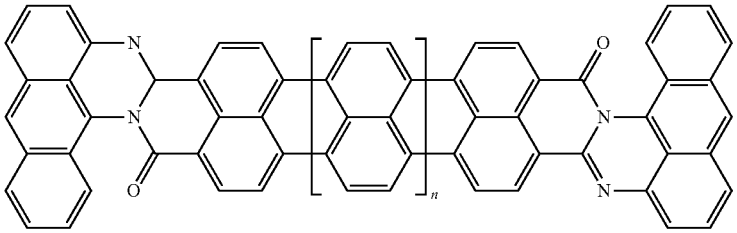

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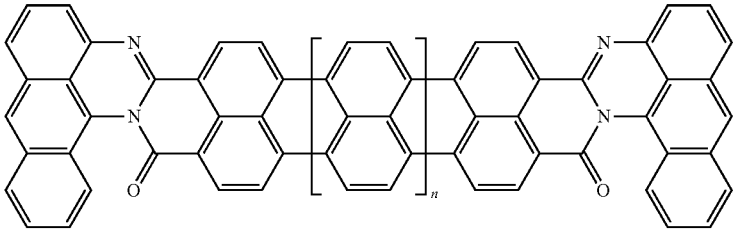


where n=0, 1, 2, 3, 4, 5, 6, 7, 8;

wherein the one or more dopant groups may be on any ring; and

wherein when there are more than one dopant groups, the dopant groups are positioned on an equal or fewer number of rings than there are dopant groups.

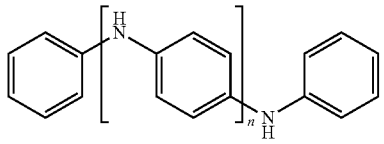
8. A capacitor according to claim **1**, wherein one or more of said insulating groups is connected to the Core via one or more of said one or more dopant groups.

9. A capacitor according to claim **6**, wherein one or more of said insulating groups is connected to the Core via one or more of said dopant groups.

10. A capacitor according to claim **1**, wherein said Core is comprised of a conjugated system wherein aromatic rings are connected via alternating single and double chain bonds and a repeating backbone, wherein any, and up to all, of the conjugated chemical structure may simultaneously be the repeating backbone.

11. A capacitor according to claim **1**, wherein said Core is selected from the group consisting of the following structural formulas 1 to 13:

1



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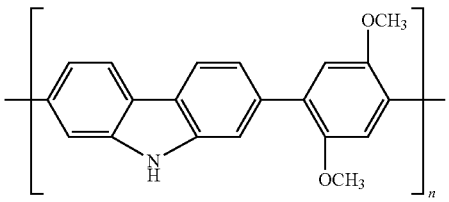

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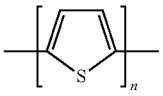

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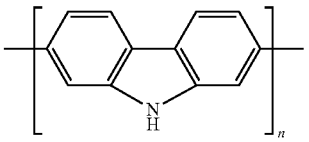

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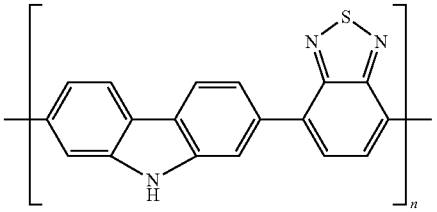

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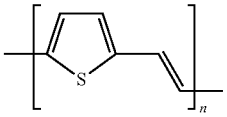

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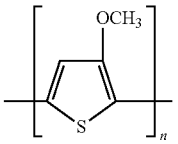
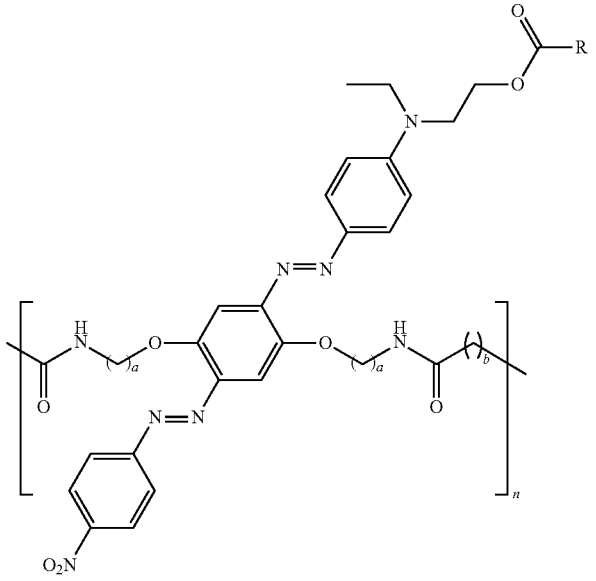


where n equals to 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12, and

8



a = 2, 3, 4; *b* = 2, 3, 4

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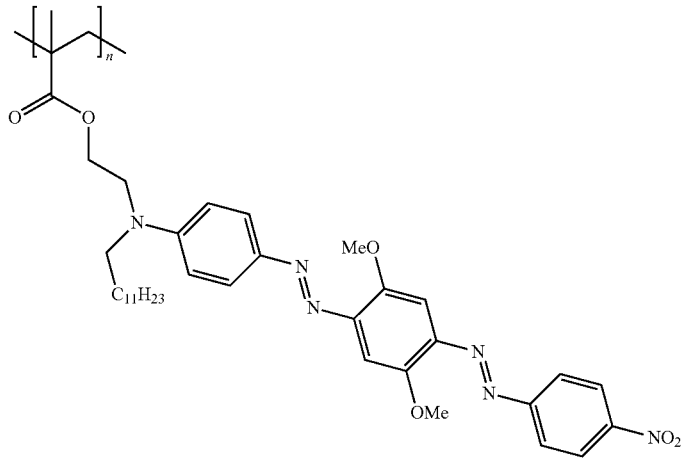

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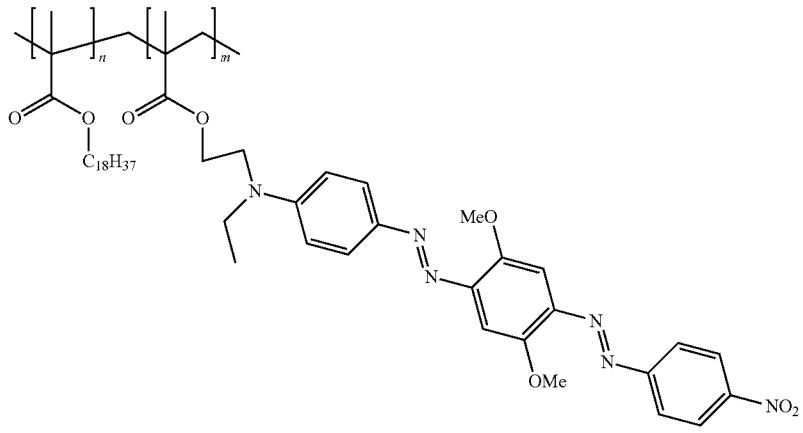

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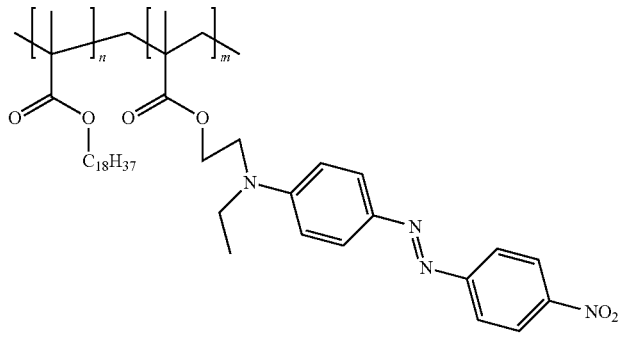

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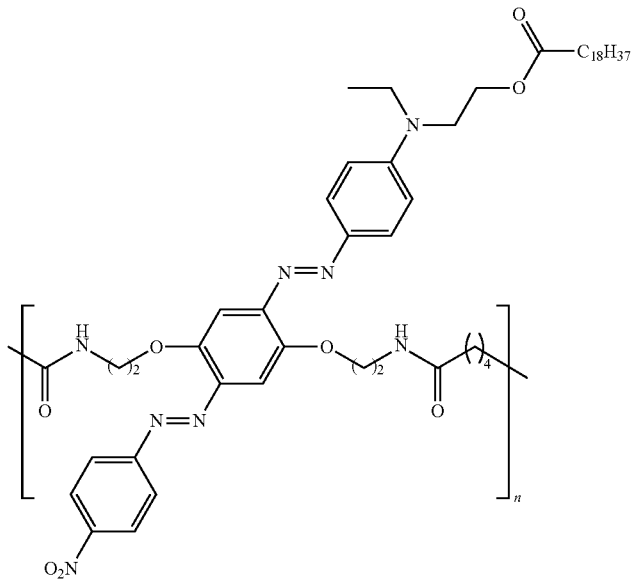

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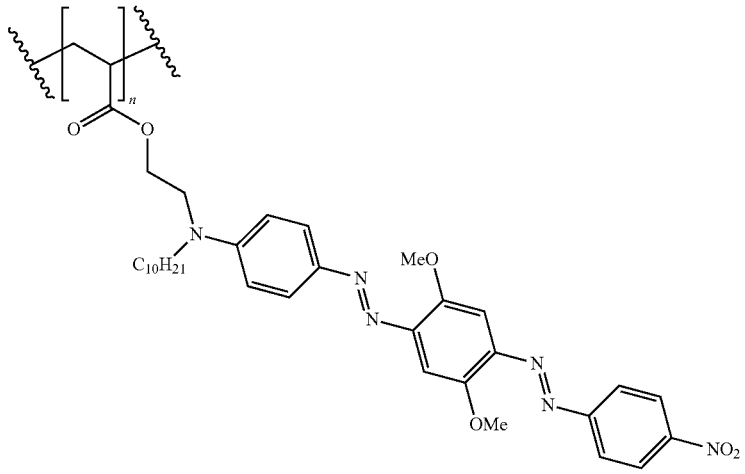

where n and m are independently an integer between 1 and 100, and phenyl groups conjugated by azo-bridges in the above examples can be extended to 3, 4, 5, 6, 7, 8, 9, 10.

12. A capacitor according to claim **1**, wherein the first and second electrodes are made of a metal.

13. A capacitor according to claim **1**, wherein the first and second electrodes are made of any metal and further comprises one or more molecular layers selected from an electro-conductive layer, a field-planarization layer, a tunneling injection blocking layer, a coulomb blocking layer or any combination thereof.

14. A capacitor according to claim **1**, wherein one or both of the first and second electrodes are made of copper, said Core includes polyaniline (PANI), and the insulating substituents D and H include fluorinated alkyl substituents.

15. A capacitor according to claim **1**, wherein said first electrode includes a metalized tape having a plastic substrate and a metal layer.

16. A capacitor according to claim **15**, wherein said plastic substrate has a thickness between about 3 μm and about 12 μm.

17. A capacitor according to claim **16**, wherein said plastic substrate includes a molecular material described by the general formula

$$D_p\text{-(Core)-}H_q \quad (I)$$

where Core is a polarizable conductive anisometric core, having conjugated π-systems, and characterized by a longitudinal axis, which form supramolecular structures by means of π-π-interaction,

D and H are insulating substituents, and

p and q are numbers of the D and H substituents accordingly, wherein said substituents are selectively attached to any available positions on the polarizable anisometric core including apex positions and lateral positions as related to the longitudinal axis, p and q are inde-

pendently selected from values 1, 2, 3, 4, and 5, Core possesses two or more dopant groups that enhances polarizability;

wherein one or more of the insulating groups D and one or more of the insulating groups H is each selected independently from the group consisting of alkyl, fluorinated alkyl, chlorinated alkyl, branched and complex alkyl, branched and complex fluorinated alkyl, branched and complex chlorinated alkyl groups, and any combination thereof;

and wherein the at two or more dopant groups are independently selected from:

—NO_2, —NH_3^+ and —NR_3^+ (quaternary nitrogen salts), counterion Cl^-, counterion Br^-, —CHO (aldehyde), —CRO (keto group), —SO_3H (sulfonic acids), —SO_3R (sulfonates), SO_2NH_2 (sulfonamides), —COOH (carboxylic acid), —COOR (esters, from carboxylic acid side), —COCl (carboxylic acid chlorides), —$CONH_2$ (amides, from carboxylic acid side), —CF_3, —CCl_3, —CN, wherein R is radical selected from the list comprising alkyl (methyl, ethyl, isopropyl, tert-butyl, neopentyl, cyclohexyl etc.), allyl (—CH_2—CH═CH_2), benzyl (—$CH_2C_6H_5$) groups, phenyl (+substituted phenyl) and other aryl (aromatic) groups. The nucleophilic groups (donors) are selected from —O^- (phenoxides, like —ONa or —OK), —NH_2, —NHR, —NR_2, —OH, —OR (ethers), —NHCOR (amides, from amine side), —OCOR (esters, from alcohol side), alkyls, —C_6H_5, vinyls, wherein R is radical selected from the list comprising alkyl (methyl, ethyl, isopropyl, tent-butyl, neopentyl, cyclohexyl etc.), allyl (—CH2-CH═CH2), benzyl (—CH2C6H5) groups, phenyl (+substituted phenyl) and other aryl (aromatic) groups.

18. An energy storage cell comprising:

one or more capacitive energy storage devices; and

a DC-voltage conversion device;

wherein each of the one or more capacitive energy storage devices includes one or more capacitors as in claim **1**, wherein the output voltage of the capacitive energy storage device is an input voltage of the DC-voltage conversion device during discharging the capacitive energy storage device,wherein the input voltage of the capacitive energy storage device is an output voltage of the DC-voltage conversion device while charging the capacitive energy storage device.

19. A method of producing a capacitor, which comprises the steps of;

a) preparation of a conducting substrate serving as one of the electrodes;

b) application of a molecular material on the substrate;

c) formation of the solid layer of the molecular material; and

d) formation of the second electrode on the solid molecular material layer;

wherein the molecular material is described by the general formula

$$D_p\text{-(Core)-}H_q \quad (I)$$

where Core is a polarizable conductive anisometric core, having conjugated π-systems and characterized by a longitudinal axis, D and H are insulating substituents,

p and q are numbers of the D and H substituents accordingly,

wherein said substituents are selectively attached to any available positions on the polarizable anisometric core including on apex positions and lateral positions as related to the longitudinal axis, and p and q are independently selected from values 1, 2, 3, 4, and 5, and Core possesses one or more selectively attached dopant groups that enhance polarizability.

20. A method according to claim **19**, wherein wherein the one or more dopant groups are selected from the group consisting of —NO_2, —NH_3^+ and —NR_3^+ (quaternary nitrogen salts), counterion Cl^-, counterion Br^-, —CHO (aldehyde), —CRO (keto group), —SO_3H (sulfonic acids), —SO_3R (sulfonates), SO_2NH_2 (sulfonamides), —COOH (carboxylic acid), —COOR (esters, from carboxylic acid side), —COCl (carboxylic acid chlorides), —$CONH_2$ (amides, from carboxylic acid side), —CF_3, —CCl_3, —CN, wherein R is radical selected from the list comprising alkyl (methyl, ethyl, isopropyl, tert-butyl, neopentyl, cyclohexyl etc.), allyl (—CH_2—CH═CH_2), benzyl (—$CH_2C_6H_5$) groups, phenyl (+substituted phenyl) and other aryl (aromatic) groups. The nucleophilic groups (donors) are selected from —O^- (phenoxides, like —ONa or —OK), —NH_2, —NHR, —NR_2, —OH, —OR (ethers), —NHCOR (amides, from amine side), —OCOR (esters, from alcohol side), alkyls, —C_6H_5, vinyls, wherein R is radical selected from the list comprising alkyl (methyl, ethyl, isopropyl, tent-butyl, neopentyl, cyclohexyl etc.), allyl (—CH2-CH═CH2), benzyl (—CH2C6H5) groups, phenyl (+substituted phenyl) and other aryl (aromatic) groups.

21. A method according to claim **19**, wherein the application step b) comprises application of a solution of the molecular material, and the solid layer formation step c) comprises drying to form a solid molecular material layer.

22. A method according to claim **19**, wherein the application step b) comprises application of a melt of the molecular material, and the solid layer formation step c) comprises cooling down to form a solid molecular material layer.

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