

# **Development, Characterization and Electromechanical Actuation Behavior of Ionic Polymer Metal Composite Actuator based on Sulfonated Poly(1,4-phenylene ether-ether-sulfone)/Carbon Nanotubes**

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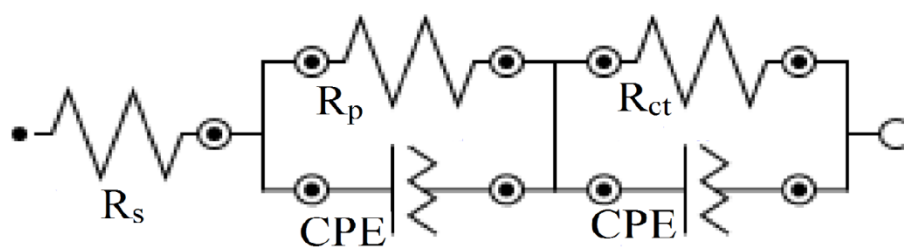
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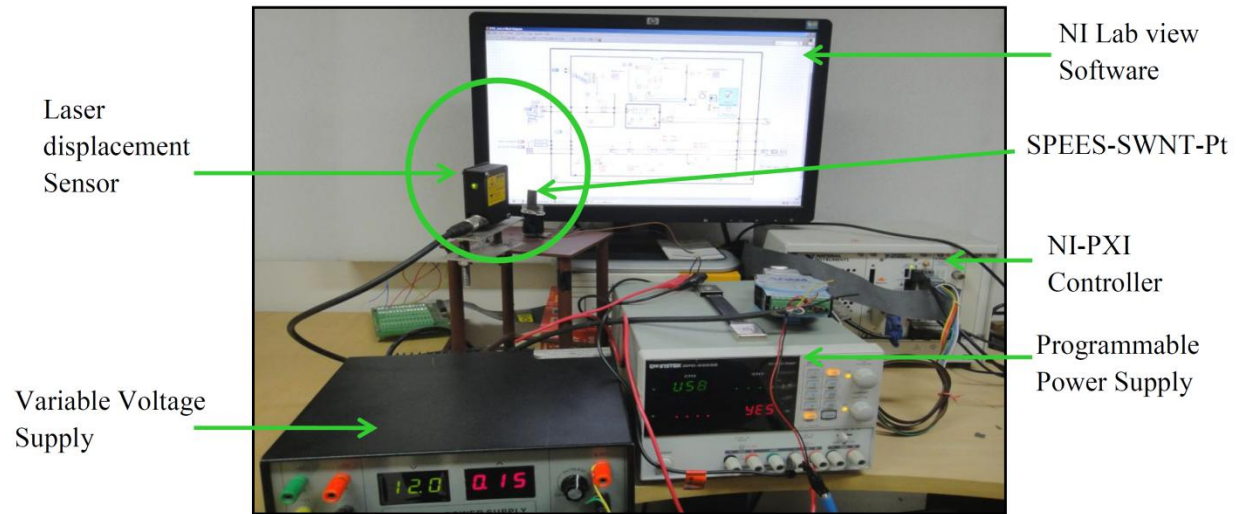
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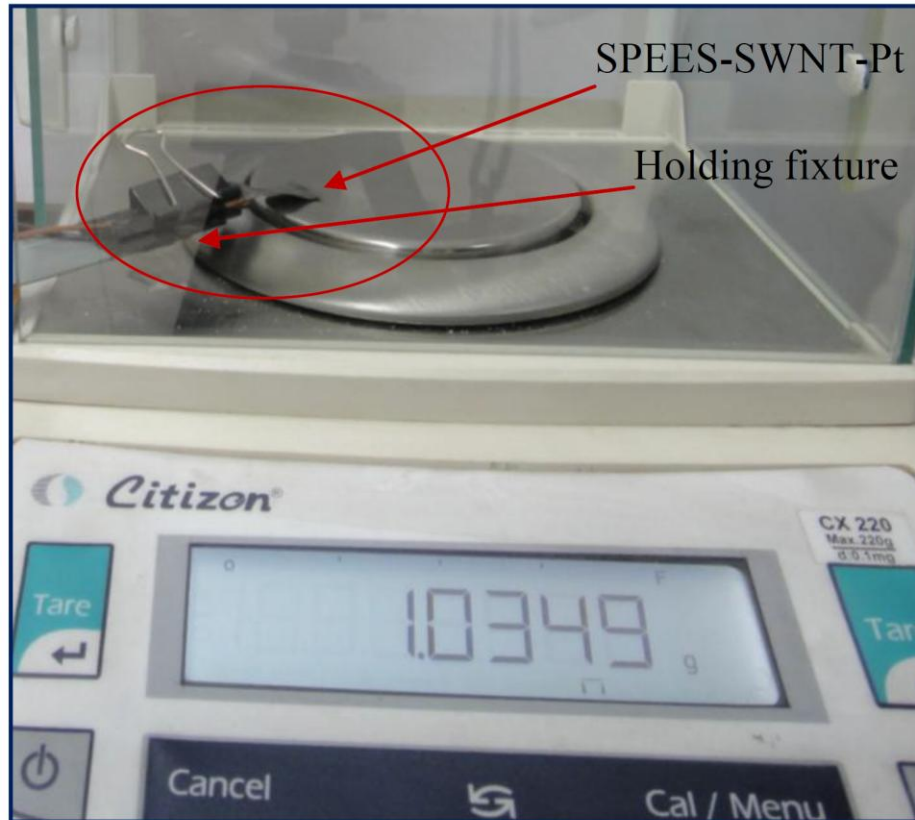
### Supplementary Information



**Supplementary Figure 1.** Equivalent circuit model to estimate the electrochemical parameters of EIS for SPEES-SWNT-Pt IPMC.



**Supplementary Figure 2.** Actual testing setup to measure the tip displacement of SPEES-SWNT-Pt based IPMC membranes.



**Supplementary Figure 3.** Testing setup for load characterization of SPEES-SWNT-Pt based IPMC membranes.

**Supplementary Table 1.** The WU %, IEC and proton conductivity of the SPEES-SWNT-Pt based IPMC membrane.

| <b>Sample</b> | <b>WU%<br/>At R.T</b> | <b>IEC<br/>(meq/g )</b> | <b>PC (<math>\sigma</math>)<br/>(S/cm)</b> |
|---------------|-----------------------|-------------------------|--------------------------------------------|
| SPEES-SWNT-Pt | 80 (24 h)             | 2.5                     | $2.321 \times 10^{-2}$                     |

**Supplementary Table 2.** Experimental tip displacement data of SPEES-SWNT-Pt IPMC membrane for trial 2.

| Deflection<br>(mm) | Voltage (V) |        |        |        |         |         |         |         |         |         |
|--------------------|-------------|--------|--------|--------|---------|---------|---------|---------|---------|---------|
|                    | 0 V         | 0.5V   | 1.0V   | 1.5V   | 2.0V    | 2.5V    | 3.0V    | 3.5V    | 4.0V    | 4.5V    |
| d1                 | 0.4254      | 1.3229 | 6.0443 | 9.4427 | 8.5338  | 11.6542 | 13.7217 | 16.5909 | 15.6132 | 16.0373 |
| d2                 | 0.4585      | 1.0145 | 3.9387 | 9.1628 | 9.154   | 10.9343 | 13.084  | 16.8455 | 16.0365 | 16.3267 |
| d3                 | 0.4176      | 0.5401 | 5.0938 | 7.9603 | 9.0125  | 14.4567 | 15.3167 | 16.5415 | 15.4406 | 16.2137 |
| d4                 | 0.2084      | 1.386  | 5.229  | 8.4758 | 9.9431  | 13.1343 | 16.3208 | 15.907  | 15.7459 | 16.1159 |
| d5                 | 0.1131      | 1.1691 | 2.3016 | 8.768  | 7.8275  | 14.7131 | 13.5123 | 15.2675 | 15.8031 | 15.9121 |
| d6                 | 0.5457      | 1.2788 | 3.415  | 7.1846 | 9.2801  | 12.6933 | 13.3019 | 16.3539 | 15.4751 | 15.9583 |
| d7                 | 0.0296      | 0.8226 | 5.7726 | 9.2121 | 11.5428 | 11.0465 | 15.5818 | 17.7025 | 15.967  | 16.0886 |
| d8                 | 0.5968      | 0.8302 | 3.4626 | 7.7842 | 10.2373 | 11.1629 | 14.0795 | 16.2845 | 15.2433 | 16.1368 |
| d9                 | 0.3026      | 1.2562 | 3.5262 | 9.3043 | 10.7943 | 10.4335 | 14.7578 | 16.959  | 15.4499 | 16.2009 |
| d10                | 0.6179      | 0.7506 | 4.6533 | 9.001  | 9.7909  | 10.1768 | 14.7407 | 16.6543 | 15.8548 | 16.0729 |

**Supplementary Table 3.** Experimental tip displacement data of SPEES-SWNT-Pt IPMC membrane for trial 3.

| Deflection<br>(mm) | Voltage (V) |        |        |        |         |         |         |         |         |         |
|--------------------|-------------|--------|--------|--------|---------|---------|---------|---------|---------|---------|
|                    | 0 V         | 0.5V   | 1.0V   | 1.5V   | 2.0V    | 2.5V    | 3.0V    | 3.5V    | 4.0V    | 4.5V    |
| d1                 | 0.6385      | 1.2247 | 6.0874 | 8.9696 | 10.4362 | 10.5598 | 14.9469 | 16.1733 | 15.5022 | 16.0426 |
| d2                 | 0.5284      | 0.9746 | 5.9491 | 6.2222 | 10.9232 | 10.374  | 13.0454 | 15.3304 | 16.0975 | 16.3765 |
| d3                 | 0.5332      | 0.9236 | 5.0159 | 8.8435 | 12.4699 | 11.3246 | 14.7257 | 17.2966 | 15.5252 | 16.2476 |
| d4                 | 0.4106      | 1.3548 | 5.168  | 7.3631 | 11.7925 | 10.9058 | 14.5598 | 15.1751 | 15.7616 | 16.1338 |
| d5                 | 0.1461      | 0.8566 | 3.6018 | 5.9809 | 10.645  | 13.7915 | 13.6256 | 18.0051 | 15.89   | 15.8777 |
| d6                 | 0.3813      | 1.3979 | 2.4122 | 8.7846 | 8.5056  | 11.7802 | 13.2747 | 15.3774 | 15.4835 | 15.9154 |
| d7                 | 0.4327      | 0.4001 | 3.316  | 6.4621 | 11.4348 | 13.6986 | 13.4417 | 17.8169 | 15.9324 | 16.0196 |
| d8                 | 0.6406      | 0.9969 | 4.393  | 6.2626 | 9.1524  | 11.5668 | 13.5499 | 17.0488 | 15.3119 | 16.1135 |
| d9                 | 0.1569      | 1.1407 | 5.946  | 6.5916 | 8.1707  | 13.5666 | 13.5078 | 14.0722 | 15.441  | 16.2443 |
| d10                | 0.4081      | 0.5054 | 2.4751 | 7.0637 | 10.3289 | 13.0084 | 12.5879 | 16.7198 | 15.9318 | 16.1159 |

**Supplementary Table 4.** Experimental tip displacement data of SPEES-SWNT-Pt IPMC membrane for trial 4.

| Deflection<br>(mm) | Voltage (V) |        |        |        |         |         |         |         |         |         |
|--------------------|-------------|--------|--------|--------|---------|---------|---------|---------|---------|---------|
|                    | 0 V         | 0.5V   | 1.0V   | 1.5V   | 2.0V    | 2.5V    | 3.0V    | 3.5V    | 4.0V    | 4.5V    |
| d1                 | 0.2699      | 1.3382 | 6.3596 | 8.5575 | 9.3792  | 11.5994 | 16.4615 | 15.0399 | 15.6112 | 16.1303 |
| d2                 | 0.1008      | 0.8031 | 5.1899 | 9.9883 | 8.4737  | 10.4688 | 15.4127 | 17.7693 | 16.0323 | 16.4046 |
| d3                 | 0.4998      | 0.7006 | 3.9458 | 6.4422 | 11.1519 | 11.9533 | 16.1999 | 16.1196 | 15.4576 | 16.2464 |
| d4                 | 0.5855      | 1.0967 | 3.4533 | 8.0025 | 8.7913  | 10.3025 | 15.1304 | 17.0799 | 15.8096 | 16.1664 |
| d5                 | 0.6316      | 1.4795 | 5.2184 | 7.0528 | 10.6757 | 11.3111 | 14.8986 | 16.3163 | 15.8202 | 15.8338 |
| d6                 | 0.211       | 1.1674 | 4.983  | 5.7453 | 8.6134  | 10.2917 | 14.4872 | 15.7063 | 15.5003 | 15.9675 |
| d7                 | 0.3404      | 1.1056 | 2.0174 | 9.3582 | 9.2996  | 13.9706 | 13.3061 | 17.7726 | 16.016  | 16.0104 |
| d8                 | 0.3152      | 0.7863 | 2.0128 | 8.1971 | 7.7266  | 11.2653 | 12.7327 | 16.0618 | 15.2664 | 16.1074 |
| d9                 | 0.477       | 0.8726 | 3.5125 | 6.7301 | 7.4252  | 12.6014 | 12.6999 | 16.2587 | 15.4755 | 16.284  |
| d10                | 0.604       | 1.2774 | 5.3452 | 6.482  | 8.5572  | 11.5324 | 15.8089 | 17.5065 | 15.9127 | 16.0816 |