## KPAN004: Application – Diagnosis of Disease Research

"*Detection of Nonpolar Molecules by Means of Carrier Scattering in Random Networks of Carbon Nanotubes: Toward Diagnosis of Diseases via Breath Samples*" -

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## Keywords

FET, CNT, VOC, Disease Detection, WF, Work Function, Kelvin Probe System, KP020


## Abstract


Field effect transistors (FETs) based on random networks (RNs) of single wall carbon nanotubes (CNTs) have several technological advantages. However, the low sensitivity (or no sensitivity) of RN-CNT sensors to nonpolar molecules is a problematic, negative feature that limits their applications in the detection of a wide variety of diseases via breath samples. This paper shows experimental evidence for the detection of both individual nonpolar molecules and patterns of nonpolar molecules, even in the presence of polar molecules in the same environment. This is done by preparing RN-CNT FETs and functionalizing them with organic films that exhibit distinctive electrical and physical (or mechanical) characteristics. Exposing the functionalized RN-CNTs to representative nonpolar breath biomarkers, and, for comparison, to polar molecules in the gas phase, and monitoring the changes in conductance, work function, and organic film thickness show that sensitivity toward nonpolar molecules stems from carrier scattering as a result of swelling of the organic film exposure to (nonpolar) chemical agents. Controlling the chemical and biological agents, which have hitherto been difficult to trace. As examples for technological impact of our findings, we describe ways to detect lung cancer and kidney disease using specially designer RN-CNT sensor arrays


## Research Area

Exhaled breath is composed mainly of nitrogen, oxygen, carbon dioxide, water and inert gases. Trace volatile organic compounds (VOCs) that are generated in the body of absorbed from the environment make up the rest of the breath. The exogenous VOCs, which originate primarily from various solvents and petroleum based products, are adsorbed in the lung via the inhales breath or absorbed in the blood through the skin. The endogenous volatiles are generated by the cellular biochemical processes of the body. Thus, measurement of VOCs in the breath can provide a window into the biochemical processes of the body.

Several classes of nonpolar VOCs can be measured in the exhaled breath. These include saturated and unsaturated hydrocarbons. Saturated hydrocarbons (e.g. ethane, pentane, and aldehydes) are formed during lipid peroxidation of fatty acid components of cell membranes, triggered by reactive oxygen species. They are considered markers of oxidative stress. Smaller quantities may be produces by protein oxidation and colonic bacterial metabolism. They have a low solubility in the blood hence are excreted in the breath with in minutes of their formation. Unsaturated hydrocarbons are also detected in the exhaled breath. One example, isoprene, is formed along the mevalonic pathway of cholesterol synthesis. Patterns that include combinations of saturated and unsaturated hydrocarbons, most of which are nonpolar in their nature, could via breath samples, characterise cancer.

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## Use of Kelvin Probe

Changes in the work function during exposure to the analytes were monitored under ambient conditions by measuring the electrical potential of contact free surfaces relative to that of a gold reference, using a commercial Kelvin probe system (Kelvin Probe System, KP020). The Kelvin probe package included a head unit with integral tip amplifier, a 2mm tip, a PCI data acquisition system, a digital electronics module, the system software, an optical baseboard with sample and Kelvin probe mounts, a 1" manual translator, and a faraday cage. The Kelvin probe data were collected for three or more different samples and averaged.

Figure 1. KP Technology KP020 System.

Work function (WF) was monitored during the exposure of RN-CNT layers without electrodes to the analytes. Figure 3 shows the evolution of the work function of a mesh of pristine CNTs when exposed successfully to decane and TMB vapour biomarkers. The WF was measured at 4.980± 0.001eV in air. No measurable change in WF was observed when flushing the device with decane. Note that the small dip at the onset of the decane exposure stems from a slight variation in air pressure. Kelvin probe measurements for measuring the WF are extremely sensitive to variations of pressure, temperature, humidity, etc. In contrast the WF decreased dramatically when exposing the CNT mesh to TMB and did not fully recover afterward. These results can be explained in terms of the polarity of the analytes. The decane molecule has a negligible dipole moment, whereas TMB acts as an electron donor. Hence there is no charge transfer from the absorbed decane molecules to the CNT mesh, which acts only as scattering centres, and the work function does not change. The aromatic TMB rings are known to interact strongly with the graphitic sidewalls of the CNTs, donate electrons to the CNT, shift the Fermi level toward the conductance band, and, thus, decrease the WF.

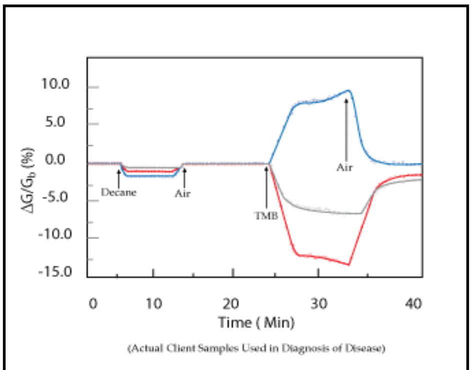


Figure 2. Conductance response, $\Delta G/G_B$ of pristine and functionalized RN-CNT chemiresistors as a function of time in chemical environments at $P_\alpha/P_o$ = 0.004.

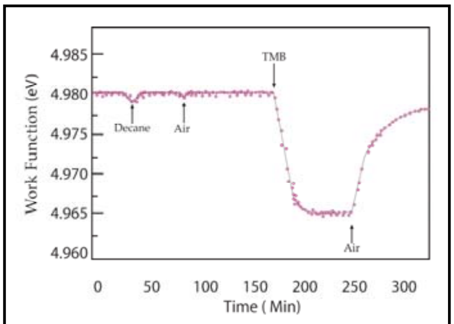


Figure 3. Work function of pristine RN of CNTs as a function of time in different environments at $P_\alpha/P_o$ = 0.004

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## Conclusion

RN-CNTs coated with films of organic monomers could find application in the precise and chemically selective sensors for molecules with negligible dipole moments, which have hitherto been difficult to trace. The use of an array of such highly sorptive films, therefore, would readily provide distinct response to healthy breath and diseased states. Experiments with sensors based on RN-CNTs that are coated with unique monomers via strong chemical bonds to thoroughly probe array response to healthy breath and diseased breath are underway and will be published elsewhere. Ultimately, these developments could lead to a sensing technology that is relatively simple to use, lightweight, low power, and able to detect diseases in a non-invasive way (i.e. via breath samples) in real time

## Reference


1. Original publication: "*Detection of Nonpolar Molecules by Means of Carrier Scattering in Random Networks of Carbon Nanotubes: Toward Diagnosis of Diseases via Breath Samples*" - Gang Peng, Ulrike Tisch and Hossam Haick.

   Full text available from:
   American Chemical Society, January 2009 [DOI: 10.1021/nl8030218 CCC]

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