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(54) **FLEXIBLE SUBSTRATE, MANUFACTURING METHOD THEREOF, AND FLEXIBLE ELECTRONIC DEVICE INCLUDING THE SAME**

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B32B 37/00	(2006.01)
B32B 37/24	(2006.01)

(52) **U.S. Cl.**

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(57) **ABSTRACT**

Provided is a flexible substrate. The flexible substrate includes a first film having a first Young's modulus, a second film on the first film and having a second Young's modulus, and a third film between the first film and the second film and having a third Young's modulus. The third Young's modulus is less than each of the first Young's modulus and the second Young's modulus.

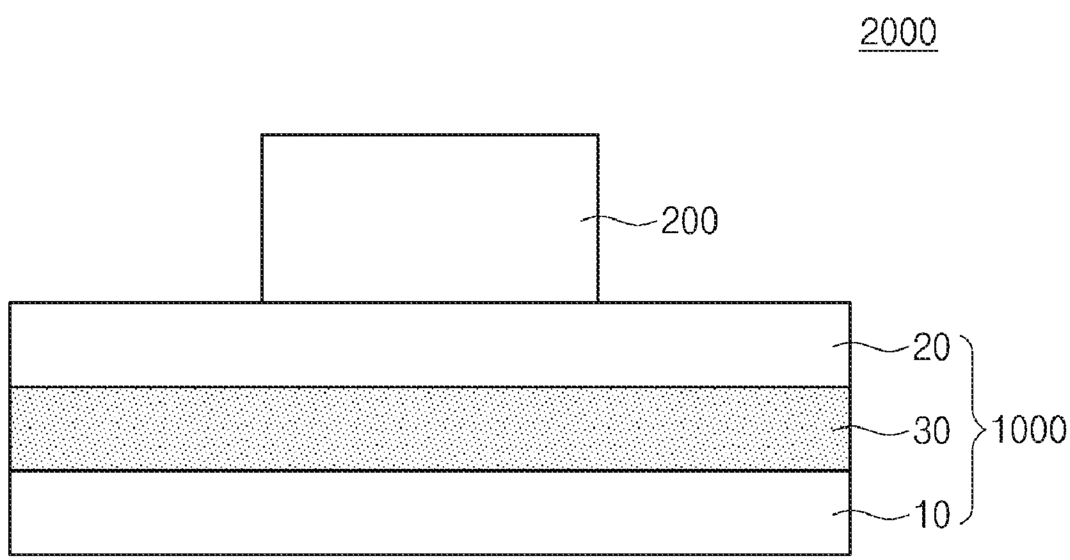


FIG. 1

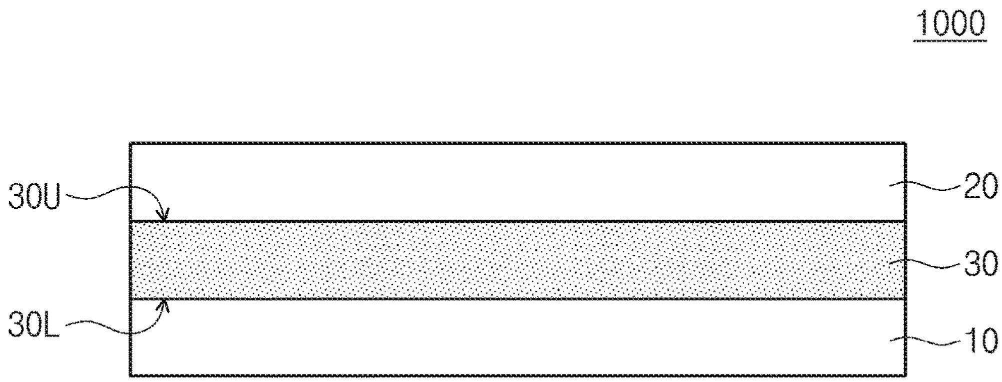


FIG. 2

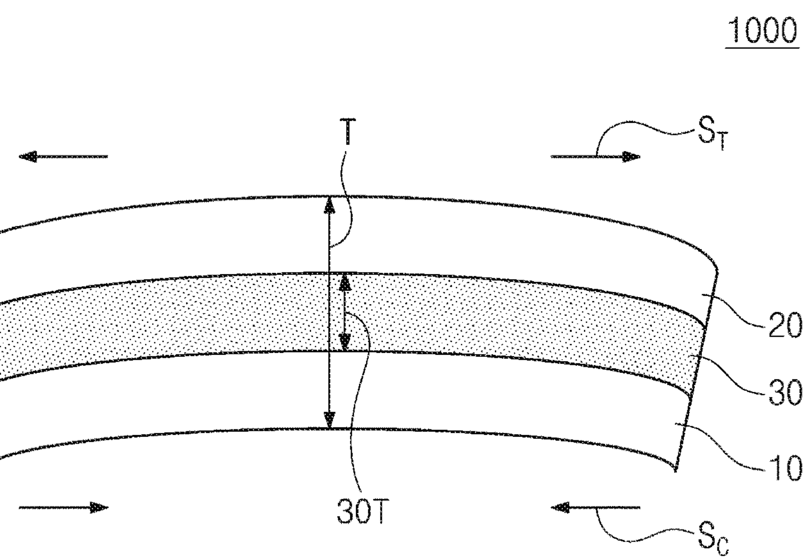


FIG. 3

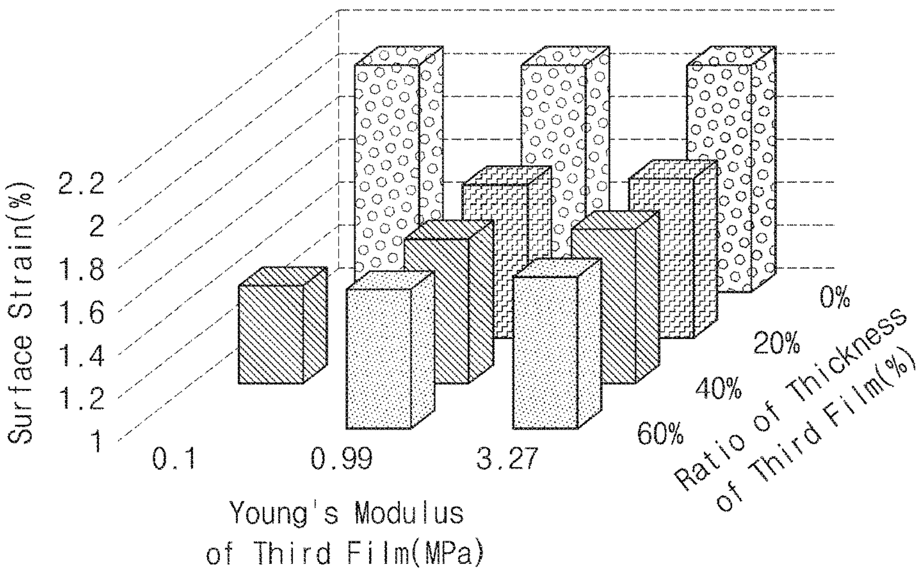

Surface Strain(%)
2.2
2
1.8
1.6
1.4
1.2
1
0.1
0.99
3.27
Young's Modulus
of Third Film(MPa)
0%
20%
40%
60%
Ratio of Thickness
of Third Film(%)

FIG. 4

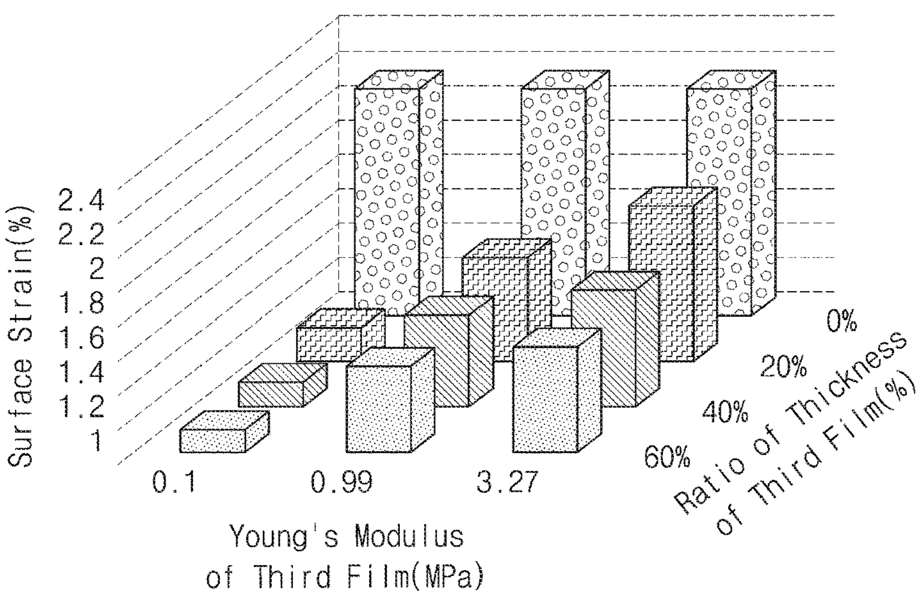
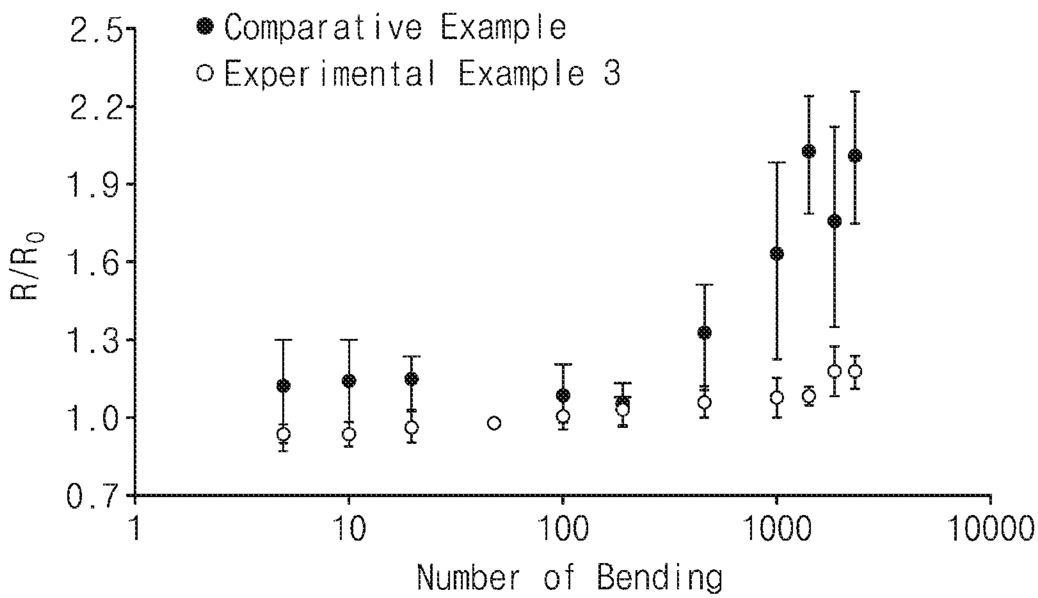

Surface Strain(%)
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.1
0.99
3.27
Young's Modulus
of Third Film(MPa)
0%
20%
40%
60%
Ratio of Thickness
of Third Film(%)

FIG. 5



Comparative Example
Experimental Example 3
2.5
2.2
1.9
1.6
1.3
1.0
0.7
R/R_0
1
10
100
1000
10000
Number of Bending

FIG. 6

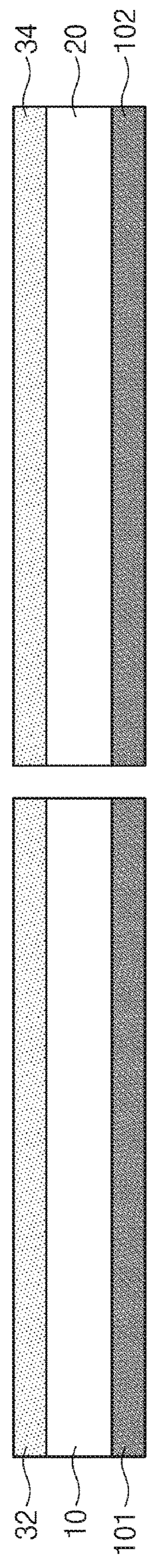


FIG. 7

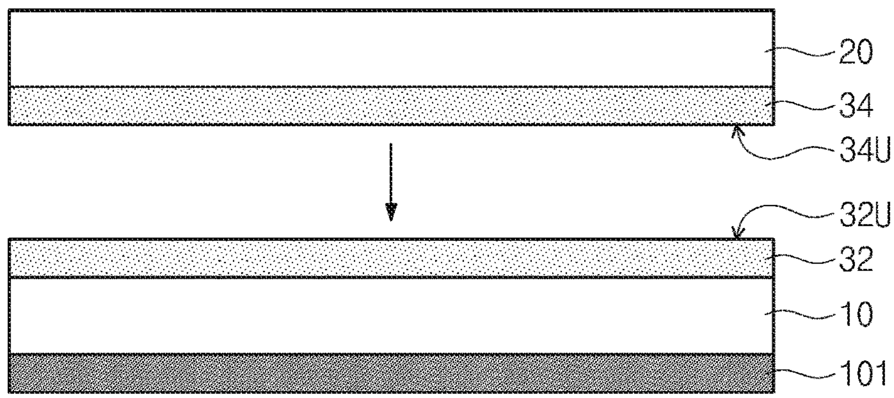


FIG. 8

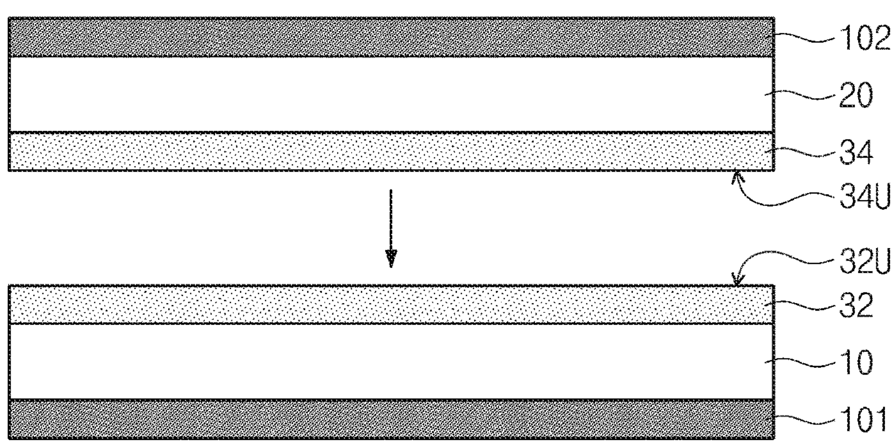


FIG. 9

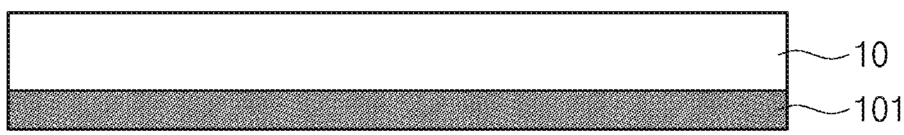


FIG. 10

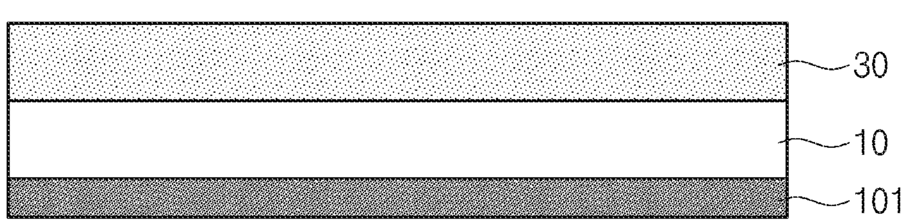


FIG. 11

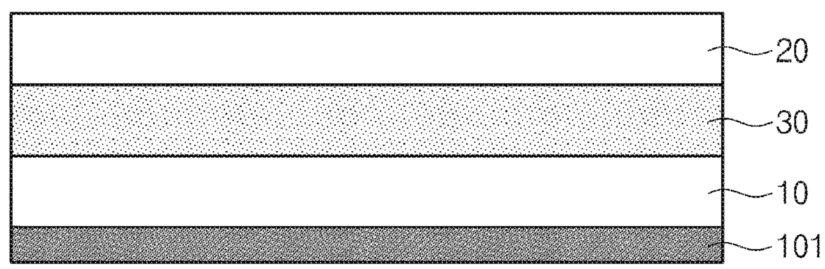


FIG. 12

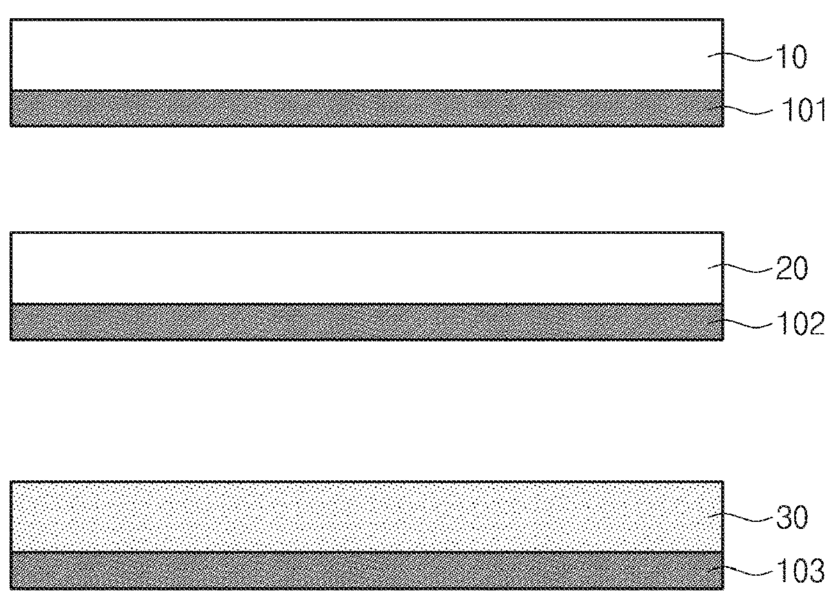


FIG. 13

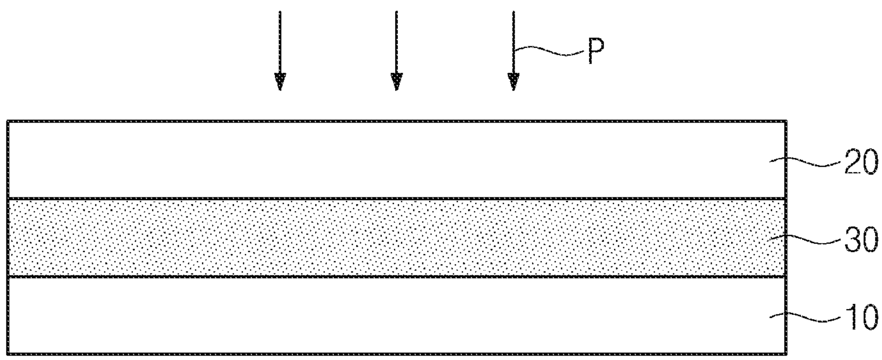


FIG. 14

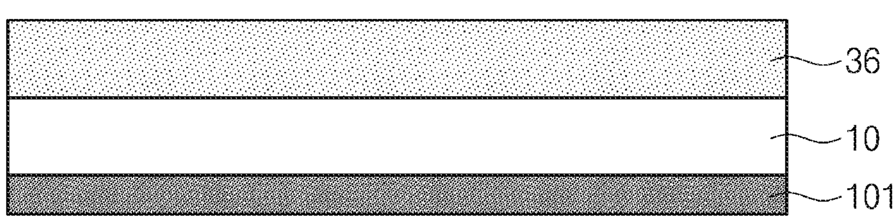


FIG. 15

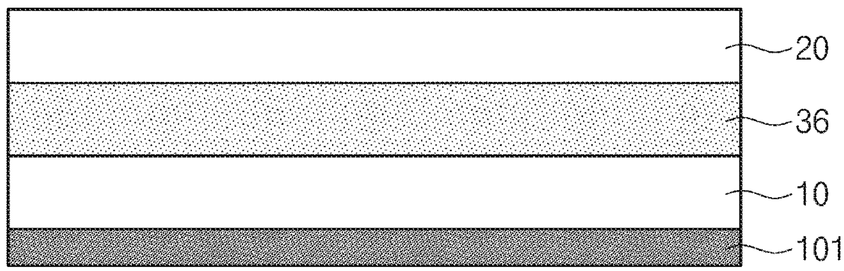


FIG. 16

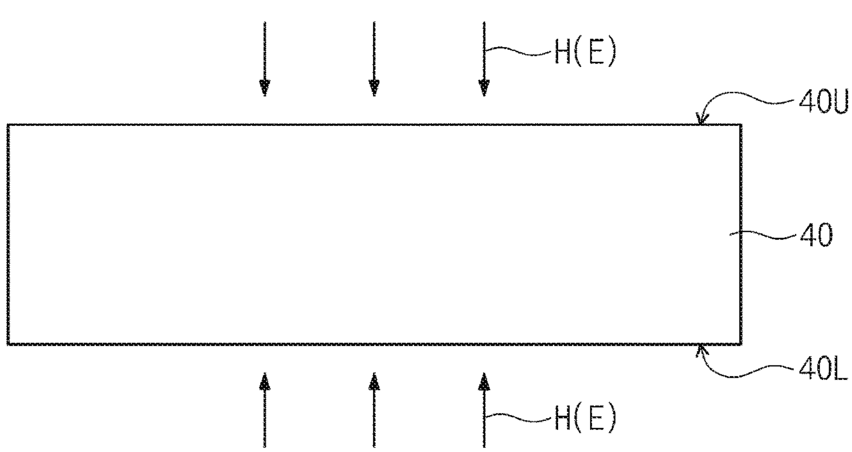
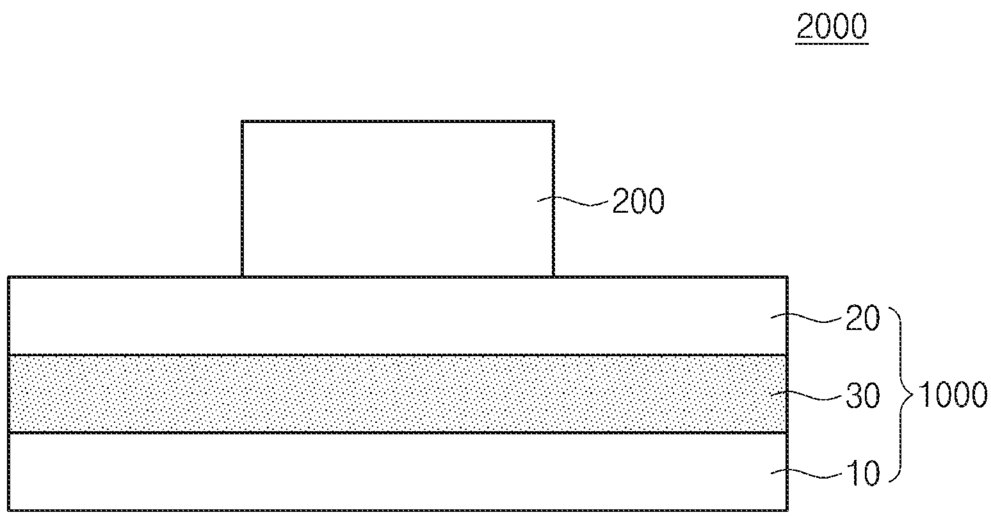


FIG. 17



FLEXIBLE SUBSTRATE, MANUFACTURING METHOD THEREOF, AND FLEXIBLE ELECTRONIC DEVICE INCLUDING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This U.S. non-provisional patent application claims priority under 35 U.S.C. § 119 of Korean Patent Application Nos. 10-2018-0006773, filed on Jan. 18, 2018, and 10-2018-0111066, filed on Sep. 17, 2018, the entire contents of which are hereby incorporated by reference.

BACKGROUND

[0002] The present disclosure herein relates to a flexible substrate that is applicable to various electronic devices, manufacturing method thereof, and a flexible electronic device including the same.

[0003] As a technology is developed in recent years, a flexible electronic device having flexibility has been developed. The flexible electronic device may include a display element or a memory element, which is disposed on a flexible substrate. For example, the flexible electronic device may include a display device, a mobile phone, a digital device, and an information communication device, which have flexibility. Since the flexible electronic device is flexibly bendable according to request of a user, portability and convenience of the user may be enhanced.

[0004] The flexible substrate may be mainly made of a polymer material having excellent flexibility. A surface strain that is applied to a surface of the flexible substrate when the flexible substrate is bent may be transmitted to the display element or the memory element, which is disposed on the surface of the flexible substrate. In this case, although the flexible substrate itself has high flexibility, the display element or the memory element may be degraded in electrical characteristics by the surface strain, and thus, the entire flexible electronic device may not be realized.

SUMMARY

[0005] The present disclosure provides a flexible substrate with surface strain reduced and a manufacturing method thereof.

[0006] The present disclosure also provides a flexible electronic device capable of minimizing performance degradation due to physical bending or deformation.

[0007] An embodiment of the inventive concept may provide a flexible substrate including: a first film having a first Young's modulus; a second film disposed on the first film and having a second Young's modulus; and a third film disposed between the first film and the second film and having a third Young's modulus. The third Young's modulus may be less than each of the first Young's modulus and the second Young's modulus.

[0008] In some embodiments, the first film and the second film may include the same material as each other.

[0009] In some embodiments, the third film may include a material different from that of each of the first film and the second film.

[0010] In some embodiments, each of the first to third films may include a polymer material.

[0011] In some embodiments, each of the first to third films may include at least one selected from the group consisting of polytetrafluoroethylene (PTFE), polyimide, polyamide, polyester, polyethylene, polypropylene, polyurethane, polydimethylsiloxane (PDMS), polyacrylate, polyarylate, and fiber reinforced plastic, and a combination thereof.

[0012] In some embodiments, each of the first film and the second film may include polyimide.

[0013] In some embodiments, the third film may include polydimethylsiloxane (PDMS).

[0014] In some embodiments, the third film may have a bottom surface that directly contacts a top surface of the first film and a top surface that directly contacts a bottom surface of the second film.

[0015] In an embodiment of the inventive concept, a method for manufacturing a flexible substrate may include: forming a first film and a first preliminary layer on a first support substrate in a sequence; forming a second film and a second preliminary layer on a second support substrate in a sequence; attaching a top surface of the first preliminary layer to a top surface of the second preliminary layer; and performing a heat treatment process to cure the first preliminary layer and the second preliminary layer, thereby forming a third film. The third film may have a Young's modulus less than that of each of the first and second films.

[0016] In some embodiments, the forming of the first preliminary layer may include applying a first composition on the first film and then performing a first heat treatment process to partially cure the first composition , the forming of the second preliminary layer may include applying a second composition on the second film and then performing a second heat treatment process to partially cure the second composition, and each of the first heat treatment process and the second heat treatment process may be performed at a temperature less than that of the heat treatment process.

[0017] In some embodiments, the attaching of the top surface of the first preliminary layer to the top surface of the second preliminary layer may include: separating the second support substrate from the second film; and providing the second film and the second preliminary layer on the first support substrate so that the top surface of the second preliminary layer faces the top surface of the first preliminary layer after the second support substrate is separated.

[0018] In some embodiments, the method may further include separating the first support substrate from the first film after the third film is formed.

[0019] In some embodiments, the attaching of the top surface of the first preliminary layer to the top surface of the second preliminary layer may include:

[0020] providing the second support substrate, the second film, and the second preliminary layer on the first support substrate so that the top surface of the second preliminary layer faces the top surface of the first preliminary layer.

[0021] In some embodiments, the method may further include separating the first support substrate and the second support substrate from the first film and the second film, respectively, after the third film is formed.

[0022] In an embodiment of the inventive concept, a flexible electronic device may include: a flexible substrate; and an electronic element disposed on the flexible substrate. The flexible substrate comprises a first film, a second film disposed on the first film, and a third film disposed between the first film and the second film, and the third film may have a Young's modulus less than that of each of the first and second films.

[0023] In some embodiments, each of the first to third films may include a polymer material.

[0024] In some embodiments, the first film and the second film may include the same polymer material as each other.

[0025] In some embodiments, the third film may include a polymer material different from that of each of the first and second films.

[0026] In some embodiments, each of the first and second films may include polyimide, and the third film may include polydimethylsiloxane (PDMS).

[0027] In some embodiments, the electronic element may include at least one of a memory element, a display element, a solar cell, a light emitting diode, and a sensor.

BRIEF DESCRIPTION OF THE FIGURES

[0028] The accompanying drawings are included to provide a further understanding of the inventive concept, and are incorporated in and constitute a part of this specification. The drawings illustrate exemplary embodiments of the inventive concept and, together with the description, serve to explain principles of the inventive concept. In the drawings:

[0029] FIG. **1** is a cross-sectional view illustrating a flexible substrate according to an embodiment of the inventive concept;

[0030] FIG. **2** is a cross-sectional view illustrating a bent state of the flexible substrate of FIG. **1**;

[0031] FIGS. **3** and **4** are graphs showing surface strains of flexible substrates according to embodiments of inventive concept;

[0032] FIG. **5** is a graph showing a surface resistance variation according to the number of bending of the flexible substrate according to embodiments of the inventive concept;

[0033] FIGS. **6** and **7** are cross-sectional views illustrating a method for manufacturing the flexible substrate according to some embodiments of the inventive concept;

[0034] FIG. **8** is a cross-sectional view illustrating a method for manufacturing the flexible substrate according to some embodiments of the inventive concept;

[0035] FIGS. **9** and **11** are cross-sectional views illustrating a method for manufacturing the flexible substrate according to some embodiments of the inventive concept;

[0036] FIGS. **12** and **13** are cross-sectional views illustrating a method for manufacturing the flexible substrate according to some embodiments of the inventive concept;

[0037] FIGS. **14** and **15** are cross-sectional views illustrating a method for manufacturing the flexible substrate according to some embodiments of the inventive concept;

[0038] FIG. **16** is a cross-sectional view illustrating a method for manufacturing the flexible substrate according to some embodiments of the inventive concept; and

[0039] FIG. **17** is a cross-sectional view illustrating a flexible electronic device including the flexible substrate according to embodiments of the inventive concept.

DETAILED DESCRIPTION

[0040] Exemplary embodiments of the present invention will be described with reference to the accompanying drawings so as to sufficiently understand constitutions and effects of the present invention. The present invention may, however, be embodied in different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the present invention to those skilled in the art. Further, the present invention is only defined by scopes of claims.

[0041] In this specification, it will also be understood that when another component is referred to as being 'on' one component, it can be directly on the one component, or an intervening third component may also be present. Also, in the figures, the dimensions of components are exaggerated for clarity of illustration. Like reference numerals refer to like elements throughout.

[0042] The embodiment in the detailed description will be described with sectional views and/or plain views as ideal exemplary views of the present invention. Also, in the figures, the dimensions of layers and regions are exaggerated for clarity of illustration. Areas exemplified in the drawings have general properties, and are used to illustrate a specific shape of a semiconductor package region. Thus, this should not be construed as limited to the scope of the present invention. Also, though terms like a first, a second, and a third are used to describe various regions and layers in various embodiments of the inventive concept, the regions and the layers are not limited to these terms. These terms are only used to distinguish one component from another component. Embodiments described and exemplified herein include complementary embodiments thereof.

[0043] In the following description, the technical terms are used only for explaining a specific exemplary embodiment while not limiting the inventive concept. In this specification, the terms of a singular form may include plural forms unless specifically mentioned. The meaning of "include," "comprise," "including," or "comprising," specifies a property, a region, a fixed number, a step, a process, an element and/or a component but does not exclude other properties, regions, fixed numbers, steps, processes, elements and/or components.

[0044] Hereinafter, embodiments of the present invention will be described with reference to the accompanying drawings.

[0045] FIG. **1** is a cross-sectional view illustrating a flexible substrate according to an embodiment of the inventive concept.

[0046] Referring to FIG. **1**, a flexible substrate **1000** may include a first film **10**, a second film **20** on the first film **10**, and a third film **30** between the first film **10** and the second film **20**. The third film **30** may have a bottom surface **30**L that directly contacts a top surface of the first film **10** and a top surface **30**U that directly contacts a bottom surface of the second film **20**. The first film **10** may have a first Young's modulus, and the second film **20** may have a second Young's modulus. In some embodiments, the first Young's modulus may be the same as the second Young's modulus. In other embodiments, the first Young's modulus may be different from the second Young's modulus. The third film **30** may have a third Young's modulus that is less than each of the first Young's modulus and the second Young's modulus.

[0047] Each of the first to third films **10**, **20**, and **30** may include a polymer material. Each of the first film **10** and the second film **20** may include a polymer material having a Young's modulus greater than that of the third film **30**, and the third film **30** may include a polymer material having a Young's modulus less than that of each of the first film **10** and the second film **20**. Each of the first to third films **10**, **20**, and **30** may include at least one selected from the group consisting of polytetrafluoroethylene (PTFE), polyimide, polyamide, polyester, polyethylene, polypropylene, polyurethane, polydimethylsiloxane (PDMS), polyacrylate, polyarylate, and fiber reinforced plastic, and a combination thereof.

[0048] The first film **10** and the second film **20** may include the same material as each other, and the third film **30** may include a material different from that of each of the first film **10** and the second film **20**. For example, the first film **10** and the second film **20** may include the same polymer material as each other, and the third film **30** may include a polymer material different from that of each of the first film **10** and the second film **20**. For example, each of the first film **10** and the second film **20** may include polyimide, and the third film **30** may include polydimethylsiloxane (PDMS).

[0049] FIG. **2** is a cross-sectional view illustrating a bent state of the flexible substrate of FIG. **1**. FIGS. **3** and **4** are graphs showing surface strains of flexible substrates according to embodiments of inventive concept. FIG. **5** is a graph showing a sheet resistance variation of .a conductor on the flexible substrate exemplified in FIG. **1** according to the number of bending of the flexible substrate according to embodiments of the inventive concept.

[0050] Referring to FIG. **2**, when the flexible substrate **1000** is bent, a tensile strain ST may be applied to one surface of the flexible substrate **1000**, and a compressive strain SC may be applied to the other surface of the flexible substrate **1000**. The tensile strain ST or the compressive strain SC, which is applied to the surface of the flexible substrate **1000**, may be referred to as a surface strain. According to an embodiment of the inventive concept, as the third film **30** has a Young's modulus less than that of each of the first and second films **10** and **20**, at least a portion of the surface strain that is applied to the flexible substrate **1000** may be reduced by inserting the third film **30**. Accordingly, the surface strain of the flexible substrate **1000** may be reduced.

[0051] The surface strain of the flexible substrate **1000** may be controlled according to a ratio of a thickness **30**T of the third film **30** with respect to an entire thickness T of the flexible substrate **1000** and variation on the third Young's modulus of the third film **30**. Hereinafter, in an experimental example 1 and an experimental example 2, the surface strain according to the bending of the flexible substrate **1000** is calculated by using a finite element method (FEM) simulation. The surface strain of the flexible substrate is calculated according to i) the ratio of the thickness **30**T of the third film **30** and ii) the variation of the third Young's modulus of the third film **30**.

Experimental Example 1

[0052] It is assumed that a total thickness T of the flexible substrate **1000** is about 20 μm, and the flexible substrate **1000** is bent with a curvature radius of about 1 mm. The first film **10** and the second film **20** are applied with a property of polyimide, and the third film **30** is applied with a property of polydimethylsiloxane (PDMS). The ratio of the thickness **30**T of the third film **30** is changed to 0%, 20%, 40%, and 60%, and the third Young's modulus of the third film **30** is changed to 0.1 MPa, 0.99 MPa and 3.27 MPa.

TABLE 1

		Surface strain (%)		
		Young's modulus of third film (MPa)		
		0.1	0.99	3.27
Ratio of thickness of third film (%)	0	2.03	2.03	2.03
	20	—	1.6922	1.7172
	40	1.4378	1.6407	1.6777
	60	—	1.6	1.656

[0053] FIG. **3** is a graph showing variation of the surface strain of the flexible substrate **1000** according to the experimental example **1** while illustrating results of table 1. Referring to FIG. **3**, as the ratio of the thickness **30**T of the third film **30** increases, and the third Young's modulus of the third film **30** decreases, the surface strain of the flexible substrate **1000** is gradually reduced.

Experimental Example 2

[0054] It is assumed that the total thickness T of the flexible substrate **1000** is about 100 μm, and the flexible substrate **1000** is bent with a curvature radius of about 5 mm. The first film **10** and the second film **20** are applied with the property of polyimide, and the third film **30** is applied with the property of polydimethylsiloxane (PDMS). The ratio of the thickness **30**T of the third film **30** is changed to 0%, 20%, 40%, and 60%, and the third Young's modulus of the third film **30** is changed to 0.1 MPa, 0.99 MPa and 3.27 MPa.

TABLE 2

		Surface strain (%)		
		Young's modulus of third film (MPa)		
		0.1	0.99	3.27
Ratio of thickness of third film (%)	0	2.236	2.236	2.236
	20	1.216	1.57	1.818
	40	1.148	1.483	1.614
	60	1.11	1.45	1.54

[0055] FIG. **4** is a graph showing variation of the surface strain of the flexible substrate **1000** according to the experimental example 2 while illustrating results of table 2. Referring to FIG. **4**, as the ratio of the thickness **30**T of the third film **30** increases, and the third Young's modulus of the third film **30** decreases, the surface strain of the flexible substrate **1000** is gradually reduced.

[0056] According to an embodiment of the inventive concept, the flexible substrate **1000** may be configured to minimize the surface strain, which is applied thereto, when the flexible substrate **1000** is bent. Due to this, even when the bending of the flexible substrate **1000** is repeated by a plurality of times, variation of the surface resistance of the flexible substrate **1000** may be minimized. Hereinafter, in an experimental example 3, a variation rate of the sheet resistance of the conductor on the flexible substrate **1000** according to the number of the bending of the flexible substrate **1000** will be verified.

Experimental Example 3

[0057] A multilayer flexible substrate, in which polyimide (thickness of about 20 μm)/PDMS (thickness of about 40 μm)/polyimide (thickness of about 20 μm) are laminated, is prepared. An indium tin oxide (ITO) thin-film having a thickness of about 100 nm is deposited on the multilayer flexible substrate. A tensile strain is applied to the ITO thin-film by bending and unbending the multilayer flexible substrate with a curvature radius of about 6 mm in a repeated manner Variation of resistances of the ITO thin-film is measured.

Comparative Example

[0058] A single-layer flexible substrate of polyimide (thickness of about 80 μm) is prepared. An indium tin oxide (ITO) thin-film having a thickness of about 100 nm is deposited on the single-layer flexible substrate. A tensile strain is applied to the ITO thin-film by bending and unbending the single-layer flexible substrate with a curvature radius of about 6 mm in a repeated manner Variation of resistances of the ITO thin-film is measured

[0059] In FIG. **5**, at a vertical axis, R**0** represents an initial resistance, and R represents a resistance that is measured after a process of bending and unbending the flexible substrate of the experimental example 3 or the comparative example is repeated. In FIG. **5**, a horizontal axis represents the repeated number of the process of bending and unbending the flexible substrate of the experimental example 3 or the comparative example. Referring to FIG. **5**, when the process of bending and unbending the single-layer flexible substrate of the comparative example is repeated by about 200 times or more, it may be seen that the variation rate of the sheet resistance of the ITO thin-film on the single-layer flexible substrate remarkably increases. In the case of the multilayer flexible substrate of the experimental example 3, although the process of bending and unbending the multilayer flexible substrate is repeated by about 2000 times, a variation rate of the sheet resistance of the ITO thin-film on the multilayer flexible substrate may be maintained at about 30% or less. That is, the resistance variation of the ITO thin-film on the multilayer flexible substrate may relatively decrease.

[0060] According to an embodiment of the inventive concept, the flexible substrate **1000** may include the third film **30** disposed between the first film **10** and the second film **20** and having a Young's modulus less than that of each of the first and second films **10** and **20**. Accordingly, when the flexible substrate **1000** is bent, the surface strain applied to the flexible substrate **1000** may be reduced. In addition, according to an embodiment of the inventive concept, when the flexible substrate **1000** is bent, the surface strain applied to the flexible substrate **1000** may be controlled to be less than a threshold value by adjusting the ratio of the thickness **30**T of the third film **30** with respect to the entire thickness T of the flexible substrate **1000** and the third Young's modulus of the third film **30**. Resultantly, variations of the electrical characteristics of the electronic element (e.g., a resistance variation of the ITO thin-film) provided on the flexible substrate **1000** may be minimized. Here, the threshold value represents a maximum value of the surface strain, which is capable of maintaining required performance of the electronic element.

[0061] FIGS. **6** and **7** are cross-sectional views illustrating a method for manufacturing the flexible substrate according to some embodiments of the inventive concept. For simplicity of description, duplicate description with that of the flexible substrate according to embodiments of the inventive concept with reference to FIGS. **1** to **5** will be omitted.

[0062] Referring to FIG. **6**, the first film **10** may be formed on a first support substrate **101**. The first support substrate **101** may be, e.g., a silicon wafer or a glass wafer. The first film **10** may be formed by applying a first film composition on the first support substrate **101** and then thermally curing the first film composition. The first film composition may be, e.g., a polyimide solution. The applying of the first film composition may be performed through methods such as spin coating, bar coating, blade coating, and pouring. A first preliminary layer **32** may be formed on the first film **10**. The forming of the first preliminary layer **32** may include: applying a first composition on the first film **10**; and performing a first heat treatment process to partially cure the first composition. The first composition may be, e.g., a polydimethylsiloxane (PDMS) solution. The applying of the first composition may be performed through methods such as spin coating, bar coating, blade coating, and pouring. When the first preliminary layer **32** includes polydimethylsiloxane (PDMS), and the first heat treatment process may be performed, e.g., at a temperature of about 60° C. during about 30 minutes to about 40 minutes. As the first composition is partially cured, the first preliminary layer **32** may has a solid shape in a viscous state.

[0063] The second film **20** may be formed on a second support substrate **102**. The second support substrate **102** may be, e.g., a silicon wafer or a glass wafer. The second film **20** may be formed by applying a second film composition on the second support substrate **102** and then thermally curing the second film composition. The second film composition may be, e.g., a polyimide solution. The applying of the second film composition may be performed through methods such as spin coating, bar coating, blade coating, and pouring. A second preliminary layer **34** may be formed on the second film **20**. The forming of the second preliminary layer **34** may include: applying a second composition on the second film **20**; and performing a second heat treatment process to partially cure the second composition. The second composition may be, e.g., a polydimethylsiloxane (PDMS) solution. The applying of the second composition may be performed through methods such as spin coating, bar coating, blade coating, and pouring. When the second preliminary layer **34** includes polydimethylsiloxane (PDMS), and the second heat treatment process may be performed, e.g., at a temperature of about 60° C. during about 30 minutes to about 40 minutes. As the second composition is partially cured, the second preliminary layer **34** may has a solid shape in a viscous state.

[0064] Referring to FIG. **7**, the second support substrate **102** may be removed from the second film **20**. The removing of the second support substrate **102** may include physically separating the second support substrate **102** from the second film **20**. After the second support substrate **102** is removed, the second film **20** and the second preliminary layer **34** may be provided on the first preliminary layer **32** so that a top surface **32**U of the first preliminary layer **32** faces a top surface **34**U of the second preliminary layer **34**. The top surface **32**U of the first preliminary layer **32** and the top surface **34**U of the second preliminary layer **34** may be attached to each other, and then a third heat treatment process may be performed. The third heat treatment process may be performed at a temperature higher than the first heat treatment process and the second heat treatment process. For example, when each of the first and second preliminary layers **32** and **34** includes polydimethylsiloxane (PDMS), the third heat treatment process may be performed at a temperature of about 120° C. during about 30 minutes. As the first preliminary layer **32** and the second preliminary layer **34** are cured by the third heat treatment process, the third film **30** in FIG. **1** may be formed. Accordingly, the flexible substrate **1000** in FIG. **1** may be manufactured.

[0065] FIG. **8** is a cross-sectional view illustrating a method for manufacturing the flexible substrate according to some embodiments of the inventive concept. For simplicity of description, the difference from the method for manufacturing the flexible substrate with reference to FIGS. **6** and **7** will be mainly described.

[0066] As described with reference to FIG. **6**, the first film **10** and the first preliminary layer **32** may be sequentially formed on the first support substrate **101**, and the second film **20** and the second preliminary layer **34** may be sequentially formed on the second support substrate **102**.

[0067] Referring to FIG. **8**, the second support substrate **102**, the second film **20**, and the second preliminary layer **34** may be provided on the first preliminary layer **32** so that the top surface **32**U of the first preliminary layer **32** faces the top surface **34**U of the second preliminary layer **34**. The top surface **32**U of the first preliminary layer **32** and the top surface **34**U of the second preliminary layer **34** may be attached to each other, and then the third heat treatment process may be performed. The third heat treatment process may be performed at a temperature higher than the first heat treatment process and the second heat treatment process. As the first preliminary layer **32** and the second preliminary layer **34** are cured by the third heat treatment process, the third film **30** in FIG. **1** may be formed. Thereafter, the first support substrate **101** and the second support substrate **102** may be removed from the first film **10** and the second film **20**, respectively. The removing of the first and second support substrates **101** and **102** may include physically separating the first and second support substrates **101** and **102** from the first and second films **10** and **20**. Accordingly, the flexible substrate **1000** in FIG. **1** may be manufactured.

[0068] FIGS. **9** and **11** are cross-sectional views illustrating a method for manufacturing the flexible substrate according to some embodiments of the inventive concept. For simplicity of description, the difference from the method for manufacturing the flexible substrate with reference to FIGS. **6** and **7** will be mainly described.

[0069] Referring to FIG. **9**, the first film **10** may be formed on the first support substrate **101**. The first film **10** may be formed by applying the first film composition on the first support substrate **101** and then thermally curing the first film composition. According to the embodiments, the thermal curing of the first film composition may be performed at a relatively low temperature. For example, the first film **10** may include low temperature curable polyimide.

[0070] Referring to FIG. **10**, the third film **30** may be formed on the first film **10**. The third film **30** may be formed by applying a third film composition on the first film **10** and then thermally curing the third film composition. The third film composition may be, e.g., a polydimethylsiloxane (PDMS) solution. The applying of the third film composition may be performed through methods such as spin coating, bar coating, blade coating, and pouring.

[0071] Referring to FIG. **11**, the second film **20** may be formed on the third film **30**. The second film **20** may be formed by applying the second film composition on the third film **30** and then thermally curing the second film composition. According to the embodiments, the thermal curing of the second film composition may be performed at a relatively low temperature. For example, the second film **20** may include low temperature curable polyimide. According to the embodiments, the first film **10**, the third film **30**, and the second film **20** may be sequentially formed on the first support substrate **101**. Thereafter, the first support substrate **101** may be removed from the first film **10**. The removing of the first support substrate **101** may include physically separating the first support substrate **101** from the first film **10**. Accordingly, the flexible substrate **1000** in FIG. **1** may be manufactured.

[0072] FIGS. **12** and **13** are cross-sectional views illustrating a method for manufacturing the flexible substrate according to some embodiments of the inventive concept. For simplicity of description, the difference from the method for manufacturing the flexible substrate with reference to FIGS. **6** and **7** will be mainly described.

[0073] Referring to FIG. **12**, the first film **10** and the second film **20** may be formed on the first support substrate **101** and the second support substrate **102**, respectively. The first film **10** and the second film **20** may be formed by the substantially same method as the method described with reference to FIG. **6**. Thereafter, the first support substrate **101** and the second support substrate **102** may be removed from the first film **10** and the second film **20**, respectively. The removing of the first and second support substrates **101** and **102** may include physically separating the first and second support substrates **101** and **102** from the first and second films **10** and **20**.

[0074] According to the embodiments, the third film **30** may be formed on a third support substrate **103**. The third support substrate **103** may be, e.g., a silicon wafer or a glass wafer. The third film **30** may be formed by applying a third film composition on the third support substrate **103** and then thermally curing the third film composition. The third film composition may be, e.g., a polydimethylsiloxane (PDMS) solution. The applying of the third film composition may be performed through methods such as spin coating, bar coating, blade coating, and pouring. The third film **30** may be formed, and then the third support substrate **103** may be removed from the third film **30**. The removing of the third support substrate **103** may include physically separating the third support substrate **103** from the third film **30**.

[0075] Referring to FIG. **13**, after the first to third support substrates **101**, **102**, and **103** are removed, the first to third films **10**, **20**, and **30** may be laminated so that the third film **30** is disposed between the first film **10** and the second film **20**. A pressure P may be applied on the laminated first to third films **10**, **20**, and **30**. For example, a pressure roller may apply the pressure P on the laminated first to third films **10**, **20**, and **30**. Accordingly, the third film **30** may be re-cured, and, as a result, the flexible substrate **1000** of FIG. **1** may be manufactured.

[0076] FIGS. **14** and **15** are cross-sectional views illustrating a method for manufacturing the flexible substrate according to some embodiments of the inventive concept. For simplicity of description, the difference from the method for manufacturing the flexible substrate with reference to FIGS. **6** and **7** will be mainly described.

[0077] Referring to FIG. **14**, the first film **10** may be provided on the first support substrate **101**. For example, the first film **10** may be formed by the substantially same method as that described with reference to FIG. **6**. For another example, the first film **10**, which is prepared separately from the first support substrate **101**, may be attached to the first support substrate **101** so that the first film **10** is fixed to the first support substrate **101**. A third film composition **36** may be applied on the first film **10**. The third film composition **36** may be, e.g., a polydimethylsiloxane (PDMS) solution. The applying of the third film composition **36** may be performed through methods such as spin coating, bar coating, blade coating, and pouring.

[0078] Referring to FIG. **15**, the second film **20**, which is separately prepared, may be provided on the first support substrate **101** on which the third film composition **36** is applied. The second film **20** may be provided to cover the third film composition **36**. Thereafter, a heat treatment process may be performed to cure the third film composition **36**. Accordingly, the third film **30** of FIG. **1** may be formed. After the third film **30** is formed, the first support substrate **101** may be removed and the flexible substrate **1000** of FIG. **1** may be manufactured.

[0079] FIG. **16** is a cross-sectional view illustrating a method for manufacturing the flexible substrate according to some embodiments of the inventive concept. For simplicity of description, the difference from the method for manufacturing the flexible substrate with reference to FIGS. **6** and **7** will be mainly described.

[0080] Referring to FIG. **16**, a single-layer flexible substrate **40** may be provided. The single-layer flexible substrate **40** may include a polymer material having a predetermined Young's modulus. The single-layer flexible substrate **40** may include at least one selected from the group consisting of polytetrafluoroethylene (PTFE), polyimide, polyamide, polyester, polyethylene, polypropylene, polyurethane, polydimethylsiloxane (PDMS), polyacrylate, polyarylate, and fiber reinforced plastic, and a combination thereof.

[0081] According to the embodiments, heat H or an electric field E may be provided to a top surface **40**U and a bottom surface **40**L of the single-layer flexible substrate **40**. A Young's modulus of each of upper and lower portions of the single-layer flexible substrate **40** may be changed by the heat H or the electric field E. The Young's modulus of each of the upper and lower portions of the single-layer flexible substrate **40** may be changed to be greater than that of an intermediate portion of the single-layer flexible substrate **40**. Accordingly, the flexible substrate **1000** in FIG. **1** may be manufactured.

[0082] FIG. **17** is a cross-sectional view illustrating a flexible electronic device including the flexible substrate according to embodiments of the inventive concept.

[0083] Referring to FIG. **17**, a flexible electronic device **2000** may include the flexible substrate **1000** of FIG. **1** and an electronic element **200** on the flexible substrate **1000**. The electronic element **200** may include at least one of a memory element, a display element, a solar cell, a light emitting diode, and a sensor, however, the embodiment of the inventive concept is not limited thereto. The electronic element **200** may be made of an electronic material such as a conductor, a semiconductor, and/or a nonconductor. According to an embodiment of the inventive concept, when the flexible substrate **1000** is bent, the surface strain applied to the flexible substrate **1000** may be reduced. Accordingly, even when the flexible substrate **1000** is bent, an external force (e.g., the surface strain) applied to the electronic element **200** on the flexible substrate **1000** may be reduced. Thus, variation of electrical characteristics of the electronic element **200** may be minimized, and, as a result, the stable flexible electronic device **2000** capable of minimizing performance degradation due to physical bending or deformation may be provided.

[0084] According to the embodiment of the inventive concept, the flexible substrate may include the first film, the second film, and the third film disposed therebetween, and the third film may include a material having a Young's modulus less than that of each of the first and second films. Accordingly, when the flexible substrate is bent, the surface strain applied to the flexible substrate may be reduced, and the external force applied to the electronic element disposed on the flexible substrate may be reduced. Thus, the stable flexible electronic device capable of minimizing performance degradation due to physical bending or deformation may be provided.

[0085] Although the exemplary embodiments of the present invention have been described, it is understood that the present invention should not be limited to these exemplary embodiments but various changes and modifications can be made by one ordinary skilled in the art within the spirit and scope of the present invention as hereinafter claimed.

What is claimed is:

1. A flexible substrate comprising:

a first film having a first Young's modulus;

a second film on the first film and having a second Young's modulus; and

a third film between the first film and the second film and having a third Young's modulus,

wherein the third Young's modulus is less than each of the first Young's modulus and the second Young's modulus.

2. The flexible substrate of claim **1**, wherein the first film and the second film comprises the same material as each other.

3. The flexible substrate of claim **2**, wherein the third film comprises a material different from that of each of the first film and the second film.

4. The flexible substrate of claim **1**, wherein each of the first to third films comprises a polymer material.

5. The flexible substrate of claim **4**, wherein each of the first to third films comprises at least one selected from the group consisting of polytetrafluoroethylene (PTFE), polyimide, polyamide, polyester, polyethylene, polypropylene, polyurethane, polydimethylsiloxane (PDMS), polyacrylate, polyarylate, and fiber reinforced plastic, and a combination thereof.

6. The flexible substrate of claim **4**, wherein each of the first film and the second film comprises polyimide.

7. The flexible substrate of claim **4**, wherein the third film comprises polydimethylsiloxane (PDMS).

8. The flexible substrate of claim **1**, wherein the third film has a bottom surface that directly contacts a top surface of the first film and a top surface that directly contacts a bottom surface of the second film.

9. A method for manufacturing a flexible substrate, the method comprising:

forming a first film and a first preliminary layer on a first support substrate in a sequence;

forming a second film and a second preliminary layer on a second support substrate in a sequence;

attaching a top surface of the first preliminary layer to a top surface of the second preliminary layer; and

performing a heat treatment process to cure the first preliminary layer and the second preliminary layer, thereby forming a third film,

wherein the third film has a Young's modulus less than that of each of the first and second films.

10. The method of claim **9**, wherein the forming of the first preliminary layer comprises applying a first composition on the first film and then performing a first heat treatment process to partially cure the first composition,

the forming of the second preliminary layer comprises applying a second composition on the second film and then performing a second heat treatment process to partially cure the second composition, and

each of the first heat treatment process and the second heat treatment process is performed at a temperature less than that of the heat treatment process.

11. The method of claim **9**, wherein the attaching of the top surface of the first preliminary layer to the top surface of the second preliminary layer comprises:

separating the second support substrate from the second film; and

providing the second film and the second preliminary layer on the first support substrate so that the top surface of the second preliminary layer faces the top surface of the first preliminary layer after the second support substrate is separated.

12. The method of claim **11**, further comprising separating the first support substrate from the first film after the third film is formed.

13. The method of claim **9**, wherein the attaching of the top surface of the first preliminary layer to the top surface of the second preliminary layer comprises:

providing the second support substrate, the second film, and the second preliminary layer on the first support substrate so that the top surface of the second preliminary layer faces the top surface of the first preliminary layer.

14. The method of claim **13**, further comprising separating the first support substrate and the second support substrate from the first film and the second film, respectively, after the third film is formed.

15. A flexible electronic device comprising:

a flexible substrate; and

an electronic element on the flexible substrate,

wherein the flexible substrate comprises a first film, a second film on the first film, and a third film between the first film and the second film, and

the third film has a Young's modulus less than that of each of the first and second films.

16. The flexible electronic device of claim **15**, wherein each of the first to third films comprises a polymer material.

17. The flexible electronic device of claim **16**, wherein the first film and the second film comprises the same polymer material as each other.

18. The flexible electronic device of claim **16**, wherein the third film comprises a polymer material different from that of each of the first and second films.

19. The flexible electronic device of claim **16**, wherein each of the first and second films comprises polyimide, and

the third film comprises polydimethylsiloxane (PDMS).

20. The flexible electronic device of claim **15**, wherein the electronic element comprises at least one of a memory element, a display element, a solar cell, a light emitting diode, and a sensor.

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