A nanotube-based electronic nose

Discriminating between household items

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Introduction

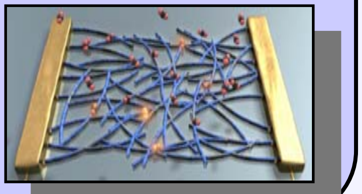
Since the 1980s, electronic noses (enoses) have relied on technologies such as chemically sensitive polymer arrays with varying signal transduction schemes or catalytic semiconductors capable of measuring the rate of substrate oxidation. However, most of these devices are limited in the molecules they detect.

We are investigating a new type of enose sensor; one that is capable of responding to a wide range of molecules -- which is very valuable if the target molecules are unknown. The sensor is comprised of a nanotube based field-effect transistor (ntFET) manufactured by Nanomix. The ntFET is constructed similarly to a traditional FET, except the doped channel is replaced by an amorphous nanotube layer. The entire structure can optionally be coated with varying substances to modify the selectivity of the sensor.

We have constructed a system to evaluate the effectiveness of the ntFET system discriminating between the odors from four household items (**vodka, tea leafs, coffee beans, banana peel**).

How The Sensors Work

As molecules in the atmosphere land on the nanotube surface, they will modify the "doping" of the nanotubes by contributing electrons or removing them – akin to doping a semiconductor by adding molecules that contribute or remove electrons from the silicon. This will vary the Conductance-Voltage curve of the sensors, which our device measures every 5 seconds. **Additional coatings will modify the binding affinity for various airborne molecules.**



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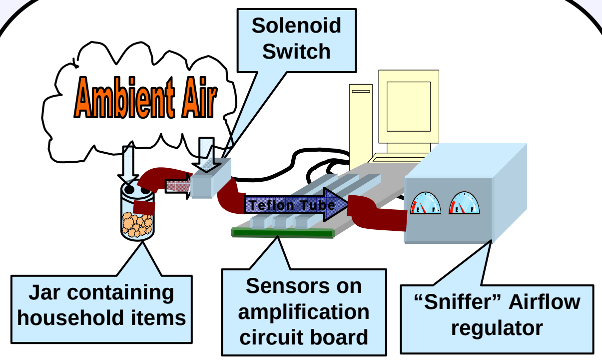
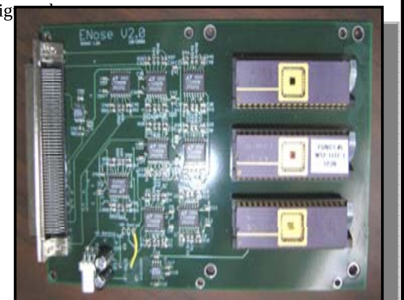
Materials and Methods



Airflow was generated by a custom-built vacuum "sniffing" system which is capable of controlling the airflow rate as well as the duration and duty cycle of suction.

Ambient air can be drawn over the sensors to purge them by way of the "Solenoid Switch" in the figure.

The custom sensor circuit board (PCB; figure to right) houses of three sensor ICs manufactured by Nanomix, each containing ten ntFETs (figure below). The PCB contains the amplification circuitry and interfaces with LabView.



Custom data acquisition device. Holds sensor ICs and amplification circuit

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MYSELF

Active area on one sensor IC. Ten ntFETs with varying physical dimensions.

Data Acquisition

Before acquiring data, the device is purged with ambient air. Various flow rates and sniffing patters were tested, and optimized for subsequent tests.

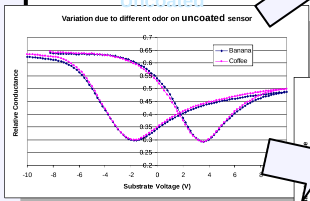
During data acquisition, the gate (substrate) voltage of the ntFET was swept at 0.2Hz from -10V to +10V then back down to -10V as the ntFETs exhibit hysteresis. The source/drain equivalents were biased to -0.1V. Collected conductance data was used to build a discriminability function to classify subsequent odor samples.

Data and Results

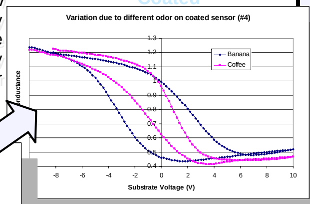
Effects of different coatings and odor sources on conduction.

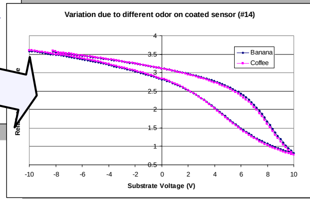
The application of a *certain* coatings to the sensor can greatly increase it's ability to discriminate for particular odor profile by altering the "binding" affinity for classes of molecules.

Uncoated



Coated



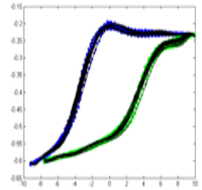


Parameterizing a response

The figure to the right represents ten response curves of an odor fit to the polynomial

$$Y = p_0 + p_1 g + p_2 g^2 + p_3 g^3 + \ldots + p_{10} g^{10}$$

Where g is the gate voltage, Y is the sensor response and p_0, p_1, ..., p_{10} are the polynomial fit parameters.



10 repeats of a single odor with fitted lines (10th degree polynomial)

Thus each response is represented as an up and down sweep, each of which is represented as the 11 parameters of the polynomial fit. Each household item is thus represented by the distribution of parameters across a number of sensors.

Subsequent samples were matched using a Mahalanobis distance to the closest item, provided that the match met a minimum distance criterion.

Discriminability of household items

After the initial training, further samples were taken, and the discriminability function **correctly classified single "sniff" acquisitions 72% of the time** (43/60 Trials). However, It has been reported that the ntFETs are highly sensitive to variations in ambient humidity, and we suspect that we can improve our predictive capability by controlling the humidity that reaches the sensors.

Conclusion

We used a nanotube-FET based sensor to discriminate between four household items: vodka, tea leafs, coffee beans, and a banana peel. We used the sensors to generate unique sigmoidal conduction-voltage curves which were used to train a discriminability function. On subsequent samplings of the items, the function correctly identified the item 72% of the time. We also found that by using ICs with different coatings, we were able to increase the discriminability of the system; however, it is a process of trial and error in determining the optimal set of coatings for a particular task. The use of the ntFETs in identifying household items has proved to be highly effective, especially given that **no knowledge of the actual group of molecules which were sensed was necessary**. We hope to expand on this technology to allow us to detect diseases in humans quickly and noninvasive – by smell alone – once properly trained.

Acknowledgments & References

This work was supported by the NIH-NIDCD and DOD.

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