[0054] Regardless of the ultimate chemical and physical state of the transducer polymer, it will include a polymer matrix. That matrix may be a homopolymer or copolymer, cross-linked or uncross-linked, linear or branched, etc. Exemplary classes of polymer suitable for use with transducers of this invention include silicone elastomers, acrylic elastomers, polyurethanes, thermoplastic elastomers, copolymers comprising PVDF, pressure-sensitive adhesives, fluoroelastomers, polymers comprising silicone and acrylic moieties, and the like. Obviously, combinations of some of these materials may be used as the polymer matrix in transducers of this invention. Copolymers and blends fall within the class of suitable polymers. One example is a blend of a silicone elastomer and an acrylic elastomer.

[0055] One suitable commercially available polymer is NuSil CF19-2186 as provided by NuSil Technology of Carpenteria, Calif. An example of a suitable silicone elastomer is Dow Coming HS3 as provided by Dow Corning of Wilmington, Del. One example of a suitable fluorosilicone is Dow Corning 730 as provided by Dow Corning of Wilmington, Del. Examples of suitable acrylics include any acrylic in the 4900 VHB acrylic series as provided by 3M Corp. of St. Paul, Minn.

[0056] Suitable actuation voltages for electroactive polymers, or portions thereof, may vary based on the material properties of the electroactive polymer, such as the dielectric constant, as well as the dimensions of the polymer, such as the thickness of the polymer film. For example, actuation electric fields used to actuate polymer **12** in **FIG. 1A** may range in magnitude from about 0 V/m to about 440 MV/m. Actuation electric fields in this range may produce a pressure in the range of about 0 Pa to about 10 MPa. In order for the transducer to produce greater forces, the thickness of the polymer layer may be increased. Actuation voltages for a particular polymer may be reduced by increasing the dielectric constant, decreasing the polymer thickness, and decreasing the modulus of elasticity, for example.

[0057] In one embodiment, polymer **12** is compliant and selected based on its elastance. A modulus of elasticity for polymer **12** less than about 100 MPa is suitable for many embodiments. In one specific embodiment, electroactive polymer **12** includes an elastic modulus less than 40 MPa. In another specific embodiment, electroactive polymer **12** is relatively compliant and includes an elastic modulus less than 10 MPa.

[0058] In one embodiment, electroactive polymer **12** is pre-strained. The performance of many polymers is notably increased when the polymers are pre-strained in area. For example, a 10-fold to 25-fold increase in area significantly improves performance of many electroactive elastomers. Pre-strain of a polymer may be described, in one or more directions, 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 comprise elastic deformation of polymer **12** and be formed, for example, by stretching the polymer in tension and holding one or more of the edges while stretched. The pre-strain may be imposed at the boundaries using a rigid frame or may also be implemented locally for a portion of the polymer. In another embodiment, portions of the polymer are cured or otherwise stiffened to increase their rigidity and hold pre-strain on a polymer. This allows pre-strain to be held without an external frame. For many polymers, pre-strain improves conversion between electrical and mechanical energy. The improved mechanical response enables greater mechanical work for an electroactive polymer, e.g., larger deflections and actuation pressures. In one embodiment, prestrain improves the dielectric strength of the polymer. In another embodiment, the pre-strain is elastic. After actuation, an elastically pre-strained polymer could, in principle, be unfixed and return to its original state.

[0059] In one embodiment, pre-strain is applied uniformly over a portion of polymer **12** to produce an isotropic pre-strained polymer. By way of example, an acrylic elastomeric polymer may be stretched by 200 to 400 percent in both planar directions. In another embodiment, pre-strain is applied unequally in different directions for a portion of polymer **12** to produce an anisotropic pre-strained polymer. In this case, polymer **12** may deflect greater in one direction than another when actuated. While not wishing to be bound by theory, it is believed that pre-straining a polymer in one direction may increase the stiffness of the polymer in the pre-strain direction. Correspondingly, the polymer is relatively stiffer in the high pre-strain direction and more compliant in the low pre-strain direction and, upon actuation, more deflection occurs in the low pre-strain direction. In one embodiment, the deflection in direction **108** of transducer portion **10** can be enhanced by exploiting large pre-strain in the perpendicular direction **110**. For example, an acrylic elastomeric polymer used as the transducer portion **10** may be stretched by 10 percent in direction **108** and by 500 percent in the perpendicular direction **110**. The quantity of pre-strain for a polymer may be based on the polymer material and the desired performance of the polymer in an application. Pre-strain suitable for use with the present invention is further described in commonly owned, copending U.S. patent application Ser. No. 09/619,848, which is incorporated by reference for all purposes.

[0060] Edges of polymer **12** may be fixed to one or more objects. The polymer may be fixed to the one or more objects according to any conventional method known in the art such as a chemical adhesive, an adhesive layer or material, mechanical attachment, etc. Transducers and polymers of the present invention are not limited to any particular geometry or type of deflection. For example, the polymer and electrodes may be formed into any geometry or shape including tubes and rolls, stretched polymers attached between multiple rigid structures, stretched polymers attached across a frame of any geometry—including curved or complex geometry's, across a frame having one or more joints, etc. Deflection of a transducer according to the present invention includes linear expansion and compression in one or more directions, bending, axial deflection when the polymer is rolled, deflection out of a hole provided in a substrate, etc. Deflection of a transducer may be affected by how the polymer is constrained by a frame or rigid structures attached to the polymer. In one embodiment, a flexible material that is stiffer in elongation than the polymer is attached to one side of a transducer induces bending when the polymer is actuated.

2. ELECTRODES

[0061] As electroactive polymers of the present invention may deflect at high strains, electrodes attached to the polymers should also deflect without compromising mechanical