Multiple-Mode Polymer-Silicon Dual Channel Gas Sensors

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I. Key Device Design Features:

- **Refreshable** memory mode chemical detection device
- **Organic Polymer Top Channel**: High chemical responsivity, "designer material", solution based fabrication
- **Silicon Bottom Channel**: Reliable device performance, fast device operation, easy device integration with the current large-scale electronics manufacturing processes
- **3 additional sensing modes**: chemical field-effect transistor (ChemFET), organic FET, and Dual Channel FET

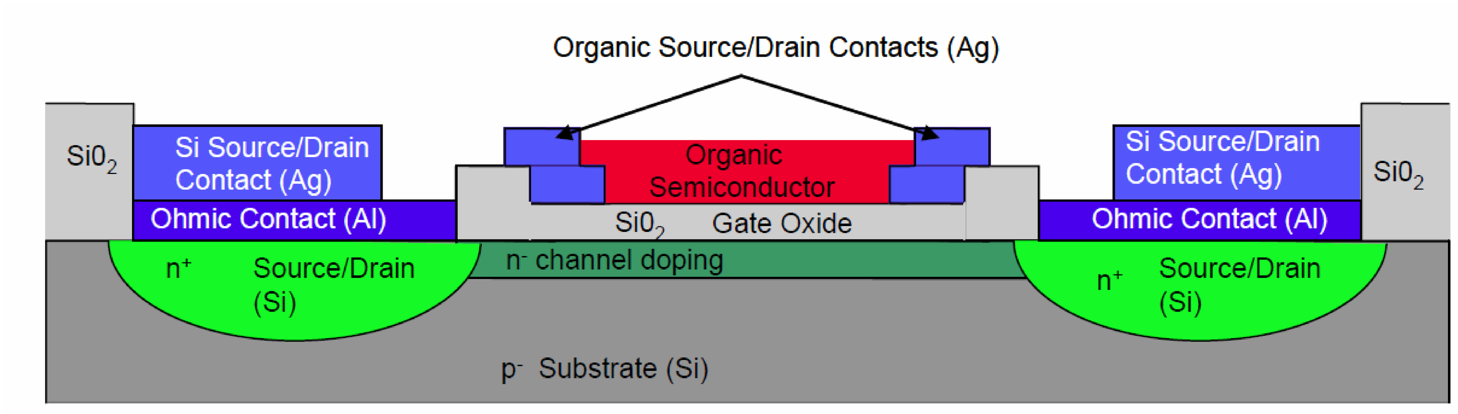

Figure 1. Dual-Channel Device Design

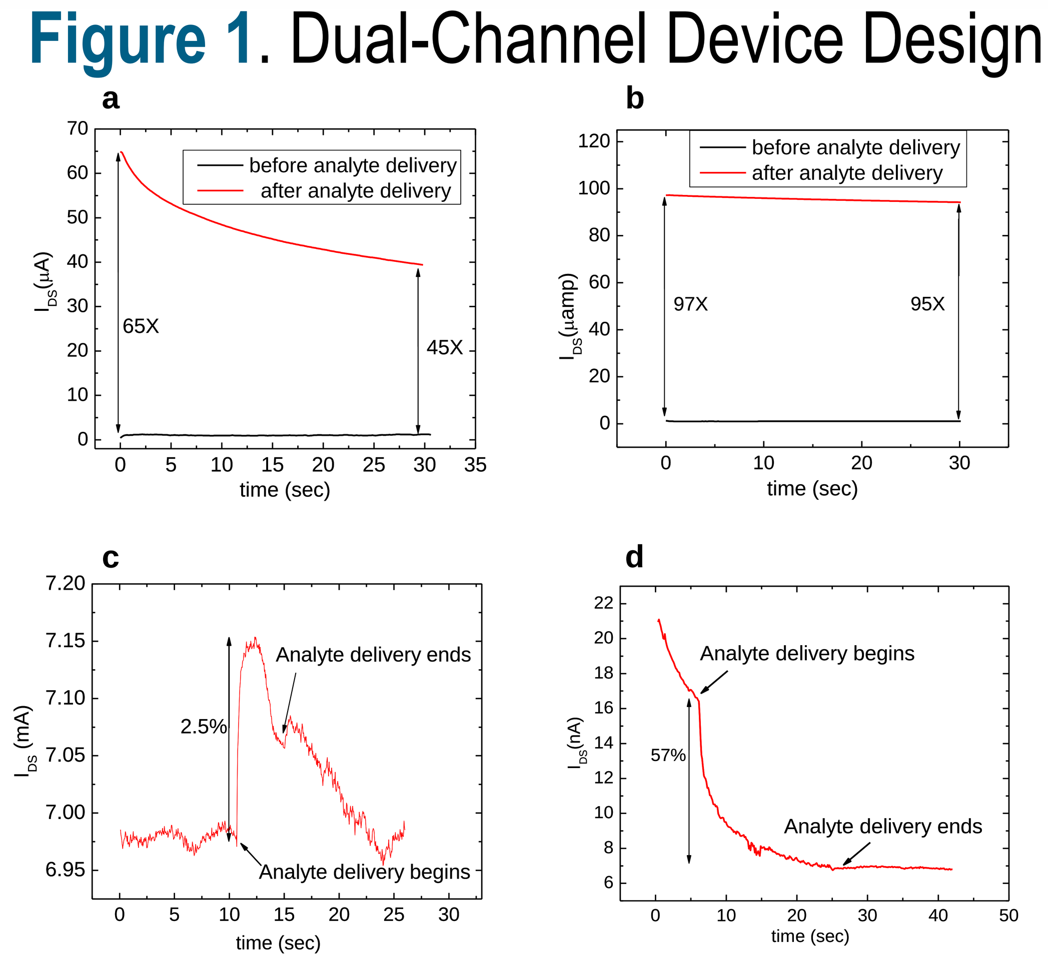

Figure 2. Multimode Operation of Dual Channel Sensors

II. Computational Methods:

- **Drift Diffusion Model:**

Drift-Diffusion Equation

$$\mathbf{J}_n(\mathbf{r},t) = n\mu_n \nabla \boldsymbol{E}_c + \mu_n k_B T G(n/N_c)\nabla n + \frac{nq}{T} D_{n,th}\nabla T$$

$$\mathbf{J}_p(\mathbf{r},t) = p\mu_p \nabla \boldsymbol{E}_v + \mu_p k_B T G(p/N_v)\nabla p - \frac{pq}{T} D_{p,th}\nabla T$$

Poisson's Equation

$$\nabla \cdot (-\varepsilon_r \nabla V) = q(p - n + N_d^+ - N_a^-)$$

Current Continuity Equation

$$\frac{\partial n}{\partial t} = \frac{1}{q}(\nabla \cdot J_n) - U_n\,, \qquad \frac{\partial p}{\partial t} = \frac{1}{q}(\nabla \cdot J_p) - U_p$$

- **Mapped Rectangular Mesh:**
  - Reduction in mesh points from free triangular for device with high aspect ratio
  - Dense near oxide interface, area of high variability; coarse far from the oxide interface, faster element growth rate

Work supported in part by NSF

This work is based upon work supported in part by the National Science Foundation under Cooperative Agreement No. EEC-1160494. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

III. Results:

- **Reducing effects of dopant spreading** can improve sensor responsivity by up to a factor of 3, can be implemented by increasing metal gate width
- **Decreased numbers of mesh elements and shorter runtimes** can be achieved with Mapped Rectangular Meshes.

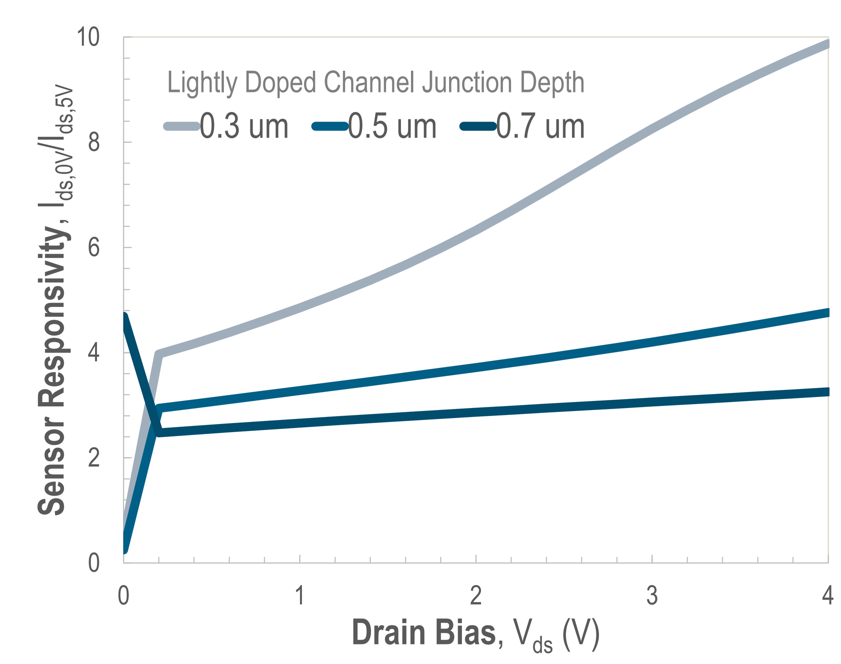

Figure 3. Dopant Spreading Reduces Responsivity

Parameter	Value	Unit
Channel Length	54	μm
Oxide Thickness	40-100	μm
Peak Channel Doping	4×10^{16}	cm^{-3}
Peak Channel Depth	0.08	μm
Channel Junction Depth	0.30	μm

Table 1: Experimental and Simulation Device Parameters

	Mapped ■	Free ▲
No. Elements	245,756	1,989,189
Runtime	24 min	2 hr 45 min

Table 2: Mesh Comparison

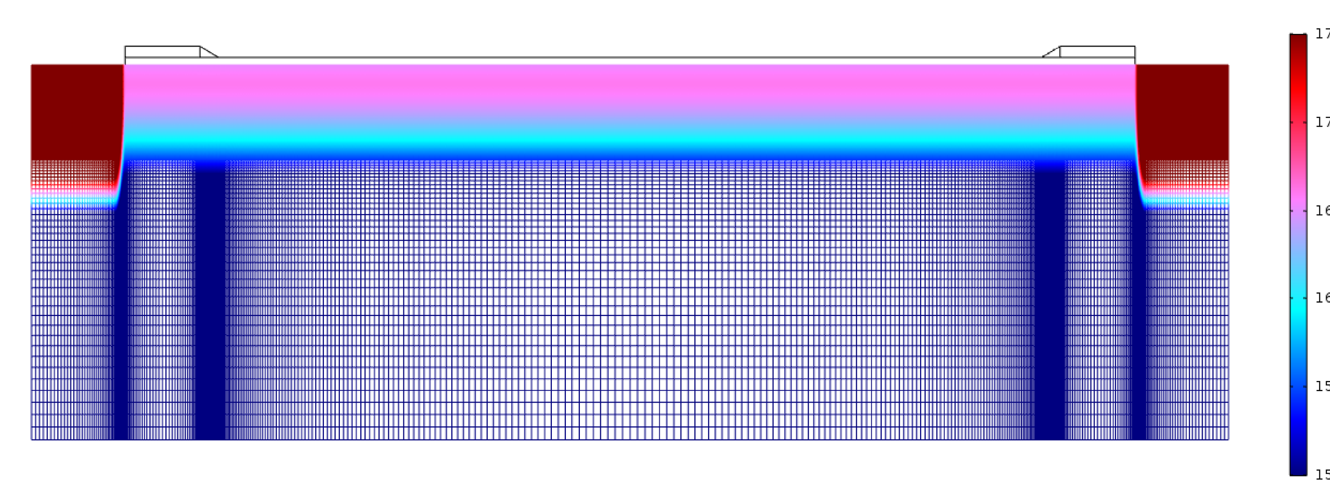

Figure 4. Wireframe Donor Doping Profile; Scale 1:10

IV. Conclusions:

- **Improvement of gate control** can further improve analyte detection sensitivity by up to 3x while simultaneously lowering the device's operation voltage in ChemFET mode.
- **Mapped Rectangular Meshing** is a good candidate for speeding up semiconductor device simulations with thick substrates while retaining high accuracy near key interfaces
- **Simulation of Dipolar Interaction** with organic semiconductors can provide further insights for this 4-terminal sensor design

References:

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