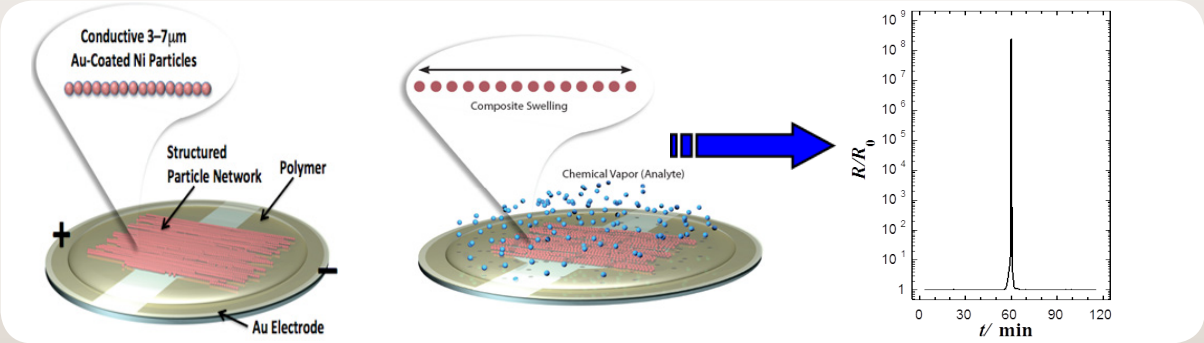
Sandia's Field-Structured Chemiresistors (FSCRs)

What are FSCRs?

FSCRs are electrically conductive composites comprising an elastomer that encapsulates a network of conductive, magnetic particles. These particles are structured into conductive pathways in a magnetic field. This conductive composite bridges two electrodes on an insulating substrate.

How do FSCRs work?

When exposed to a volatile organic compound (VOC), the polymer absorbs the VOC and swells the polymer. This swelling causes the encapsulated particle network to pull apart, breaking inter-particle connections and therefore causing the resistance of the composite to increase. This increase in resistance is correlated to the concentration of the VOC in the environment.



What applications are a good fit for chemiresistors?

Chemiresistors excel at simple, low-power *in situ* VOC monitoring.

FSCR attributes:

- Response is reversible
- FSCRs require little power (< 10mW) and very simple transduction infrastructure
- FSCRs are inexpensive and simple to manufacture and are size scalable
- Sensitivity can be tailored to sense in any concentration regime
- FSCRs can be made to act as chemical switches for simple, assay-type measurements. The switching point of these sensors can be tuned for a particular concentration of a target analyte
- Chemiresistors can be made to be selective to particular classes of analytes by changing the polymer phase of the composite
- Arrays of chemiresistors with varying selectivity can be used for low-level analyte discrimination
- FSCR response can be predicted for any analyte by calibrating with only one analyte
- A great deal of research effort has been spent on the engineering aspects of carbon-black chemiresistors (selective-polymer arrays, packaging, discrimination algorithms); FSCRs can utilize this infrastructure seamlessly
- FSCRs, like strain gauges, are sensitive to changes in temperature; this can be mitigated by using FSCRs in Wheat stone bridge circuit or controlling temperature

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Can FSCRs be used to detect aqueous-phase VOCs?

Yes. There are two approaches: (1) house the sensor behind a semi-permeable membrane and measure the VOCs that permeate from the water into the vapor phase, and (2) directly immerse the sensor in water where VOCs will partition from the aqueous phase into the polymer (Fig 1). The second option has been briefly demonstrated, but shows promise as a novel application for class of sensors.

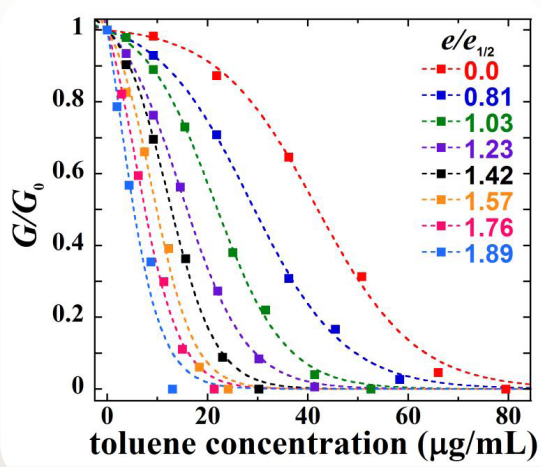

Figure 1: *A single FSCR can be reversibly tuned to cover a broad range of concentration at low sensitivity or a narrow range at high sensitivity like a chemical switch*

Why are chemiresistors not currently commonly used in chemical sensing applications?

Early generations of chemiresistors were made by randomly dispersing carbon-black within the polymer and relying on a high loading of particles to reach the point at which the composite is electrically conductive. These sensors were plagued with issues including: irreversibility (carbon black permanently absorbs VOCs), sensor-to-sensor reproducibility, and low sensitivity. Field-structured chemiresistors are a recent development and completely solve these problems which had prevented carbon-black chemiresistors from becoming a viable sensor technology.

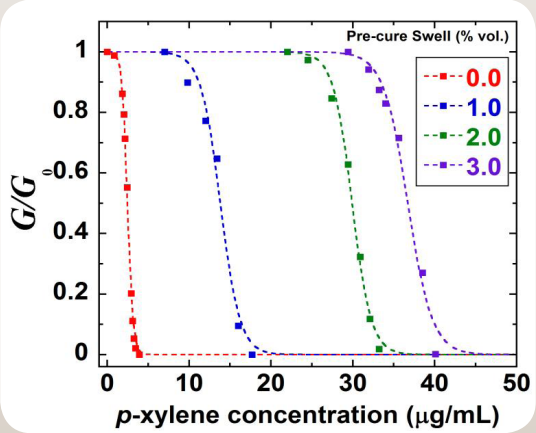

Figure 2: *Response curves for an array of FSCRs demonstrates the ability to maintain sensitivity while tailoring the switching point*

What applications are not a good fit for chemiresistors?

Chemiresistors are not gas-chromatograph mass-spectrometers (GCMS). FSCRs cannot match the analyte-discrimination power or sensitivity of GCMS. As such FSCRs are not suited to applications where discrimination is needed for analytes within the same class of chemicals (i.e. differentiating between toluene and benzene) or where extremely low detection limits are required.

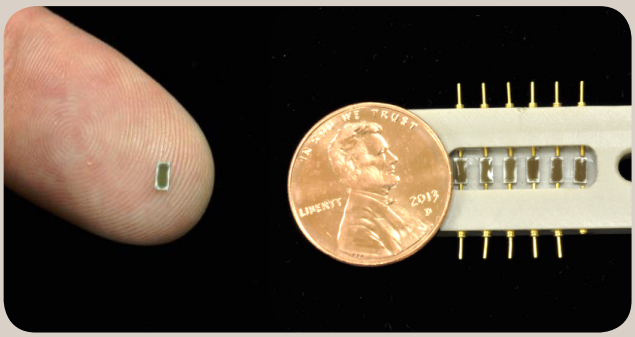

Figure 3: *Size comparisons of FSCRs to a finger and a penny*

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