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(54) **Title**: AUTOMATED MANUFACTURING PROCESSES FOR PRODUCING DEFORMABLE POLYMER DEVICES AND FILMS

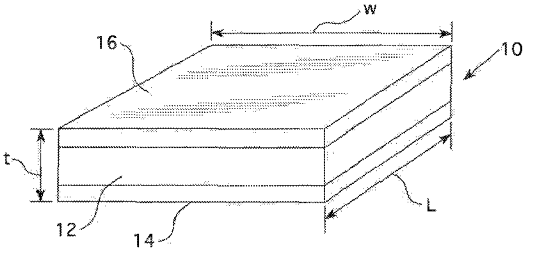


FIG. 1A

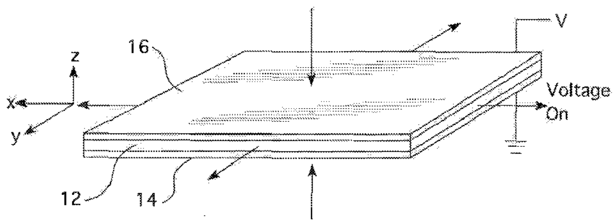


FIG. 1B

(57) **Abstract**: A process for producing a patterned deformable polymer film for use in a deformable polymer device is disclosed. The process includes positioning an intermediary layer between a deformable film and a process tooling and printing at least one electrode on the deformable film by depositing an. ink to form the at least one electrode on a first surface of the deformable film, wherein the intermediary layer permits release of the deformable film from the process tooling subsequent to the printing process. Films produced by the inventive processes may find use in electroactive polymer devices.

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# AUTOMATED MANUFACTURING PROCESSES FOR PRODUCING DEFORMABLE POLYMER DEVICES AND FILMS

## RELATED APPLICATIONS

This application claims the benefit, under 35 USC § 119(e), of U.S. Provisional Application Nos.: 61/477,675 filed April 21, 2011 entitled "AUTOMATED EPAM MANUFACTURING PROCESSES"; 61/477,709 filed April 21, 2011 entitled "LINER-LESS PRINTING "; 61/482,751 filed May 5, 2011 entitled "LINER-LESS PRINTING II"; 61/447,832 filed March 1, 2011 entitled, "FIBRILLATED STRUCTURE FOR ELECTRODE"; 61/546,683 filed October 13, 2011 "MODIFIED SOFT TOOLING AND EFFECT OF TROUGHS IN PRINT THICKNESS"; and 61/549,799 filed October 21, 2011 entitled, "USE CONTINUOUS WEB FRAME BELT FOR ROLL-TO-ROLL CARTRIDGE PRINTING/PROCESS" the entirety of each of which are incorporated by reference.

## FIELD OF THE INVENTION

The present invention is directed in general to manufacturing and more specifically, to high volume manufacturing processes for producing electroactive polymer films and devices.

## BACKGROUND OF THE INVENTION

A tremendous variety of devices used today rely on actuators of one sort or another to convert electrical energy to mechanical energy. Conversely, many power generation applications operate by converting mechanical action into electrical energy. Employed to harvest mechanical energy in this fashion, the same type of device may be referred to as a generator. Likewise, when the structure is employed to convert physical stimulus such as vibration or pressure into an electrical signal for measurement purposes, it may be characterized as a sensor. Yet, the term "transducer" may be used to generically refer to any of the devices.

A number of design considerations favor the selection and use of advanced dielectric elastomer materials, also referred to as "electroactive polymers", for the fabrication of transducers. These considerations include potential force, power density, power conversion/consumption, size, weight, cost, response time, duty cycle, service requirements, environmental impact, etc. As such, in many applications, electroactive polymer technology offers an ideal replacement for piezoelectric, shape-memory alloy and electromagnetic devices such as motors and solenoids.

An electroactive polymer transducer comprises two electrodes having deformable characteristics and separated by a thin elastomeric dielectric material. When a voltage difference is applied to the electrodes, the oppositely charged electrodes attract each other thereby compressing the polymer dielectric layer therebetween. As the electrodes are pulled closer together, the dielectric polymer film becomes thinner (the Z-axis component contracts) as it expands in the planar directions (along the X- and Y-axes), i.e., the displacement of the film is in-plane. The electroactive polymer film may also be configured to produce movement in a direction orthogonal to the film structure (along the Z-axis), i.e., the displacement of the film is out-of-plane. U.S. Pat. No. 7,567,681 discloses electroactive polymer film constructs which provide such out-of-plane displacement – also referred to as surface deformation or as thickness mode deflection.

The material and physical properties of the electroactive polymer film may be varied and controlled to customize the deformation undergone by the transducer. More specifically, factors such as the relative elasticity between the polymer film and the electrode material, the relative thickness between the polymer film and electrode material and/or the varying thickness of the polymer film and/or electrode material, the physical pattern of the polymer film and/or electrode material (to provide localized active and inactive areas), the tension or pre-strain placed on the electroactive polymer film as a whole, and the amount of voltage applied to or capacitance induced upon the film may be controlled and varied to customize the features of the film when in an active mode.

Numerous applications exist that benefit from the advantages provided by such electroactive polymer films whether using the film alone or using it in an electroactive polymer actuator. One of the many applications involves the use of electroactive polymer transducers as actuators to produce haptic feedback (the communication of information to a user through forces applied to the user's body) in user interface devices. There are many known user interface devices which employ haptic feedback, typically in response to a force initiated by the user. Examples of user interface devices that may employ haptic feedback include keyboards, keypads, game controller, remote control, touch screens, computer mice, trackballs, stylus sticks, joysticks, etc. The user interface surface can comprise any surface that a user manipulates, engages, and/or observes regarding feedback or information from the device. Examples of such interface surfaces include, but are not limited to, a key (e.g., keys on a keyboard), a game pad or buttons, a display screen, etc.

The haptic feedback provided by these types of interface devices is in the form of physical sensations, such as vibrations, pulses, spring forces, etc., which a user senses either directly (e.g., via touching of the screen), indirectly (e.g., via a vibrational effect such a when a cell phone vibrates in a purse or bag) or otherwise sensed (e.g., via an action of a moving body that creates a pressure disturbance sensed by the user). The proliferation of consumer electronic media devices such as smart phones, personal media players, portable computing devices, portable gaming systems, electronic readers, etc., can create a situation where a sub-segment of customers would benefit or desire an improved haptic effect in the electronic media device. However, increasing haptic capabilities in every model of an electronic media device may not be justified due to increased cost or increased profile of the device. Moreover, customers of certain electronic media devices may desire to temporarily improve the haptic capabilities of the electronic media device for certain activities.

Use of electroactive polymer materials in consumer electronic media devices as well as the numerous other commercial and consumer applications highlights the need to increase production volume while maintaining precision and consistency of the films.

## SUMMARY OF THE INVENTION

Electroactive polymer devices that can be used with these designs include, but are not limited to planar, diaphragm, thickness mode, roll, and passive coupled devices (hybrids) as well as any type of electroactive polymer device described in the commonly assigned patents and applications cited herein.

In some variations, the electroactive polymer actuator comprises at least one electroactive polymer cartridge, where the electroactive polymer cartridge includes an electroactive polymer film comprising a dielectric elastomer layer, wherein a portion of the dielectric elastomer layer is between a first and a second electrodes wherein the overlapping portions of the electrodes define an active area comprising the active portion, whereupon application of a triggering signal to the electrodes causes movement of the active area to produce the haptic effect.

The electroactive polymer actuator can include a plurality of discrete electroactive polymer cartridges coupled together, where the electroactive polymer actuator includes an increased active portion comprising each active area of each electroactive polymer cartridge.

As noted above, there remains a need to mass produce such electroactive polymer devices while maintaining the performance characteristics obtained through batch production or lower volume manufacturing processes.

The present disclosure includes a process for high volume fabrication of a deformable polymeric film device. In one variation, the process comprises continuously advancing a film of an elastomeric material from a supply of elastomeric material, optionally mechanically straining the film to create a first pre-strained film section that remains continuous with the supply of elastomeric material, supporting the film section such that the first film section comprises a supported portion and an unsupported portion, depositing an ink to create at least a first electrode on a first side of the unsupported portion of the first film section, and depositing the ink to create at least a second electrode on a second side of the unsupported portion of the first film section opposing the first electrode and forming at least one opposing electrode pair to complete at least a first section of electroactive polymeric film and collecting the first section of electroactive polymeric film.

Optionally, the process can further include mechanically straining the film to create a second pre-strained film section that remains continuous with the film, supporting the second pre-strained film section such that the second pre-strained film section comprises a supported portion and an unsupported portion, depositing an ink to create at least a first electrode on a first side of the unsupported portion of the second pre-strained film section, printing at least a second electrode on a second side of the unsupported portion of the second pre-strained film section opposing the first electrode to form at least one opposing electrode pair to complete at least a second section of electroactive polymeric film and collecting the second section of electroactive polymeric film.

In some variations of the inventive process, the film section may be supported by increasing the rigidity of a portion of the film section.

The process can further include stacking or laminating at least the first and second sections to create a multi-layer film.

In some variations of the inventive manufacturing process, layers of structural or adhesive material can be applied to the electroactive polymer film either before or during the stacking or lamination process step.

The processes described herein may include advancing the film of an elastomeric material from the supply of elastomeric material by unwinding a supply roll of the elastomeric material. The film may be advanced at a constant rate or in a stepwise fashion where each section of the film stops at each of a series of process stations for a given dwell time.

In some variations of the manufacturing process, supporting the first pre-strained film section comprises applying a supporting layer to the first pre-strained film section and/or applying UV or thermal treatment the first pre-strained film section.

As part of the inventive manufacturing process, the film can optionally be reinforced with a tape or other material applied to the edges to prevent tearing or tear propagation. The tape or the applied material can be stretchable or patterned in such a way as to enable the film to stretch.

Applying pre-strain to the film can include the use of a first and second belt member on respective near and far edges of the film, where the first and second belt members each comprise a top surface and a bottom surface sandwiching the film, and where the belt member comprises a material having a Young's Modulus greater than a Young's Modulus of the film. Optionally, the belt members can comprise perforated belt members and where perforation rollers are used to mechanically strain the film.

One method of creating the perforated belts is to laminate or cast the polymer film onto a release liner that has fine perforated lines parallel to the web direction similar to the perforated lines along the edges of pin-fed printer paper. During the inventive transducer manufacturing process, the center region of the release liner can be separated from the unsupported regions of the film and from strips of release liner along the edges of the film by tearing along the perforated lines. The remaining strips of release liner serve as perforated belts and may have additional perforations defining holes which are punched out by pins or sprockets on the perforation rollers. Alternatively, these holes may be punched, drilled, or cut as part of the transducer manufacturing process.

The strain of the film may be bi-directional or uni-directional to produce an isotropic pre-strained film section or an anisotropic pre-strained film section.

The use of the tooling and processes described herein also allow for using a screen printing process where the first pre-strained film section is advanced against a process tooling as the ink is applied to the pre-strained film.

In certain variations, the inventive process may include the use of "soft tooling". For example, the printing process can further comprise positioning a removable liner between the first pre-strained film section and the process tooling to assist in release of the first pre-strained film section from the process tooling. Alternatively, or in combination, the printing process can include positioning an engineered surface and/or a compliant layer between the first pre-strained film section and the process tooling to assist in release of the first pre-strained film section from the process tooling. In yet another variation, the process can include positioning a deformable layer between the first pre-strained film section and a process tooling, where the deformable layer allows release of the first pre-strained film section without the use of a liner affixed to the first pre-strained film section. The deformable layer may comprise a foam layer.

Soft tooling permits varying pressures on the same surface of the film. For example, the processes described herein can further include a deformable layer that comprises at least one cavity in a surface of the deformable layer such that application of the deformable layer against the first pre-strained film section allows for a first pressure at the cavity and a second pressure at the surface to permit printing of varying ink depths on the first pre-strained film section.

The inventive manufacturing process may also include applying at least a frame and/or an output bar to the first section of electroactive polymer films to assemble an electroactive polymer actuator device. Alternatively, the process to collect the first section of electroactive polymer film comprises winding a plurality of electroactive polymer films to form a roll of electroactive polymer films.

Another variation of the process described below includes producing an electroactive polymer film for use in an electroactive polymer device. In one variation, the process includes pre-straining a section of elastomeric film to produce a pre-strained elastomeric film, supporting the pre-strained elastomeric film; positioning an intermediary layer between the pre-strained elastomeric film and a process tooling and screen printing at least one electrode on the pre-strained elastomeric film by depositing an ink to form the electrode on a first surface of the pre-strained elastomeric film, where the intermediary layer permits release of the second surface from the process tooling subsequent to the screen printing process.

The intermediary layer can include a removable liner. Alternatively, or in combination, the intermediary layer may include an engineered surface and/or a compliant layer, where the engineered surface comprises a surface selected from the group consisting of a parchment paper, a screen mesh, a textured surface, a non-stick surface and a polymer sheet.

In another variation, the intermediary layer comprises a deformable layer. For example, the deformable layer can comprise an ethylene vinyl acetate foam material. The deformable layer can comprise similarly soft materials such as silicones and polyurethane gels or foams with the appropriate surface release properties for the film. Use of a deformable layer also allows for a plurality of cavities in the deformable layer. The cavities permit regions of varying pressure during screen printing, the process further comprising depositing ink at varying levels on the first surface of the pre-strained elastomeric film.

Another variation disclosed herein the present invention includes an electroactive polymer film for use in an electroactive polymer device prepared by a process comprising the steps of pre-straining a section of elastomeric film, screen printing at least one electrode on a surface of the section of elastomeric film using a deformable layer between the elastomeric film and a process tooling, where the deformable layer comprises one or more cavities permitting varying pressures during deposition of ink to deposit ink sections having varying depths on the elastomeric film; and affixing one or more frames, output bars, or flexures to the film surface.

In addition to screen printing, other printing processes such as flexography, pad printing, gravure printing, ink jet printing, and aerosol jet printing may prove useful in the present manufacturing process.

These and other features, objects and advantages of the invention will become apparent to those persons skilled in the art upon reading the details of the invention as more fully described below. In addition, variations of the processes and devices described herein include combinations of the embodiments or of aspects of the embodiments where possible are within the scope of this disclosure even if those combinations are not explicitly shown or discussed.

## BRIEF DESCRIPTION OF THE DRAWINGS

The invention is best understood from the following detailed description when read in conjunction with the accompanying drawings. To facilitate understanding, the same reference numerals have been used (where practical) to designate similar elements are common to the drawings. Included in the drawings are the following:

Figs. 1A and 1B illustrate a top perspective view of a transducer before and after application of a voltage in accordance with one embodiment of the present invention;

Fig. 2A illustrates an exemplary electroactive polymer cartridge;

Fig. 2B illustrates an exploded view of an electroactive polymer actuator, inertial mass and actuator housing;

Fig. 3A illustrates a schematic roll-to-roll process for preparing an elastomeric film into an electroactive polymer film;

Fig. 3B illustrates two rolls of electroactive polymer films being combined to produce an electroactive polymer device;

Figs. 4A to 4D illustrate an example of using a stiff belt member to assist in controlling the desired strain on an elastomeric film;

Fig. 5A illustrates a variation of a printing process useful in manufacturing electroactive polymer actuators;

Fig. 5B illustrates a variation of a printing configuration that eliminates the requirement of a liner similar to that shown in Fig. 5A;

Fig. 5C demonstrates yet another variation of a tooling configuration where the film contacts a foam layer directly without the use of any layer as shown in Figs. 5A and 5B;

Fig. 6 shows an etched foam layer that allows for deposition of varying ink levels in the same printing process;

Fig. 7A depicts the square patterned microstructure of an electroactive polymer film which has been screen printed;

Fig. 7B shows the fibrillated microstructure of an electroactive film printed by flexographic printing;

Fig. 8 illustrates the inventive process using a continuous web frame to hold pre-strained silicone film;

Fig. 9 demonstrates aligning several printing stations sequentially on the web; and

Fig. 10 illustrates one layout of the line according to the process of the present invention.

Variation of the invention from that shown in the figures is contemplated.

## DETAILED DESCRIPTION OF THE INVENTION

Examples of electroactive polymer devices and their applications are described, for example, in U.S. Pat. Nos. 7,394,282; 7,378,783; 7,368,862;

7,362,032; 7,320,457; 7,259,503; 7,233,097; 7,224,106; 7,211,937; 7,199,501; 7,166,953; 7,064,472; 7,062,055; 7,052,594; 7,049,732; 7,034,432; 6,940,221; 6,911,764; 6,891,317; 6,882,086; 6,876,135; 6,812,624; 6,809,462; 6,806,621; 6,781,284; 6,768,246; 6,707,236; 6,664,718; 6,628,040; 6,586,859; 6,583,533; 6,545,384; 6,543,110; 6,376,971; 6,343,129; 7,952,261; 7,911,761; 7,492,076; 7,761,981; 7,521,847; 7,608,989; 7,626,319; 7,915,789; 7,750,532; 7,436,099; 7,199,501; 7,521,840; 7,595,580; and 7,567,681, and in U.S. Patent Application Publication Nos. 2009/0154053; 2008/0116764; 2007/0230222; 2007/0200457; 2010/0109486; and 2011/128239, and PCT Publication No. WO2010/054014, the entireties of which are incorporated herein by reference.

The present invention provides a process for producing a patterned deformable polymer film for use in a deformable polymer device, the process including positioning an intermediary layer between a deformable film and a process tooling and printing at least one electrode on the deformable film by depositing an ink to form the at least one electrode on a first surface of the deformable film, wherein the intermediary layer permits release of the deformable film from the process tooling subsequent to the printing process.

Films useful in the present invention include, but are not limited to those made from polymers such as silicone, polyurethane, acrylate, hydrocarbon rubber, olefin copolymer, polyvinylidene fluoride copolymer, fluoroelastomer styrenic copolymer, and adhesive elastomer.

It is noted that the figures discussed herein schematically illustrate exemplary configurations of devices that employ electroactive polymer films or transducers having such electroactive polymer films. Many variations are within the scope of this disclosure, for example, in variations of the device, the electroactive polymer transducers can be implemented to move a mass to produce an inertial haptic sensation. Alternatively, the electroactive polymer transducer can produce movement in the electronic media device when coupled to the assembly described herein. Electroactive transducers manufactured with the processes disclosed here can be used as actuators, generators, or sensors in many other applications including, without limitation, fluid handling systems, motion control, adaptive optical devices, vibration control systems, and energy harvesting systems.

In any application, the displacement created by the electroactive polymer transducer can be exclusively in-plane which is sensed as lateral movement, or can be out-of-plane (which is sensed as vertical displacement). Alternatively, the electroactive polymer transducer material may be segmented to provide independently addressable/movable sections so as to provide angular displacement of the housing or electronic media device or combinations of other types of displacement. In addition, any number of electroactive polymer transducers or films (as disclosed in the applications and patent listed herein) can be incorporated in the user interface devices described herein.

The electroactive polymer transducer may be configured to displace to an applied voltage, which facilitates programming of a control system used with the subject tactile feedback devices. Electroactive polymer transducers are ideal for such applications for a number of reasons. For example, because of their light weight and minimal components, electroactive polymer transducers offer a very low profile and, as such, are ideal for use in sensory/haptic feedback applications.

Figs. 1A and 1B illustrate an example of an electroactive polymer film or membrane **10** structure. A thin elastomeric dielectric film or layer **12** is sandwiched between compliant or stretchable electrode plates or layers **14** and **16**, thereby forming a capacitive structure or film. The length "l" and width "w" of the dielectric layer, as well as that of the composite structure, are much greater than its thickness "t". Preferably, the dielectric layer has a thickness in the range from about 10 μm to about 100 μm, with the total thickness of the structure in the range from about 15 μm to about 10 cm. Additionally, it is desirable to select the elastic modulus, thickness, and/or the geometry of electrodes **14, 16** such that the additional stiffness they contribute to the actuator is generally less than the stiffness of the dielectric layer **12**, which has a relatively low modulus of elasticity, i.e., less than about 100 MPa and more preferably less than about 10 MPa, but is likely thicker than each of the electrodes. Electrodes suitable for use with these compliant capacitive structures are those capable of withstanding cyclic strains greater than about 1% without failure due to mechanical fatigue.

As seen in Fig. 1B, when a voltage is applied across the electrodes, the unlike charges in the two electrodes **14**, **16** are attracted to each other and these electrostatic attractive forces compress the dielectric film **12** (along the Z-axis). The dielectric film **12** is thereby caused to deflect with a change in electric field. As electrodes **14**, **16** are compliant, they change shape with dielectric layer **12**. In the context of the present invention, "deflection" refers to any displacement, expansion, contraction, torsion, linear or area strain, or any other deformation of a portion of dielectric film **12**. Depending on the architecture, e.g., a frame, in which capacitive structure **10** is employed (collectively referred to as a "transducer"), this deflection may be used to produce mechanical work. Various different transducer architectures are disclosed and described in the above-identified patent references.

With a voltage applied, the transducer film **10** continues to deflect until mechanical forces balance the electrostatic forces driving the deflection. The mechanical forces include elastic restoring forces of the dielectric layer **12**, the compliance or stretching of the electrodes **14**, **16** and any external resistance provided by a device and/or load coupled to transducer **10**. The resultant deflection of the transducer **10** as a result of the applied voltage may also depend on a number of other factors such as the dielectric constant of the elastomeric material and its size and stiffness. Removal of the voltage difference and the induced charge causes the reverse effects.

In some cases, the electrodes **14** and **16** may cover a limited portion of dielectric film **12** relative to the total area of the film. This may be done to prevent electrical breakdown around the edge of the dielectric or achieve customized deflections in certain portions thereof. Dielectric material outside an active area (the latter being a portion of the dielectric material having sufficient electrostatic force to enable deflection of that portion) may be caused to act as an external spring force on the active area during deflection. More specifically, material outside the active area may resist or enhance active area deflection by its contraction or expansion.

The dielectric film **12** may be pre-strained. The pre-strain improves conversion between electrical and mechanical energy, i.e., the pre-strain allows the dielectric film **12** to deflect more and provide greater mechanical work. Pre-strain of a film may be described as the change in dimension in a direction after pre-straining relative to the dimension in that direction before pre-straining. The pre-strain may include elastic deformation of the dielectric film and be formed, for example, by stretching the film in tension and fixing one or more of the edges while stretched. The pre-strain may be imposed at the boundaries of the film or for only a portion of the film and may be implemented by using a rigid frame or by stiffening a portion of the film.

The transducer structure of Figs. 1A and 1B and other similar compliant structures and the details of their constructs are more fully described in many of the referenced patents and publications disclosed herein.

Fig. 2A illustrates an exemplary electroactive polymer cartridge **12** having an electroactive polymer transducer film **26** placed between rigid frame **8** where the electroactive polymer film **26** is exposed in openings of the frame **8**. The exposed portion of the film **26** includes two working pairs of thin elastic electrodes **32** on either side of the cartridge **12** where the electrodes **32** sandwich or surround the exposed portion of the film **26**. The electroactive polymer film **26** can have any number of configurations. However, in one example, the electroactive polymer film **26** comprises a thin layer of elastomeric dielectric polymer (e.g., made of acrylate, silicone, urethane, thermoplastic elastomer, hydrocarbon rubber, fluoroelastomer, copolymer elastomer, or the like). When a voltage difference is applied across the oppositely-charged electrodes **32** of each working pair (i.e., across paired electrodes that are on either side of the film **26**), the opposed electrodes attract each other thereby compressing the dielectric polymer layer **26** therebetween. The area between opposed electrodes is considered the active area. As the electrodes are pulled closer together, the dielectric polymer **26** becomes thinner (i.e., the Z-axis component contracts) as it expands in the planar directions (i.e., the X- and Y-axes components expand) (See Figs. 1B for axis references). Furthermore, in variations where the electrodes contain conductive particles, like charges distributed across each electrode may cause conductive particles embedded within that electrode to repel one another, thereby contributing to the expansion of the elastic electrodes and dielectric films. In alternate variations, electrodes do not contain conductive particles (e.g., textured sputtered metal films). The dielectric layer **26** is thereby caused to deflect with a change in electric field. As the electrode material is also compliant, the electrode layers change shape along with dielectric layer **26**. As stated hereinabove, deflection refers to any displacement, expansion, contraction, torsion, linear or area strain, or any other deformation of a portion of dielectric layer **26**. This deflection may be used to produce mechanical work. As shown, the dielectric layer **26** can also include one or more mechanical output bars **34**. The bars **34** can optionally provide attachment points for either an inertial mass (as described below) or for direct coupling to a substrate in the electronic media device.

In fabricating a transducer, an elastic film **26** can be stretched and held in a pre-strained condition usually by a rigid frame **8**. In those variations employing a four-sided frame, the film can be stretched bi-axially. It has been observed that pre-strain improves the dielectric strength of the polymer layer **26**, thereby enabling the use of higher electric fields and improving conversion between electrical and mechanical energy, i.e., the pre-strain allows the film to deflect more and provide greater mechanical work. Preferably, the electrode material is applied after pre-straining the polymer layer, but may be applied beforehand. The two electrodes provided on the same side of layer **26**, referred to herein as same-side electrode pairs, i.e., electrodes on the top side of dielectric layer **26** and electrodes on a bottom side of dielectric layer **26**, can be electrically isolated from each other. The opposed electrodes on the opposite sides of the polymer layer form two sets of working electrode pairs, i.e., electrodes spaced by the electroactive polymer film **26** form one working electrode pair and electrodes surrounding the adjacent exposed electroactive polymer film **26** form another working electrode pair. Each same-side electrode pair can have the same polarity, whereas the polarity of the electrodes of each working electrode pair is opposite each other. Each electrode has an electrical contact portion configured for electrical connection to a voltage source.

In this variation, the electrodes **32** are connected to a voltage source via a flex connector **30** having leads **22, 24** that can be connected to the opposing poles of the voltage source. The cartridge **12** also includes conductive vias **18, 20**. The conductive vias **18, 20** can provide a means to electrically couple the electrodes **8** with a respective lead **22** or **24** depending upon the polarity of the electrodes.

The cartridge **12** illustrated in Fig. 2A shows a 3-bar actuator configuration. However, the devices and processes described herein are not limited to any particular configuration, unless specifically claimed. Preferably, the number of the bars **34** depends on the active area desired for the intended application. The total amount of active area e.g., the total amount of area between electrodes, can be varied depending on the mass that the actuator is trying to move and the desired frequency of movement. In one example, selection of the number of bars is determined by first assessing the size of the object to be moved, and then the mass of the object is determined. The actuator design is then obtained by configuring a design that will move that object at the desired frequency range. Clearly, any number of actuator designs is within the scope of the disclosure.

An electroactive polymer actuator for use in the processes and devices described herein can then be formed in a number of different ways. For example, the electroactive polymer can be formed by stacking a number of cartridges **12** together, having a single cartridge with multiple layers, or having multiple cartridges with multiple layers. Manufacturing and yield considerations may favor stacking single cartridges together to form the electroactive polymer actuator. In doing so, electrical connectivity between cartridges can be maintained by electrically coupling the vias **18, 20** together so that adjacent cartridges are coupled to the same voltage source or power supply.

The cartridge **12** shown in Fig. 2A includes three pairs of electrodes **32** separated by a single dielectric layer **26**. In one variation, as shown in Fig. 2B, two or more cartridges **12** are stacked together to form an electroactive actuator **14** that is coupled to an inertial mass **50**. Alternatively, the electroactive actuator **14** can be coupled directly to the electronic media device through a temporary attachment plate or frame. As discussed below, the electroactive actuator **14** can be placed within a cavity **52** that allows for movement of the actuator as desired. The pocket **52** can be directly formed in a housing of a haptic case. Alternatively, pocket **52** can be formed in a separate case **56** positioned within the housing of the device. If the latter, the material properties of the separate case **56** can be selected based upon the needs of the actuator **14**. For example, if the main body of the haptic housing assembly is flexible, the separate case **56** can be made rigid to provide protection to the electroactive actuator and/or the mass **50**. In any event, variations of the device and processes described herein include size of the cavity **52** with sufficient clearance to allow movement of the actuator **14** and/or mass **50** but a close enough tolerance so that the cavity **52** barrier (e.g., the haptic housing or separate case **56**) serves as a limit to prevent excessive movement of the electroactive actuator **14**. Such a feature prevents the active areas of the actuator **14** from excessive displacement that can shorten the life of the actuator or otherwise damage the actuator.

Additional examples of electroactive polymer films can be found in the commonly assigned patents and patent applications disclosed and incorporated by reference herein. Roll-to-roll manufacturing is a desirable way to produce high volumes of electroactive polymer devices. Roll-to-roll manufacturing comprises providing the unprocessed stock film material in a roll form, processing the material as the stock material unrolls and ultimately singulating the finished electroactive polymer devices at the conclusion of the assembly process. One can also have a roll-to-sheet process where the film is advanced by sections in a step-and-repeat fashion. The line is organized as a series of processing stations, and a film section is advanced from station to station along the web.

The final configuration of the electroactive polymer films presents challenges when trying to produce these films in high volume. For example, the materials are preferably pre-strained to a specific, well-controlled degree prior to assembly. Maintenance of a consistent web speed and tension and registration of multiple printing or patterning steps are especially difficult on a deformable substrate. Also, elastomeric materials are often prone to damage during the manufacturing process and this damage can limit performance and reliability of the finished film.

To address these concerns and limitations, a novel process for producing electroactive polymer devices addresses the issues discussed above. In one variation the process includes separating the stock film material **300**, typically a silicone from a release liner (i.e., a liner of material that prevents the film from sticking together). Although, the stock film material **300** may comprise any material used for fabrication of electroactive polymer devices, such as disclosed in the references incorporated by reference herein. The roll-to-roll process can include rollers treated to release the stock film material **300** as it passes through the various manufacturing processes. For example, such treatment can include TEFLON coatings or other release (or non-stick) coatings that prevents the film from adhering to the roller. The rollers may also be covered with an intermediary layer such as an engineered surface, a removable liner, a compliant layer, or a deformable layer. Examples of engineered surfaces include, but are not limited to, parchment paper, texture surfaces, screen mesh, non-stick surfaces, and polymer sheets. Examples of deformable layers include, but are not limited to, foams and soft network materials such those made from ethylene vinyl acetate, silicone and polyurethanes. In an alternate variation, the process can include replacing the roll of the stock film material **300** with a feed direct from an extrusion or other manufacturing process that directly produces the film material **96**.

As the film material **96** unwinds from the stock roll **300**, a release liner **330** that separates layers of the film material **96** can be rewound **302**. As noted herein, the film material **96** may be pre-strained. In the illustrated variation the film material **96** is stretched in a machine direction (direction parallel to the travel of the material **96**) using, for example rollers **302** travelling at different speeds. The material **96** is then stretched in a transverse direction using a separate mechanism **304**. Variations include simultaneously stretching the material **96** in a machine and transverse direction (i.e., bi-axial stretchers). The desired stretch will depend upon the application as well as the desired performance of the electroactive polymer device. For example, the material can be stretched 30% in either or both the machine and transverse direction.

In some cases, it may be desirable to provide a layer of support to the film **96** after stretching. If so, a lamination layer **308** can be added to the film **96** to provide additional support for processing of the film. As discussed below, the lamination **308** also serves to reduce the occurrence of breaks in the film **96** as well as limit the breakage areas to non-critical sections of the film **96**. This lamination layer **308** is sometimes referred to as a "rip-stop" layer or film. The rip-stop lamination layer may also include any number of openings that allow for further processing of the film **96**. Though not shown, any number of cutouts can be included in the rip-stop layer **308** as long as the ability to provide support is not lost and the film **96** does not buckle during processing. The rip-stop layer **308** may comprise any number of polymeric materials, including polyethylene terephthalate, polyester and polycarbonate. The rip-stop layer **308** may have a surface treatment to optimize its interaction with the film **96**. To provide sufficient support and tear resistance, the rip-stop layer **308** should have good surface blocking or bond to the film **96**. Accordingly, the rip-stop layer **308** can be laminated to the film **96** using an adhesive layer, coatings, or tape. Preferably, the rip-stop layer **308** may include openings that allow for further processing of the film **96** into the electroactive polymer device. These openings may be created by any conventional process such as stamping, cutting, etching, etc. Although the laminated film **96** with rip-stop **308** can proceed through the manufacturing process, as illustrated in Fig. 3A, alternate variations of the process can include re-winding the film **96** after lamination with the rip-stop layer **308.**

A printed layer can be used as an alternative to a laminated rip-stop layer. The printed material can be any material that can be applied to the film and cured or dried in place that is tougher and more tear resistant than the film. Examples of suitable materials include, but are not limited to, polyurethanes, silicones, acrylates, and epoxy systems.

Next, the film **96** with rip-stop **308** is fed through one or more electrode printing assemblies **310**. The electrode printing assembly **310** may also optionally print the bus bar connection for the electrodes on both sides of the film **96**. Any number of web-printing processes can produce the electrodes necessary for the electroactive polymer device, including flexographic printing, gravure (also called rotogravure or roto printing), screen printing, rotary screen printing, ink jet printing, aerosol jet printing, etc. The printing process may be adjusted for the offset caused by the openings in the rip-stop layer (for example, the print rollers can have raised bosses that are timed to print on the unlaminated portion of the film **96**). Furthermore, registration of the film **96** web positions may be necessary to ensure electrodes are printed within the openings of the rip-stop lamination as well as on the web of film **96**. Any such registration commonly used in printing or similar applications may be applied to the process disclosed herein.

Fig. 3A also illustrates printing occurring on both surfaces of the film **96**. As noted above, electrode placement is required on each side of the film **96**. In alternate variations of the process, printing can occur on a single side of the film **96**, which is then rewound and reprocessed with printing occurring on the opposite side in a subsequent process. Alternatively, the single-sided printed film may be stacked or laminated where the single electrode can be used to service two adjacent films in a multilayer stack. In any case, registration may be necessary to ensure that printing of electrodes on opposing sides of the film material and on different sections of the film is within manufacturing tolerances.

Once the electrodes are placed on the film **96**, the film **96** can be re-wound **312** with an interleaf or separation layer **314** positioned between layers of the film **96**. Alternatively, the film **96** can continue for additional processing to assemble the electroactive polymer frame and support structures as described herein.

Fig. 3B illustrates an example of further processing of the printed elastomeric film **96** material in a process that produces a double layered electroactive polymer device. As shown, two sources of the printed film **96** can be fed **316** or unwound and joined to form a double layer of electroactive polymer film **96**. The film may optionally be bonded or laminated depending upon the desired application. Next, one or more cartridge frames **318** may be added or bonded to the film **96** on both sides of the double layered electroactive polymer film **96**. In addition to placement of the frames, one or more output bars or center discs **320** may be positioned by each electrode on the opposing sides of the double layer electroactive polymer film **96**. Structural elements such as flexures may also be placed onto the film. Additional printing stations may be used to print adhesives or structural materials for the frames, flexures, and output bars. Finally, the finished electroactive polymer devices can be removed from the web (e.g., die cut, punched, laser cut, etc.). Clearly, variations of the process may include removal of the materials after any stage of processing so the device can be completed in a batch process rather than on the conveyor assembly system. Moreover, variations of the process include re-winding of the finished electroactive polymer device for subsequent removal.

In an alternate variation, a process for fabricating an electroactive polymer device may include UV, thermal, or surface treatment of the elastomeric polymer. The present inventors have found that UV treatment of the film prior to depositing electrodes on the film results in improved stroke performance of the finished actuator. While not wishing to be bound to any particular theory, the present inventors believe UV exposure, silicone, polyurethane, acrylate, hydrocarbon rubber, olefin copolymer, polyvinylidene fluoride copolymer, fluoroelastomer, styrenic copolymer, and adhesive elastomer may change the surface energy of the film to improve uniformity of the electrode deposition. Further, the inventors speculate that UV curing may change the bulk modulus or other properties of the elastomer making it more compliant and UV treatment may modify residual functional groups in the polymer film that cross-link during thermal loading in the manufacturing process.

Regardless of the actual mechanism, the present inventors have found UV curing is an effective treatment to improve the stroke performance of actuators. In one example, UV curing improved a pulse response of an actuator by 20% and characterized the actuators with lower resonant frequency as compared to a non-UV cured elastomer. The parameters for UV curing will vary depending on a number of factors and the desired application of the end electroactive polymer device. In one example, it was found that UV curing of 6.5-7.0 J/cm$^2$ was an optimum point of UV treatment that improved stroke performance for actuators. Another unexpected benefit of UV curing (prior to deposition of electrodes) is that the queue time between UV curing and electrode printing was not a sensitive factor. In the study conducted by the present inventors, the queue time could last as long as 25 days. This finding may potentially allow for UV curing during or immediately after pre-straining the film. In some cases, it may be possible to treat the elastomer during film manufacture so that the benefits are retained from when the elastomeric film is made to when the film is processed as described herein.

One of the problems with attempting to use roll-to-roll manufacturing for elastomeric films (such as silicone) is that the film is relatively thin (e.g., 23 μm) while having a very low modulus. The compliant film cannot remain flat without applying pre-strain but at the same time, the film can tear or break easily. Furthermore, to ensure that the device is manufactured to meet high actuator performance, the film requires a high level of applied strain during printing and lamination. Without a frame to hold and maintain the pre-strain, the electrode pattern printed on the film has a high chance of deforming and registration of the printed patterns is likely to be poor. If the film deforms during the printing operations, the film may be rendered non-functional for use in the electroactive polymer actuators.

To address this issue, a variation of the inventive manufacturing process includes applying a uni-axial pre-strain to the electroactive polymer film. Experiments have shown that uni-axial strain can match the stroke performance of regular bi-axial pre-strained films under certain conditions.

Uni-axial pre-strain magnitude can be defined by an index of thickness, the same as biaxial pre-strain after stretching. For example, uni-axial strain (67% thickness direction and 0% strain in XY direction) and biaxial strain (30% in two directions) can have similar film thickness ranges. The longer output bar direction is parallel to the uni-axial pre-strain direction.

To achieve uni-axial pre-strain in a roll-to-roll system, perforated belts **360**, as shown in Figs. 4A and 4B, may be used to hold the two edges of the elastomeric film **96** in the web (longitudinal) direction. The uni-axial strain may be applied by stretching the film in lateral direction, while in the web direction there is zero or low pre-strain. The output bar of the electroactive polymer cartridge can be designed to be perpendicular to the web direction. One variation of the process includes the use of perforation (or sprocket or pin-fed) rollers to hold the belts and film while controlling the degree and direction of strain (See Figs. 4C and 4D).

The lateral and longitude position of the belts **360** can be controlled precisely through the perforation rollers so the local strain will be consistent and stable. This allows for multiple printing and curing steps as described herein. The major strain is defined by the distance between two belts **360** on the two long edges of elastomeric film **96**.

The belts **360** may be constructed from a material that is much stiffer than the elastomeric film. For example, the belts **360** can comprise polyethylene terephthalate, which has a Young's Modulus between 2800-3100 MPa and tensile strength is 55-75 MPa. In contrast, silicone (a common material for the elastomeric film) has Young's Modulus of 1-5 MPa and tensile strength is 5-8 MPa. Accordingly, polyethylene terephthalate is about 1000 times stiffer than silicone film.

When applying tension through the rollers **362**, the majority of force will be applied to the polyethylene terephthalate belt **360** rather than the film **96**. For example, assuming 5% elongation on the web, 400 out of 401 parts of force is applied on the polyethylene terephthalate belt while 1 part is applied on silicone film (assuming polyethylene terephthalate is 50 μm thick and 25 mm wide; while silicone film is 25 μm thick and 500 mm wide). This avoids the need to use tension rollers directly on the silicone film to control the strain of the film. If tension rollers were used, any small change in tension applied to the silicone film would lead to a great change in film elongation which would be difficult to control.

Biaxial stretching may be accomplished with perforated belts if the belts are constructed of stretchable material or are segmented, e.g. with perforated lines, so sections of the belt can separate upon stretching along the web direction while remaining engaged with the perforated rollers or guide chains along the edge of the web.

Fig. 5A illustrates a variation of a printing process useful in manufacturing electroactive polymer transducers. This process can be especially useful in large volume manufacturing of the transducers. Fig. 5A illustrates a configuration used in a screen print process for large volume manufacturing of electroactive polymer actuators. In this variation, an elastomeric film **96** is held in a frame **340** with a liner **342** that is attached to the backside of the film. The liner **342** assists in release of the film **96** from the aluminum vacuum tooling **344** after the screen printing process. The liner **342** also serves to stabilize the film **96**, which improves control over dimensional tolerances of the printed film **96**. Although liners **342** are effective, the use of the liners may increase process time, setup time, and cost while reducing throughput of the manufacturing process. Furthermore, increased handling of the electroactive polymer film, from applying and removing the liners, can increase the chances of damage to the film. Moreover, the liners can damage the film if the liner does not release easily or if air or other particles become trapped between the film and the liner.

Fig. 5B illustrates a variation of a printing configuration that eliminates the requirement of a liner similar to that shown in Fig. 5A. In this variation the electroactive polymer film **96** remains secured to a frame. The setup also includes a base plate (e.g. constructed from aluminum or a similar material) having vacuum openings **346** used to retain the film **96**. The variation illustrated in Fig. 5B includes an engineered top surface **348** (e.g., parchment paper, screen mesh, polymer sheet, textured surface, non-stick surface, or a similar material). The engineered surface **348** should have sufficient tack properties that it holds tolerance, provides differential release from the screen, and releases the elastomeric film **96** after the printing process. The printing configuration also may include a compliant intermediate layer **350** that creates a relatively soft, firm, and level surface for printing. The compliant layer **350** may include a very high bond adhesive, rubber, or other similar material. As illustrated, the print tooling configuration may include vacuum apertures **346** to assist in holding the film **96** in place during printing and to ease release (via cessation of the vacuum force).

Fig.5C demonstrates yet another variation of a tooling configuration used for screen printing of the film **96**. In this variation, the film **96** contacts a deformable layer such as a foam sheet **352** directly without the use of any type of layer such as the engineered surface or the liner described in Figs. 5A and 5B. The deformable layer provides a soft tooling effect and may comprise a material such as ethylene vinyl acetate foam. In one example, the deformable layer comprises an ethylene-vinyl acetate film with 2 mm thickness and a 75+/- 5 Shore 00 hardness. Other soft materials such as silicones and polyurethanes may also be used. The deformable layer may have a textured or treated surface to aid in its release properties from the film. As with the other variations, the foam layer **352** includes a plurality of vacuum holes that help secure the film **96** to the foam and release the film upon cessation of the vacuum force. With some open-celled foams, vacuum holes may not be needed.

The soft tooling described in Fig. 5C above provides an additional benefit by allowing formation of patterns which aid in the manufacturing process. For example, as shown in Fig. 6, the foam layer may be etched to produce a pattern **356** that is related to the design of the feature or part being printed on the elastomeric film. The illustration shown in Fig. 6 relates to a pattern **356** that assists in creating a bus bar on the electroactive polymer device. As the modified tooling **354** contacts the film (not shown in Fig. 6), the compression of the soft tooling allows for differential pressure zones based on the depth and/or size of the pattern **356**. For example, in the modified soft tooling **354** shown the regions containing the patterns **356** will create zones of lower pressure than the continuous regions **358**. Accordingly, during screen printing, the lower pressure zones will result in greater print thickness compared to the remainder of the printed electrode. The ability to perform multiple thickness printing in one step has the potential to improve throughput as compared to needing sequential printing steps.

Apart from improving efficiency, the ability to produce areas of varying thickness also results in improved device performance. For example, in one example, printing of a thicker bus bar with modified soft tooling resulted in a bus bar resistivity that was four times lower than resistivity of the bus bar produced with unmodified soft tooling. Generally, the depth of the pattern is calculated based on the initial print pressure, tooling hardness and ink viscosity. In one example, the depth of the patterns ranged between 150-200 μm for electrode ink given a 1.7 mm ethylene vinyl acetate foam.

Any of the tooling configurations discussed above may optionally include additional materials that enhance maintenance, serviceability, or improve performance. Examples of such materials include, but are not limited to, coatings, adhesives, release agents, etc. These tooling configurations may also be used to print inks other than conductive electrode inks and print onto deformable substrates other than those used for electroactive polymer transducers.

In another embodiment of the present invention a fibrillated (net) microstructure that demonstrates extra stability in sheet resistance under large strain cycles is provided. An electroactive polymer structure comprises a dielectric polymer film and two compliant electrodes. When a voltage is applied across the electrodes, the film contracts and expands in area. Flexographic printing, rather than screen printing, can produce a fibrillated (or net) microstructure as shown in Fig. 7B. Comparing the square pattern microstructure (shown in Fig. 7A) made by screen printing with this net microstructure resulting from flexographic printing in conjunction with Table 1, reveals a significant improvement in the consistency of sheet resistance, using the same dielectric polymer film and the carbon ink in the two processes.

The preferred flexographic layers are: rip-stop / electrode / bus bar / adhesive / pressure sensitive adhesive. To build up such a robust structure, the conductivity of electrodes should be kept consistent under cycling strain. Sheet resistance can vary from 25k to 125k as with screen printing; with a production flexographic tool, the consistency can be well controlled.

**Table 1**

| **Printing Process** | **Initial reading** | **Removal of liner** | **100% XY strain manipulation for 10 times** |
|---|---|---|---|
| Screen printing | 550 | 1700 | 4500 |
| Flexographic printing | 65 | 64 | 70 |

Alternatively, similar net structures may be made through control of ink surface tension, creation of proper mechanical pre-tension of the dielectric film, or taking advantage of some other printing processes, such as ink jet/aerosol jet/curtain/slot/wire coating. The pattern on the roller is also a design factor with possibilities of cell pattern or line (curve) patterns with different angles. Controlling the density of the fibrillated structure may allow one conductive material to be used for charge distribution, with or without an additional coating of lower conductivity ink as electrodes.

The inventive fibrillated microstructure may be built up for use as electrodes or bus lines by certain printing processes or wetting/dewetting patterns from controlling the surface tension of the materials. A complicated mask or template may not be necessary to produce such a net pattern.

Figs. 8-10, show the inventive concept of using a web flex frame with open precut patterns sandwich with stretched silicone film, loading of substrates for printing multiple layers, and final lamination. The substrates may be loaded continuously or advanced in a step and repeat fashion. As shown in Fig. 8, web frame **82** holds pre-strained silicone film **86** in shape without deformation during web movement. The web frame **82** is similar to a rigid aluminum frame; but the web frame is continuous with flexibility in the Z direction so it can be driven by rolls **88**. There are two sets of web frames **81, 82** on the top **81** and the bottom **82** of the silicone film **86**. Surface tension, blocking forces, magnetic force (permanent or electro-driven), or mechanical interlocks may be used to sandwich the silicone film between web frames **81, 82**. The web frame holder material may include rubber coated metal foil as a composite material allowing flexibility in the Z direction to move as the web and rigidity in the X-Y directions to hold the film. The rubber or coating surface may be designed to be released from silicone film after lamination is completed so that the debris of silicone film after device singulation can be easily cleaned before starting another cycle.

As shown in Fig. 9, several printing stations **92, 94** may be aligned sequentially on the web **90**; lamination module **196** is the last step on the web. Through the open window precut on the web frame, there is a printing station **92** to deposit inks on silicone film. The printing direction may be perpendicular to the web movement direction to conserve space so the line may be shorter. There may be curing or drying stations (not shown) between printing station(s). To save time or shorten the length of the web path, the ink may only be dried or partially cured instead of fully cured before the film moves to a subsequent printing station.

After adhesive printing **94**, there is a laminating station **196** that may be arranged in a perpendicular direction as well. A rotary die cutting station (not shown) may be used to make patterns of frame layers on a roll. The pre-cut frame pattern may have pressure sensitive adhesive on one or both sides so it is ready for lamination.

An example process flow for the lamination process for a four-layer electroactive polymer transducer is as follows:

1. The precut frame layer is transferred to the lamination station as the frame top layer;
2. layer 4 with adhesive on the web frame holder is transferred to the lamination station, pressure/heat is applied and the web frame holder is removed;
3. step 2 is repeated with layers 3, 2, 1, sequentially,
4. the precut frame bottom layer is laminated to the stack.

The frame layers may be precut on a rotary die cutter. The lamination station may have a thermal heating function to pre-cure adhesive in-between layers such that each new layer adheres to previous layers tightly. After lamination, the entire sheet of cartridge stack may be sent to the curing station for final full cure and singulation with a die cutter.

The layers may have different patterns of electrode and bus bar. This may be done without introducing extra printing steps. One way to do this, for example, is to make the electrode/bus left on the left half of screen and electrode/bus right on right half of the layer. Many other combinations may be envisioned to produce this on one single continuous web.

As shown in Fig. 10, in one embodiment, layout of the line is as follows: stretching → sandwiching → printing(s) → lamination.

The web movement on the sandwiched frame-film-frame may be more complex than as illustrated. For example, a means to flip the web may be included so both sides of film may be printed with screen printing or flexographic printing. If non-contact printing is applied, such as aerosol jetting, both sides may be printed simultaneously to simplify the web design.

As for other details of the present invention, materials and alternate related configurations may be employed as within the level of those with skill in the relevant art. The same may hold true with respect to process-based aspects of the invention in terms of additional acts as commonly or logically employed. In addition, though the invention has been described in reference to several examples, optionally incorporating various features, the invention is not to be limited to that which is described or indicated as contemplated with respect to each variation of the invention. Various changes may be made to the invention described and equivalents (whether recited herein or not included for the sake of some brevity) may be substituted without departing from the true spirit and scope of the invention. Any number of the individual parts or subassemblies shown may be integrated in their design. Such changes or others may be undertaken or guided by the principles of design for assembly.

Also, it is contemplated that any optional feature of the inventive variations described may be set forth and claimed independently, or in combination with any one or more of the features described herein. Reference to a singular item, includes the possibility that there are plural of the same items present. More specifically, as used herein and in the appended claims, the singular forms "a," "an," "said," and "the" include plural referents unless the specifically stated otherwise. In other words, use of the articles allow for "at least one" of the subject item in the description above as well as the claims below. It is further noted that the claims may be drafted to exclude any optional element. As such, this statement is intended to serve as antecedent basis for use of such exclusive terminology as "solely," "only" and the like in connection with the recitation of claim elements, or use of a "negative" limitation. Without the use of such exclusive terminology, the term "comprising" in the claims shall allow for the inclusion of any additional element - irrespective of whether a given number of elements are enumerated in the claim, or the addition of a feature could be regarded as transforming the nature of an element set forth in the claims. Stated otherwise, unless specifically defined herein, all technical and scientific terms used herein are to be given as broad a commonly understood meaning as possible while maintaining claim validity.

## WHAT IS CLAIMED IS:

1. A process for producing a patterned deformable polymer film for use in a deformable polymer device, the process comprising:

positioning an intermediary layer between a deformable film and a process tooling; and

printing at least one electrode on the deformable film by depositing an ink to form the at least one electrode on a first surface of the deformable film, wherein the intermediary layer permits release of the deformable film from the process tooling subsequent to the printing process.

2. The process according to Claim 1, wherein the ink is deposited by one selected from the group consisting of screen printing, pad printing, gravure printing, ink jet printing, flexographic printing and aerosol jet printing.

3. The process according to one of Claims 1 and 2, wherein the intermediary layer comprises at least one selected from the group consisting of an engineered surface, a removable liner, a compliant layer and a deformable layer.

4. The process according to Claim 3, wherein the engineered surface is a surface selected from the group consisting of a parchment paper, a textured surface, a non-stick surface, screen mesh and a polymer sheet.

5. The process according to Claim 3, wherein the deformable layer comprises a foam material.

6. The process according to Claim 3, wherein the deformable layer comprises a plurality of cavities, wherein the cavities permit regions of varying pressure during screen printing, and wherein the process further comprises depositing ink at varying levels on the first surface of the deformable film.

7. The process according to any one of Claims 1 to 6, wherein the deformable polymer film comprises an electroactive polymer film.

8. The process according to any one of Claims 1 to 7 further comprising:
advancing a deformable film of an elastomeric material from a supply of elastomeric material;
mechanically straining the deformable film to create a first pre-strained film section remaining continuous with the supply of elastomeric material;
supporting the first pre-strained film section such that the first pre-strained film section comprises a supported portion and an unsupported portion;
depositing ink to create at least a first electrode on a first side of the unsupported portion of the first pre-strained film section;
depositing ink to create at least a second electrode on a second side of the unsupported portion of the first pre-strained film section opposing the first electrode and forming at least one opposing electrode pair to complete at least a first section of electroactive polymeric film; and
collecting the first section of electroactive polymeric film.

9. The process according to Claim 8, further comprising:
mechanically straining the deformable film to create a second pre-strained film section remaining continuous with the deformable film;
supporting the second pre-strained film section such that the second pre-strained film section comprises a supported portion and an unsupported portion;
depositing ink to create at least a first electrode on a first side of the unsupported portion of the second pre-strained film section; and
collecting the second section of electroactive polymeric film.

10. The process according to Claim 9, further comprising stacking or laminating the first and second sections of electroactive polymeric film together.

11. The process according to any one of Claims 8 to 10 further comprising applying at least one structural component selected from the group consisting of output bars, frames and flexures.

12. The process according to Claim 8, wherein the film of elastomeric material comprises a first and second belt member on respective near and far edges of the film, and wherein each belt member comprises a material having a Young's Modulus greater than a Young's Modulus of the film.

13. The process according to Claim 12, wherein the first and second belt members comprise perforated belt members and wherein perforation rollers are used to mechanically strain the film.

14. The process according to Claim 8, wherein the film of elastomeric material is mechanically strained substantially in a direction selected from the group consisting of transverse to the direction of travel of the advancing film, parallel to the direction of travel of the advancing film, equally in transverse and parallel directions, or in an unequal combination of transverse and parallel directions.

15. The process according to Claim 8, wherein the film is advanced in a step-wise fashion.

16. The process according to Claim 8, wherein collecting the first section of electroactive polymer film comprises winding a plurality of sections of electroactive polymer film to form a roll of electroactive polymer films.

17. The process according to Claim 16 further comprising feeding at least two rolls of electroactive polymer films into a lamination station and applying at least one selected from the group consisting of a frame, an output bar, and a flexure to at least the first layer of electroactive polymer films to assemble a multi layered electroactive polymer actuator device.

18. The process according to any one of Claims 8 to 17, wherein supporting the first pre-strained film section comprises applying a supporting layer to the first pre-strained film section.

19. The process according to any one of Claims 1 to 18, wherein the pre-strained electroactive polymer has an elastic modulus below 100 MPa.

20. The process according to any one of Claims 1 to 19, wherein the polymer is selected from the group consisting of silicone, polyurethane, acrylate, hydrocarbon rubber, olefin copolymer, polyvinylidene fluoride copolymer, fluoroelastomer, styrenic copolymer, and adhesive elastomer.

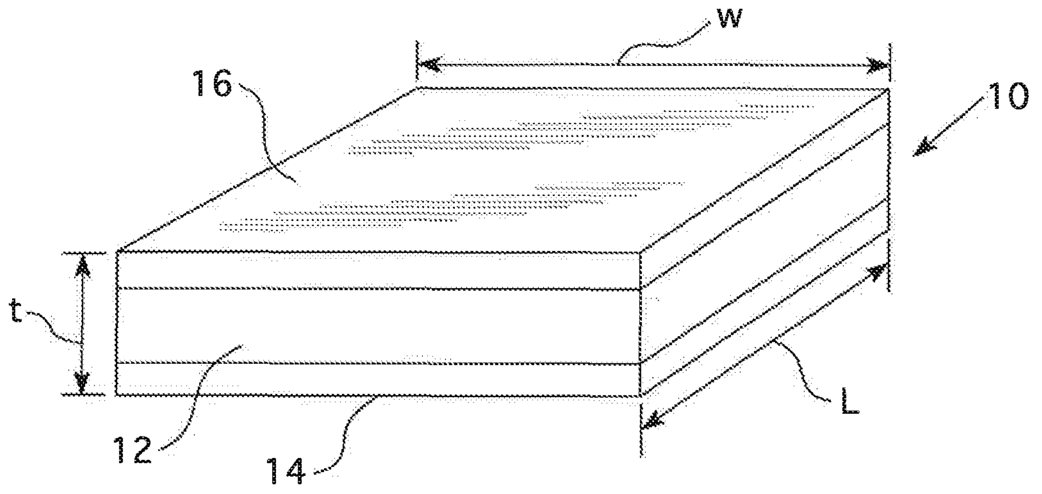


FIG. 1A

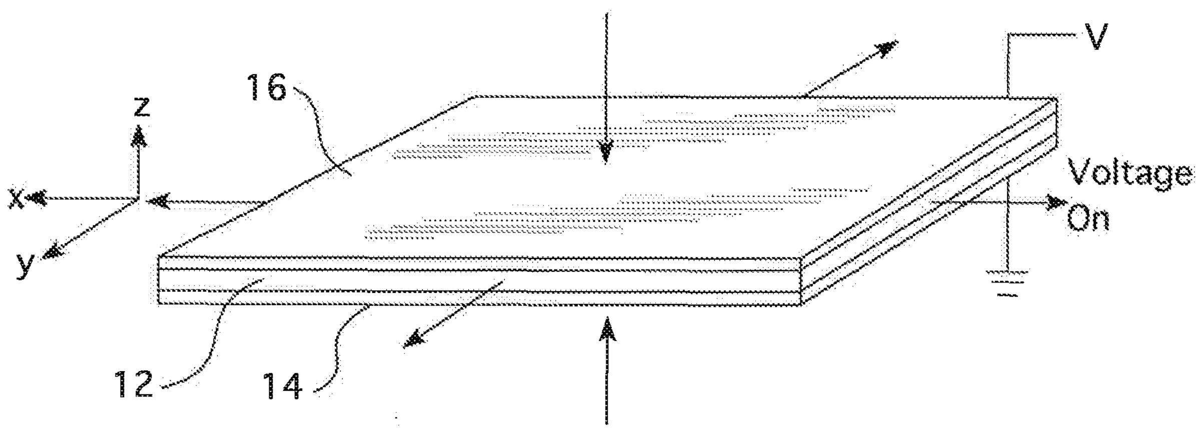


FIG. 1B

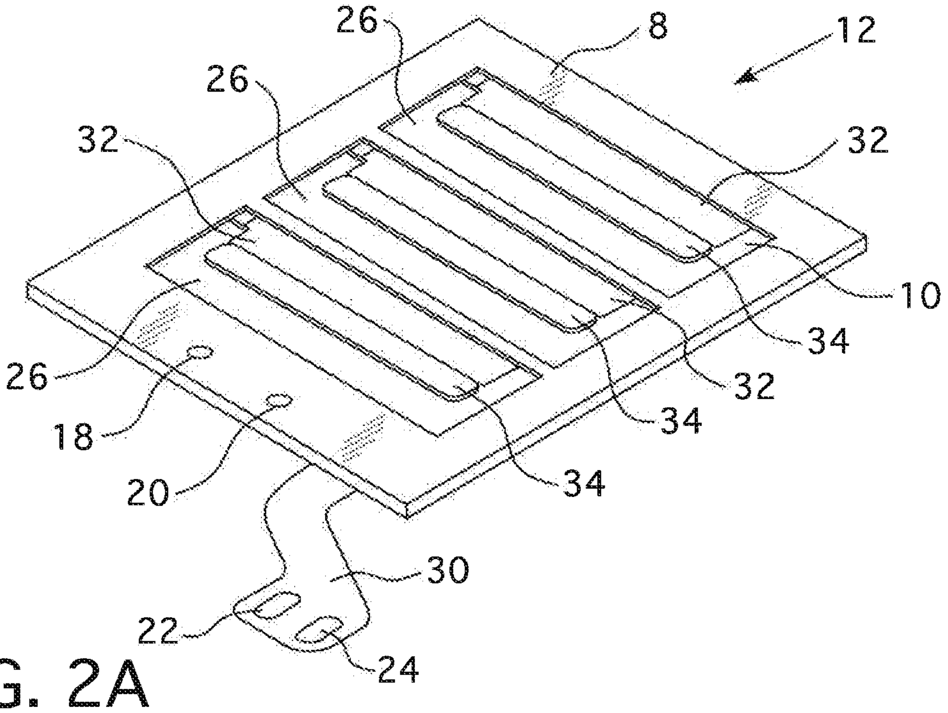


FIG. 2A

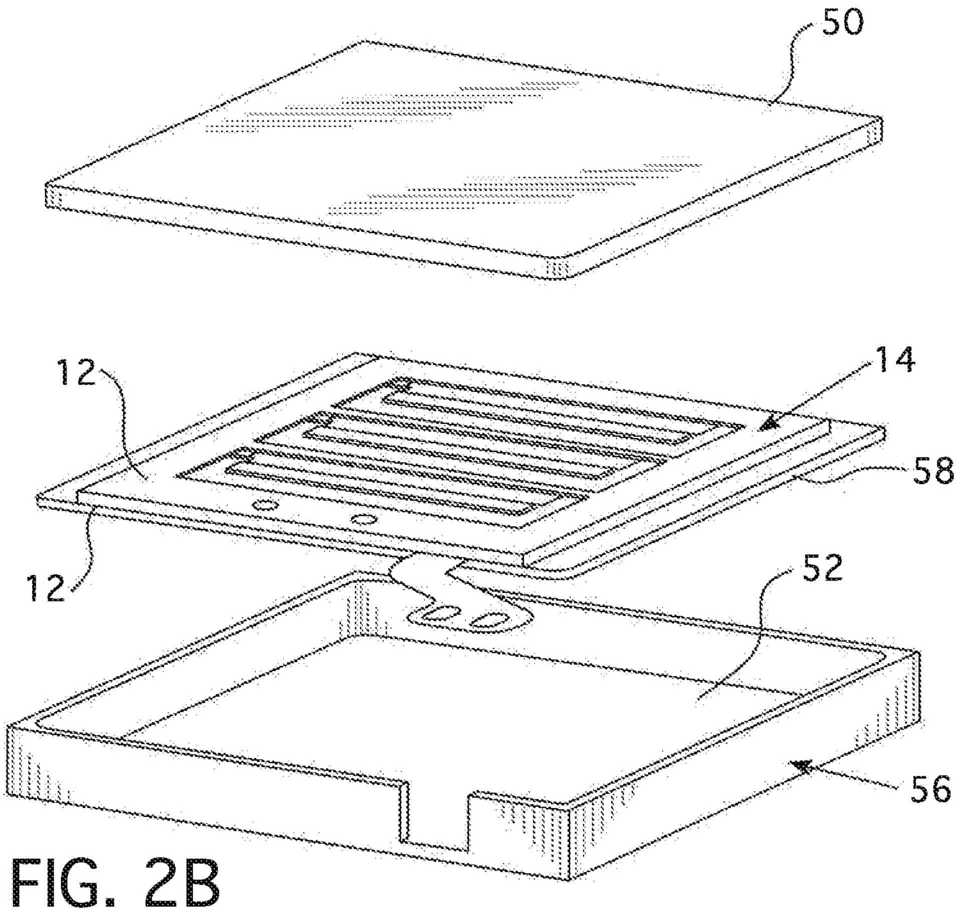


FIG. 2B

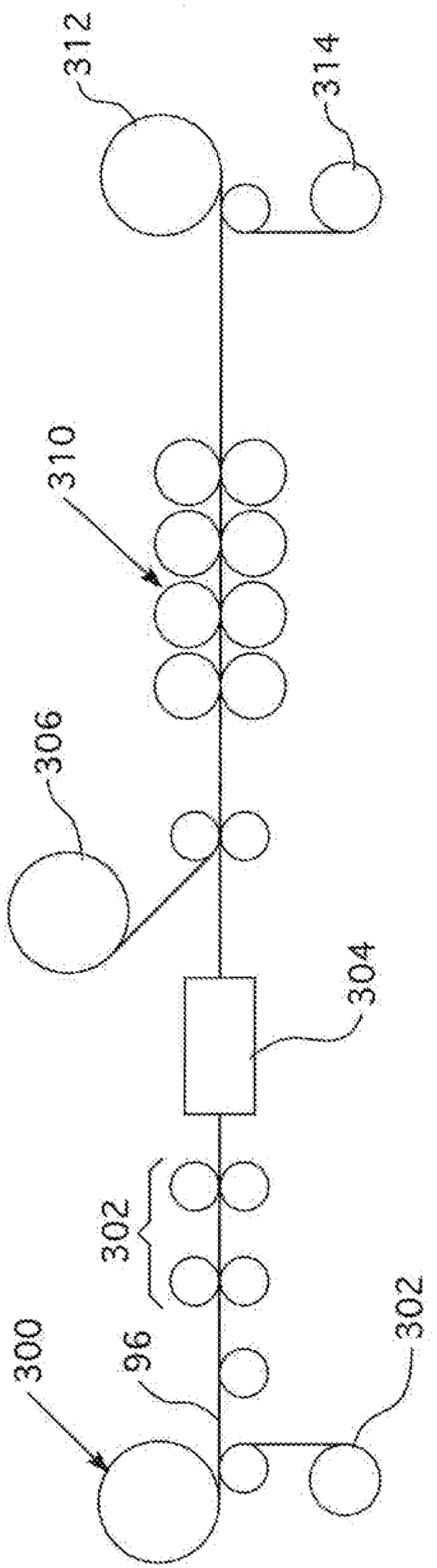


FIG. 3A

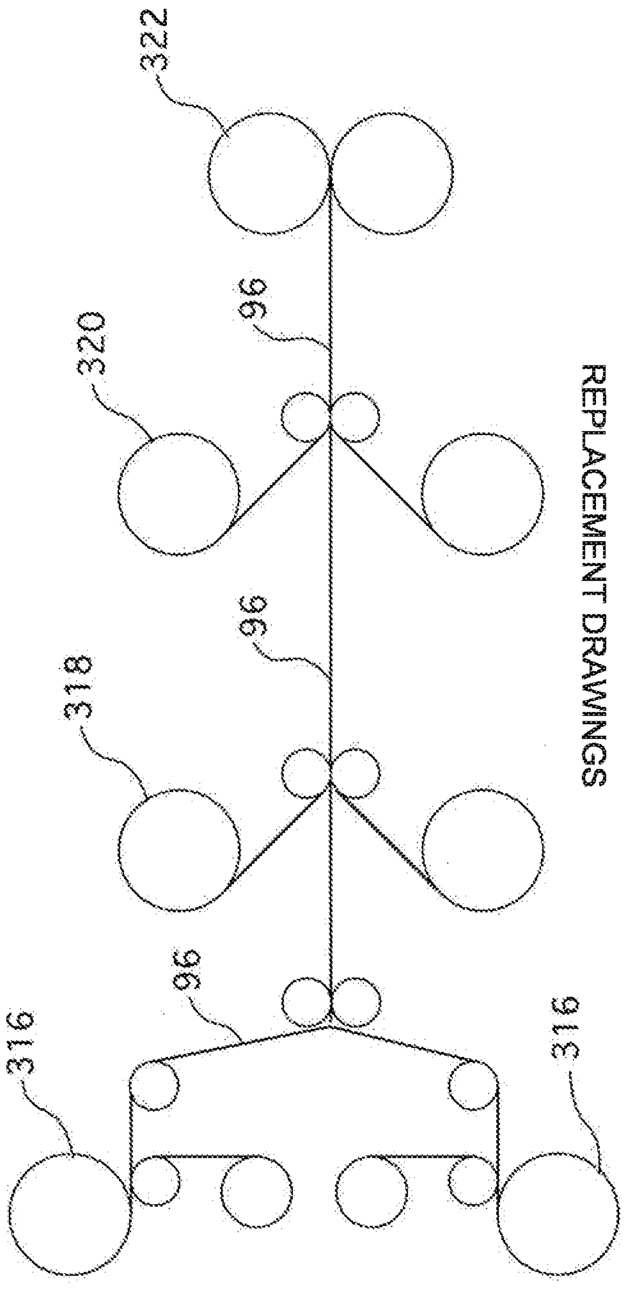


FIG. 3B

REPLACEMENT DRAWINGS

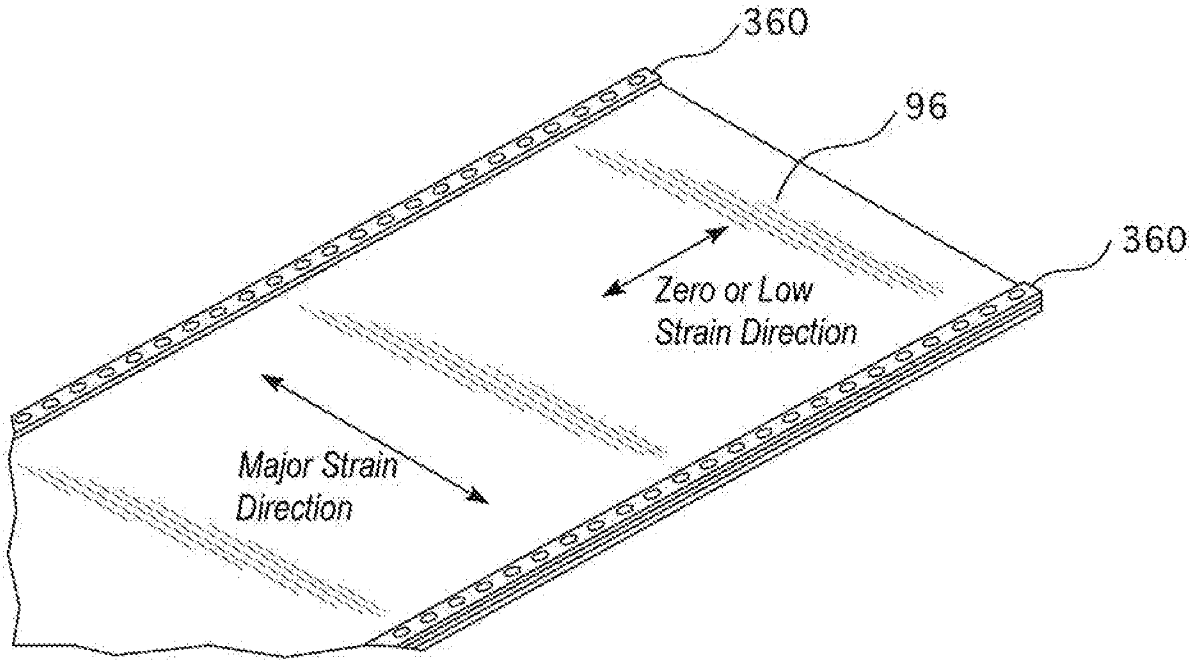
360
96
360
Zero or Low
Strain Direction
Major Strain
Direction

FIG. 4A

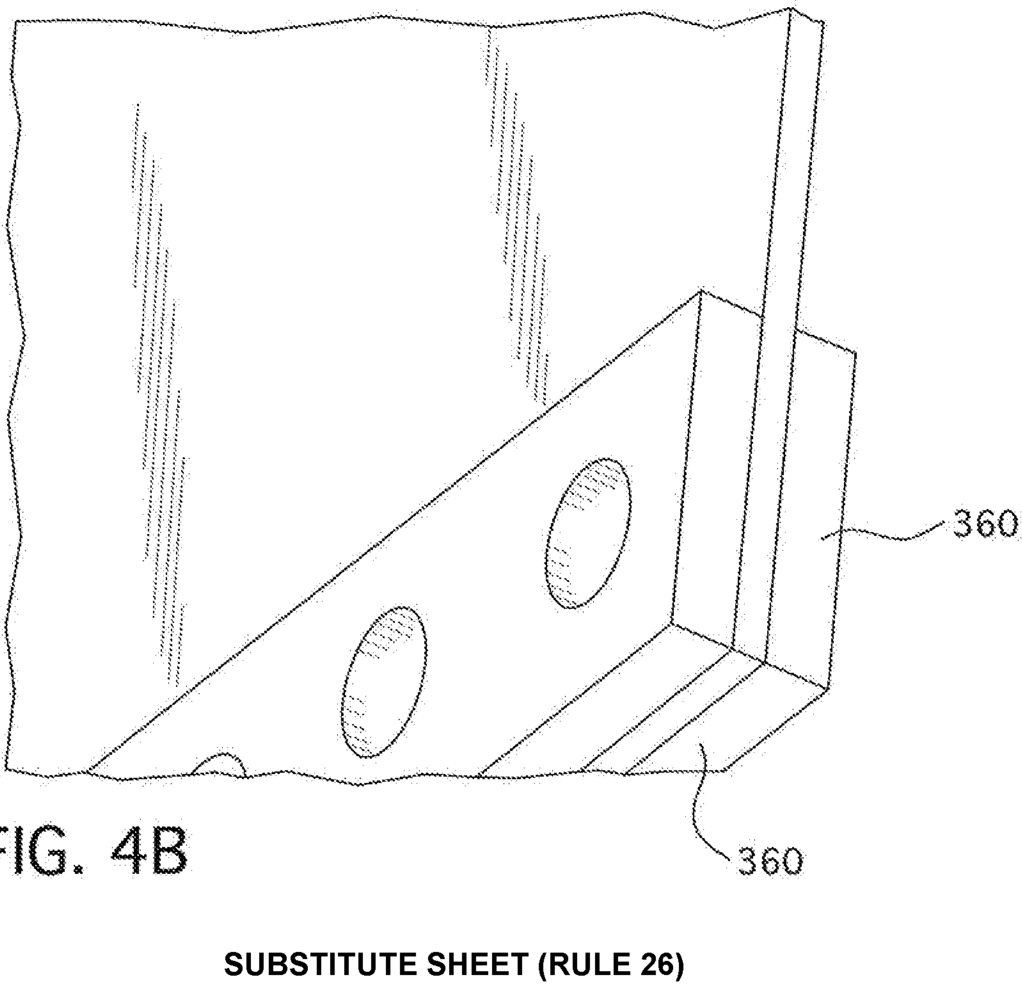
360
360

FIG. 4B

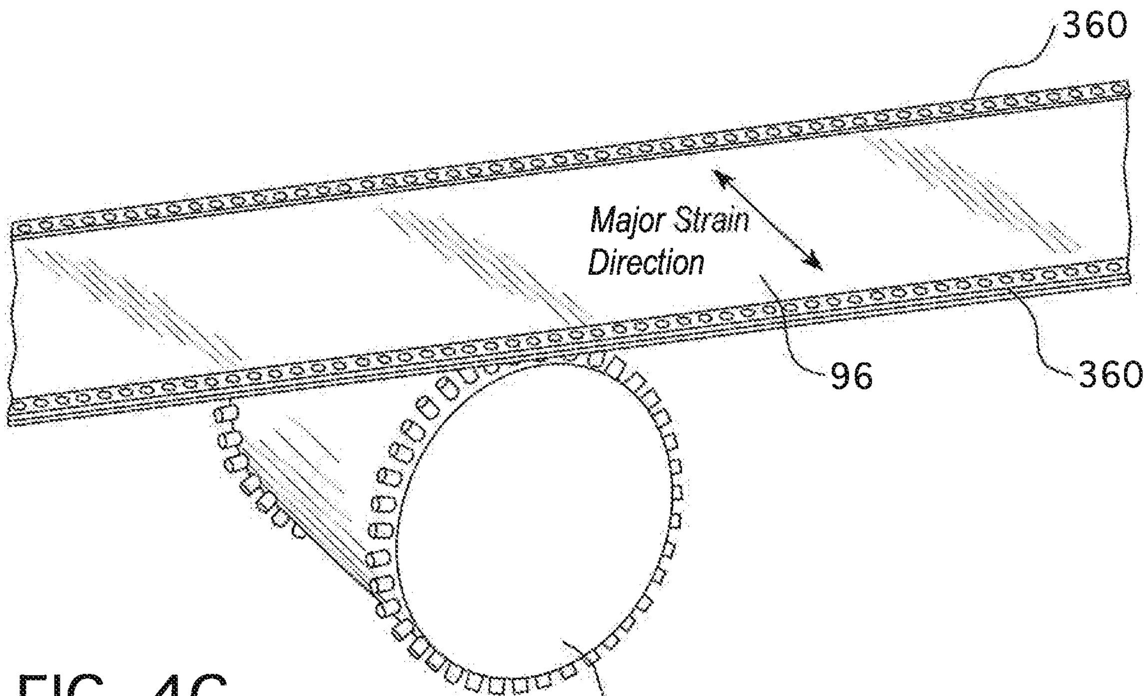
360
Major Strain Direction
96
360
362

FIG. 4C

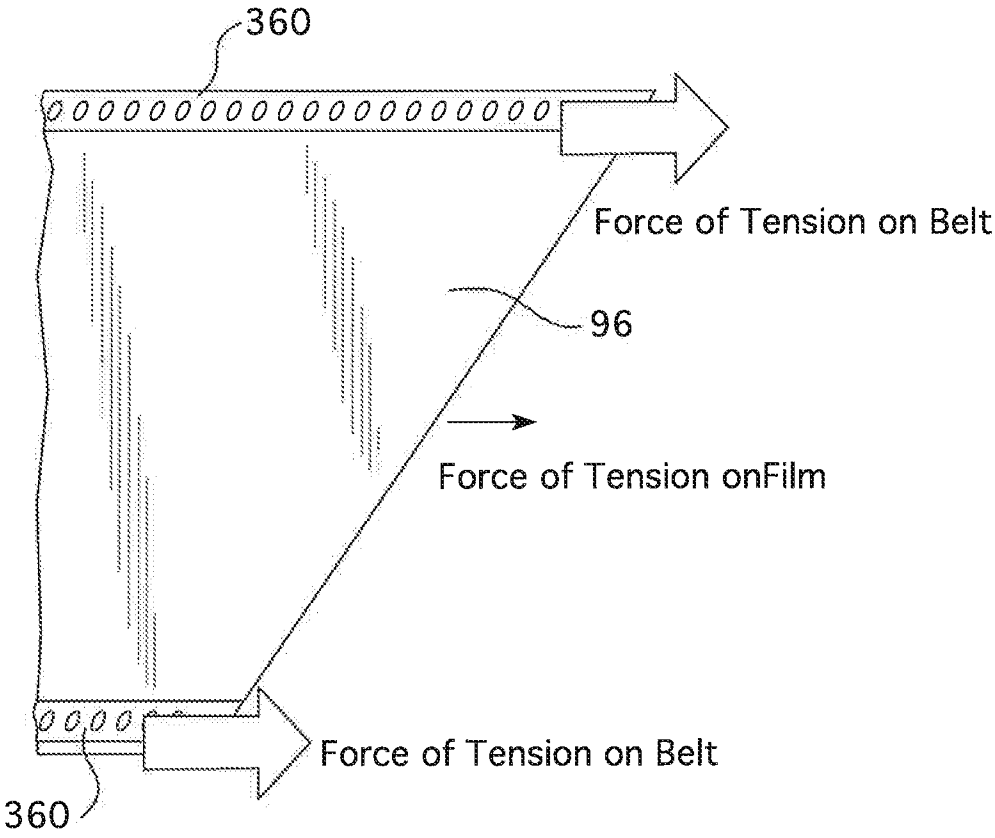
360
Force of Tension on Belt
96
Force of Tension onFilm
Force of Tension on Belt
360

FIG. 4D

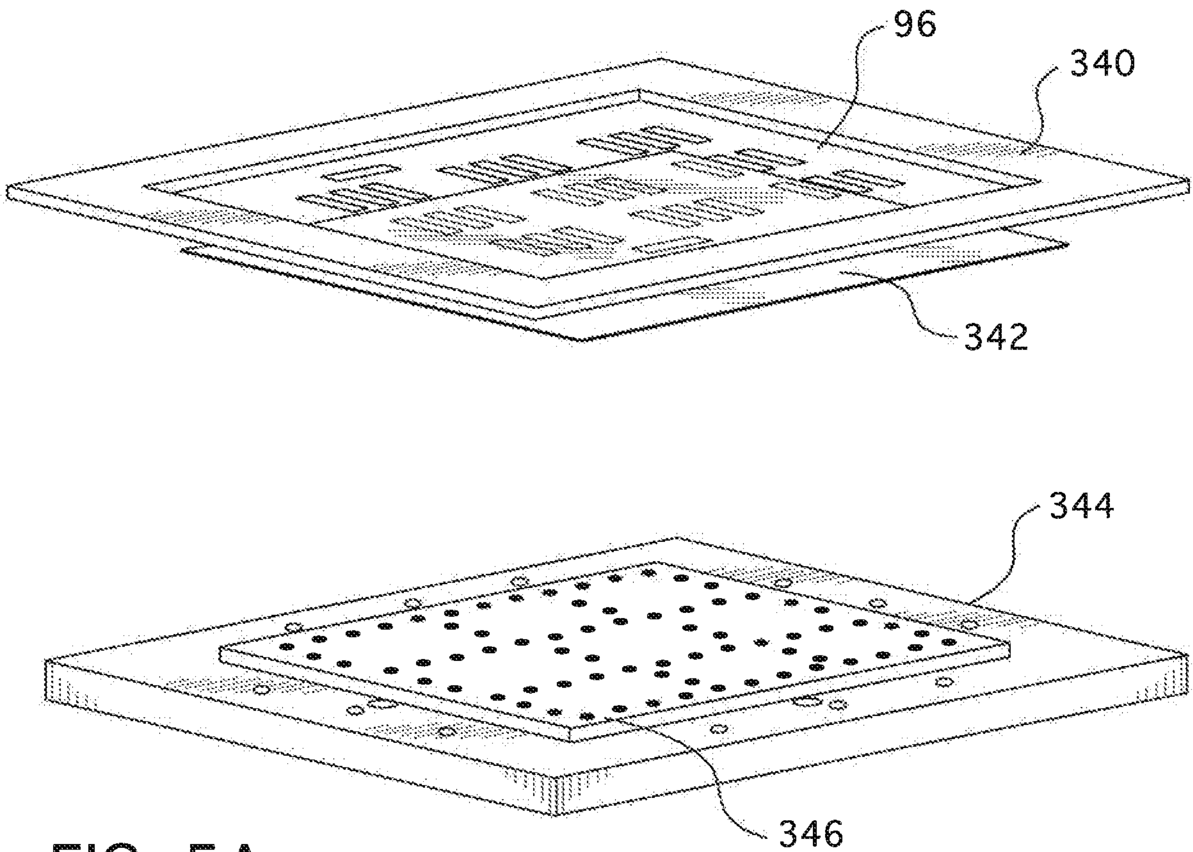


FIG. 5A

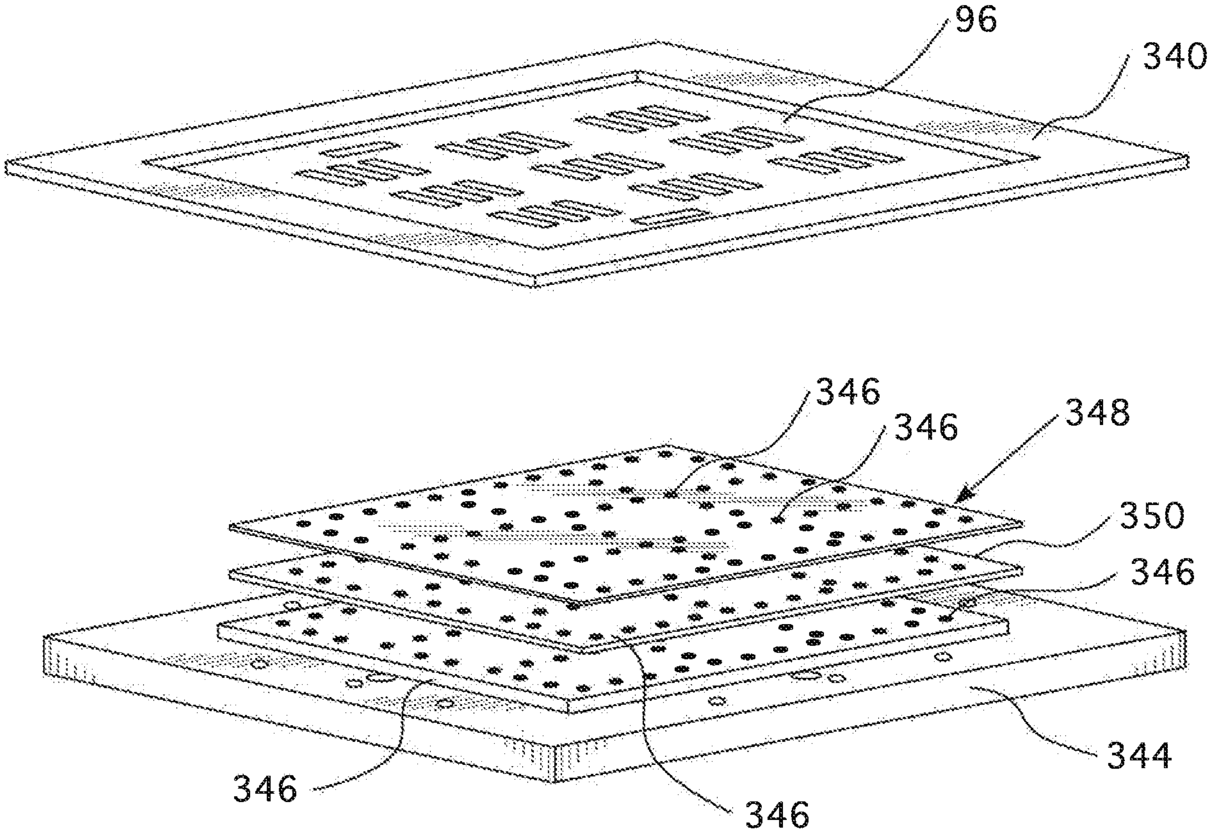


FIG. 5B

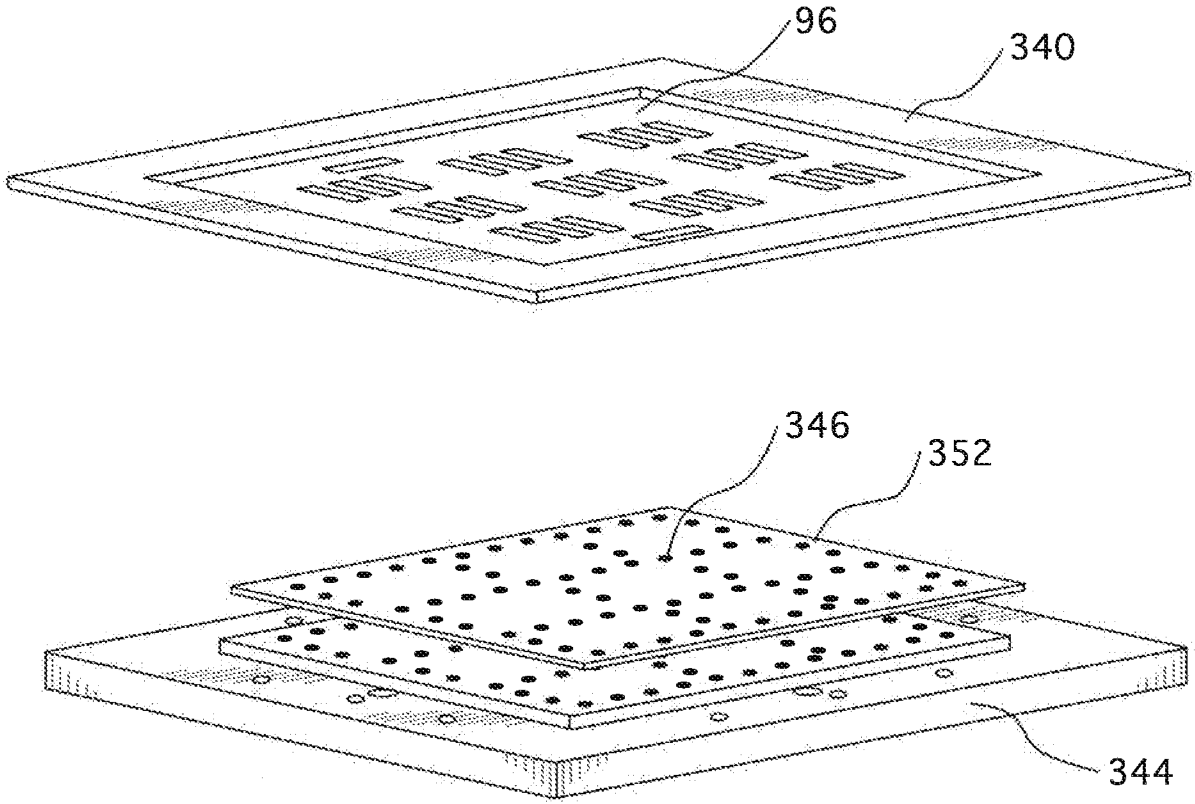


FIG. 5C

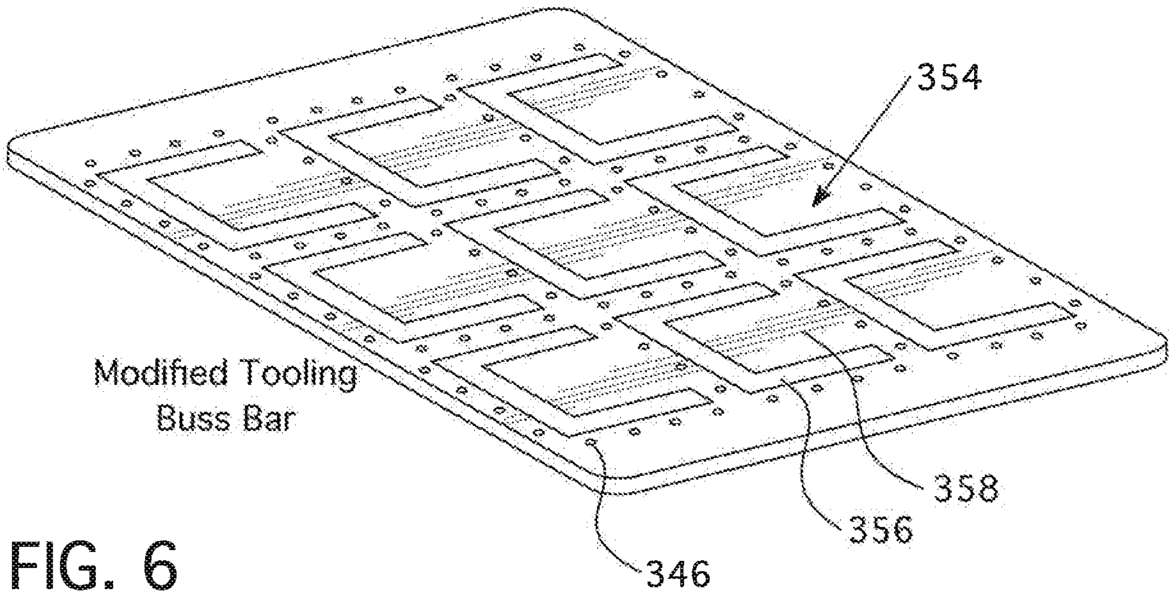


FIG. 6

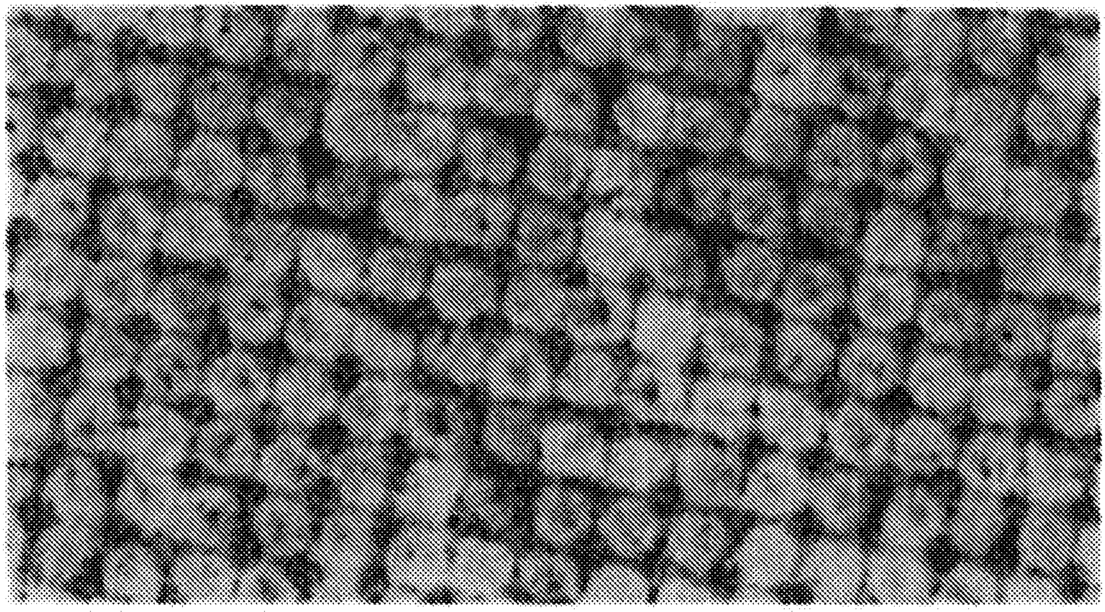

FIG. 7A

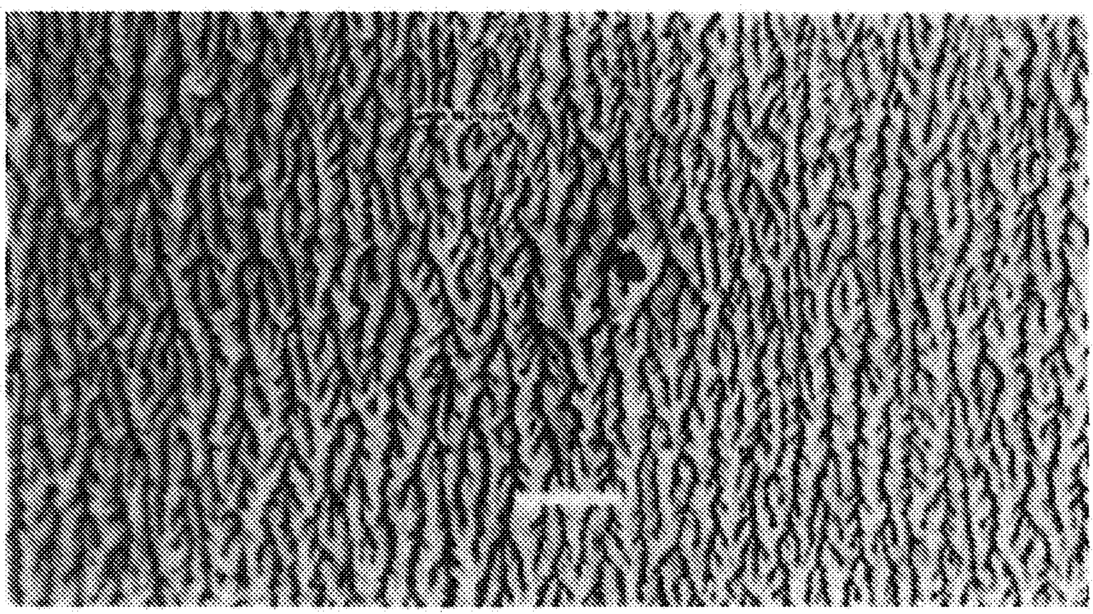

FIG. 7B

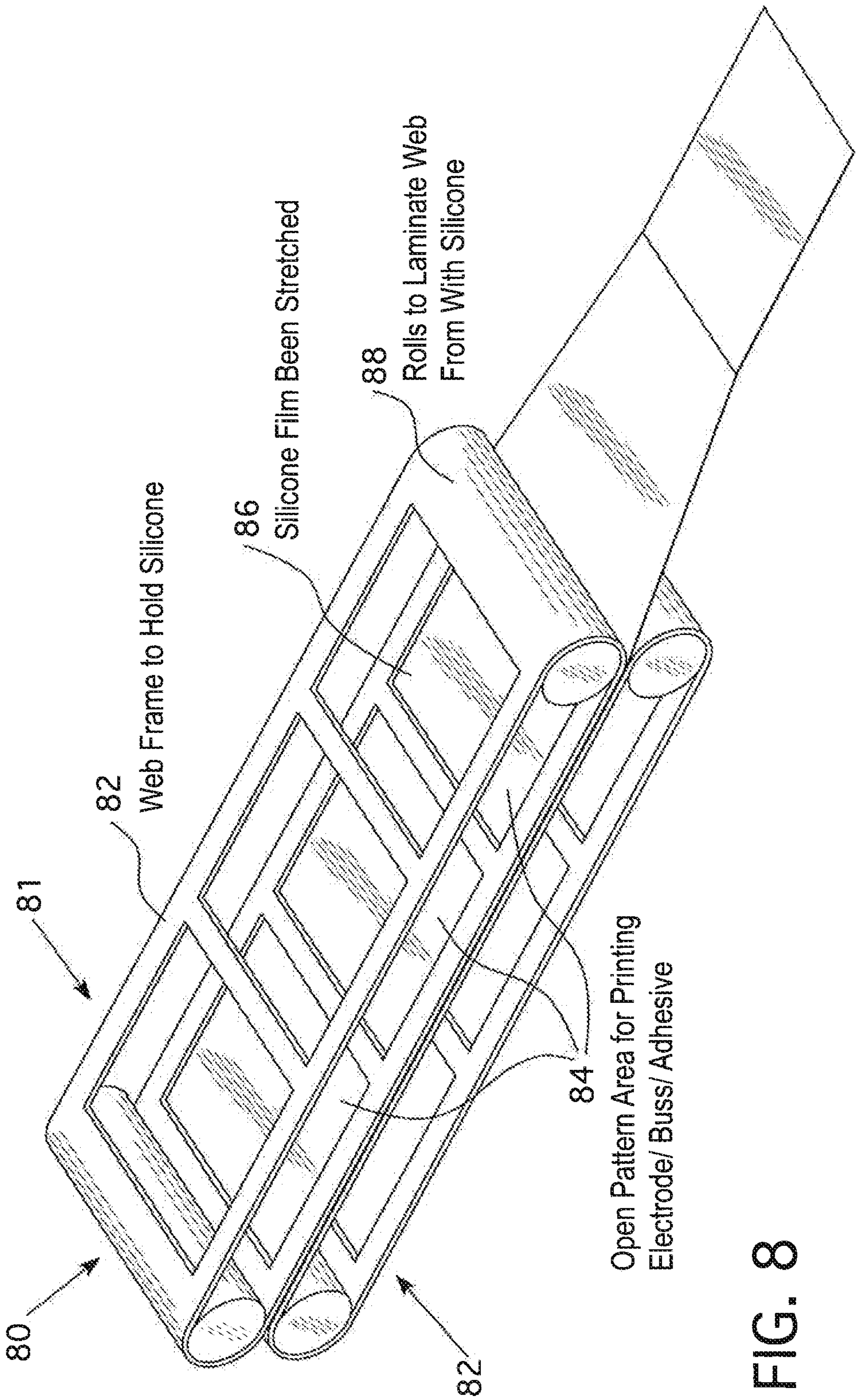
81
82
Web Frame to Hold Silicone
86
Silicone Film Been Stretched
88
Rolls to Laminate Web
From With Silicone
84
Open Pattern Area for Printing
Electrode/ Buss/ Adhesive
80
82

FIG. 8

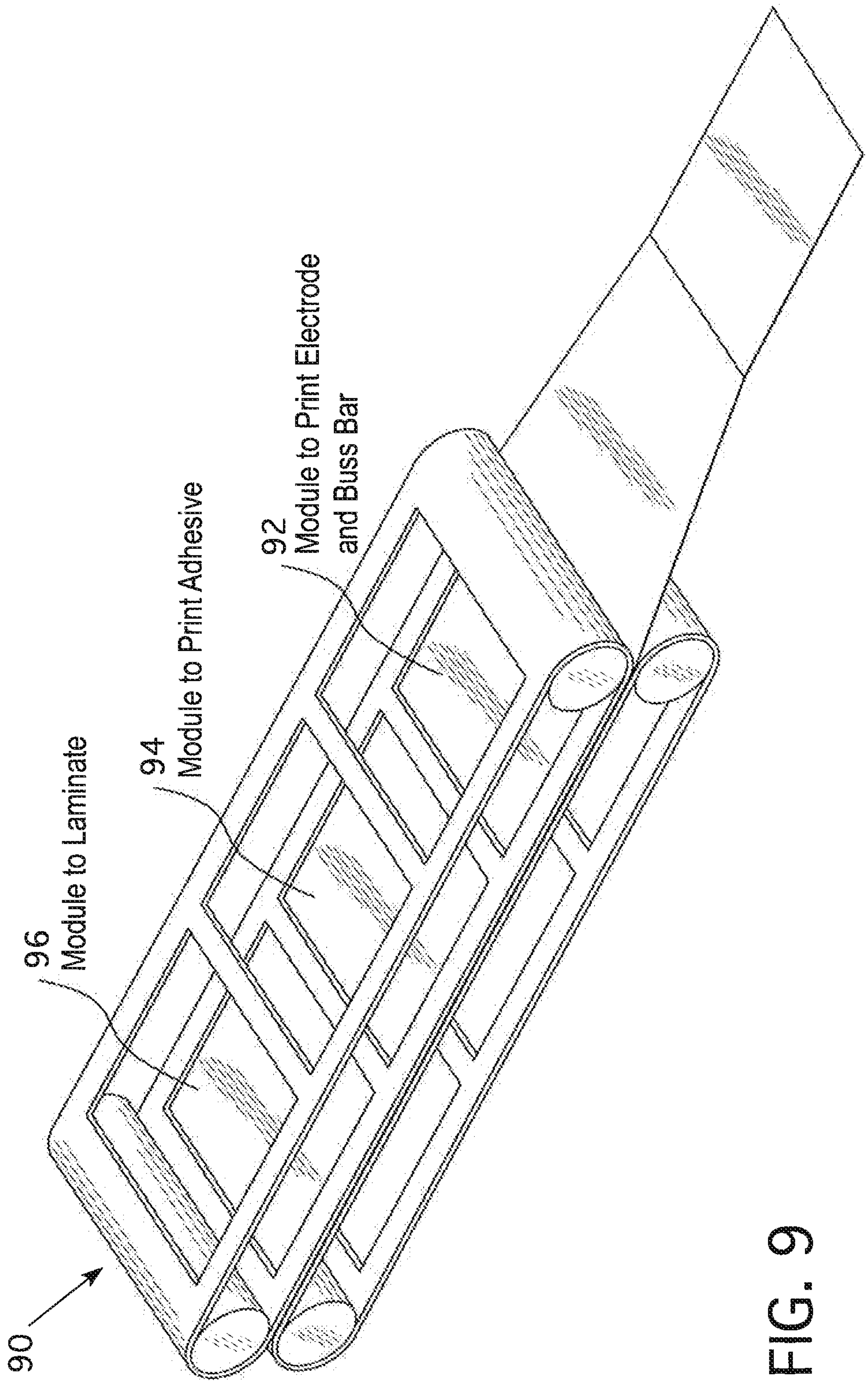
90
96
Module to Laminate
94
Module to Print Adhesive
92
Module to Print Electrode
and Buss Bar

FIG. 9

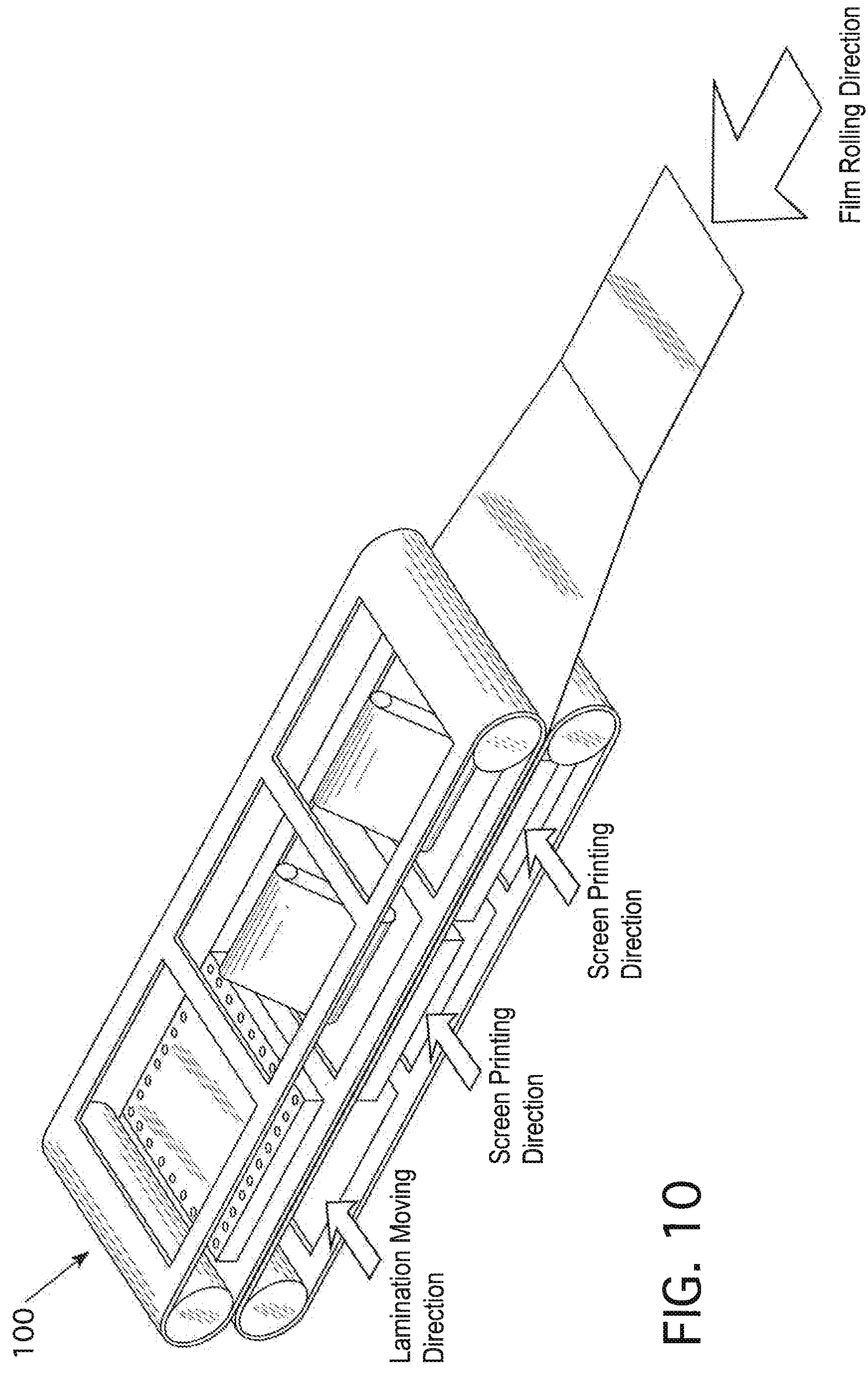
Film Rolling Direction
Screen Printing
Direction
Screen Printing
Direction
Lamination Moving
Direction
100

FIG. 10