Verification of Dielectric Charging in MEMOSA
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**Motivation:** Dielectric charging is one of the major causes of MEMS failure. During device operation, charges are trapped inside the thin dielectric layer, leading to uncontrollable changes of actuation voltage versus time and eventually, complete device failure.

**Goal:** The simulation seeks to predict trapped charge density in the dielectric insulator as a function of time, dielectric thickness and voltage.

**Model:** A 1-D model has been developed to capture all physics and then incorporated in 3-D in MEMOSA.

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**Governing equations**

- **Electrostatics:** A Poisson equation is solved in the dielectric and the air gap to obtain the electric field

\[ \nabla^2 \varphi = -\frac{\rho}{\varepsilon} \quad E = -\nabla \varphi \]

\( \varphi \): potential field \( E \): electric field
\( \varepsilon \): dielectric constant \( \rho \): charge density

Note: Charge density is divided in two parts: the charge in traps \( (n_t) \) and the charge in the conduction band \( (n_c) \). They are solved in a coupled way in the charge transport equations.

- **Charge transport:** Multiple mechanisms contribute to dielectric charging. Among them, the most important ones for the PRISM device are tunneling, emission, capture, and injection.

\[
\begin{align*}
\frac{\partial n_t}{\partial t} &= S_{\text{tunneling}} - S_{\text{emission}} + S_{\text{capture}} \\
\frac{\partial n_c}{\partial t} &= S_{\text{emission}} - S_{\text{capture}} + S_{\text{injection}} - V \cdot (\nabla n_c) + \mu \nabla^2 n_c \\
S_{\text{tunneling}} &= \frac{4 \pi m}{h^3} \frac{1}{N^2} \int T(E) \beta(E) S(E) f(E) dE \\
S_{\text{emission}} &= \sigma_n E(x) [N - n_t(x)] \\
S_{\text{capture}} &= \sigma_{n_c} v_n (N - n_t(x)) \\
S_{\text{injection}} &= \gamma n_{t_0} E(x) \exp \left( -\frac{E(x)}{k_B T} \right) + \frac{q E(x)}{k_B T \pi \sigma_{n_0} E(x)} \\
\end{align*}
\]

**Linear system**

The charge transport equations for each cell can be discretized into the following form

\[
\frac{\partial n_t}{\partial t} = A n_t + \sum_{i=0}^{\text{cell}} A_{ni} n_{ni} + B_i \\
\]

\( i \) is the cell index
\( n_t, n_c \) are stored and solved in a coupled way

The entire linear system is written as:

\[
\begin{bmatrix} A_0 & \cdots & A_{n-1} & \cdots & A_N \\ \vdots & & \vdots & & \vdots \\ A_{n-1} & \cdots & A_0 & \cdots & A_N \\ \end{bmatrix} \begin{bmatrix} n_0 \\ \vdots \\ n_{n-1} \\ \vdots \\ n_N \end{bmatrix} + \begin{bmatrix} B_0 \\ \vdots \\ B_{n-1} \\ \vdots \\ B_N \end{bmatrix} = 0
\]

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**Mesh and timestep independence**

A 2500 cell mesh gives an error of 1.7% wrt a 10000 cell mesh

A time step scale of 1.1 gives an error of 1.1% wrt a time step scale of 1.02