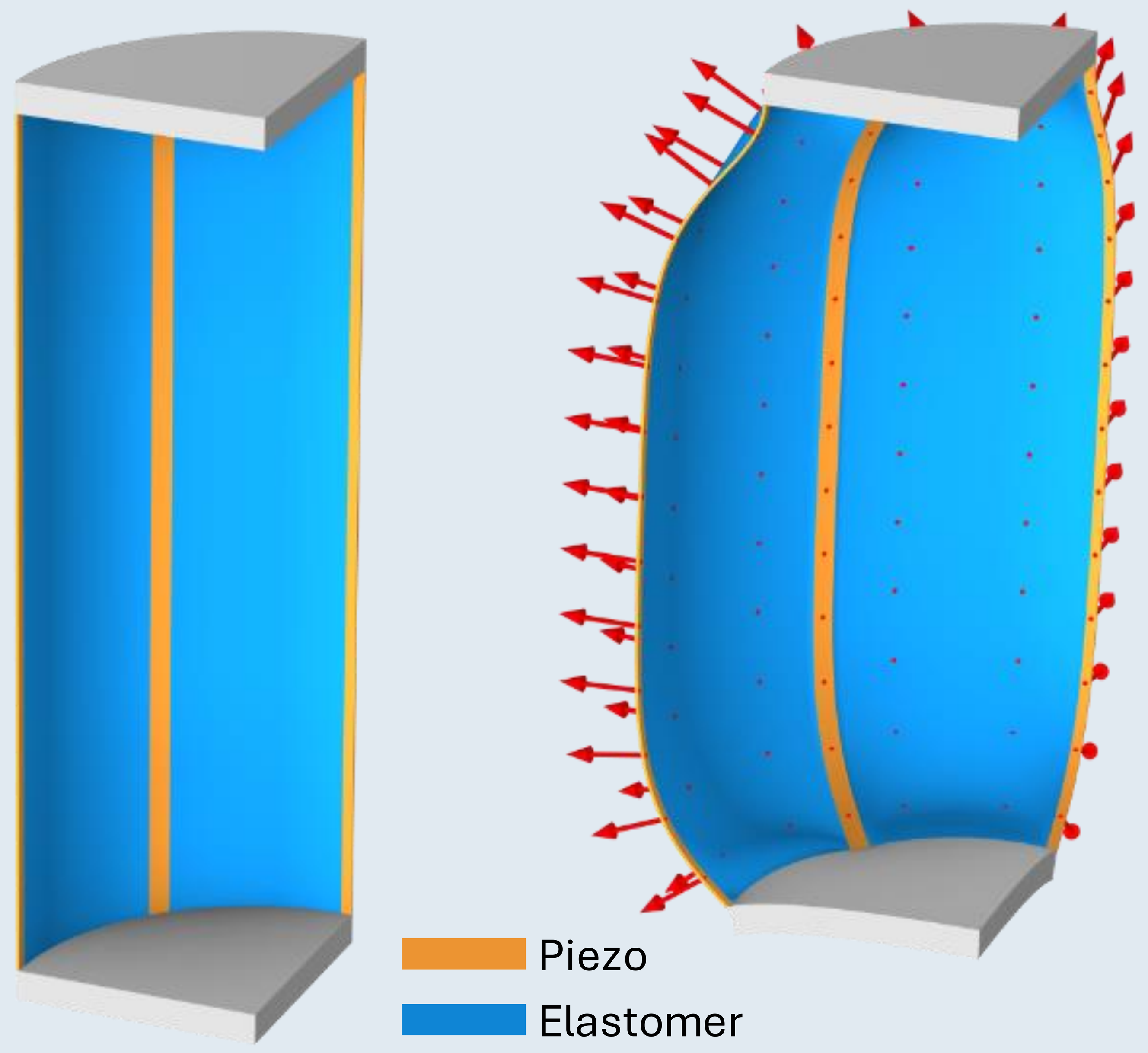

Modeling of Piezoelectrically Enhanced Soft Artificial Muscles

Piezoelectric soft artificial muscles provide actuation in robotics, medical devices, and wearable technologies. Their high power-to-weight ratios make them ideally suited for such applications. However, the coupled nonlinear relationship between their geometry, material response and performance poses a challenge for their design. Simulating the performance of such artificial muscle devices in COMSOL Multiphysics® allows the coupled physics to be accurately represented and enables rapid concept testing, design iteration, and material selection.

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Introduction

Artificial muscles are soft devices that mimic the motion of muscles and can change their shape or stiffness in response to external stimuli. Most soft artificial muscles (soft actuators) rely on finite material deformation to achieve the desired function such as bending, contraction, extension, twisting, snapping, etc. In addition to finite material deformation, some artificial muscles can respond to multiple external stimuli (i.e. fluid pressure, electric field, humidity, temperature, etc.) making the relationship between stimuli and response multidimensional and highly nonlinear.

Finite element-based multiphysics simulation is key to understanding the behavior of soft artificial muscles, greatly accelerating the design and material selection processes. Additionally, identifying the appropriate external stimuli (i.e., magnitude of fluid pressure, voltage amplitude and frequency) to develop actuators with a target behavior or response is significantly faster with simulation than experimental prototyping.

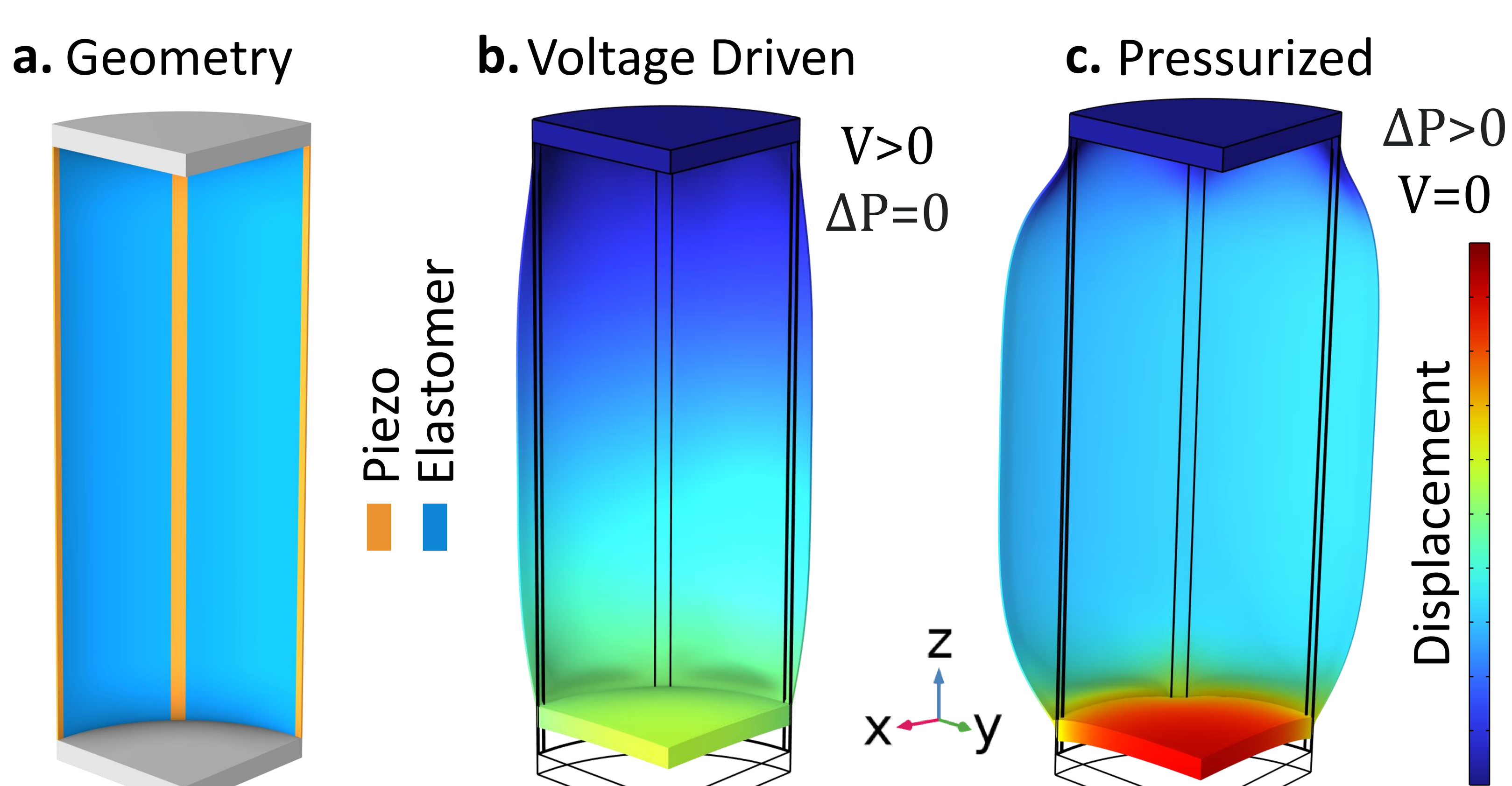

FIGURE 1. (a) Geometry of a piezoelectrically enhanced soft artificial muscle that uses a combination of strip-shaped piezo elements and a cylindrical elastomer matrix to contract upon (b) the application of an electric field (voltage V) or (c) inflation by pressure ΔP. Color indicates vertical displacement.

Methodology

We consider an elastomeric cylinder matrix with height 150 mm, diameter 80 mm, and thickness 0.5 mm encapsulating 8 piezoelectric strips of height 150 mm and width 3.5 mm (Figure 1a). The elastomeric cylinder has a Young's modulus of 10 MPa and 0.45 Poisson's ratio, whereas the piezo strips are comprised of PZT-5A.

The cylindrically shaped muscle can be actuated by supplying an electric field at the piezo strips (Figure 1b), by inflating the enclosed cavity (Figure 1c), or by a combination of the two methods to achieve complex actuation sequences. The higher stiffness of the piezo strips compared to the elastomer matrix makes the muscle contract upon application of voltage or fluidic pressure. We quantify the contraction of the artificial muscle by the distance between the cylinder caps.

Results

We performed finite element simulations of the actuation of the piezo artificial muscle to determine muscle contraction due to applied voltage without pressure (Figure 2, green curve) or fluid pressure without voltage (Figure 2, blue curve). The muscle contracts up to 10 mm in length using 75 kPa of pressure or 130 kV of voltage. Next, we combined voltage and pressure stimuli to produce more complex responses, including alternating voltage between 0 and 100 kV at a frequency of $1/6\pi$ and fixed pressure (Figure 3a) and alternating both pressure and voltage, the former with a frequency of $1/2\pi$ and the latter with a frequency of $1/6\pi$ (Figure 3b). This study demonstrates the power of multiphysics simulation to predict the response of piezoelectrically enhanced soft artificial muscles and to optimize excitation parameters such as inflation pressure, voltage amplitude and frequency.

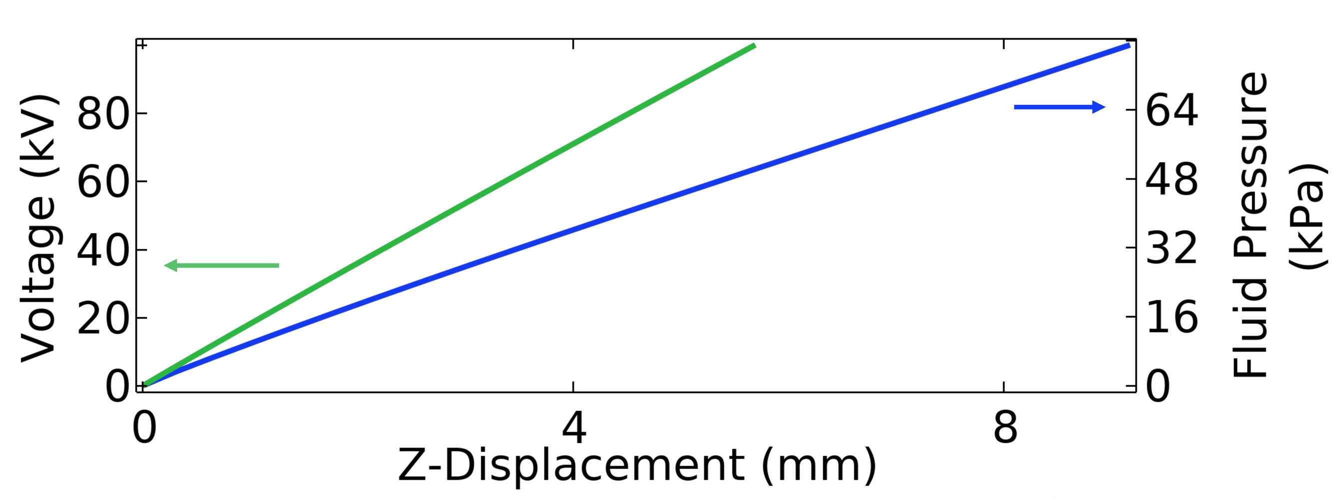

FIGURE 2. Dependent of output contractive displacement on input voltage and fluid pressure, applied separately.

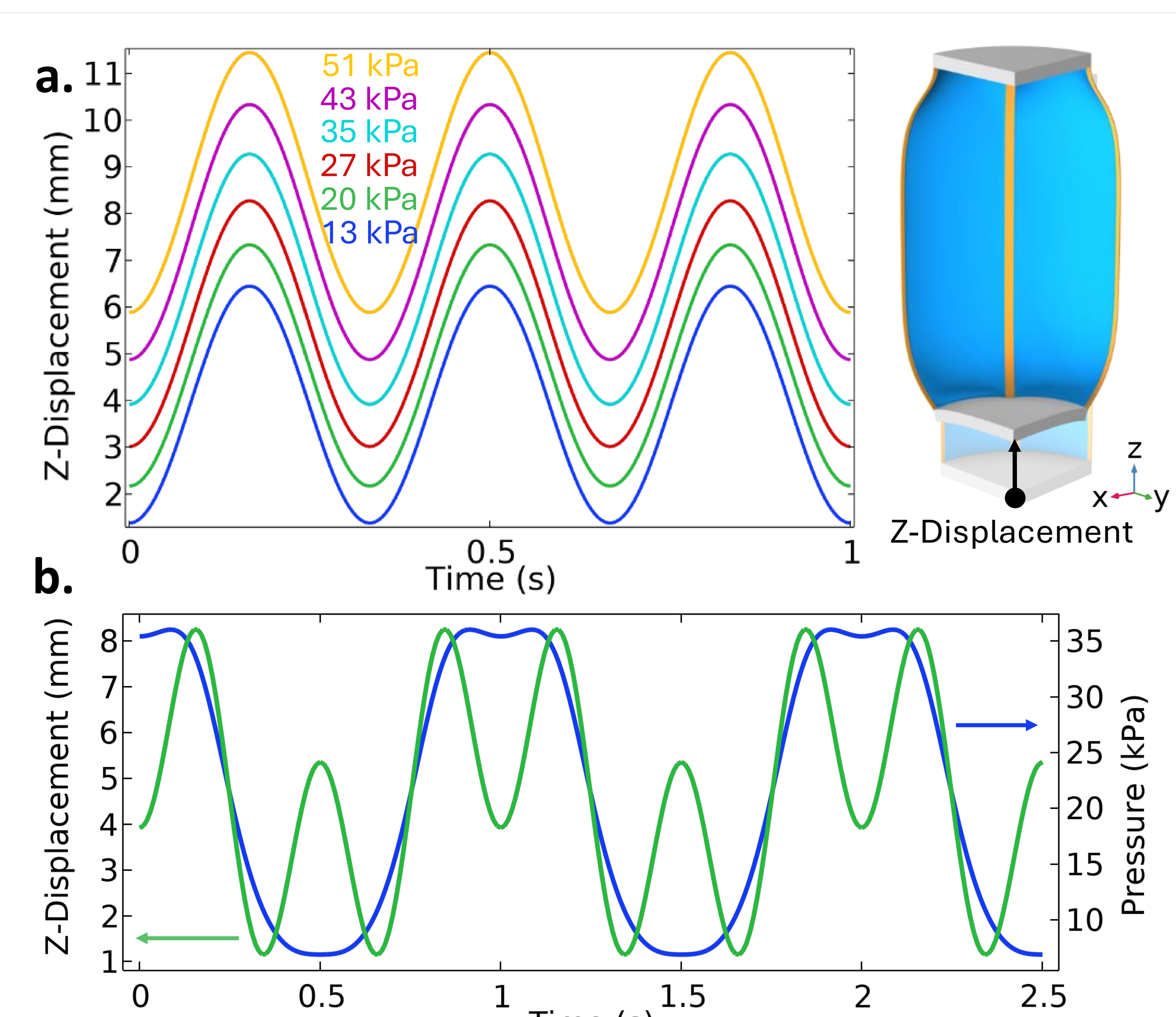

FIGURE 3. Contractive displacement of the artificial muscle during combined actuation using (a) fixed pressure with alternating voltage and (b) alternating both pressure and voltage.

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