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(54) **COMPLIANT MICRO DEVICE TRANSFER HEAD WITH INTEGRATED ELECTRODE LEADS**

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(51) **Int. Cl.**
H01L 27/14 (2006.01)

(52) **U.S. Cl.**
USPC **257/414**; 257/415

(58) **Field of Classification Search**
CPC H01H 59/009; H01H 1/0036; H01H 1/20; H01H 35/14; H01H 2037/008; H01H 2059/0018; H01H 2059/0081
USPC 257/414, 415; 438/48
See application file for complete search history.

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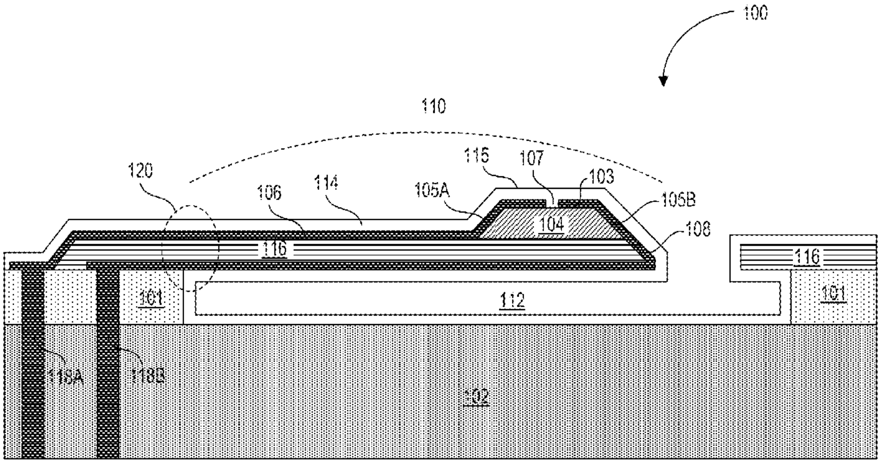
(57) **ABSTRACT**

A compliant micro device transfer head and head array are disclosed. In an embodiment a micro device transfer head includes a spring arm having integrated electrode leads that is deflectable into a space between a base substrate and the spring arm.

21 Claims, 12 Drawing Sheets



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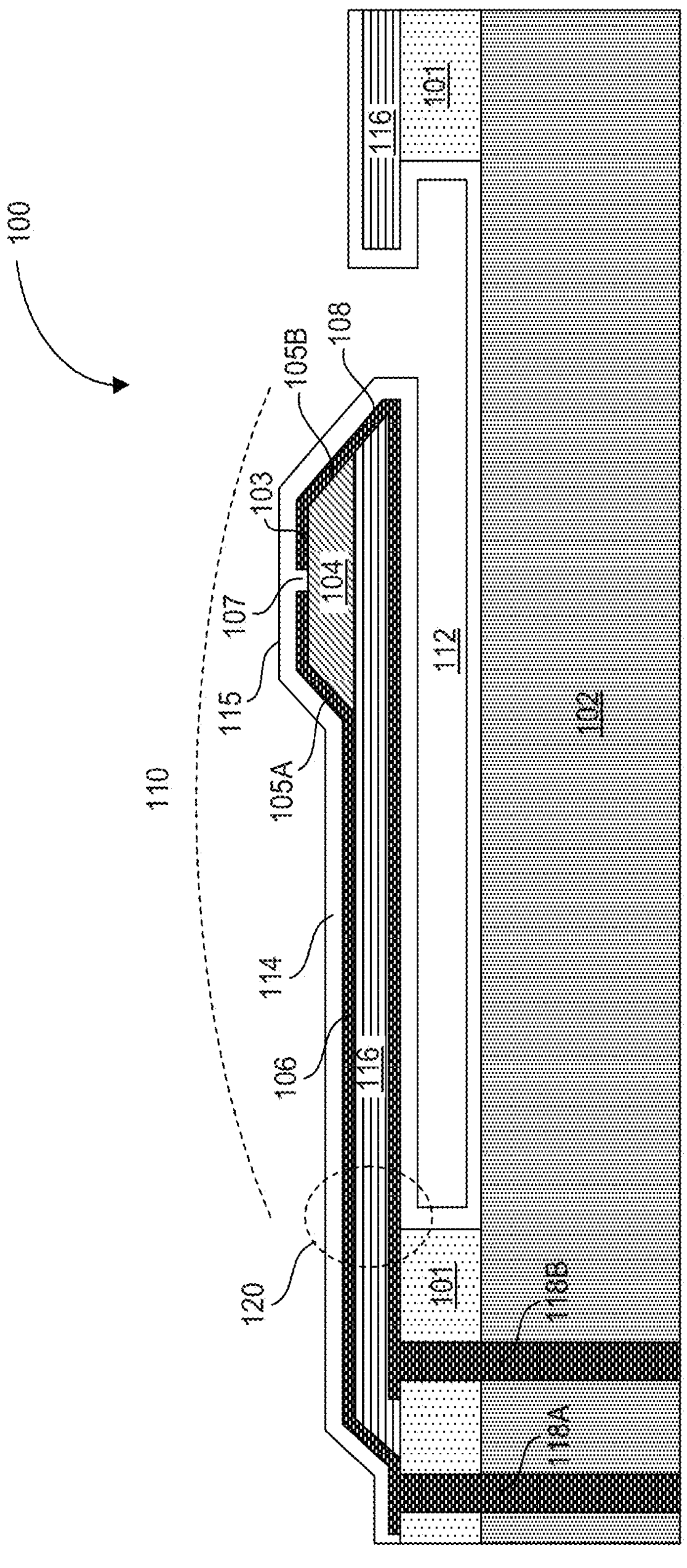
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FIG. 1

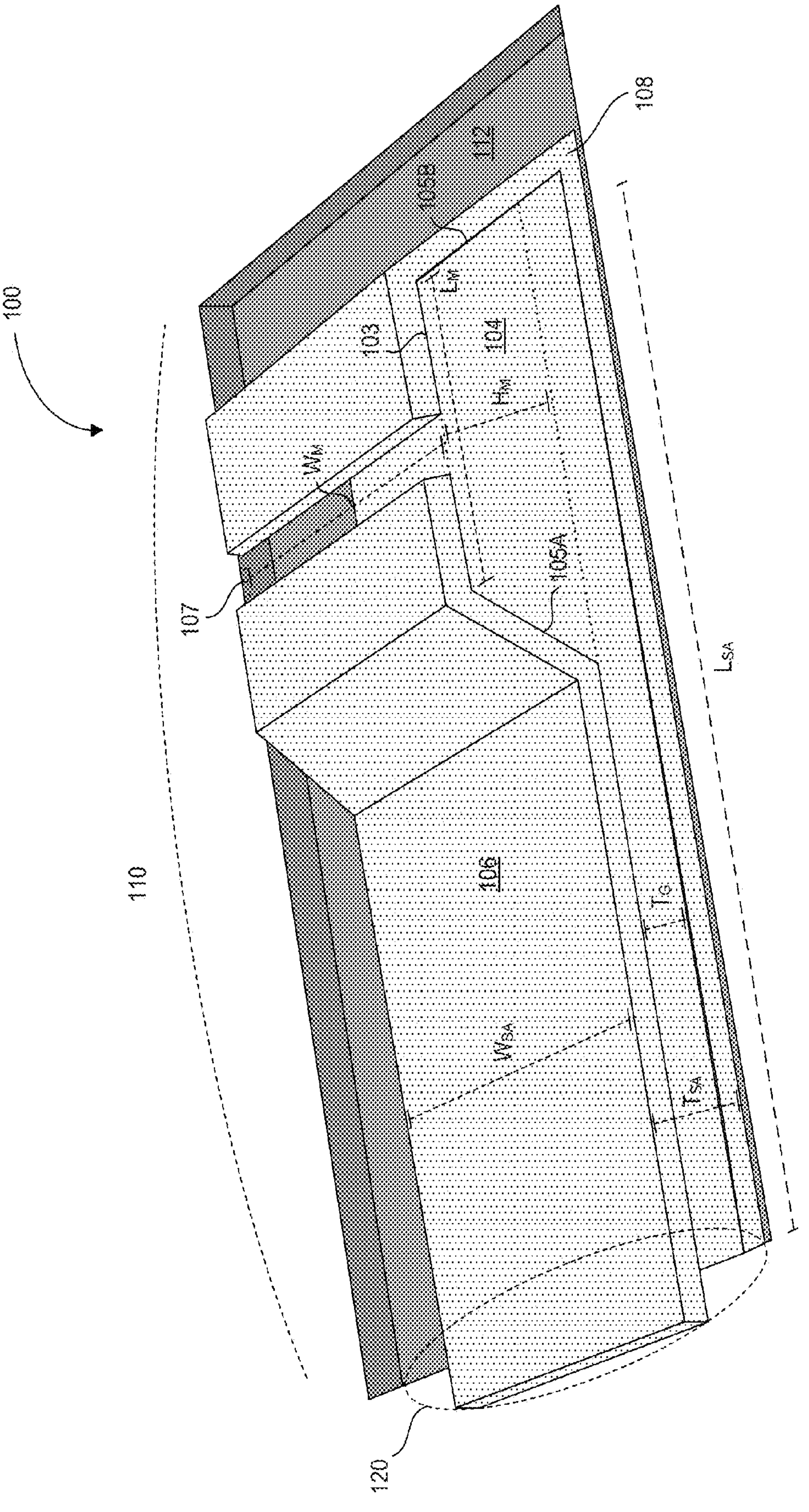
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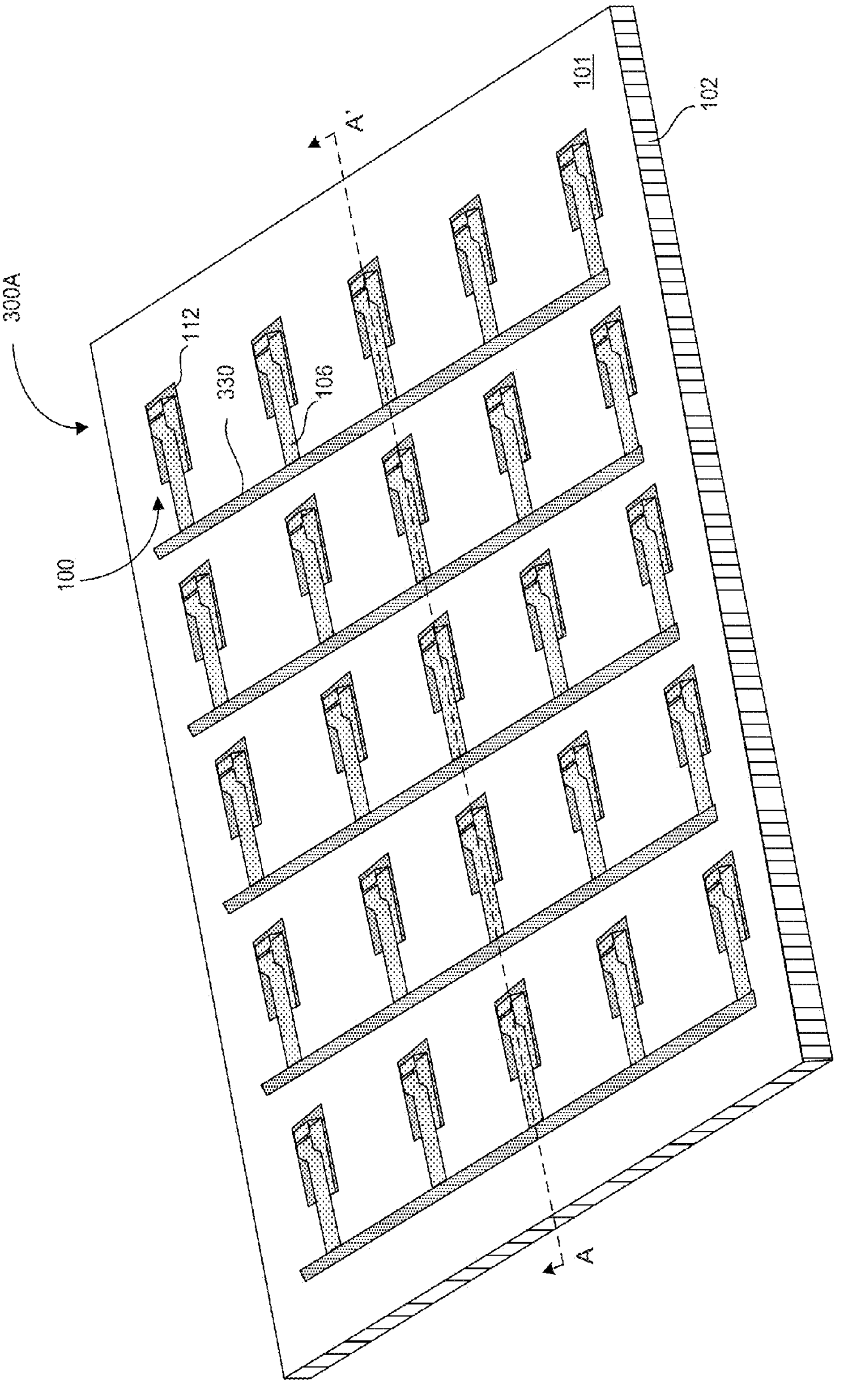
FIG. 2



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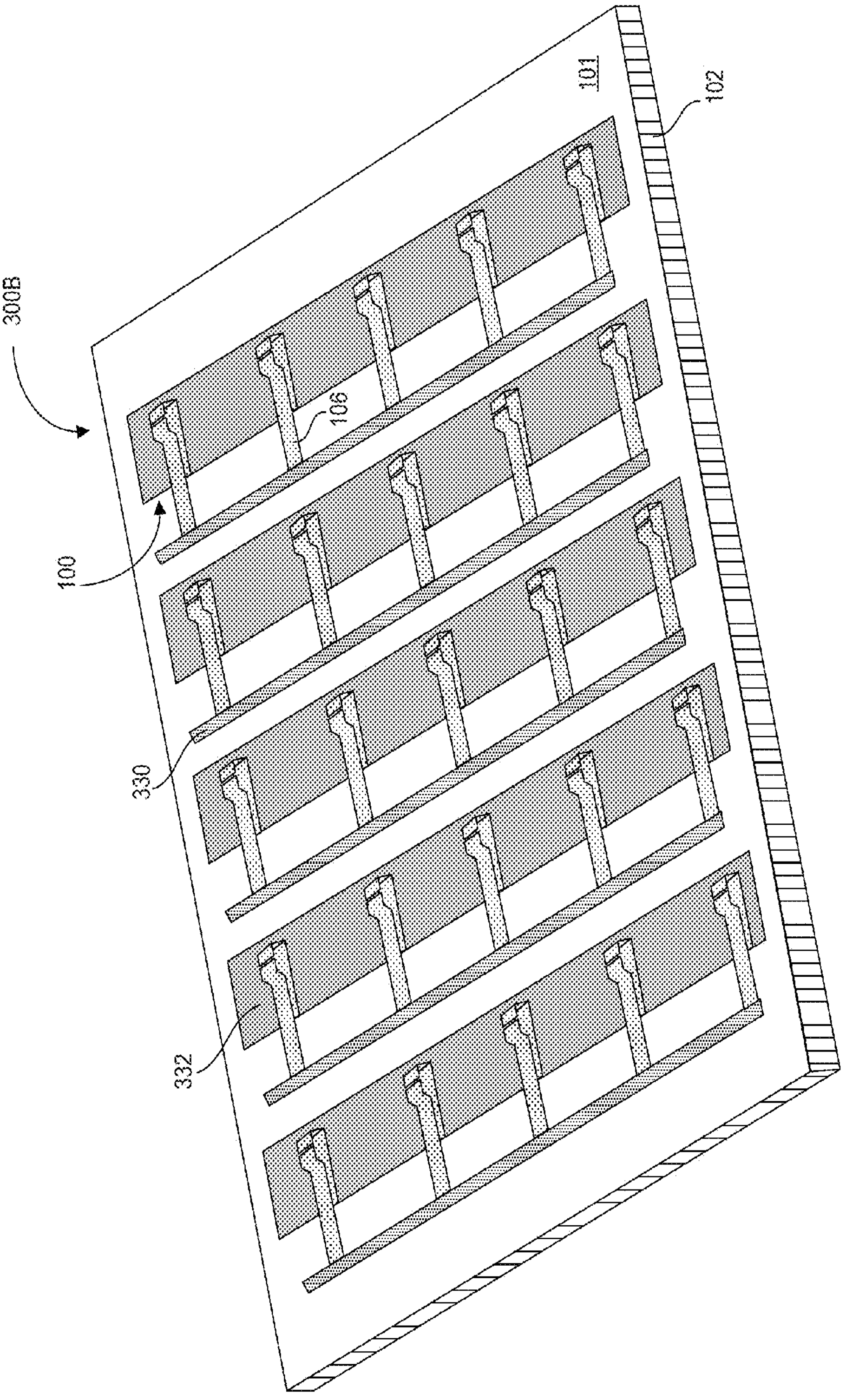


FIG. 3B

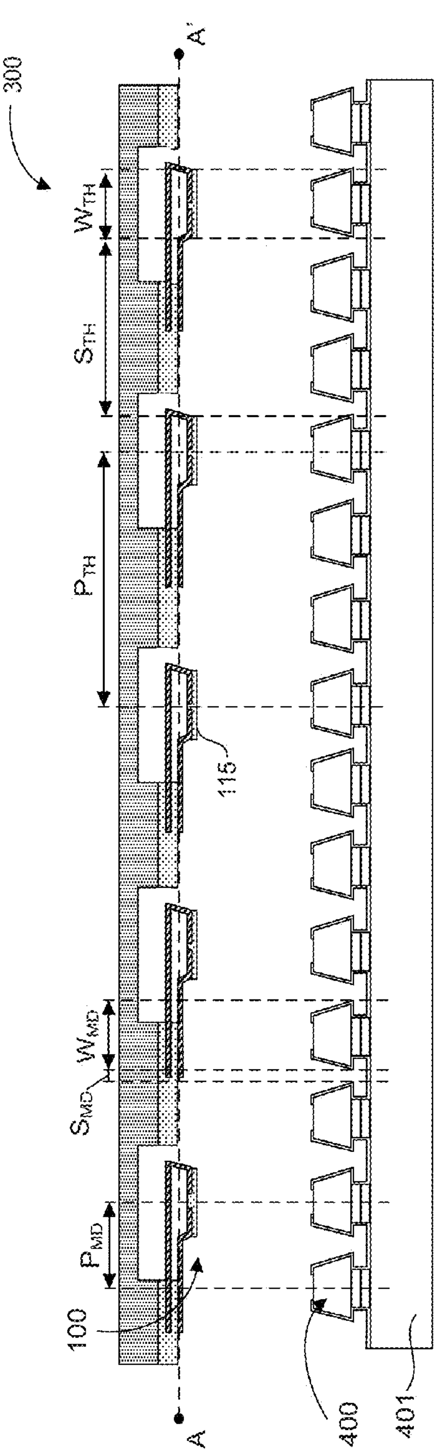


FIG. 4A

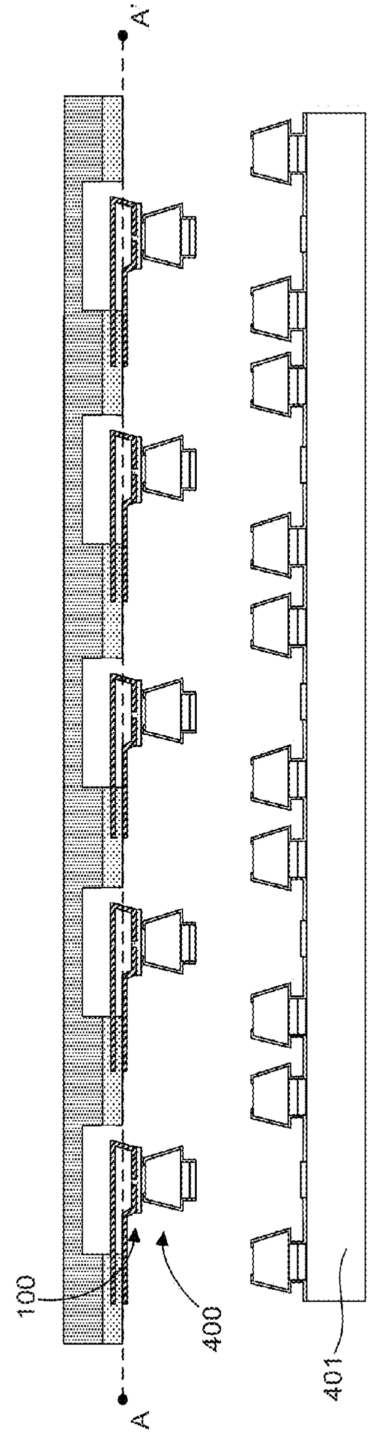
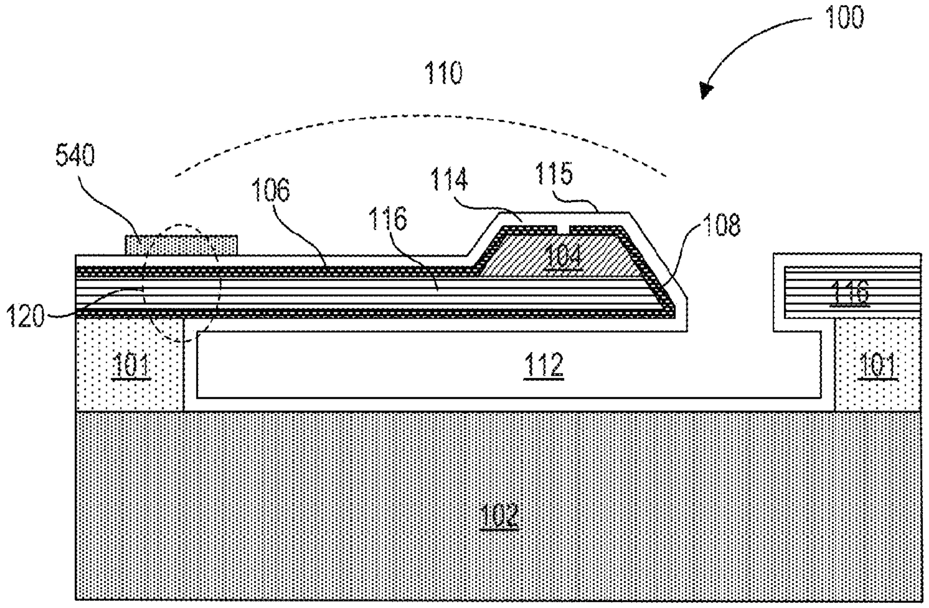


FIG. 4B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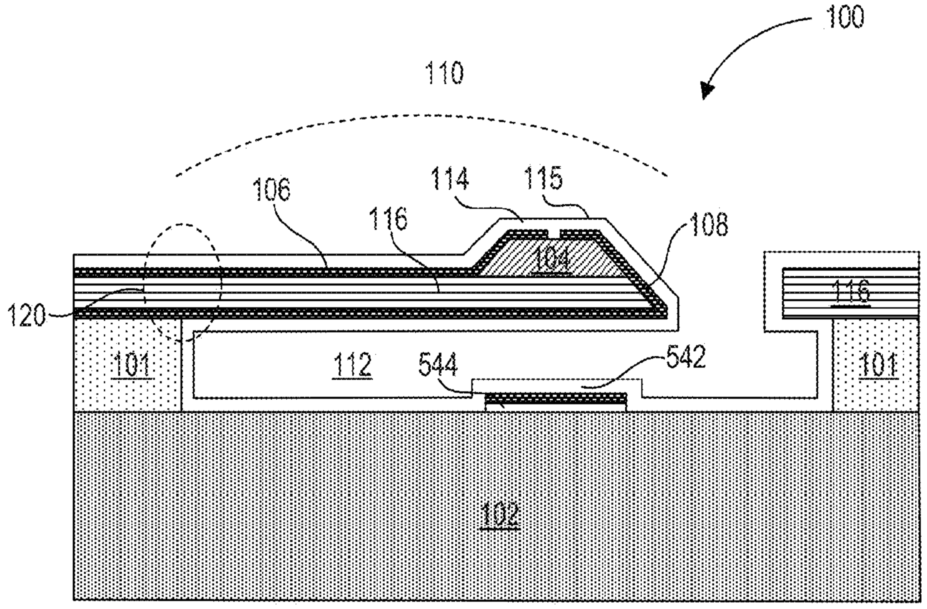
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FIG. 5B

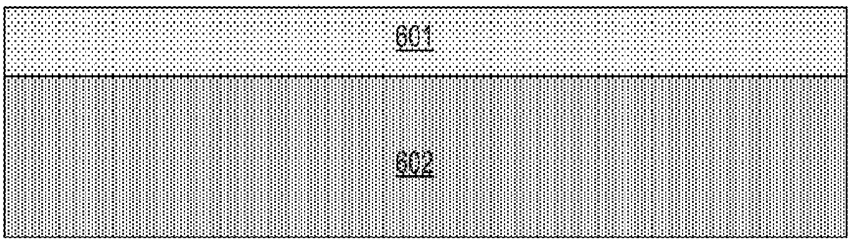


FIG. 6A

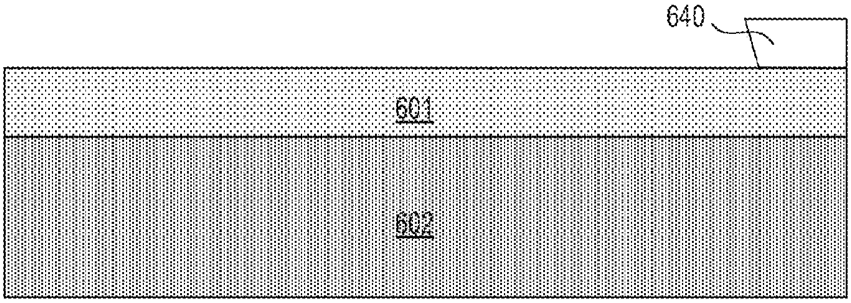


FIG. 6B

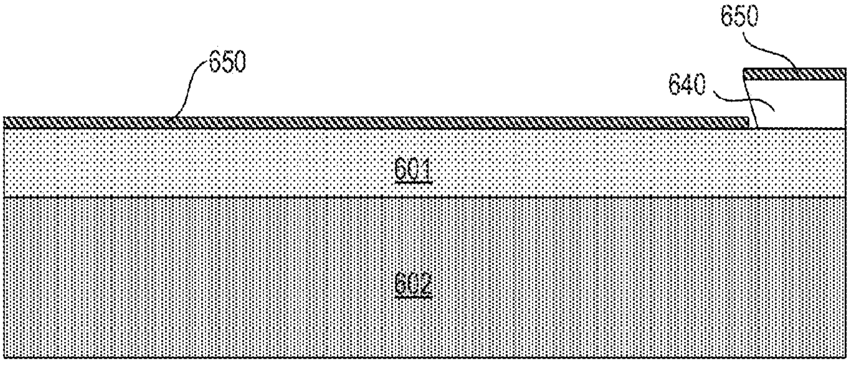


FIG. 6C

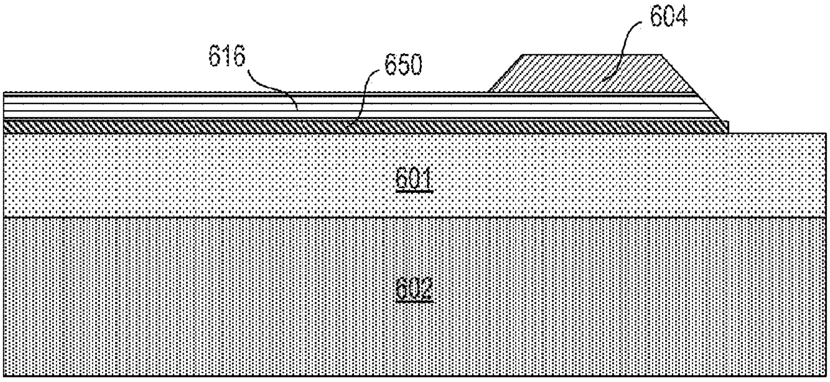


FIG. 6D

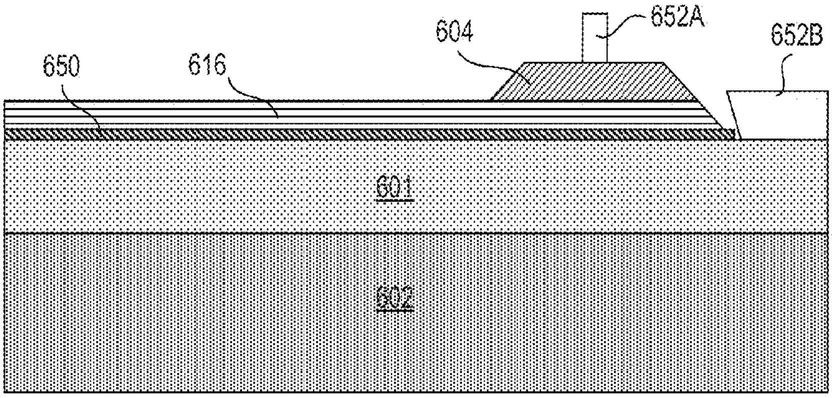


FIG. 6E

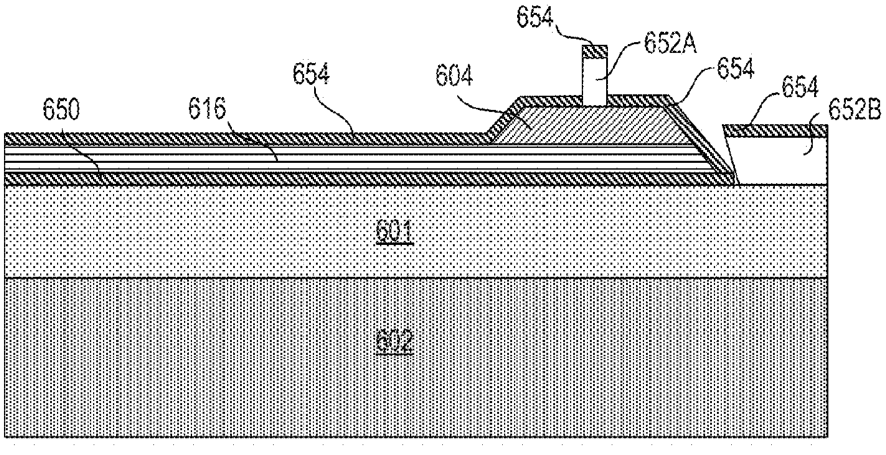


FIG. 6F

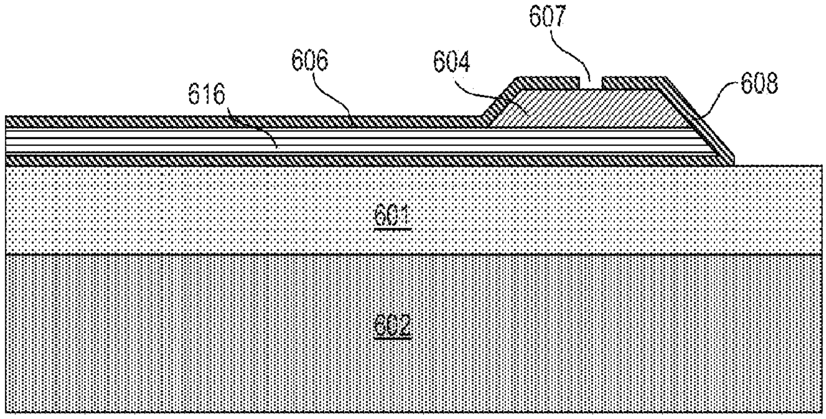


FIG. 6G

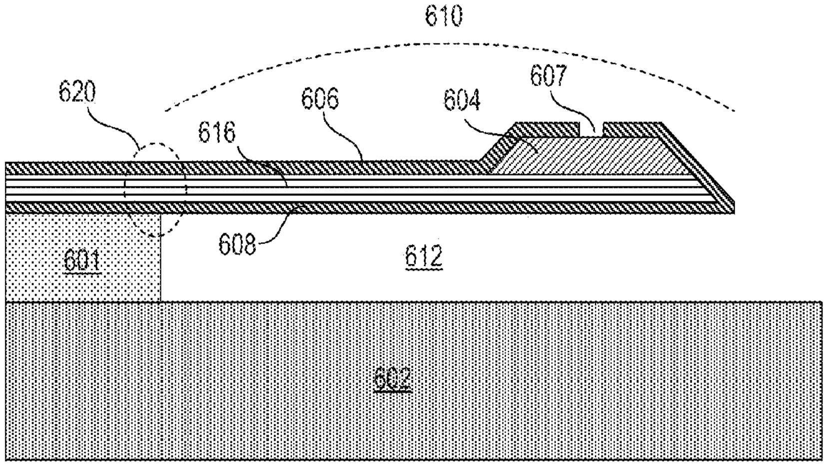


FIG. 6H

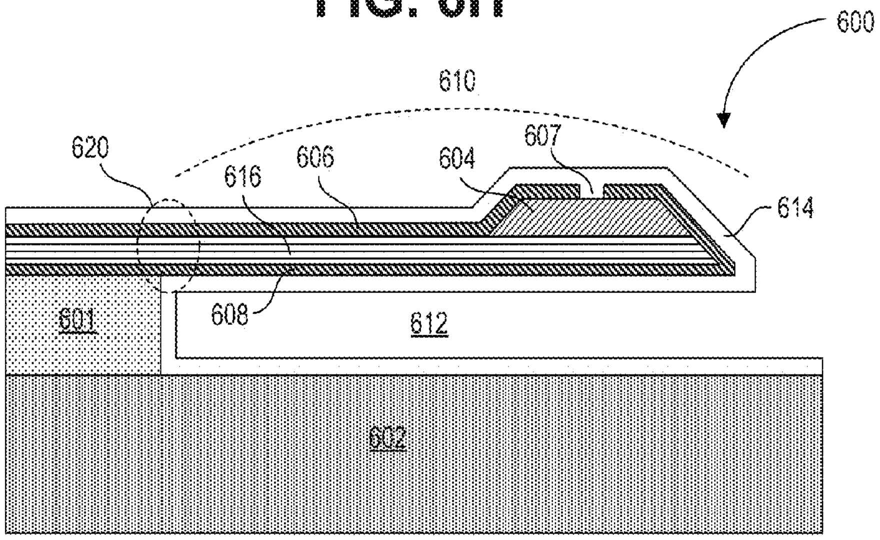


FIG. 6I

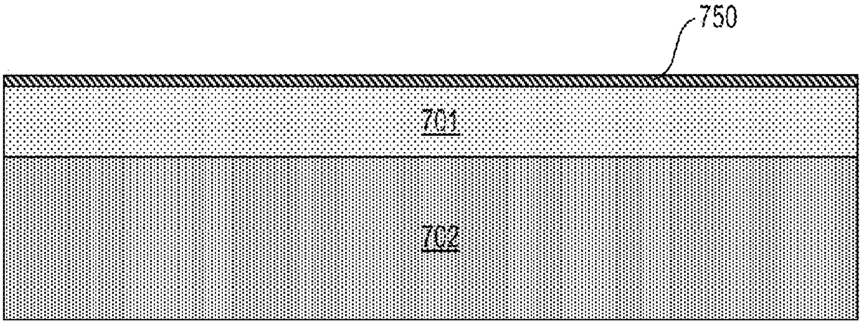


FIG. 7A

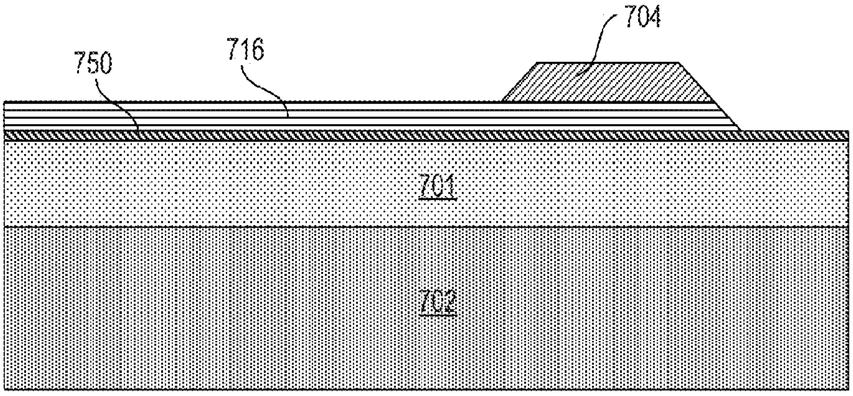


FIG. 7B

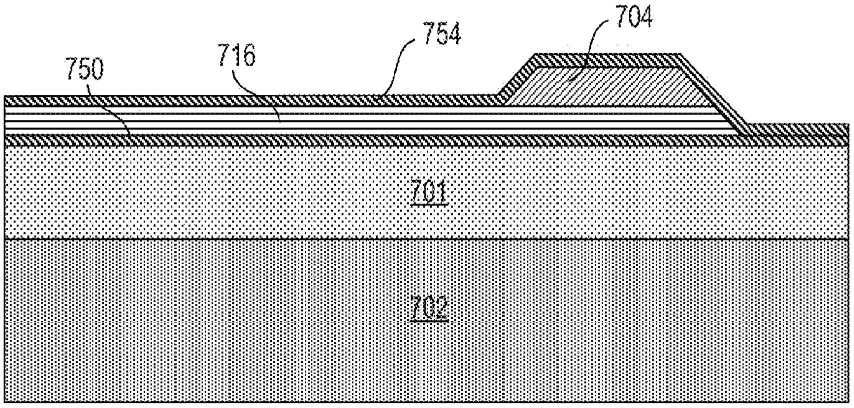


FIG. 7C

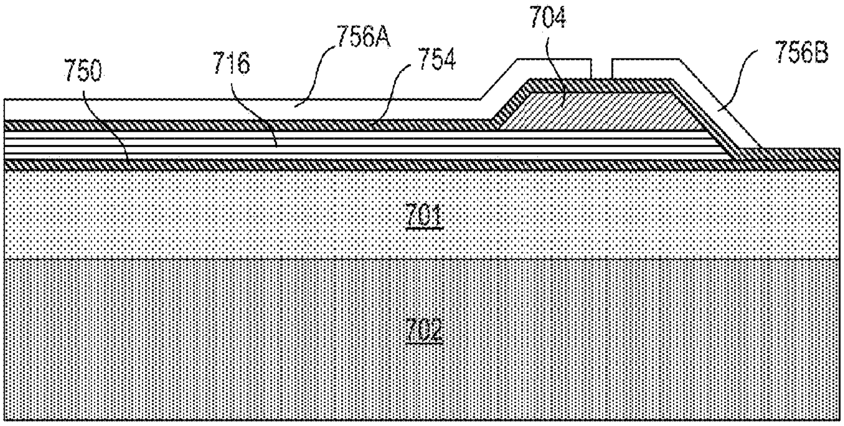


FIG. 7D

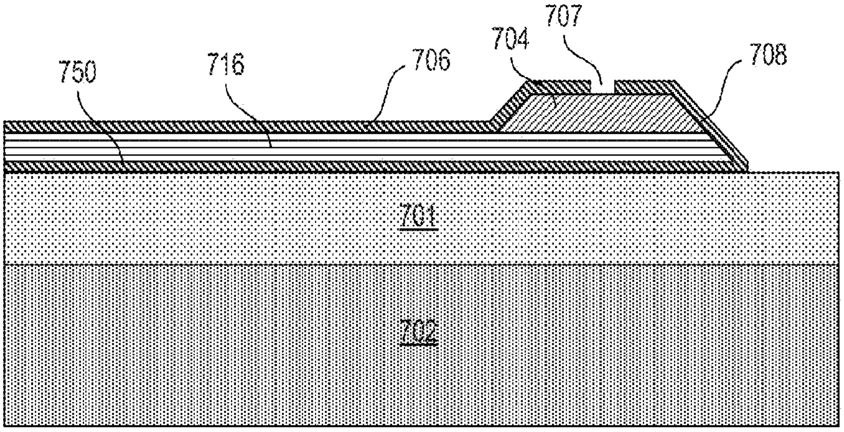
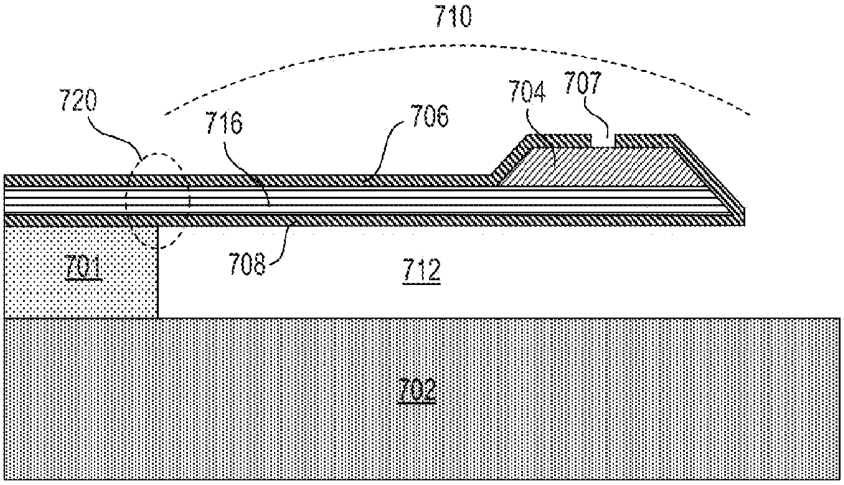


FIG. 7E



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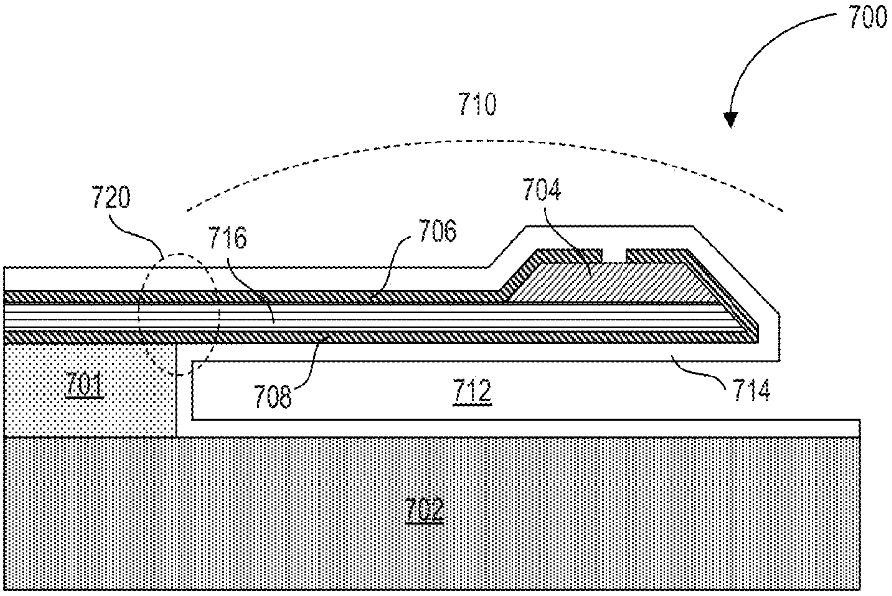

FIG. 7G

COMPLIANT MICRO DEVICE TRANSFER HEAD WITH INTEGRATED ELECTRODE LEADS

BACKGROUND

1. Field

The present invention relates to micro devices. More particularly, embodiments of the present invention relate to a compliant micro device transfer head and transfer head array and a method for forming a compliant micro device transfer head and transfer head array.

2. Background Information

Integration and packaging issues are one of the main obstacles for the commercialization of micro devices such as integration of radio frequency (RF) microelectromechanical systems (MEMS) microswitches, light-emitting diode (LED) integration onto image display systems, and MEMS or quartz-based oscillators.

Traditional technologies for transferring of devices include transfer by wafer bonding from a transfer wafer to a receiving wafer. One such implementation is "direct printing" involving one bonding step of an array of devices from a transfer wafer to a receiving wafer, followed by removal of the transfer wafer. Another such implementation is "transfer printing" involving two bonding/debonding steps. In transfer printing a transfer wafer may pick up an array of devices from a donor wafer, and then bond the array of devices to a receiving wafer, followed by removal of the transfer wafer.

Some printing process variations have been developed where a device can be selectively bonded and debonded during the transfer process. Still, in both traditional and variations of the direct printing and transfer printing technologies, the transfer wafer must be debonded from a device after bonding the device to the receiving wafer. In addition, the entire transfer wafer with the array of devices is involved in the transfer process.

SUMMARY OF THE INVENTION

A compliant micro device transfer head and head array and method of forming a compliant micro device transfer head and head array are disclosed. In an embodiment, the micro device transfer head includes a base substrate, a spring anchor coupled to the base substrate, a spring arm coupled to the spring anchor, and a dielectric layer. In an embodiment, the spring arm includes a mesa structure suspended over the base substrate, a top electrode extending laterally from the spring anchor and over the mesa structure, and a bottom electrode extending laterally from the spring anchor underneath the mesa structure and wrapping around and over the mesa structure. In an embodiment, the dielectric layer covers the top electrode and the bottom electrode over the mesa structure.

The spring arm may further include a template filling an internal volume defined by the top electrode and the bottom electrode, where the template includes the mesa structure. The template may be formed from an insulating material, such as silicon dioxide, nitride, or air. The top electrode and the bottom electrode may be metal. In an embodiment, the dielectric layer covers a top surface of the top electrode. The micro device transfer head may further include a strain sensor formed over the dielectric layer at an interface of the spring anchor and the spring arm. The mesa structure may be suspended over an underlying space. In an embodiment, the spring arm is coupled to the base substrate via a dielectric layer. The underlying space may be a cavity in the dielectric layer. The micro device transfer head may additionally include a sensor electrode on a bottom surface of the underlying space, such that the sensor electrode is vertically aligned with the mesa structure. The micro device transfer head may further include routing in the base substrate, wherein the routing is electrically connected to the top electrode and bottom electrode.

In an embodiment, a method for forming a transfer head includes forming a dielectric layer over a substrate, forming a first electrode layer over the dielectric layer, forming a template on the first electrode layer, where the template includes a mesa structure, forming a second electrode layer over the template, patterning the second electrode layer and first electrode layer to form a bottom electrode and a top electrode, and removing a portion of the dielectric layer from underneath the bottom electrode to form a spring arm coupled to the substrate by a spring anchor. The spring arm may include the mesa structure, such that the mesa structure is suspended over the substrate, the top electrode extending laterally from the spring anchor and over the mesa structure, and the bottom electrode extending laterally from the spring anchor underneath the mesa structure and wrapping around and over the mesa structure.

In an embodiment, patterning the second electrode layer and first electrode layer includes forming a first negative pattern on the substrate defining a first portion of a bottom electrode, sputtering the first electrode layer over the substrate and the first negative pattern, and removing the first negative pattern along with portions of the first electrode layer formed on the first negative pattern. In an embodiment, patterning the second electrode layer and first electrode layer includes, forming a second negative pattern on the template, wherein the second negative pattern defines the top electrode and a second portion of the bottom electrode, forming the second electrode layer over the template and the second negative pattern, and removing the second negative pattern along with portions of the second electrode layer formed over the second negative pattern. In another embodiment, patterning the second electrode layer and first electrode layer includes forming a pattern to define a first portion of the bottom electrode in the first electrode layer and patterning to remove exposed portions of the first electrode layer to form the first portion of the bottom electrode. In another embodiment, patterning the second electrode layer and first electrode layer includes forming a pattern to define the top electrode and a second portion of the bottom electrode in the second electrode layer and patterning to remove exposed portions of the second electrode layer to form the second portion of the bottom electrode. The template may be formed from an insulating material or from photoresist. The method may further include removing the template. In an embodiment, the method further includes forming a dielectric layer covering the top electrode and the bottom electrode over the mesa structure.

In an embodiment of the invention, a micro device transfer head array includes a base substrate and an array of transfer heads. In an embodiment, each transfer head includes a spring anchor coupled to the base substrate, a spring arm coupled to the spring anchor, and a dielectric layer covering the top electrode and the bottom electrode over the mesa structure. In an embodiment, the spring arm includes a mesa structure suspended over the base substrate, a top electrode extending laterally from the spring anchor and over the mesa structure, and a bottom electrode extending laterally from the spring anchor underneath the mesa structure and wrapping around and over the mesa structure. The micro device transfer head array may further include routing in the base substrate, wherein the routing is electrically connected to the top electrode and bottom electrode. The micro device transfer head array may further include a conductive ground plane formed over the dielectric layer and surrounding each of the transfer heads.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional side view illustration of a micro device transfer head in accordance with an embodiment of the invention.

FIG. **2** is an isometric illustration of a micro device transfer head in accordance with an embodiment of the invention.

FIGS. **3**A-**3**B are isometric illustrations of a micro device transfer head array in accordance with an embodiment of the invention.

FIGS. **4**A-**4**B are cross-sectional side view illustrations of an array of micro device transfer heads picking up an array of micro LED devices in accordance with an embodiment of the invention.

FIGS. **5**A-**5**B are cross-sectional side view illustrations of sensor components of a micro device transfer head in accordance with an embodiment of the invention.

FIGS. **6**A-**6**I are cross-sectional side view illustrations of a method for forming a micro device transfer head in accordance with an embodiment of the invention.

FIGS. **7**A-**7**G are cross-sectional side view illustrations of sensor components of a cantilever micro device transfer head in accordance with an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the present invention describe a compliant micro device transfer head and head array, and a method of formation. In various embodiments, description is made with reference to figures. However, certain embodiments may be practiced without one or more of these specific details, or in combination with other known methods and configurations. In the following description, numerous specific details are set forth, such as specific configurations, dimensions and processes, etc., in order to provide a thorough understanding of the present invention. In other instances, well-known semiconductor processes and manufacturing techniques have not been described in particular detail in order to not unnecessarily obscure the present invention. Reference throughout this specification to "one embodiment," "an embodiment" or the like means that a particular feature, structure, configuration, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. Thus, the appearances of the phrase "in one embodiment," "an embodiment" or the like in various places throughout this specification are not necessarily referring to the same embodiment of the invention. Furthermore, the particular features, structures, configurations, or characteristics may be combined in any suitable manner in one or more embodiments.

The terms "over", "to", "between" and "on" as used herein may refer to a relative position of one layer with respect to other layers. One layer "over" or "on" another layer or bonded "to" another layer may be directly in contact with the other layer or may have one or more intervening layers. One layer "between" layers may be directly in contact with the layers or may have one or more intervening layers.

The terms "micro" device or "micro" LED structure as used herein may refer to the descriptive size of certain devices or structures in accordance with embodiments of the invention. As used herein, the terms "micro" devices or structures are meant to refer to the scale of 1 to 100 μm. However, it is to be appreciated that embodiments of the present invention are not necessarily so limited, and that certain aspects of the embodiments may be applicable to larger, and possibly smaller size scales. In an embodiment, a single micro device in an array of micro devices, and a single electrostatic transfer head in an array of electrostatic transfer heads both have a maximum dimension, for example length or width, of 1 to 100 μm. In an embodiment, the top surface of the transfer head has a maximum dimension of 3 to 10 μm. In an embodiment a pitch of an array of micro devices, and a corresponding array of electrostatic transfer heads is (1 to 100 μm) by (1 to 100 μm), for example a 10 μm by 10 μm pitch or 5 μm by 5 μm pitch.

In one aspect, embodiments of the invention describe an array of compliant transfer heads that may be used for mass transfer of an array of pre-fabricated micro devices. For example, the pre-fabricated micro devices may have a specific functionality such as, but not limited to, an LED for light-emission, silicon IC for logic and memory, and gallium arsenide (GaAs) circuits for radio frequency (RF) communications. In some embodiments, arrays of micro LED devices, which are poised for pick up, are described as having a 10 μm by 10 μm pitch, or 5 μm by 5 μm pitch. At these densities a 6 inch substrate, for example, can accommodate approximately 165 million micro LED devices with a 10 μm by 10 μm pitch, or approximately 660 million micro LED devices with a 5 μm by 5 μm pitch. A transfer tool including an array of transfer heads matching an integer multiple of the pitch of the corresponding array of micro LED devices can be used to pick up and transfer the array of micro LED devices to a receiving substrate. For example, the micro device may be contacted with the transfer head and a voltage applied to a pair of electrodes in the transfer head to create a grip pressure on the micro device. The transfer head picks up the micro device and then releases the micro device onto a receiving substrate. In this manner, it is possible to integrate and assemble micro LED devices into heterogeneously integrated systems, including substrates of any size ranging from micro displays to large area displays, and at high transfer rates. For example, a 1 cm by 1 cm array of micro device transfer heads can pick up and transfer more than 100,000 micro devices, with larger arrays of micro device transfer heads being capable of transferring more micro devices. Each compliant transfer head in the array of compliant transfer heads may also be independently controllable, which enables selective pick up and release of the micro devices.

In another aspect, the spring arm can compensate for variations in height of the micro devices or for particulate contamination on top of a micro device. For example, one end of the spring arm is anchored to the substrate by a spring anchor, while the opposing end of the spring arm is suspended over the substrate. A spring arm associated with a taller or contaminated micro device may deflect towards the substrate more than a spring member associated with a shorter micro device in an array of micro devices, so that each compliant transfer head may make contact with each micro device, ensuring that each intended micro device is picked up.

In another aspect, the electrode components of the transfer head are an integral part of the compliant transfer head structure. For example, a top and bottom electrode function both structurally, to enable the compliant spring effect of the spring arm portion of the transfer head, and electrically, to generate the electrostatic grip pressure that picks up the micro device. In an embodiment, the electrodes solely determine the structural and deflection characteristics of the spring arm. In another embodiment, the volume between the top electrode and bottom electrode is filled with a gap material that also contributes to the structural and deflection characteristics of the spring arm.

In an embodiment, the spring arm includes two electrodes: a top electrode extending from the spring anchor and over a mesa structure, and a bottom electrode extending from the spring anchor, underneath the mesa structure, and wrapping around and over the mesa structure. In this manner, a bipolar electrode is formed on the top surface of the mesa structure. The top surface of the mesa structure is sized to correspond to the area of the top surface of the micro devices to be picked up. A dielectric layer is formed over the top and bottom electrodes over the mesa structure to provide a suitable surface for contacting a micro device with the desired grip pressure.

Each transfer head may additionally include a sensor, which can monitor an amount of deflection of the spring arm when the transfer head is brought into contact with a micro device, enabling detection of whether contact has been made with a micro device, whether a micro device is irregularly shaped or contaminated, or whether a micro device is attached to the transfer head and has successfully been picked up.

In another aspect, a method for forming the transfer head includes forming electrodes over a template comprising a mesa structure. In an embodiment, the template is retained as part of the transfer head. In another embodiment, the template is removed, resulting in a hollow transfer head defined by the top and bottom electrodes. The electrodes can be patterned, for example, by a negative liftoff method, where the metal electrode material is formed over a photoresist pattern, which is then removed to leave metal where no photoresist was formed. The electrodes can alternatively be patterned formed by deposition and patterning, for example, by conventional lithography.

Referring now to FIG. **1**, a cross-sectional side view of a compliant transfer head **100** is illustrated in accordance with an embodiment of the invention. The transfer head **100** includes a spring arm **110** coupled to dielectric layer **101** on base substrate **102** via spring anchor **120**. Spring arm **110** includes a top electrode **106**, a bottom electrode **108**, and a mesa structure **104** having a top surface **103** and tapered sidewalls **105**A/**105**B. Top electrode **106** extends laterally from the spring anchor **120** and over the top surface **103** of a mesa structure **104**. Bottom electrode **108** extends laterally from the spring anchor **120**, underneath the mesa structure **104** and wraps around and over the top surface **103** of mesa structure **104**. A dielectric layer **114** covers the top electrode **106** and bottom electrode **108** on the top surface **103** of mesa structure **104**.

Base substrate **102** may be formed from a variety of materials such as silicon, ceramics and polymers that are capable of providing structural support. Base substrate **102** may have a conductivity between 10^3 and 10^{18} ohm-cm. In an embodiment, base substrate **102** has a dielectric layer **101** disposed thereon. In an embodiment, dielectric layer **101** electrically isolates bottom electrode **108** from a semiconductor substrate **102**. Dielectric layer **101** may be any appropriate dielectric material, for example silicon dioxide or silicon nitride. In an embodiment, the thickness of dielectric layer **101** is selected to correspond to the desired depth of space **112**. For example, the thickness of dielectric layer **101** may be from 0.5 μm to 2 μm. In an embodiment, space **112** is a cavity in dielectric layer **101**. In another embodiment, space **112** is a cavity in substrate **102**.

In an embodiment, base substrate **102** and dielectric layer **101** include routing, such as through vias **118**A, **118**B, to connect the micro device transfer head **100** to the working electronics of an electrostatic gripper assembly. In an embodiment, a through via **118**A connects to top electrode **106** and a through via **118**B connects bottom electrode **108**, as shown in FIG. **1**. It is to be understood that base substrate **102** and dielectric layer **101** may include additional routing beyond what is illustrated in FIG. **1**.

In an embodiment, top electrode **106** and bottom electrode **108** wrap around a template comprising gap material **116** and mesa structure **104**. In an embodiment, gap material **116** extends from spring anchor **120**, separating bottom electrode **108** from top electrode **106**. In an embodiment, the gap material **116** possesses a dielectric strength greater than the applied electric field so as to avoid shorting between top electrode **106** and bottom electrode **108** during operation of the transfer head. As such, gap material **116** may be formed from a variety of materials including photoresist, polyimide, amorphous silicon, polysilicon, or dielectric materials, for example inorganic dielectrics such as silicon dioxide and silicon nitride, or organic dielectrics such as benzocyclobutene (BCB). In an embodiment, gap material **116** is filled with air. The thickness of gap material **116** may depend on a number of factors, such as the dimensions of the electrodes, the amount of deflection of the spring arm, or the voltage applied to the electrodes during a pickup operation. In an embodiment, gap material **116** is from 2 μm to 5 μm thick. In accordance with the illustrated embodiment, gap material **116** covers the surface of dielectric layer **101** that surrounds space **112**, such as that shown adjacent to the suspended end of spring arm **110**.

Mesa structure **104** is suspended above space **112**, opposite the spring anchor **120** on spring arm **110**, according to an embodiment of the invention. In an embodiment, mesa structure **104** protrudes away from base substrate **102**. Mesa structure **104** has top surface **103**, which may be planar, and tapered sidewalls **105**A/**105**B. In an embodiment, sidewalls **105**A/**105**B may be tapered up to 10 degrees, for example. Tapering the sidewalls **105**A/**105**B may be beneficial in forming the electrodes **106**/**108** as described further below. Mesa structure **104** may be formed from the same or different material than gap material **116**. In an embodiment, mesa structure **104** is a patterned oxide layer, such as silicon dioxide. In another embodiment, mesa structure **104** is filled with air.

The dimensions of mesa structure **104** may depend upon the specific dimensions of the micro devices to be picked up, as well as the thickness of any layers formed over the mesa structure. The specific dimensions of mesa structure **104** will be discussed below with reference to FIG. **2**. In an embodiment, the height, width, and planarity of an array of mesa structures on a base substrate are uniform across the base substrate so that each micro device transfer head is capable of making contact with each corresponding micro device during the pick up operation. In an embodiment, the surface area of the top surface **115** of each micro device transfer head **100** is slightly larger, approximately the same, or less than the surface area of the top surface of the each micro device in the corresponding micro device array so that a transfer head does not inadvertently make contact with a micro device adjacent to the intended corresponding micro device during the pick up operation. Since additional layers may be formed over the mesa structure **104** (e.g. electrodes **106**/**108**, and dielectric layer **114**) the surface area of the mesa structure may account for the thickness of the overlying layers so that the surface area of the top surface **115** of each micro device transfer head is slightly larger, approximately the same, or less than the surface area of the top surface of the each micro device in the corresponding micro device array.

In an embodiment, top electrode **106** covers a portion of top surface **103** of mesa structure **104**, runs down sidewall **105**A of the mesa structure, and along the top surface of gap material **116** to spring anchor **120**. Top electrode **106** may then connect to conductive routing, such as a through via **118**A, in dielectric layer **101** and substrate **102**. In an embodiment, bottom electrode **108** covers a portion of top surface **103** of mesa structure **104** and wraps around sidewall **105**B, running underneath mesa structure **104** and gap material **116** to spring anchor **120**. Bottom electrode **108** may also connect to conductive routing in dielectric layer **101** and substrate **102**, for example a through via **118**B. In an embodiment, the portions of top electrode **106** and bottom electrode **108** formed over the top surface **103** of mesa structure **104** are separated by a gap **107**. In accordance with an embodiment, electrodes **106**/**108** cover the maximum amount of surface area of the top surface **103** of the mesa structure **104** as possible while remaining within patterning tolerances. Minimizing the amount of free space increases the capacitance and resultant grip pressure that can be achieved by the micro device transfer head.

The material from which electrodes **106**/**108** are formed is selected to have a suitable elastic modulus to meet the structural and deflection requirements of the spring arm and also a suitable electrical conductivity to meet the electrical requirements of the electrostatic grip function of the transfer head, according to an embodiment of the invention. A variety of conductive materials including metals, metal alloys, refractory metals, and refractory metal alloys may be employed to form top electrode **106** and bottom electrode **108**. In an embodiment, electrodes **106**/**108** include a high melting temperature metal such as platinum or a refractory metal or refractory metal alloy. For example, an electrode may include platinum, titanium, vanadium, chromium, zirconium, niobium, molybdenum, ruthenium, rhodium, hafnium, tantalum, tungsten, rhenium, osmium, iridium and alloys thereof. Refractory metals and refractory metal alloys generally exhibit higher resistance to heat and wear than other metals. Top electrode **106** and bottom electrode **108** may be from 100 to 1000 nm thick. In an embodiment, electrodes **106**/**108** are each an approximately 500 Å (0.05 μm) thick layer of titanium tungsten (TiW) refractory metal alloy.

In an embodiment, dielectric layer **114** is formed on the surfaces of spring arm **110** and underlying space **112**. In an embodiment, dielectric layer **114** covers the exposed surfaces of the top electrode **106** and bottom electrode **108** forming the spring arm **110**. The dielectric layer **114** may also cover other exposed layers on transfer head **100**, dielectric layer **101**, substrate **102**, and gap material **116**. In an embodiment, the dielectric layer **114** has a suitable thickness and dielectric constant for achieving the required grip pressure of the micro device transfer head **100**, and sufficient dielectric strength to not break down at the operating voltage. The dielectric layer **114** may be a single layer or multiple layers. In an embodiment, the dielectric layer **114** is 0.5 μm to 2.0 μm thick, though the thickness may be more or less depending upon the specific topography of the transfer head **100** and underlying mesa structure **104**. Suitable dielectric materials may include, but are not limited to, aluminum oxide (Al_2O_3) tantalum oxide (Ta_2O_5), halfnium (HfO_2), and silicon dioxide (SiO_2). In accordance with embodiments of the invention, the dielectric layer **114** possesses a dielectric strength greater than the applied electric field so as to avoid shorting of the transfer head during operation. The dielectric layer **113** can be deposited by a variety of suitable techniques such as chemical vapor deposition (CVD), atomic layer deposition (ALD) and physical vapor deposition (PVD) such as sputtering. The dielectric layer **114** may additionally be annealed following deposition. In one embodiment, the dielectric layer **114** possesses a dielectric strength of at least 400 V/μm. Such a high dielectric strength can allow for the use of a thinner dielectric layer. Techniques such as ALD can be utilized to deposit uniform, conformal, dense, and/or pin-hole free dielectric layers with good dielectric strength. Multiple layers can also be utilized to achieve such a pin-hole free dielectric layer. Multiple layers of different dielectric materials may also be utilized to form dielectric layer **114**. In an embodiment, the underlying electrodes **106**/**108** include platinum or a refractory metal or refractory metal alloy possessing a melting temperature above the deposition temperature of the dielectric layer material(s) so as to not be a limiting factor in selecting the deposition temperature of the dielectric layer **114**.

The materials and dimensions of the components of transfer head **100** are selected to enable deflection of spring arm **110** into space **112** over the working temperature range of the micro device transfer process. In an embodiment, the components and dimensions of spring arm **110** are selected to enable deflection of approximately 0.5 μm into space **112** when the top surface of transfer head **100** is subjected to up to 10 atm of pressure at operating temperatures up to 350° C.

Referring now to FIG. **2**, an isometric view of a compliant transfer head **100** is illustrated in accordance with an embodiment of the invention. Certain features and components of the transfer head **100** that are illustrated in FIG. **1** are omitted in FIG. **2** in order to more clearly illustrate other features. For example, the dielectric layer covering electrodes **106**/**108** has been omitted.

Spring arm **110** has a thickness T_{SA}, width W_{SA}, and length L_{SA}, according to an embodiment of the invention. The thickness T_{SA} of spring arm **110** depends on the elastic moduli and dimensions of the materials and components from which it is formed. In an embodiment, spring arm **110** has a thickness T_{SA} of up to 8 μm. In an embodiment, the width W_{SA} of spring arm **110** is sufficient to accommodate additional spring arm and transfer head elements, such as electrodes **106**/**108** and mesa structure **104**. For example, where a micro device is 3 μm to 5 μm wide, the width W_{SA} of the spring arm may also be 3 μm to 5 μm, and where a micro device is 8 μm to 10 μm wide, the width W_{SA} of the spring arm may also be 8 μm to 10 μm. The length L_{SA} of spring arm **110** is long enough to enable spring arm **110** to deflect into space **112**, but less than the pitch of the transfer heads **100** in the transfer head array. In an embodiment, the length L_{SA} of spring arm **110** is 10× longer than the width W_{SA}. In an embodiment, the length L_{SA} of spring arm **124** may be from 10 μm to 100 μm.

Gap material **116** extends laterally from the spring anchor **120** between bottom electrode **108** and top electrode **106**, according to an embodiment of the invention. In an embodiment, the thickness T_G of gap material **116** depends on a number of factors, such as the dimensions of the electrodes, the desired amount of deflection of the spring arm, the voltage applied to the electrodes during a pickup operation. In an embodiment, the thickness T_G of gap material **116** is from 2 μm to 5 μm.

Mesa structure **104** generates a profile that protrudes away from the surface of gap material **116** so as to provide a localized contact point to pick up a specific micro device during a pick up operation, according to an embodiment of the invention. The height of mesa structure **104** elevates the surface of the transfer head that will contact the micro device to be picked up, enabling targeted pickup of a corresponding micro device in a micro device array. In an embodiment, mesa structure **104** has a height H_M of approximately 1 μm to 5 μm, or more specifically approximately 2 μm. The surface area dimensions ($L_M \times W_M$) of mesa structure **104** may be sized to correspond to the area of the top surface of the micro device to be picked up. The surface area of the mesa structure may account for the thickness of electrodes **106**/**108** and the dielectric layer (not shown) so that the surface area of the top surface of each micro device transfer head is slightly larger, approximately the same, or less than the surface area of the top surface of the each micro device in the corresponding micro device array. In an exemplary embodiment, the length L_M and width W_M of mesa structure **104** are each from 2 μm to 7 μm in order to achieve a top surface of the transfer head **100** having length and width dimensions that are each from 3 μm to 10 μm.

The electrodes **106**/**108** may cover the maximum amount of the surface area of the top surface **103** of the mesa structure **104** as possible while still preserving gap **107** between top electrode **106** and bottom electrode **108**. The minimum amount of separation distance may be balanced by considerations for maximizing surface area, while avoiding electrical breakdown between the electrodes. For example, gap **107** may be 0.5 μm or less, and the minimum separation distance may be limited by the thickness of the electrodes. It is to be appreciated that the mesa array may have a variety of different pitches, and that embodiments of the invention are not limited to the exemplary 7 μm×7 μm top surface **103** of the mesa structure **104** in a 10 μm pitch.

FIGS. **3A-3B** are isometric view illustrations of an array of **300**A/**300**B of micro device transfer heads **100** with a compliant bipolar electrode as previously described with regard to FIGS. **1-2**. For purposes of clarity, certain elements of the transfer head have not been illustrated, for example, the dielectric layer covering the top surface of each mesa structure. In FIG. **3**A, each transfer head **100** in transfer head array **300**A is deflectable into an underlying space **112**, according to an embodiment of the invention. FIG. **3**B illustrates an embodiment of a transfer head array **300**B where each transfer head **100** is deflectable into underlying trench **332** that extends underneath multiple transfer heads **100**.

Each top electrode **106** of a transfer head **100** is coupled to a bus line **330**, according to an embodiment of the invention. Each bottom electrode **108** may also be coupled to a separate bus line (not illustrated). In an embodiment, bus line **330** is connected to additional routing within the dielectric layer **101** and substrate **102**. It is to be appreciated that additional conductive routing or different routing configurations may be used to control the transfer heads **100**. In an embodiment, a conductive ground plane (not shown) is formed over the dielectric layer **101**, surrounding the array of transfer heads **100** to assist in the prevention of arcing between transfer heads, particularly during the application of high operating voltages.

FIGS. **4A-4B** are cross-sectional side view illustrations of an array of micro device transfer heads, taken along the line A-A' in FIG. **3**, shown picking up an array of micro devices in accordance with an embodiment of the invention. In FIG. **4**A, an array of transfer heads **100** is positioned above an array of micro LED devices **400** on carrier substrate **401**, according to an embodiment. In the particular embodiment illustrated, the pitch P_{TH} of the array of transfer heads **100** is an integer multiple of the pitch P_{MD} of the micro LED devices **400**, with the pitch P_{TH} of the array of transfer heads being the sum of the spacing S_{TH} between the top surfaces **115** of adjacent transfer heads **100** and the width W_{TH} of the top surface **115** of a transfer head **100**. In another embodiment, the pitch P_{TH} of the transfer heads is equal to the pitch P_{MD} of the micro LED devices.

In one embodiment, the array of micro LED devices **400** have a pitch P_{MD} of 10 μm, with each micro LED device having a spacing S_{MD} of 2 μm and a maximum width W_{MD} of 8 μm. In an exemplary embodiment, the top surface of the each micro LED device **400** has a width W_{MD} of approximately 8 μm. In such an exemplary embodiment, the width W_{TH} of the top surface **115** of a corresponding transfer head **100** is approximately 10 μm or smaller so as to avoid making inadvertent contact with an adjacent micro LED device. In another embodiment, the array of micro LED devices **400** may have a pitch P_{MD} of 5 μm, with each micro LED device having a spacing S_{MD} of 2 μm and a maximum width W_{MD} of 3 μm. In an exemplary embodiment, the top surface of the each micro LED device **400** has a W_{MD} width of approximately 3 μm. In such an exemplary embodiment, the width W_{TH} of the top surface **115** of a corresponding transfer head **100** is approximately 3 μm or smaller so as to avoid making inadvertent contact with an adjacent micro LED device **400**. However, embodiments of the invention are not limited to these specific dimensions, and may be any suitable dimension.

FIG. **4**B is a side view illustration of the array of micro device transfer heads picking up a portion of an array of micro LED devices **400** in accordance with an embodiment of the invention. In a particular embodiment illustrated in FIG. **4**B, every transfer head **100** in the array is activated to pick up a micro LED device **400**. In another embodiment, transfer heads **100** may be selectively activated, such that a subset of the array of transfer heads **100** picks up a micro LED device **400**.

The portion of the array of micro devices may then be released onto at least one receiving substrate to complete the transfer process. Thus, the array of micro LED devices can all be released onto a single receiving substrate, or selectively released onto multiple substrates. For example, the receiving substrate may be, but is not limited to, a display substrate, a lighting substrate, a substrate with functional devices such as transistors or ICs, or a substrate with metal redistribution lines.

FIGS. **5A-5B** each illustrate an embodiment of a micro device transfer head incorporating a sensor. Sensors can serve a variety of purposes during operation of the transfer head. For example, where a sensor is used to measure an amount of deflection of the transfer head, this information can be used to determine if (1) contact has been made with a micro device to be picked up, (2) contamination is present on the micro device, or alternatively the micro device has been damaged or deformed, or (3) whether a micro device has been picked up.

FIG. **5**A illustrates a cross sectional side view of a transfer head comprising a strain sensor **540**, according to an embodiment of the invention. In an embodiment, strain sensor **540** is a strain gauge capable of measuring the amount of deflection of spring arm **110** into space **112**. When the top surface **115** of transfer head **100** contacts the surface of a micro device during a pick up operation, it may deflect some amount in response to the contact pressure. By measuring the amount of deflection of a spring arm **110** and comparing it to the amount of deflection known to indicate optimum contact with a micro device surface, strain sensor **540** can indicate whether the top surface **115** of transfer head **100** has contacted the top surface of a micro device in an array and as such is ready to execute a pick up operation. Detection of too little deflection may indicate that a micro device is absent from that position in the array, while detection of too much deflection may indicate separation or incomplete contact between the surface of the micro device and the surface of the transfer head due to either the presence of contamination particles or an otherwise damaged or deformed micro device. In both cases, a voltage may not be applied to the transfer head so as not to attempt to pick up the absent or damaged micro device. In the case where contamination is detected, a cleaning operation may be applied to the transfer head, micro device, or their respective array prior to reattempting the pick up operation.

In another embodiment, strain sensor **540** is capable of measuring a resonant frequency of spring arm **100**. For example, a resonant frequency of spring arm **110** may be measured upon contacting the transfer head on a bare substrate and lifting off of the bare substrate without a micro device. A different resonant frequency of spring arm **110** may be measured upon contacting the transfer head to a micro device and picking up the micro device. As such, the strain sensor **540** is capable of detecting whether a micro device has been picked up, due to differences in the resonant frequency when a micro device is or is not present.

In an embodiment, strain sensor **540** is formed on dielectric layer **114** over the interface of spring anchor **120** and spring arm **110**. In an embodiment, dielectric layer **114** electrically isolates sensor **540** from top electrode **106**. When spring arm **110** deflects into space **112**, the strain along spring arm **110** is not uniform; spring arm **110** experiences the maximum amount of strain at the interface with spring anchor **120**. In an embodiment, strain sensor **540** spans the interface of spring anchor **120** and spring arm **110**, so as to be subject to the maximum amount of stress associated with the deflection of spring arm **110**.

In an embodiment, strain sensor **540** includes a piezoelectric material. A piezoelectric material accumulates charge in response to an applied mechanical stress. The accumulation of charge along strained surfaces of a piezoelectric sensor can generate a measurable voltage related to the amount of strain. As such, as spring arm **110** deflects into space **112**, the voltage between the upper and lower surface of the strain sensor increases as the strain at the interface of spring anchor **120** and spring arm **110** increases, enabling calculation of the amount of deflection of spring arm **110**. Piezoelectric materials include, for example, crystalline materials such as quartz and ceramic materials such as lead zirconate titanate (PZT).

In another embodiment, strain sensor **540** is formed from a piezoresistive material. The electrical resistivity of a piezoresistive material changes in response to an applied mechanical stress. As such, strain sensor **540** may be subject to an electrical current, so that when spring arm **110** deflects into space **112**, the electrical resistivity of strain sensor **540** increases as the strain at the interface of spring anchor **120** and spring arm **110** increases, causing a measurable increase in the voltage across the sensor. The amount of deflection can be calculated from the changes in voltage. Piezoresistive materials include, for example, polycrystalline silicon, amorphous silicon, monocrystalline silicon, or germanium.

In an embodiment, spring arm **110** oscillates at a resonant frequency due to contact with a bare substrate or a micro device, as discussed above. In an embodiment, the oscillation results in a correspondingly oscillating amount of strain at the interface of spring anchor **120** and spring arm **110**, which can be detected by strain sensor **540**. The differences in oscillating strain for a spring arm **110** that has contacted a bare substrate versus a spring arm **110** that has picked up a micro device enable the use of a piezoelectric or piezoresistive strain sensor **540** to determine if a transfer head has successfully picked up a micro device during a pickup operation.

Referring to FIG. **5**B, a sensor electrode **542** is formed on substrate **102**, according to an embodiment of the invention. In an embodiment, sensor electrode **542** is formed within space **112**, in alignment with mesa structure **104**. In an embodiment, a layer of dielectric material **544** isolates sensor electrode **542** from semiconductor substrate **102**. In another embodiment, sensor electrode **542** is formed directly on base substrate **102**. In an embodiment, dielectric layer **114** covers opposing electrode **542**.

In an embodiment, sensor electrode **542** and bottom electrode **108** function together as a capacitive sensor. The capacitance between two parallel conductors increases as the distance between the conductors decreases. In an embodiment, a voltage is applied across sensor electrode **542** and bottom electrode **108**. As the spring arm **110** is depressed within space **112** toward base substrate **102**, the distance between electrodes **542** and **108** decreases, causing the capacitance between them to increase. In this manner, the amount of deflection of spring arm **110** can be calculated from changes in the capacitance between electrodes **542** and **108** across dielectric layer **114** and space **112**. Dielectric **114** prevents shorting between the electrodes in the case where spring arm **110** is fully depressed within space **112**. Sensor electrode **542** may be formed from any suitable conductive material, such as those discussed above with respect to electrodes **106** and **108**.

In another application, sensor electrode **542** may be used to measure the resonant frequency of spring arm **110**. As discussed above, in an embodiment, spring arm **110** oscillates at a resonant frequency determined in part by the weight of elements forming spring arm **110**. The oscillation may result in a corresponding oscillating capacitance between sensor electrode **542** and bottom electrode **108**. After a micro device has been picked up by the transfer head, the additional weight of the micro device may change the resonant frequency of spring arm **110**, resulting in changes in the oscillating capacitance as measured by electrodes **542** and **108**. In this manner, electrodes **542** and **108** may be used to determine if a transfer head has successfully picked up a micro device during a pickup operation. Additionally, it may be determined whether to apply a cleaning operation to the transfer head array or micro device array prior to reattempting a pick up operation.

FIGS. **6**A-**6**I illustrate a method for forming a micro device transfer head using a negative lift-off technique, according to an embodiment of the invention. In an embodiment, a substrate **602** having a dielectric layer **601** formed thereon is provided, as shown in FIG. **6**A. Substrate **602** and dielectric layer **601** have the characteristics discussed above with respect to substrate **102** and **101**, respectively. In an embodiment, base substrate **602** is silicon and dielectric layer **601** is silicon dioxide. Dielectric layer **601** and base substrate **602** may include routing (not shown) to control the subsequently formed transfer head. The thickness of dielectric layer **601** will correspond to the thickness of the subsequently formed space between the spring arm and the base substrate, and as such is chosen to enable the desired degree of deflection of the transfer head. In an embodiment, dielectric layer **601** is 0.5-2 μm thick.

Next, in FIG. **6**B, first pattern **640** is formed on the surface of dielectric layer **601** to define a portion of the bottom electrode of the transfer head. In an embodiment, first pattern **640** is formed in the areas where electrode metal is not desired. For example, first pattern **640** may be formed along the perimeter of what will be the length and width of the spring arm portion of the transfer head. In an embodiment, first pattern **640** is formed from photoresist.

In FIG. **6**C, first electrode layer **650** is formed over the surface of dielectric layer **601** and first pattern **640**, according to an embodiment of the invention. First electrode layer **650** may be formed from any metal or conductive material suitable for forming the electrode elements of the spring arm of a transfer head, as discussed above with respect to materials for electrodes **106** and **108**. First electrode layer **650** may be formed using any appropriate method, such as plating, CVD, or PVD. In an embodiment, first electrode layer **650** is formed by sputter deposition. First electrode layer **650** may be from 0.1-1 μm thick. In an embodiment, first electrode layer **650** is a 500 Å thick layer of TiW. In an embodiment, first pattern **640** may then be removed along with the portion of first electrode layer **650** formed thereon.

Referring now to FIG. **6**D, a template is formed over first electrode layer **650**. In an embodiment, the template includes gap material **616** and mesa structure **604**. Mesa structure **604** may be formed from the same or different material than gap material **616**. In one embodiment, mesa structure **604** is integrally formed with gap material **616**. In an embodiment, the materials filling gap material **616** and mesa structure **604** are selected to be resistant to other processes used to define the transfer head. In another embodiment, the materials filling gap material **616** and mesa structure **604** are selected to be removed during subsequent processing to form the transfer head.

Gap material **616** and mesa structure **604** may each be formed from a variety of materials, including photoresist, polyimide, amorphous silicon, polysilicon, or dielectric materials, for example inorganic dielectrics such as silicon dioxide and silicon nitride, or organic dielectrics such as benzocyclobutene (BCB). For example, where gap material **616** and mesa structure **604** are formed from a dielectric such as silicon dioxide or silicon nitride, a layer of dielectric may first be blanket deposited over first electrode layer **650** and then patterned by any appropriate method known in the art to form the template comprising gap material **616** and mesa structure **604**. In an embodiment, anisotropic etching techniques can be utilized to form tapered sidewalls for mesa structure **604**. In another embodiment, gap material **616** and mesa structure **604** are defined using a photoresist material that is hard-baked to resist subsequent processing to form the transfer head. In another embodiment, gap material **616** and mesa structure **604** are formed from photo-defined polyimide.

The dimensions of the gap material **616** and mesa structure **604** are determined by the desired dimensions of the top surface of the transfer head after the formation of additional device components, such as the electrodes and the dielectric layer, as described above with respect to FIGS. **1**-**2**. In an embodiment, gap material **616** is 2 to 5 μm thick. In an embodiment, mesa structures **604** are 7 μm×7 μm wide and 2 μm high.

Next, in FIGS. **6**E-**6**G, a negative patterning technique is used to form additional components of the electrodes. In FIG. **6**E, second pattern **652**A/**652**B is formed on mesa structure **604**, according to an embodiment of the invention. In an embodiment, second pattern **652**A defines the space separating the two electrodes to be formed on top of mesa structure **604**. In an embodiment, second pattern **652**B defines what will be the end of the spring arm portion of the transfer head.

Referring to FIG. **6**F, second electrode layer **654** is blanket deposited over the top surfaces of the template comprising gap material **616**, mesa structure **604**, and second pattern **652**A/**652**B, according to an embodiment of the invention. Similarly to first electrode layer **654**, second electrode layer **654** may be formed using a non-conformal method, such as PVD. In an embodiment, second electrode layer **654** is formed from the same material as first electrode layer **650**. Second electrode layer **654** may be from 0.1 to 1 μm thick. In an embodiment, second electrode layer **650** is a 500 Å thick layer of TiW.

Next, in FIG. **6**G, second pattern **652**A/**652**B is removed, along with the portions of second electrode layer **654** formed thereon, according to an embodiment of the invention. In an embodiment, removal of second pattern **652**A/**652**B defines top electrode **606** from second electrode layer **654**. A bottom electrode **608** is defined by the remaining portion of first electrode layer **650** and a portion of the second electrode layer, according to an embodiment. In an embodiment, bottom electrode **608** runs underneath mesa structure **604** and wraps around and over mesa structure **604**. In an embodiment, the removal of second pattern **652**A defines space **607** between top electrode **606** and bottom electrode **608**. In a case where the template comprising gap material **616** and mesa structure **604** is formed from photoresist, the photoresist template may also be removed during the process used to remove second pattern **652**A/**652**B.

Referring to FIG. **6**H, a portion of dielectric layer **601** is then etched to form space **612**, according to an embodiment of the invention. In an embodiment, dielectric layer **601** material is laterally etched from underneath bottom electrode **608** to create spring arm **610** of a desired length. An amount of dielectric layer **601** material may remain on the surfaces of bottom electrode **608** and/or substrate **602** after the formation of space **612**. Spring arm **610** is attached to dielectric layer **601** via spring anchor **620**. Dielectric layer **601** material may be removed by any appropriate method, for example, a timed wet etch process. In an embodiment, space **612** is formed by using a wet etch process that is selective to dielectric layer **601** material over bottom electrode **608** material and substrate **602** material. In an embodiment, the process used to remove dielectric material **601** to create space **612** also removes the dielectric material forming the template comprising gap material **616** and mesa structure **604**, so that gap material **616** and mesa structure **604** are air-filled. In an embodiment, the process used to remove dielectric material is precisely controlled to laterally etch underneath bottom electrode **608** to form spring arm **610** without etching portions of dielectric material that are critical to the transfer head structure. In another embodiment, the dielectric material forming the template comprising gap material **616** and mesa structure **604** has been selected so that it is not etched by the process used to remove a portion of dielectric layer **601**.

Dielectric layer **614** is then conformally deposited over the surfaces of spring arm **610** and underlying space **612**, as shown in FIG. **6**I, according to an embodiment of the invention. In an embodiment, dielectric layer **614** conforms to the surfaces of electrodes **606**/**608** and the surfaces of dielectric layer **601** and substrate **602** exposed within space **612**. In an example embodiment where mesa structure **604** and gap material **616** are air-filled, dielectric layer **614** may also form on the surfaces of top electrode **606** and bottom electrode **608** that are internal to the spring arm **610**. In an embodiment, dielectric layer **614** has a suitable thickness and dielectric constant for achieving the required grip pressure of the micro device transfer head, and sufficient dielectric strength to not break down at the operating voltage. Dielectric layer **614** may be a single layer or multiple layers. Suitable dielectric materials may include, but are not limited to, Al_2O_3, Ta_2O_5, HfO_2, and SiO_2 as described above with respect to dielectric layer **114**. In an embodiment, dielectric layer **614** is from 0.5 to 1 μm thick. In an embodiment, dielectric layer **614** is a 0.5 μm thick layer of Al_2O_3. In an embodiment, dielectric layer **614** is deposited by atomic layer deposition (ALD).

FIGS. **7A-7G** illustrate a method for forming a micro device transfer head, according to an embodiment of the invention. In an embodiment, a substrate **702** is provided, having dielectric layer **701** and first electrode layer **750** formed thereon, as shown in FIG. **7A**. In an embodiment, substrate **702**, dielectric layer **701**, and first electrode layer **750** may each have the characteristics discussed above with respect to substrate **602**, dielectric layer **601**, and first electrode layer **650**, respectively. In an embodiment, base substrate **702** is silicon, dielectric layer **701** is silicon dioxide, and first electrode layer **750** is TiW. Dielectric layer **701** may be from 0.5-2 μm thick. First electrode layer **750** may be from 100 to 1000 nm thick.

Referring to FIG. **7B**, a template comprising gap material **716** and mesa structure **704** is formed over first electrode layer **750**. The materials and dimensions of gap material **716** and mesa structure **704** may be as for gap material **116**/**616** and mesa structure **104**/**604**, respectively, discussed above. The materials used to form gap material **716** and mesa structure **704** may be selected to either be resistant to subsequent fabrication processes or, alternatively, to be removed during subsequent processes. In an embodiment where gap material **716** and mesa structure **704** are formed from the same material as dielectric layer **701**, first electrode layer **750** protects the surface of dielectric layer **701** during the etching processes that define gap material **716** and mesa structure **704**.

Next, in FIG. **7C**, second electrode layer **754** is formed, according to an embodiment of the invention. In an embodiment, second electrode layer **754** is blanket deposited over the exposed top surfaces of gap material **716**, mesa structure **704**, and dielectric layer **701** according to an embodiment of the invention. Second electrode layer **754** may be formed by any appropriate method, such as CVD or PVD. Second electrode layer **754** is formed from any conductive material suitable for the formation of electrodes, as discussed above with respect to second electrode layer **654**.

Next, first electrode layer **750** and second electrode layer **754** are patterned to form top and bottom electrodes, according to an embodiment of the invention. In FIG. **7D**, pattern **756A**/**756B** is formed over second electrode layer **754**, according to an embodiment. In an embodiment, pattern **756A** covers the portion of second electrode layer **754** that will form the top electrode. In an embodiment, pattern **756B** covers the portion of second electrode layer **754** that will form a portion of the bottom electrode. Pattern **756A**/**756B** may be formed from any suitable material, such as a photoresist or hardmask material.

The portions of second electrode layer **754** and first electrode layer **750** that are not protected by pattern **756A**/**756B** are then etched to define top electrode **706** and bottom electrode **708**, according to an embodiment. Second electrode layer **754** and first electrode layer **750** may be etched by any appropriate method. In an embodiment, a wet etch having a selectivity of at least 10:1 for the material forming electrode layers **750**/**754** over the material forming the mesa structure **704** is used. In an embodiment, the wet etch used to pattern electrode layers **750**/**754** has a selectivity of at least 10:1 for the material forming electrode layers **750**/**754** over the material forming dielectric layer **701**.

Pattern **756A**/**756B** may then be removed by an appropriate method, as shown in FIG. **7E**. In an embodiment, the process used to remove pattern **756A**/**756B** also removes the material filling gap material **716** and mesa structure **704**. For example, where the template including gap material **716** and mesa structure **704** is formed from photoresist, the process that removes pattern **756A**/**756B** may also remove the photoresist filling gap material **716** and mesa structure **704**. In another embodiment, the material filling gap material **716** and mesa structure **704** is not removed by the process used to remove pattern **756A**/**756B**.

Next, as shown in FIG. **7F**, a portion of dielectric layer **701** is removed from between bottom electrode **708** and substrate **702** to form space **712**, according to an embodiment of the invention. In an embodiment, dielectric layer **701** is laterally etched underneath bottom electrode **708** to form space **712** and spring arm **710**, which is suspended above space **712** and attached to dielectric layer **701** at spring anchor **720**. Dielectric layer **701** may be removed by any appropriate process, such as a timed wet etch. As discussed above with respect to FIG. **6H**, in an embodiment, where the material forming the template comprising gap material **716** and mesa structure **704** is a dielectric material, the process used to remove a portion of dielectric layer **701** may also remove all or a portion of the dielectric material filling the template, forming a hollow spring arm **710**. In an embodiment, the process used to remove dielectric material is precisely controlled to laterally etch underneath bottom electrode **708** to form spring arm **710** without etching dielectric material that is critical to the transfer head structure.

Referring to FIG. **7G**, dielectric layer **714** is then conformally deposited over the surfaces of the spring arm **710** and underlying space **712**. In an embodiment, dielectric layer **714** conforms to the surfaces of electrodes **706**/**708** and the surfaces of dielectric layer **701** and substrate **702** exposed within space **712**. In an example embodiment where mesa structure **704** and gap material **716** are air-filled, dielectric layer **714** may also form on the surfaces of top electrode **706** and bottom electrode **708** that are internal to the spring arm **710**. In an embodiment, the dielectric layer **714** has a suitable thickness and dielectric constant for achieving the required grip pressure of the micro device transfer head, and sufficient dielectric strength to not break down at the operating voltage. The dielectric layer **714** may be a single layer or multiple layers. Suitable dielectric materials may include, but are not limited to, Al_2O_3, Ta_2O_5, HfO_2, and SiO_2 as described above with respect to dielectric layer **114**. In an embodiment, dielectric layer **714** is from 0.5 to 1 μm thick. In an embodiment, dielectric layer **714** is a 0.5 μm thick layer of Al_2O_3. In an embodiment, dielectric layer **714** is deposited by atomic layer deposition (ALD).

In utilizing the various aspects of this invention, it would become apparent to one skilled in the art that combinations or variations of the above embodiments are possible for forming a micro device transfer head and head array, and for transferring a micro device and micro device array. Although the present invention has been described in language specific to structural features and/or methodological acts, it is to be understood that the invention defined in the appended claims is not necessarily limited to the specific features or acts described. The specific features and acts disclosed are instead to be understood as particularly graceful implementations of the claimed invention useful for illustrating the present invention.

What is claimed is:

1. A micro device transfer head comprising:

a base substrate;

a spring anchor coupled to the base substrate;

a spring arm coupled to the spring anchor, the spring arm including:

  a mesa structure suspended over the base substrate;

  a top electrode extending laterally from the spring anchor and over the mesa structure; and

  a bottom electrode extending laterally from the spring anchor underneath the mesa structure and wrapping around and over the mesa structure, wherein the top electrode and the bottom electrode are electrically isolated from each other; and

a dielectric layer covering the top electrode and the bottom electrode over the mesa structure.

2. The micro device transfer head of claim **1**, wherein the spring arm further comprises a template defined by the top electrode and the bottom electrode, wherein the template comprises the mesa structure.

3. The micro device transfer head of claim **2**, wherein the template is filled with a dielectric material.

4. The micro device transfer head of claim **2**, wherein the template is filled with air.

5. The micro device transfer head of claim **1**, wherein the top electrode and the bottom electrode are metal.

6. The micro device transfer head of claim **1**, wherein the spring arm is deflectable into an underlying space.

7. The micro device transfer head of claim **6**, wherein the spring arm is coupled to the base substrate via a layer of dielectric material, and wherein the underlying space is a cavity in the dielectric layer.

8. The micro device transfer head of claim **6**, further comprising a sensor electrode on a bottom surface of the underlying space, wherein the sensor electrode is vertically aligned with the mesa structure.

9. The micro device transfer head of claim **6**, wherein the dielectric layer conforms to the spring arm and the underlying space.

10. The micro device transfer head of claim **9**, further comprising a strain sensor formed over a portion of the dielectric layer covering an interface of the spring anchor and the spring arm.

11. The micro device transfer head of claim **1**, wherein the top surface of the transfer head has a length from 1 to 100 μm and a width from 1 to 100 μm.

12. The micro device transfer head of claim **1**, further comprising routing in the base substrate, wherein the routing is electrically connected to the top electrode and the bottom electrode.

13. The micro device transfer head of claim **12**, wherein the routing comprises through vias in the base substrate.

14. The micro device transfer head of claim **1**, wherein the top electrode and bottom electrode are form a bipolar electrode on a top surface of the mesa structure.

15. A micro device transfer head array comprising:

a base substrate; and

an array of transfer heads, each transfer head including:

a spring anchor coupled to the base substrate;

a spring arm coupled to the spring anchor, the spring arm including:

a mesa structure suspended over the base substrate;

a top electrode extending laterally from the spring anchor and over the mesa structure; and

a bottom electrode extending laterally from the spring anchor underneath the mesa structure and wrapping around and over the mesa structure, wherein the top electrode and the bottom electrode are electrically isolated from each other; and

a dielectric layer covering the top electrode and the bottom electrode over the mesa structure.

16. The micro device transfer head array of claim **15**, wherein each spring arm is deflectable into an underlying space.

17. The micro device transfer head array of claim **16**, wherein the underlying space is a trench extending underneath a plurality of transfer heads.

18. The micro device transfer head array of claim **15**, further comprising routing in the base substrate, wherein the routing is electrically connected to the top electrode and bottom electrode of each transfer head.

19. The micro device transfer head of claim **18**, wherein the routing comprises through vias in the base substrate.

20. The micro device transfer head array of claim **15**, further comprising a conductive ground plane formed over the dielectric layer and surrounding each of the transfer heads.

21. The micro device transfer head of claim **15**, wherein the top electrode and bottom electrode of each transfer head form a bipolar electrode on a top surface of the mesa structure.

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