Trace Explosive Vapor Detection Using Silicon Nanowires in a Vertical Array with a Porous Electrode

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Abstract:
The proliferation of improvised explosive devices (IEDs) and recent terrorist attempts like the infamous Shoe Bomber, Underwear Bomber, and Toner Cartridge Plot have demonstrated a significant need for portable and sensitive sensors for detection of explosive vapors. The Silicon Nanowires in a Vertical Array with a Porous Electrode (SiN-VAPO) architecture has been developed to address this need with parts-per-billion detection limits for nitroaromatics, such as dinitrotoluene and trinitrotoluene (TNT). An initial-slope method has been used to establish calibration curves for model compounds like nitrogen dioxide and ammonia and provides a mechanism for obtaining quantitative results with the SiN-VAPO sensor.

Key words: Explosives, Sensor, Vapor, Nitroaromatics, Silicon Nanowires, Porous Electrode

Introduction
Field effect transistor-based chemical sensors (ChemFETs) based on nanowires have been researched for military, industrial, and commercial applications as gas phase chemical detectors. While nanowire-based ChemFETs have demonstrated an extreme sensitivity to vapors because of their large surface-to-volume ratios, they have continually underperformed as portable, field deployable sensors. The lack of performance is due to a combination of supporting substrate effects, humidity, 1/f noise from a reduced number of charge carriers in single nanowire configurations, Schottky barrier formation at the contacts, and shot noise from wire-to-wire junctions in multiple, overlapping nanowire configurations.

The SiN-VAPO sensor addresses these problems with a combination of Metal-Assisted Chemical Etched (MACE) nanowires and a two-stage nanosphere lithography method [1,2]. Silicon nanowires are etched out of bulk silicon wafers in a vertical configuration. A porous top electrode is formed on top of the vertical nanowires creating a massive parallel array of nanowire sensors with rapid, uniform access to the analytes of interests. Fig. 1 shows a conceptual drawing of the architecture and a SEM image of the final sensor. The vertical configuration reduces substrate effects while maximizing sensing surface area. The massive parallel array eliminates noisy wire-to-wire junctions and increases the number of charge carriers.

![Fig 1.](image)

Fig 1. (A) A conceptual drawing of silicon nanowires in a vertical array with a porous top electrode. (B) A scanning electron microscopy image of the porous top electrode in alignment with the metal-assisted chemical etched silicon nanowire array.

Results
A trace explosives test bed was developed to evaluate prototype sensor performance under a variety of environmental conditions. An impactor-inspired sample chamber with uniquely flexible electronics was used to evaluate the SiN-VAPO sensor performance to nitrogen dioxide, ammonia, DNT, and TNT in humidified air. Fig. 2 shows the response to ammonia and nitrogen dioxide over the parts-per-billion concentration range using the test bed and sample chamber. A GC-MS was modified to monitor analyte concentration in real-time during sensor evaluation. Fig. 3 shows the response of the SiN-VAPO sensor to DNT in humidified air compared in real-time to the online GC-MS instrumentation. The SiN-
VAPOR sensor responds similarly to the current commercially available instrumentation of explosive vapor detection.

![Graph showing sensor response to ammonia and nitrogen dioxide](image)

**Fig. 2.** Response to ammonia and nitrogen dioxide in humidified air at various concentrations in the parts-per-billion concentration range. The sensor was exposed to 2 minutes of clean air followed by 2 minutes of analyte with a 10 minute recovery of clean air. The ammonia response is designated as an increase in resistance and the nitrogen dioxide exposure results in a decrease in resistance.

![Graph showing response to 40 ppb of dinitrotoluene](image)

**Fig. 3.** The response to 40 ppb of dinitrotoluene for the SiN-VAPOR sensor (black) and a modified GC-MS for online vapor detection (red) in humidified air.

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**References**
