that can overcome, or at least ameliorate, one or more of the disadvantages described above.

In addition, there is a need to provide a piezoelectric multilayer device that possesses enhanced electrical energy output.

Summary

According to an ~~first~~ aspect, there is provided a method for forming a piezoelectric device comprising the steps of:

(a) depositing a first electrode;

(b) depositing a piezoelectric polymer material layer on the first electrode layer to thereby cover the first electrode layer while leaving a region of the first electrode layer uncovered;

(c) depositing a second electrode layer on the piezoelectric polymer material layer;

(d) depositing a piezoelectric polymer material layer on the second electrode layer to thereby cover the second electrode layer while leaving a region of the second electrode layer uncovered; and

(e) repeating steps (a) to (c), and optionally step (d), to build multiple repeating first electrode layers separated from the second electrode layers by piezoelectric polymer material layers, wherein all of the uncovered regions of the first electrode layers converge at a point A to integrally form a first electrode and all of the uncovered regions of the second electrode layers converge at a point B to integrally form a second electrode in which point A is displaced at a distance from point B, wherein said piezoelectric polymer material layer is a ferroelectric polymer comprising monomers selected from the group consisting of vinyls, vinylidene halides, acrylonitriles, amides,

fluoroethylenes, halides and combinations thereof.

Advantageously, the electrodes may be integrally formed as the piezoelectric device is being formed such that the process may exclude a step of connecting an

external electrode to the piezoelectric device. As such, the process may advantageously exclude an additional step of etching or cutting the piezoelectric material layers in order to connect the external electrode to the layers. The process may also exclude the step of using an adhesive to connect the external electrode to the piezoelectric device. In this way, the piezoelectric device formed by the disclosed process may not face problems of having the electrodes falling out once the adhesive loses its adhesion ability. In addition, the presence of the adhesive, which is usually electrically inactive, may lead to a local clamping effect which unfavourably affects the electrical output of the piezoelectric device.

Advantageously, the disclosed process may not require the step of spin-coating when depositing the piezoelectric material layers. Still advantageously, the disclosed process may not require the step of screen-printing when depositing the piezoelectric material layers. Hence, by avoiding the use of spin-coating or screen-printing, the piezoelectric material layers having a desired large area can be deposited. Impurities such as organic residue from the printing vehicle are not present.

Advantageously, a low cost piezoelectric homopolymer (such as poly(vinylidene fluoride) or PVDF) can be used in the disclosed process as an alternative to the more expensive PVDF-copolymer.

According to another embodiment~~a second aspect~~, there is provided a piezoelectric device comprising a plurality of repeating layers having the following sequence:

(a) a first electrode layer,

(b) a piezoelectric material layer covering the first electrode layer while leaving a region of the first electrode layer uncovered,

(c) a second electrode layer, and optionally

(d) a piezoelectric material layer covering the second electrode layer while leaving a region of the second electrode layer uncovered,

wherein all of the uncovered regions of the first electrode layers are connected together at a point A and all of the uncovered regions of the second electrode layers are connected together at a point B wherein point A is displaced at a distance from point B.

It is to be noted that at least two piezoelectric material layers are required to be present in the piezoelectric device.

Advantageously, the disclosed piezoelectric device may have a more reliable electrode connection as compared to prior art piezoelectric devices due to the direct connection of the various electrode layers with each other.

According to another embodiment~~a third aspect~~, there is provided an energy storage device comprising the piezoelectric device as defined above. The energy storage device can work under mechanical bending mode such that when a mechanical force or acceleration is applied on the (flexible) substrate with the piezoelectric material multilayers, electricity can be generated due to the strain in the piezoelectric material multilayers through the piezoelectric effect.

According to another embodiment~~a fourth aspect~~, there is provided a wafer of piezoelectric devices comprising:

a substrate; and

a plurality of piezoelectric devices as defined above disposed on the substrate.

Advantageously, this may allow the piezoelectric devices to be mass-produced at low cost. The individual piezoelectric devices can then be separated from each other by cutting or dicing the wafer.

Claims

1. A method for forming a piezoelectric device comprising the steps of:

(a) depositing a first electrode layer;

(b) depositing a piezoelectric polymer material layer on said first electrode layer to thereby cover said first electrode layer while leaving a region of said first electrode layer uncovered;

(c) depositing a second electrode layer on said piezoelectric polymer material layer;

(d) depositing a piezoelectric polymer material layer on said second electrode layer to thereby cover said second electrode layer while leaving a region of said second electrode layer uncovered; and

(e) repeating steps (a) to (c), and optionally step (d), to build multiple repeating first electrode layers separated from the second electrode layers by piezoelectric polymer material layers, wherein all of the uncovered regions of said first electrode layers converge at a point A to integrally form a first electrode and all of the uncovered regions of said second electrode layers converge at a point B to integrally form a second electrode, in which point A is displaced at a distance from point B, wherein said piezoelectric polymer material layer is a ferroelectric polymer comprising monomers selected from the group consisting of vinyls, vinylidene halides, acrylonitriles, amides, fluoroethylenes, halides and combinations thereof.

2. The method according to claim 1, further comprising the step of heating the substrate after each piezoelectric polymer material layer depositing step to thereby improve the piezoelectric property of the piezoelectric polymer material layer.

3. The method according to claim 1 or claim 2, wherein said first and second electrode layers are deposited via vapor deposition.

4. The method according to claim 3, wherein said vapor deposition is physical vapor deposition.

5. The method according to claim 4, wherein said physical vapor deposition comprises electron-beam evaporation.

6. The method according to any one of the preceding claims, wherein said first and second electrode layers are deposited through a mask.

7. The method according to any one of the preceding claims, wherein said first and second electrode layers independently comprise a metal.

8. The method according to claim 7, wherein said first and second electrode layers are comprised of aluminium.

9. The method according to any one of the preceding claims, wherein the step of depositing the piezoelectric polymer layers comprises the step of dip coating.

~~10. The method according to any one of the preceding claims, wherein said piezoelectric polymer material layers comprise an organic polymer.~~

~~11. The method according to claim 10, wherein said organic polymer is a ferroelectric polymer.~~

~~12. The method according to claim 11, wherein said ferroelectric polymer comprises monomers selected from the group consisting of vinyls, vinylidene halides, acrylonitriles, amides, fluoroethylenes, halides and combinations thereof.~~

~~13.~~10. The method according to any one of the preceding claims~~claim 11 or claim 12~~, wherein said ferroelectric polymer is PVDF-based polymer.

~~14.~~11. The method according to any one of the preceding claims~~ 11 to 13~~, wherein said ferroelectric polymer is poly(vinylidene fluoride and trifluoroethylene).

~~15.~~12. The method according to claim 10~~13~~, wherein said PVDF-based polymer is PVDF homopolymer in admixture with a hydrated salt.

~~16. A piezoelectric device comprising a plurality of repeating layers having the following sequence:~~

~~(a) a first electrode layer,~~

~~(b) a piezoelectric polymer material layer covering said first electrode layer while leaving a region of said first electrode layer uncovered,~~

~~(c) a second electrode layer, and optionally~~

~~(d) a piezoelectric polymer material layer covering said second electrode layer while leaving a region of said second electrode layer uncovered,~~

~~wherein all of the uncovered regions of said first electrode layers are integrally formed and contact each other at a point A and all of the uncovered regions of said second electrode layers are integrally formed and contact each other at a point B wherein point A is displaced at a distance from point B.~~

~~17. The piezoelectric device according to claim 16, wherein said first electrode layer is deposited on a substrate made of a flexible material.~~

~~18. The piezoelectric device according to claim 16 or claim 17, wherein said first and second electrode layers independently comprise a metal.~~

~~19. The piezoelectric device according to any one of claims 16 to 18, wherein said piezoelectric polymer material layers comprise an organic polymer.~~

~~20. The piezoelectric device according to claim 19, wherein said organic polymer is a ferroelectric polymer.~~

~~21. The piezoelectric device according to claim 20, wherein said ferroelectric polymer comprises monomers selected from the group consisting of vinyls, vinylidene halides, acrylonitriles, amides, fluoroethylenes, halides and combinations thereof.~~

~~22. The piezoelectric device according to any one of claims 16 to 21, wherein the thickness of said first and second electrode layers are individually selected from the range of 0.05 μm to 1 μm.~~

~~23. The piezoelectric device according to any one of claims 16 to 22, wherein the thickness of said piezoelectric polymer material layers are individually selected from the range of 2 μm to 30 μm.~~

~~24. The piezoelectric device according to any one of claims 18 to 23, wherein the thickness ratio of the~~

~~piezoelectric polymer material layer to the respective electrode layer is more than 20.~~

~~25. The piezoelectric device according to claim 24, wherein the thickness ratio of the piezoelectric polymer material layer to the respective electrode layer is more than 50.~~

~~26. An energy storage device comprising the piezoelectric device according to any one of claims 16 to 25.~~

~~27. A wafer of piezoelectric devices comprising:~~

~~a substrate; and~~

~~a plurality of piezoelectric devices according to any one of claims 16 to 25 disposed on said substrate.~~