Design and Simulation of Electroactive Polymer Based Artificial Muscles for Biomedical Application

A. S. Tripathi*[1], B. P. Chatterjee[2] and S. Das[3]

[1]Advanced Technology Development Centre, Indian Institute of Technology, Kharagpur, [2]Dept. of Cardiology, Medical College and Hospital, Kolkata, [3]School of Medical Science and Technology, Indian Institute of Technology, Kharagpur

Introduction

Electro-active polymer (EAP) based actuators are one of the suitable contenders for use in artificial muscles based bio-medical application because of their biocompatibility and lower active actuation voltage requirement phenomenon. At present Ionic polymer metal composites (IPMC), a type of EAP based actuator are being developed for various applications [1]. IPMC actuator generally consist sandwiched ionic polymer (Nafion) layer between two metal (gold) electrodes (Fig.1).

In the present work electromechanical response of the IPMC actuator, based on applied voltage were examined by transient study. By simulation study tip displacement and stress generation required for bi-directional bending of the EAP based artificial muscles were analyzed. Simulation work has been carried out in COMSOL Multiphysics 5.2 with electromechanical, ionic transport and partial differential equation (PDE) multi-physics coupling.

Computational Methods

- Electromechanical response of the IPMC based actuator was analyzed by modelling Electrode-polymer coupling [2,3] uni-directionally using Nernst-Planck equation.:

$$\frac{\partial C}{\partial t} + \nabla(-D\nabla C - z\mu FC\nabla\phi) = 0$$

In electromechanical response ,the velocity of the species was neglected and assumed to be zero.

- Initially, IPMC actuator strip of 20x1 mm^2 area (17 mm free length), with 254.5 micron total thickness was used for simulation.

- Transient study was performed to analyze the tip displacement of the actuator and its stress-strain generation with voltage variation from 0-5V.

- After that, effect of actuator strip length variation on tip displacement and stress, corresponding to applied voltage was analyzed.

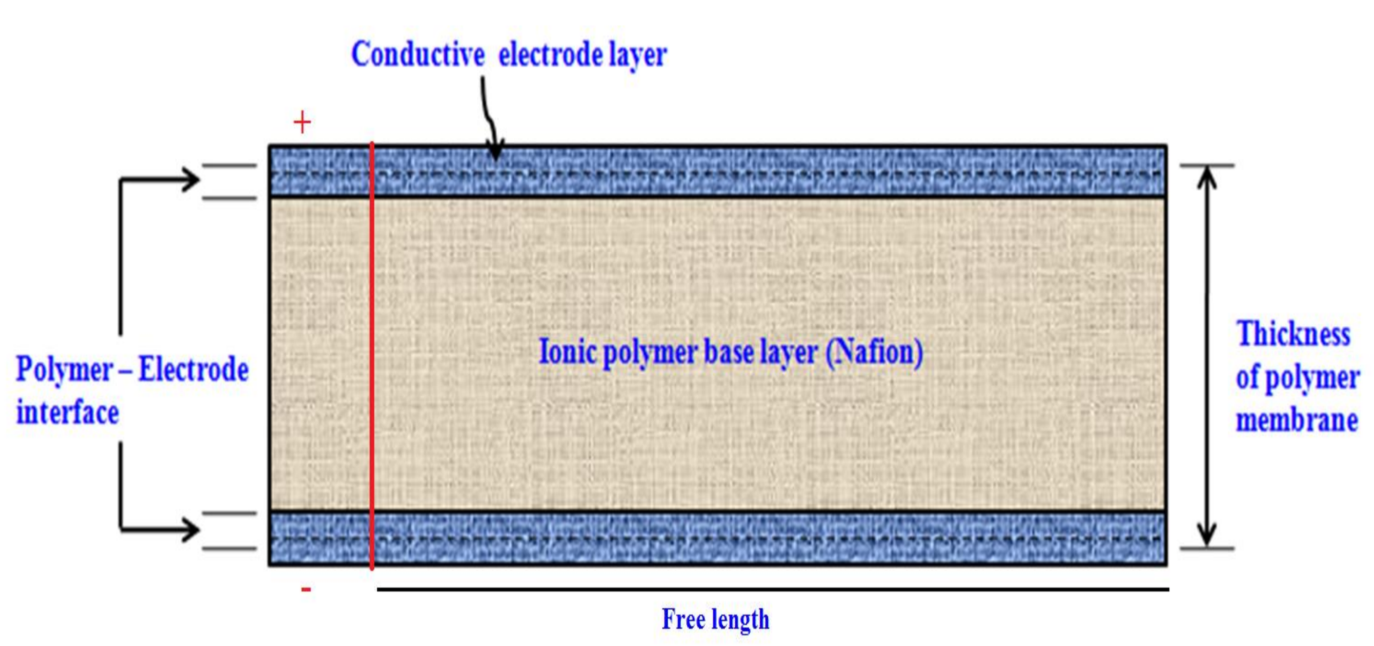

Figure 1: IPMC actuator block diagram.

Results

- Figure 2 shows the IPMC actuator response based on applied voltage. Maximum observed displacement was 5.45 mm at 5V DC supply and maximum generated stress was found 8.30 MPa. Stress-Strain response was almost liner up to 3.5 V.
- In time dependent study (Figure 3) , maximum response time for the actuator was found 10 seconds, which explain the maximum time required for maximum tip displacement and stress response of the IPMC actuator from initial to final state.
- Figure 4 depicts the effect of actuator strip length variation on tip deformation and stress, tip displacement and stress response both were improved when free length of the actuator increased from 14 to 20 mm.

Table 1. Parameter value for simulation

Variable	***Value***	***Units***
IPMC Density	3385	Kg/m^3
Young's Modulus IPMC (Hydrated)	0.5	GPa
Electric field coefficient	5e-5	V/m
Cations concentration	1200	mol/m^3
Diffusion coefficient	5e-11	m^2 /s

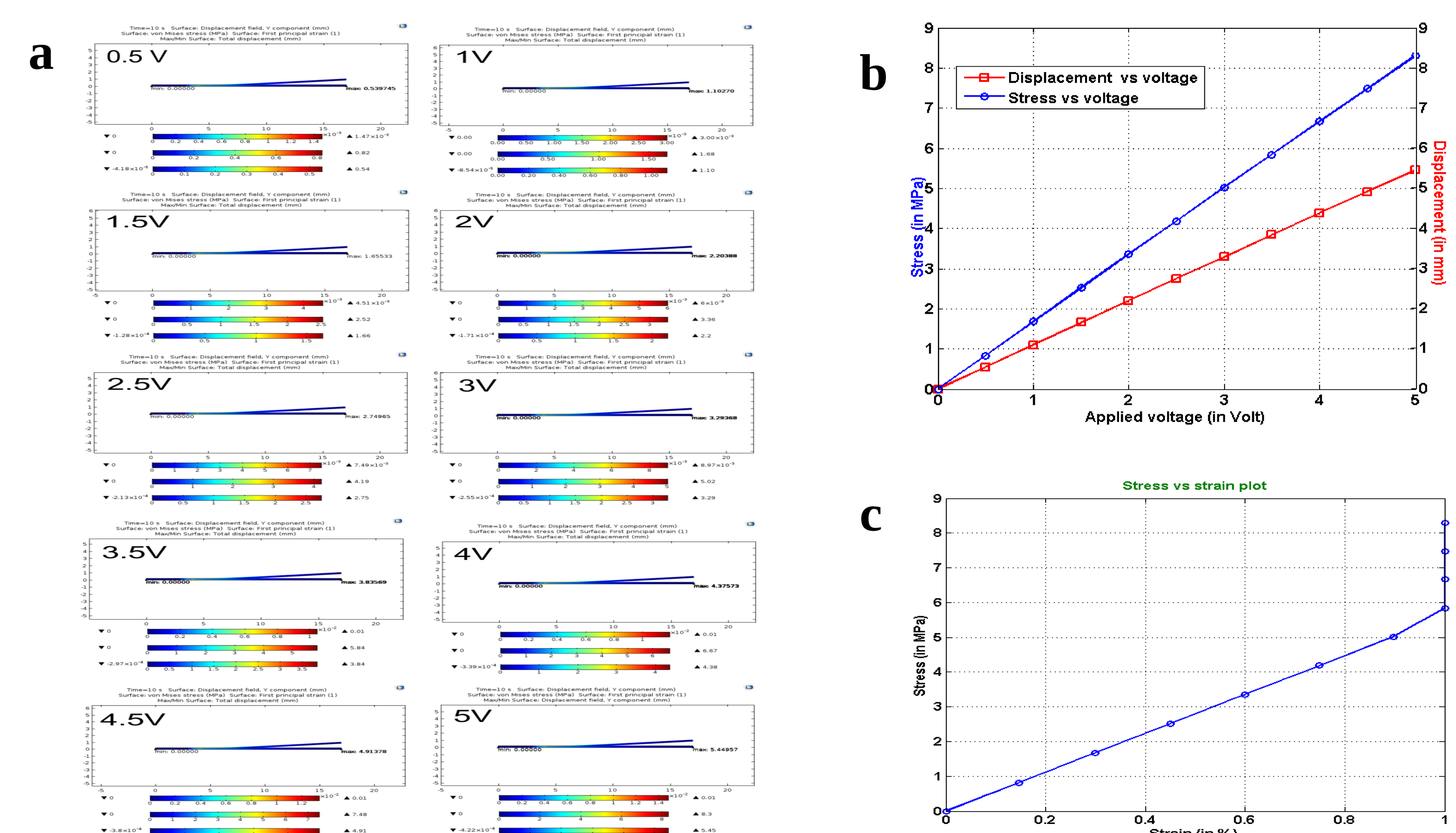

Figure 2: (a) Voltage dependent response of IPMC actuator, (b) Stress & Displacement vs Voltage and (c) Stress vs Strain.

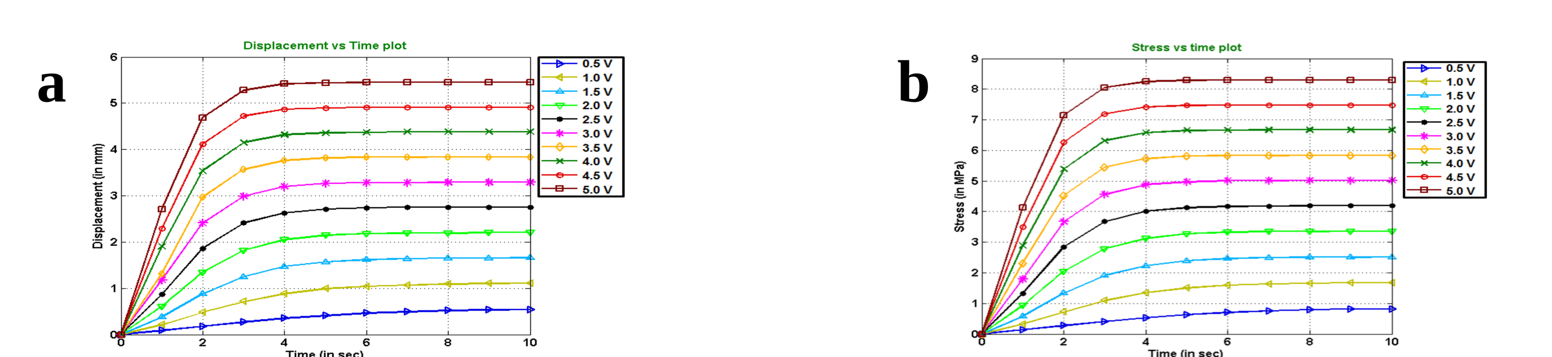

Figure 3: Transient analysis of IPMC actuator shows: (a) Displacement and, (b) Stress variation with time for various applied voltage.

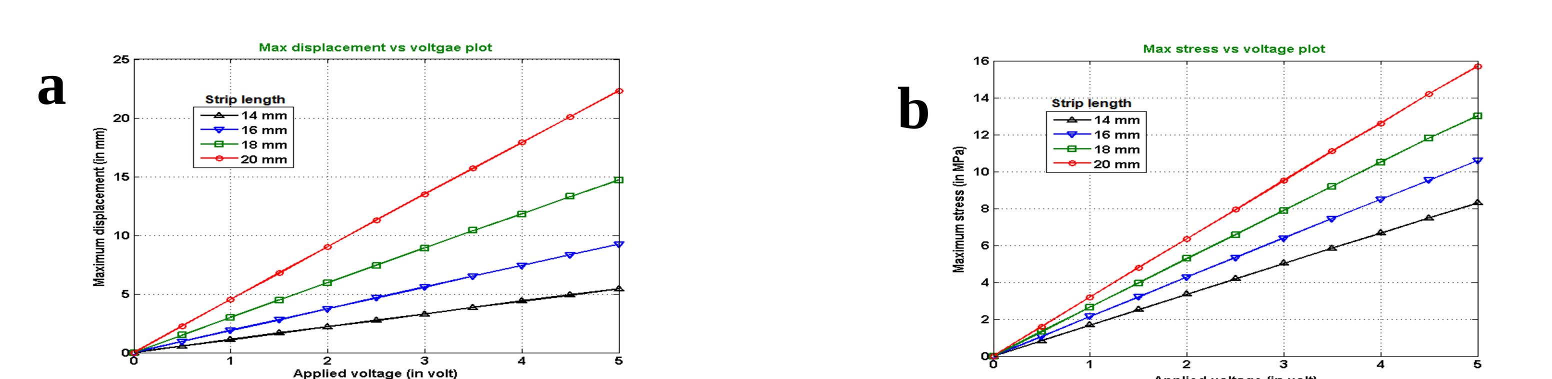

Figure 4: Variation of IPMC (a) Tip Displacement and, (b) Stress with applied voltage for different strip length.

Conclusions

- COMSOL Multiphysics was successfully used to study the IPMC actuator tip deflection induced due to applied voltage.
- At low voltage , IPMC actuator has shown good bending response which makes it useful for artificial muscles based biomedical application ,where low operating voltage and biocompatibility are the main issues of concern.
- Further, high performance can be achieved by modification in actuator geometry as well as material properties.

References

[1] K. Farinholt and D. J. Leo, Modeling of electromechanical charge sensing in ionic polymer transducers, Mech. Mater., 2004, 36(5–6), 421–433.
[2] D. Pugal, Physics based model of ionic polymer-metal composite electromechanical and mechanoelectrical transduction, PhD dissertation, UNR, 2012.
[3] S. Nemat-Nasser and J. Y. Li, Electromechanical response of ionic polymer-metal composites, J. Appl. Phys., 2000, 87(7), 3321–3331.