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Potter

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(54) **ELECTROSTATIC LEVITATION AND ATTRACTION SYSTEMS AND METHODS**

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Related U.S. Application Data

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(51) **Int. Cl.**[7] **H02N 1/00**

(52) **U.S. Cl.** **310/309**; 307/400; 29/886

(58) **Field of Search** 310/309; 438/455; 307/400; 29/886; 381/191

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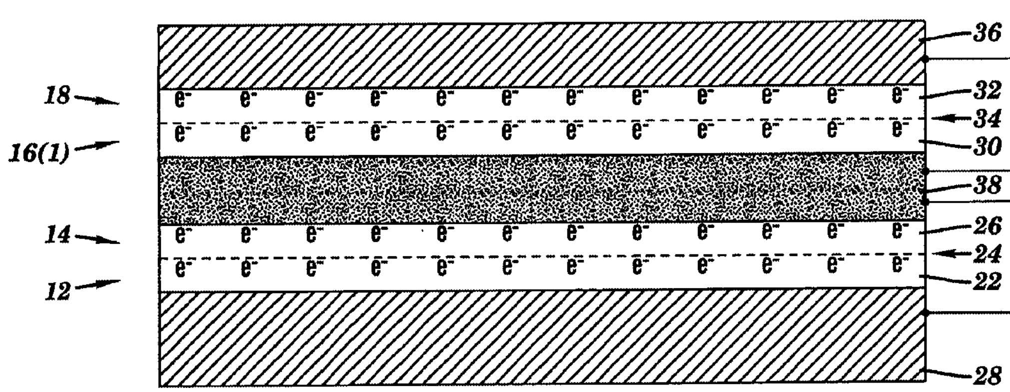
(57) **ABSTRACT**

An electrostatic interaction system includes a first structure having a first fixed electrostatic charge and a second structure having a second fixed electrostatic charge. The polarity of the first and second fixed electrostatic charges determines a positional relationship of the first structure to the second structure.

23 Claims, 6 Drawing Sheets



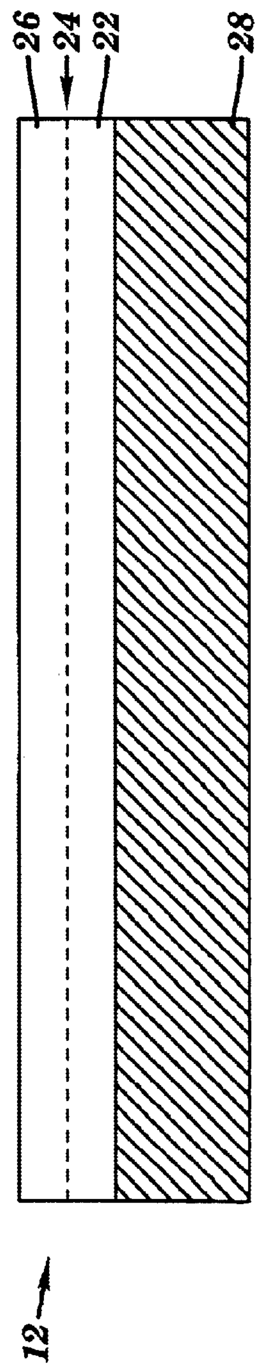


FIG. 1

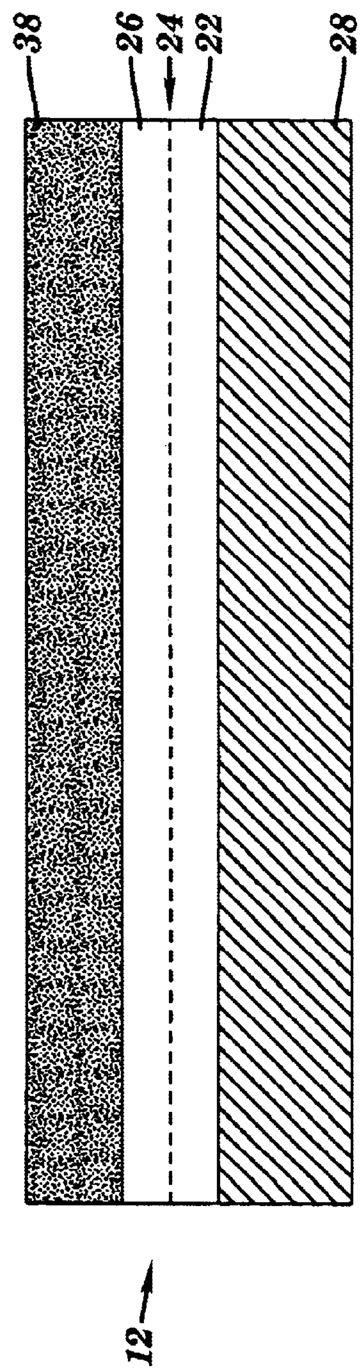


FIG. 2

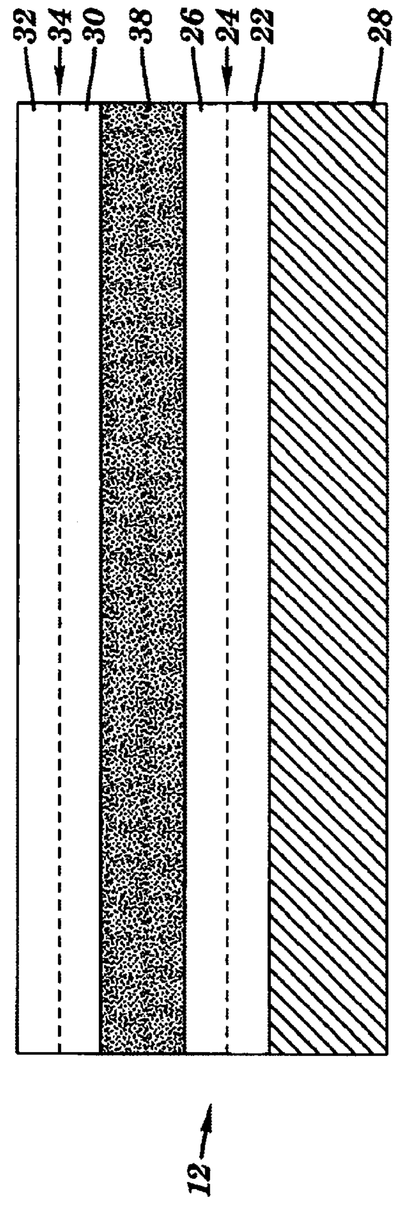


FIG. 3

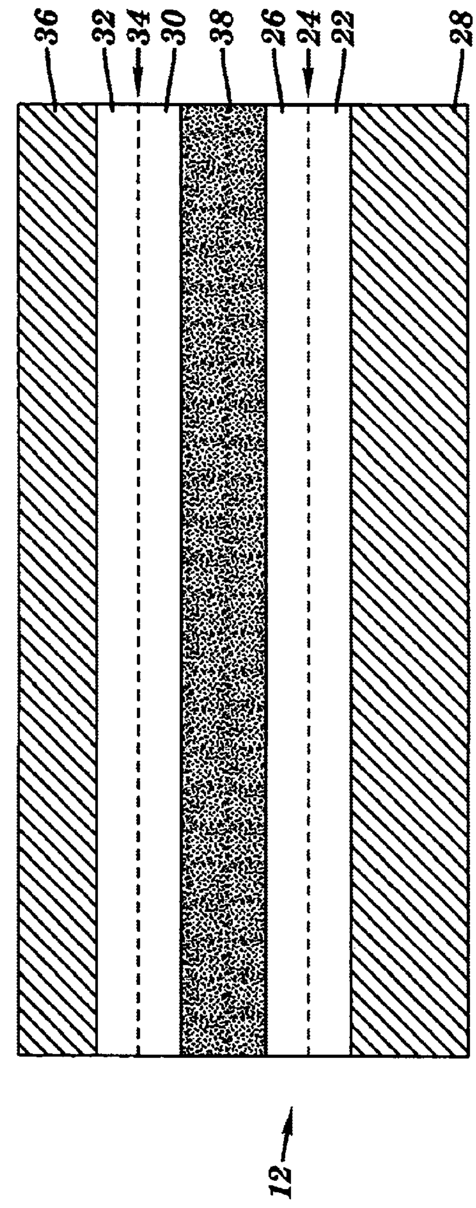


FIG. 4

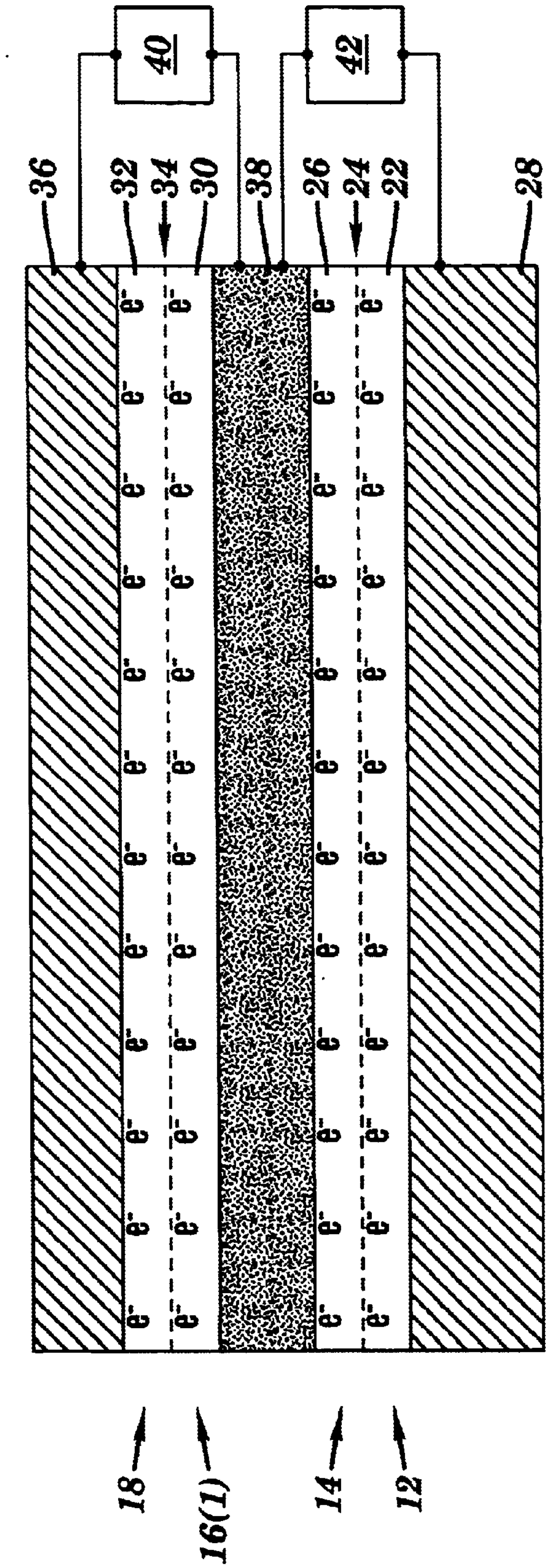


FIG. 5

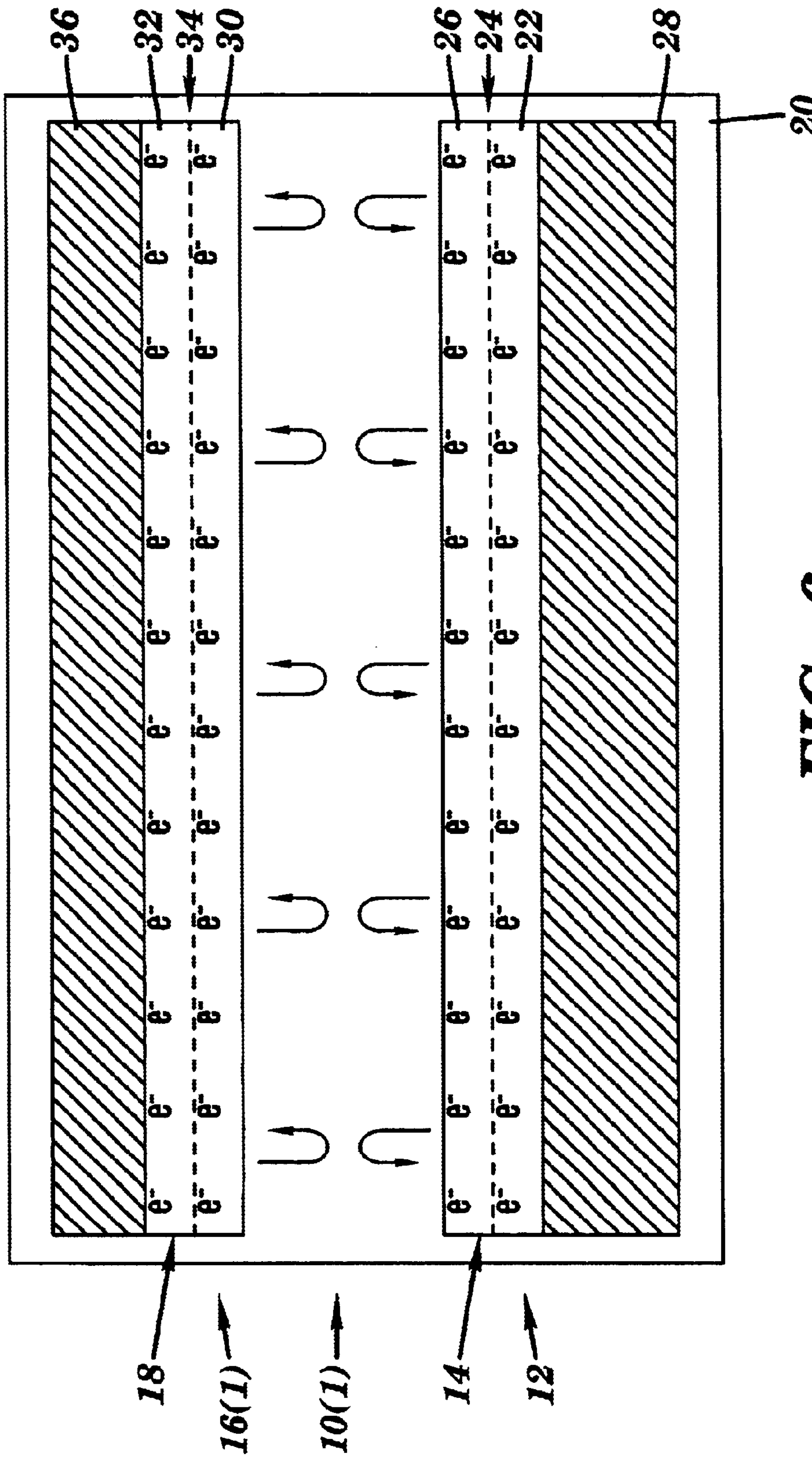


FIG. 6

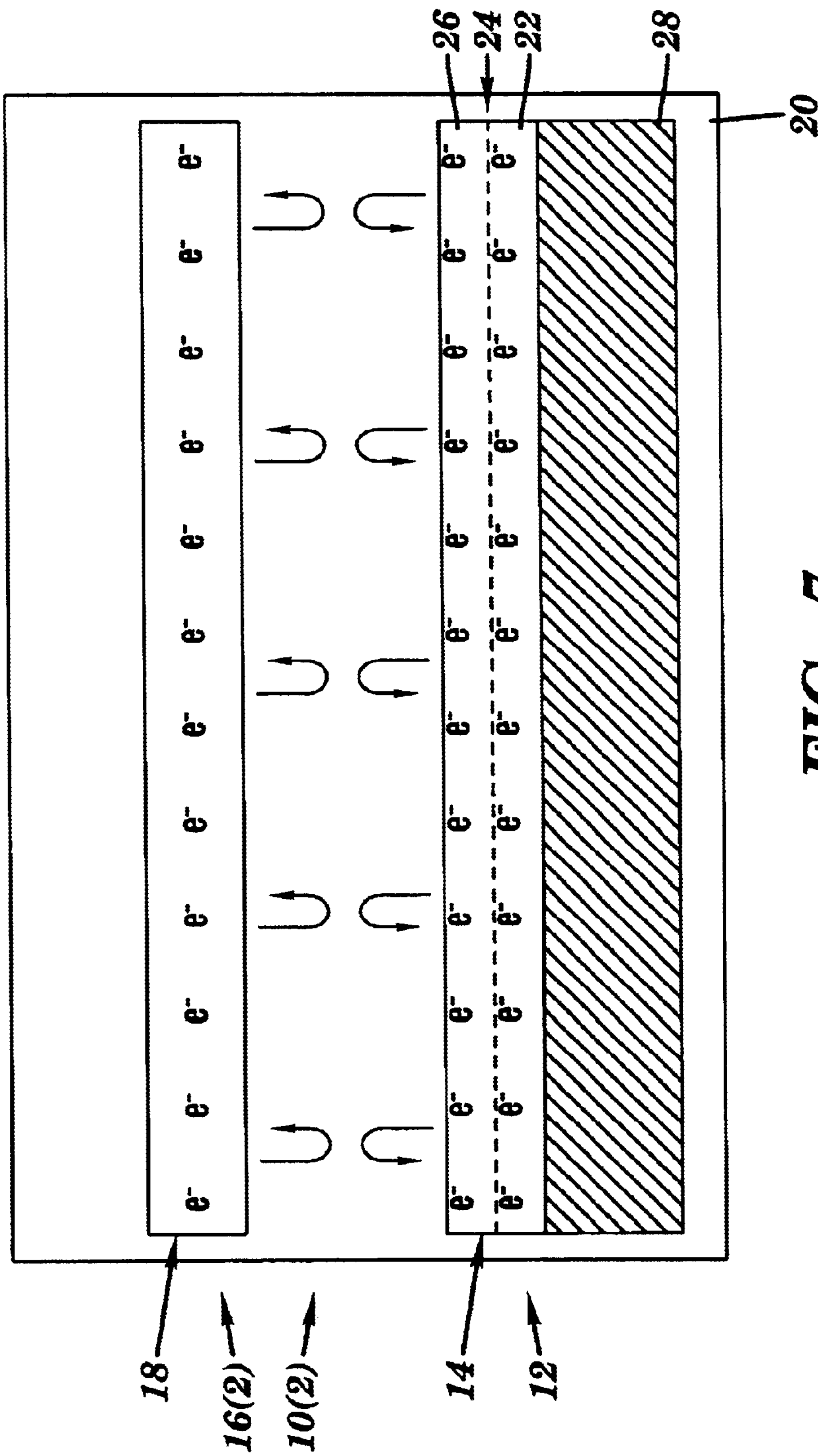


FIG. 7

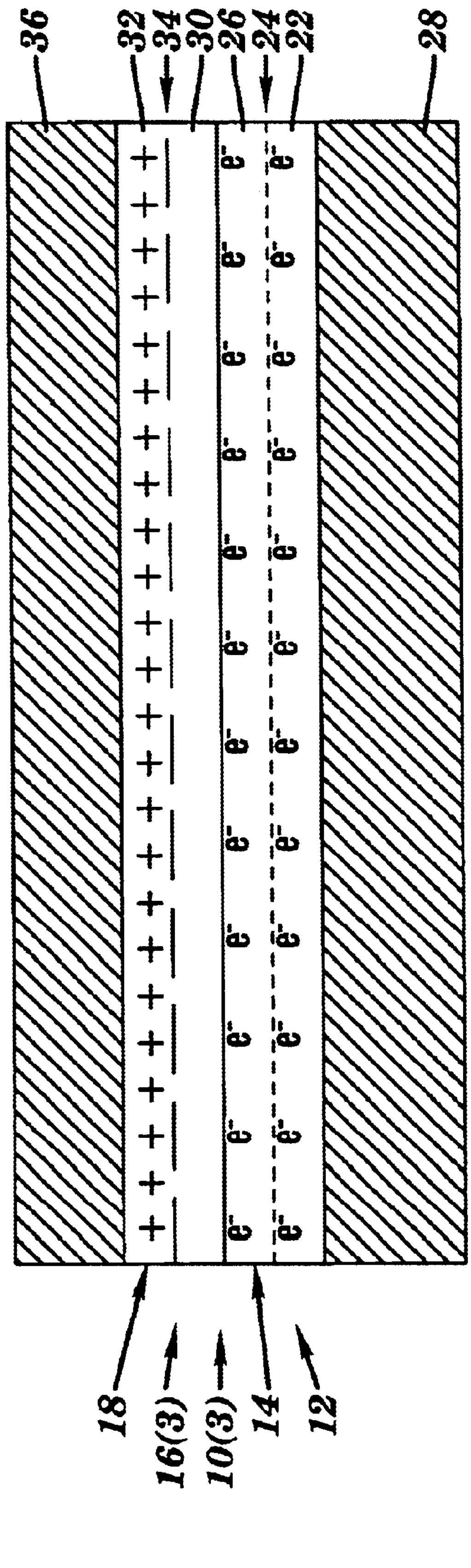


FIG. 8

ELECTROSTATIC LEVITATION AND ATTRACTION SYSTEMS AND METHODS

The present invention claims the benefit of U.S. Provisional Patent Application Ser. No. 60/297,327, filed Jun. 11, 2001, which is hereby incorporated by reference in its entirety.

FIELD OF THE INVENTION

This invention relates to electrostatic devices and a methods and, more particularly, to electrostatic levitation and attraction systems and methods thereof.

BACKGROUND OF THE INVENTION

In the macroscopic realm, there is often an undesirable restriction of the relative movement between two surfaces. This tendency of two surfaces to stick to each other is called friction and can be significantly reduced by introducing an intermediate material, i.e. a lubricant, that is slippery between the surfaces.

In the microscopic realm, there also is an undesirable restriction of the relative movement between two surfaces. Unfortunately, unlike the macroscopic realm, the introduction of an intermediate material between the surfaces may actually increase the propensity of micro components to stick together. Furthermore, in the micro and nano realms short-range forces, such as the van der Waals and electrostatic forces, become extremely important and often lead to serious limitations in the overall design and miniaturization of components. This effect is often referred to as stiction.

SUMMARY OF THE INVENTION

An electrostatic interaction system in accordance with one embodiment of the present invention includes a first structure having a first fixed electrostatic charge and a second structure having a second fixed electrostatic charge. The polarity of the first and second fixed electrostatic charges determines a positional relationship of the first structure to the second structure.

A method for making an electrostatic interaction system in accordance with another embodiment of the present invention includes providing a first structure having a first fixed electrostatic charge and providing a second structure having a second fixed electrostatic charge. The polarity of the first and second fixed electrostatic charges determines a positional relationship of the first structure to the second structure.

An electrostatic levitation system in accordance with another embodiment of the present invention includes a first structure having a first fixed electrostatic charge and a second structure having a second fixed electrostatic charge. The polarity of the first and second fixed electrostatic charges is the same and holds the first and second structures in a spaced apart positional relationship.

An electrostatic attraction system in accordance with another embodiment of the present invention includes a first structure having a first fixed electrostatic charge and a second structure having a second fixed electrostatic charge. The polarity of the first and second fixed electrostatic charges is opposite which attracts and holds the first and second structures together.

The present invention provides an electrostatic levitation system that has a compensating force that is sufficient to keep micro components from actually coming within the short-range distances from each other. This technique provides levitation without using magnetism. The present application has a variety of applications including electrostatic bearings. One of the features of the invention is the use of imbedded repulsive electrostatic forces to overcome stiction.

The present invention also provides an electrostatic attraction system that has a complementary force that is sufficient to attract components to each other.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1–6** are cross-sectional view of a method of making an electrostatic levitation system in accordance with one embodiment of the present invention;

FIG. **7** is a cross-sectional view of an electrostatic levitation system in accordance with another embodiment of the present invention; and

FIG. **8** is a cross-sectional view of an electrostatic attraction system in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION

Electrostatic interaction systems **10(1)–10(3)** in accordance with embodiments of the present invention are illustrated in FIGS. **6–8**. The electrostatic interaction systems **10(1)–10(3)** each include a first structure **12** having a first fixed electrostatic charge **14** and a second structure **16(1)**, **16(2)**, or **16(3)** having a second fixed electrostatic charge **18**. The polarity of the first and second fixed electrostatic charges **14** and **18** determines a positional relationship of the first structure **12** to the second structure **16(1)**, **16(2)**, or **16(3)**. The present invention provides electrostatic interaction systems, such as electrostatic levitation systems **10(1)** and **10(2)** and electrostatic attraction systems **10(3)**, for microscopic environments.

Referring to FIG. **6**, an electrostatic levitation system **10(1)** in accordance with one embodiment is illustrated. The system **10(1)** may include a housing **20** for the first and second structures **12** and **16(1)**. A variety of different types of housings, such as a bearing case, with a variety of different configurations can be used.

The first structure **16(1)** includes a first insulating layer **22**, such as SiO_2, located on a second insulating layer **26**, such as Si_3N_4, although other materials and other numbers of layers could be used. A first interface **24** is located between the first and second insulating layers **22** and **26** and the first fixed electrostatic charge **14** having a negative polarity is stored at the first interface **24**, although the first fixed electrostatic charge **14** could have a positive polarity and depending on the number of layers, the first structure **12** can have more interfaces where fixed electrostatic charge can be stored. Although a first structure **12** made of first and second insulating layers **22** and **26** is shown, other types of members which can hold a fixed charge can also be used, such as an electret. The first stored fixed electrostatic charge **14** has a magnitude of at least 1×10^{12} charges per cm^2, although the magnitude can vary depending on the application.

An optional first component **28**, such as a machine part, is connected to the first insulating layer **22**, although other types of first components can be used. The first component **28** is made of a conductive material, such as poly silicon, although other types of materials, such as an insulating material, can be used. If first component **28** is made of an insulating material, then other techniques for imbedding the fixed charge in the interface **24** may be used, such as using an electron gun.

The second structure **16(1)** includes a third insulating layer **30**, such as Si_3N_4, located on a fourth insulating layer **32**, such as SiO_2, although other materials and other numbers of layers could be used. A second interface **34** is located at the interface between the third and fourth insulating layers **30** and **32** and the second fixed electrostatic charge **18** also having a negative polarity is stored at the second interface **34**, although the second fixed electrostatic charge **18** could have a positive polarity and depending on the number of layers, the second structure **16(1)** can have more interfaces where fixed electrostatic charge can be stored. Although a second structure **16(1)** made of first and second insulating layers **30** and **32** is shown, other types of members which can hold a fixed charge can also be used, such as an electret. The second stored fixed electrostatic charge **18** has a magnitude of 1×10^{12} charges per cm^2, although the magnitude can vary depending on the application.

An optional second component **36**, such as a machine part, is connected to the fourth insulating layer **32**, although other types of second components can be used. The second component **36** is made of a conductive material, such as poly silicon, although other types of materials, such as an insulating material, can be used. If second component **36** is made of an insulating material, then other techniques for imbedding the fixed charge in the interface **34** may be used, such as using an electron gun.

If the first and second stored fixed electrostatic charges **14** and **18** in the first and second structures **12** and **16(1)** have the same polarity or sign, then an electrostatic repulsion force results which is sufficient to keep the two structures **12** and **16(1)** in a spaced apart relation with each other. If the housing **20** is included it provides a casing to hold the first and second structures **12** and **16(1)** in their spaced apart relation to each other. This embodiment mitigates of sliding friction and the short range stiction.

Referring to FIG. **7**, an electrostatic levitation system **10(2)** in accordance with another embodiment is illustrated. The electrostatic levitation system **10(2)** is the same as the electrostatic levitation system **10(1)** shown in FIG. **6**, except as described below. Elements in FIG. **7** which are identical to those elements in FIG. **6** have like reference numerals. In this particular embodiment, the second structure **16(2)** is an electret, such as a polymer with residual polarization charge, with a second stored fixed electrostatic charge **18**, although other types of members which can hold a fixed charge can be used. Additionally, in this particular embodiment a second component **36** is not connected to the second structure **16(2)**, although other configurations are possible, such as having a second component **36** connected to the second structure **16(2)**, but not having a first component **28** connected to the first structure **12**.

Referring to FIG. **8**, an electrostatic attraction system **10(3)** in accordance with another embodiment is illustrated. The electrostatic attraction system **10(3)** is the same as the electrostatic levitation system **10(1)** shown in FIG. **6**, except as described below. Elements in FIG. **8** which are identical to those elements in FIG. **6** have like reference numerals. In this particular embodiment, the first structure **12** has a first a fixed electrostatic charge **14** with a negative polarity and the second structure **16(3)** has a second fixed electrostatic charge **18** with a positive polarity, although other arrangements are possible, such as the first structure **12** having a first a fixed electrostatic charge **14** with a positive polarity and the second structure **16(3)** having a second electrostatic fixed charge **18** with a negative polarity. Another possible arrangement is a fixed charge in one of the first and second structures and an induced charge in the other one of the first and second structures which will result in an electrostatic attraction force to keep the first and second structures together.

If the first and second stored fixed electrostatic charges **14** and **18** in the first and second structures **12** and **16(3)** have the opposite polarity or sign, then an electrostatic attraction force results which is sufficient to keep the two structures **12** and **16(3)** together.

A method for making an electrostatic levitation system **10(1)** in accordance with one embodiment is shown in FIGS. **1–6**. Referring to FIG. **1**, an insulating layer **22**, such as SiO_2, is deposited on the first component **28**, such as Si, and another insulating layer **26**, such as Si_3N_4, is deposited on the insulating layer **22** to form a member with a high density of electronic charge traps at an interface **24** between layers **22** and **26**, although other numbers of layers could be deposited, other materials could be used for each of the layers, and other types of members, such as a dual insulator graded interface, multiple delta layered interface, or an electret, could be used in place of insulating layers **22** and **26**.

Referring to FIG. **2**, a sacrificial conducting layer **38**, such as poly silicon, is deposited on the insulating layer **26**, although other types of materials could be used for layer **38**.

Referring to FIG. **3**, an insulating layer **30** is deposited on the sacrificial conducting layer **38**, such as Si_3N_4, and another insulating layer **32** is deposited on the insulating layer **30**, such as SiO_2, to form a member with a high density of electronic charge traps at an interface **34** between layers **30** and **32**, although other numbers of layers could be deposited, other materials could be used for each of the layers, and other types of members with a fixed electrostatic charge, such as an electret, could be used in place of insulating layers **30** and **32**.

Referring to FIG. **4**, a second component **36**, such as Si, is connected to the insulating layer **32**, although other types of materials could be used. For example, the second component **36** may be a conducting sacrificial layer which is subsequently removed using standard removal procedures for sacrificial layers, such as by chemical etching.

Referring to FIG. **5**, an electrical bias from a power supply **42** is applied between the first component **28** and the sacrificial conducting layer **38** to cause electrons to be injected into the first structure **12**. This in turn will cause electrons to be trapped at interface **24** between layers **22** and **26**, although other techniques for injecting the electrons into the interface **24** could be used, such as using an electron gun or equilibrium charge from processing. Although the injection of electrons into the interface **24** is shown, other techniques can also be used, such as the extraction of electrons from the interface **24** to leave a net positive charge, i.e. hole injection, at the interface **24**. Typically, higher charge levels can be obtained for the trapped electron case.

An electrical bias from a power supply **40** is also applied between the sacrificial conducting layer **38** and the second component **36**, causing electrons to be trapped at the interface **34**, although other techniques for injecting the electrons into the interface **34** could be used, such as using an electron gun or equilibrium charge from processing. Although the injection of electrons into the interface **34** is shown, other techniques can also be used, such as the extraction of electrons from the interface **34** to leave a net positive charge, i.e. hole injection, at the interface **34**. Typically, higher charge levels can be obtained for the trapped electron case.

Referring to FIG. **6**, once the fixed electrostatic charge **14** and **18** at the interfaces **24** and **34** has been obtained, the sacrificial layer **38** is removed. A variety of techniques for removing the sacrificial layer **38** can be used, such as by chemical etching. Again, the second component **36** may be a conducting sacrificial layer and subsequently be removed by standard process procedures at this time. The resulting first and second components **28** and **36** are held in a spaced apart relation by repulsive electrostatic forces from the fixed electrostatic charges **14** and **18** at the interfaces **24** and **34**.

Referring to FIG. **7**, the method for making the electrostatic levitation system **10(2)** is the same as shown and described for making electrostatic levitation system **10(1)**, except that second structure **16(1)** with insulating layers **30** and **32** is replaced with another second structure **16(2)** which is an electret, although other members which can hold a fixed charge can be used for second structure **16(2)** and for first structure **12**.

Referring to FIG. **8**, the method for making the electrostatic attraction system **10(3)** is the same as shown and described with reference to FIGS. **1**–**6** for making electrostatic levitation system **10(1)**, except that the obtained fixed electrostatic charges **14** and **18** in the interfaces **24** and **34** is opposite to attract the structures **12** and **16(3)** together. In this embodiment, electrons are injected into interface **24** and electrons are extracted from interface **34** to create the attraction force, although other arrangements can be used.

Having thus described the basic concept of the invention, it will be rather apparent to those skilled in the art that the foregoing detailed disclosure is intended to be presented by way of example only, and is not limiting. Various alterations, improvements, and modifications will occur and are intended to those skilled in the art, though not expressly stated herein. These alterations, improvements, and modifications are intended to be suggested hereby, and are within the spirit and scope of the invention. Additionally, the recited order of processing elements or sequences, or the use of numbers, letters, or other designations therefor, is not intended to limit the claimed processes to any order except as may be specified in the claims. Accordingly, the invention is limited only by the following claims and equivalents thereto.

What is claimed is:

1. An electrostatic interaction system comprising:

a first structure comprising at least a first pair of insulating layers with a first interface located at a junction between the first pair of insulating layers and with first fixed, monopole, electrostatic charges are stored at the first interface; and

a second structure comprising at least a second pair of insulating layers with a second interface located at a junction between the second pair of insulating layers and with second fixed, monopole, electrostatic charges are stored at the second interface;

wherein a polarity of the first and second fixed electrostatic charges determines a positional relationship of the first structure to the second structure.

2. The system as set forth in claim **1** wherein the polarity of the first and second fixed electrostatic charges is the same and holds the first and second structures in a spaced apart positional relationship with each other.

3. The system as set forth in claim **1** wherein the polarity of the first and second fixed electrostatic charges is opposite and attracts and holds the first and second structures together.

4. The system as set forth in claim **1** further comprising at least one component connected to one of the first and second structures.

5. The system as set forth in claim **1** further comprising a housing, the first and second structures located in at least a portion of the housing.

6. A method for making an electrostatic interaction system, the method comprising:

providing a first structure comprising at least a first pair of insulating layers with a first interface located at a junction between the first pair of insulating layers and with first fixed, monopole, electrostatic charges are stored at the first interface; and

providing a second structure comprising at least a second pair of insulating layers with a second interface located at a junction between the second pair of insulating layers and with second fixed, monopole, electrostatic charges are stored at the second interface;

wherein a polarity of the first and second fixed electrostatic charges determines a positional relationship of the first structure to the second structure.

7. The method as set forth in claim **6** wherein the polarity of the first and second fixed electrostatic charges is the same and holds the first and second structures in a spaced apart positional relationship with each other.

8. The method as set forth in claim **6** wherein the polarity of the first and second fixed electrostatic charges is opposite and attracts the first and second structures together.

9. The method as set forth in claim **6** further comprising providing at least a first component which is connected to one of the first and second structures.

10. The method as set forth in claim **6** further comprising providing a housing, the first and second structures located in at least a portion of the housing.

11. A method for making an electrostatic interaction system, the method comprising:

providing a first structure having a first fixed electrostatic charge; and

providing a second structure having a second fixed electrostatic charge, wherein a polarity of the first and second fixed electrostatic charges determines a positional relationship of the first structure to the second structure;

providing at least a first component which is connected to one of the first and second structures;

wherein the providing the first structure further comprises:

depositing a first insulating layer on the first component, at least a portion of the first component is made of a conductive material;

depositing at least a second insulating layer on the first insulating layer, a first interface is located at a junction between the first and second insulating layers; and

depositing a sacrificial layer on the second insulating layer, at least a portion of the sacrificial layer is made of a conductive material.

12. The method as set forth in claim **11** further comprising:

depositing a third insulating layer on the sacrificial layer; and

depositing a fourth insulating layer on the third insulating layer, a second interface is located at a junction between the third and fourth insulating layers.

13. The method as set forth in claim **12** further comprising connecting a second component to the fourth insulating material, at least a portion of the second component made of a conductive material.

14. The method as set forth in claim 13 further comprising:

applying a first electrical bias between the sacrificial layer and the first component to inject the first fixed electrostatic charge; and

applying a second electrical bias between the sacrificial layer and the second component to inject the second fixed electrostatic charge.

15. The method as set forth in claim 14 further comprising removing the sacrificial layer.

16. The method as set forth in claim 14 wherein a polarity of the first and second electrical biases is the same.

17. The method as set forth in claim 14 wherein a polarity of the first and second electrical biases is opposite.

18. An electrostatic levitation system comprising:

a first structure comprising at least a first pair of insulating layers with a first interface located at a junction between the first pair of insulating layers and with first fixed, monopole, electrostatic charges are stored at the first interface; and

a second structure comprising at least a second pair of insulating layers with a second interface located at a junction between the second pair of insulating layers and with second fixed, monopole, electrostatic charges are stored at the second interface;

wherein a polarity of the first and second fixed electrostatic charges is the same and holds the first and second structures in a spaced apart positional relationship.

19. The system as set forth in claim 18 further comprising at least one component connected to one of the first and second structures.

20. The system as set forth in claim 18 further comprising a housing, the first and second structures located in at least a portion of the housing.

21. An electrostatic attraction system comprising:

a first structure comprising at least a first pair of insulating layers with a first interface located at a junction between the first pair of insulating layers and with first fixed, monopole, electrostatic charges are stored at the first interface; and

a second structure comprising at least a second pair of insulating layers with a second interface located at a junction between the second pair of insulating layers and with second fixed, monopole, electrostatic charges are stored at the second interface;

wherein a polarity of the first and second fixed electrostatic charges is opposite which attracts and holds the first and second structures together.

22. The system as set forth in claim 21 further comprising at least one component connected to one of the first and second structures.

23. The system as set forth in claim 21 further comprising a housing, at least one of the first and second structures located in at least a portion of the housing.

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