RF-MEMS performance and reliability: Sensitivity analysis and UQ
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Coarse-grained model for RF-MEMS

Motivation:

\[ V_{PI}(t) = \frac{y_d V}{V_{PI}} \left[ \frac{483}{8} \frac{E}{1 - \nu^2} \frac{y_0^2}{y_0^2 + \epsilon^2} \right] \frac{1}{V_{PI}} \]

\[ V_{PO}(t) = V_{PO}(0) - \frac{\pi y_d \epsilon_0}{2 V_{PO}} \frac{y_0^2}{y_d^2} \]

Dynamics:

\[ t_{PI} = \frac{\pi y_d \epsilon_0}{2 V_{PI}} \frac{y_0^2}{y_d^2} \]

Verification: Membrane dynamics

\[ \rho \frac{\partial^2 y}{\partial t^2} + \frac{E I \partial^4 y}{
\epsilon_0^2 \partial x^4} = 0 \]

Number of Modes = 11

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Performance:

Reliability:

\[ n_f(x) = \frac{A_{SCM}(x) N_f}{A_{SCM}(x)} \left[ 1 - \exp \left( -\frac{t}{q} \right) \right] \]

Verification: Dielectric charging

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>St. Deviation</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lm: Membrane Length ((\mu m))</td>
<td>500</td>
<td>10</td>
<td>Measurements</td>
</tr>
<tr>
<td>Hm: Membrane Thickness ((\mu m))</td>
<td>1.85</td>
<td>0.3</td>
<td>Measurements</td>
</tr>
<tr>
<td>E: Young modulus (GPa)</td>
<td>350</td>
<td>80</td>
<td>Measurements</td>
</tr>
<tr>
<td>yd: Airgap ((\mu m))</td>
<td>3.5</td>
<td>0.26</td>
<td>Measurements</td>
</tr>
<tr>
<td>yd: Dielectric Thickness (nm)</td>
<td>191</td>
<td>16</td>
<td>Measurements</td>
</tr>
<tr>
<td>(\epsilon_r): Dielectric constant (-)</td>
<td>7.9</td>
<td>0.5</td>
<td>Literature/Guess</td>
</tr>
<tr>
<td>(\Delta\gamma): Barrier Height (eV)</td>
<td>1.5</td>
<td>0.2</td>
<td>Measurements</td>
</tr>
<tr>
<td>N(_T): Trap density (cm(^{-3}))</td>
<td>2e18</td>
<td>1e18</td>
<td>Measurements</td>
</tr>
<tr>
<td>(\gamma): Capture cross section (cm(^2))</td>
<td>1e-17</td>
<td>5e-18</td>
<td>Literature/Guess</td>
</tr>
<tr>
<td>(m^*): Effective mass (-)</td>
<td>0.5</td>
<td>0.2</td>
<td>Measurements</td>
</tr>
<tr>
<td>(\gamma): FP attempt frequency (s(^{-1}))</td>
<td>1e12</td>
<td>5e11</td>
<td>Literature</td>
</tr>
</tbody>
</table>

Sensitivity defined as:

\[ S(I,O) = \frac{\left| O_{max} - O_{min} \right|}{O_{avg}} \times \frac{I_{avg}}{I_{max} - I_{min}} \]

Uncertainty Quantification

<table>
<thead>
<tr>
<th>Input Parameters</th>
<th>Performance</th>
<th>Dynamics</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>(\mu=48.5V)</td>
<td>(\mu=8.9V)</td>
<td>(\mu=5.6\mu)</td>
</tr>
<tr>
<td>(\sigma=10.7V)</td>
<td>(\sigma=1.9V)</td>
<td>(\sigma=0.92\mu)</td>
<td>(\sigma=1m/s)</td>
</tr>
<tr>
<td>(\mu=10.6m/s)</td>
<td>(\mu=6m/s)</td>
<td>(\mu=1m/s)</td>
<td>(\mu=1KHz)</td>
</tr>
<tr>
<td>(\sigma=10^7)</td>
<td>(\sigma=10^7)</td>
<td>(\sigma=10^7)</td>
<td>(\sigma=10^7)</td>
</tr>
</tbody>
</table>

Conclusions:

1) \(V_{PI}\) is most sensitive to \(L_m\), \(H_m\), \(y_0\) and \(E\) whereas, \(V_{PO}\) is sensitive to most of the parameters.
2) \(t_{PI}\) is most sensitive to \(L_m\), \(H_m\) and \(y_0\) whereas, \(V_{PI}\) is most sensitive to \(H_m\), \(y_0\), and \(\epsilon_r\).
3) TFAIL is most sensitive to \(y_d\), \(\epsilon_0\), \(m^*\), \(N_T\).