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Explosives

A microsensor for trinitrotoluene vapour

Sensing devices designed to detect explosive vapours are bulky, expensive and in need of technological improvement — dogs remain the most effective detectors[1] in the fight against terrorism and in the removal of land-mines[2,3]. Here we demonstrate the deflagration of trinitrotoluene (TNT) in a small localized explosion on an uncoated piezoresistive microcantilever. This explosive-vapour sensor, which has a detection capability that is comparable to that of a dog, should enable extremely sensitive, miniature detection devices to be used on a large scale.

Microcantilevers with specific coatings can be used for chemical detection[4,5], but TNT molecules, which are intrinsically 'sticky', readily adhere to uncoated cantilever surfaces[6]. When the source of TNT is removed, the TNT molecules slowly desorb. We found that applying a voltage pulse to an integrated piezoresistor during this desorption process causes the cantilever temperature to rise beyond the deflagration point of TNT, resulting in a miniature deflagration. Our cantilevers did not degrade after hundreds of pulses (10–25 volts) and deflagrations.

We monitored deflagration by capturing magnified high-speed video images, by measuring the deflection due to released heat using an optical beam-bounce technique that is used in atomic-force microscopy, and by measuring resonance-frequency shifts and heat added with a piezoelectric/piezoresistive cantilever[7] operated in self-sensing mode by means of an a.c. bridge circuit[8]. The circuit's output increases with mass loading of adsorbed TNT and increasing temperature; it decreases with mass desorption and decreasing temperature.

A five-event TNT-detection test, using the self-sensing platform described, is illustrated in Fig. 1. During event 1, before loading with TNT, a reference voltage pulse (25 volts) is applied to the piezoresistive heater, causing a temporary upward spike in circuit output that is due to heating. TNT loading (event 2) causes a gradual upward shift in sensor output, which then gradually decreases when the TNT begins to desorb from the cantilever (event 3). The second pulse (5 volts) during desorption does not raise the cantilever temperature sufficiently for deflagration (event 4). The third pulse (25 volts) causes deflagration, as shown by a visible smoke plume, and a dramatic mass decrease, which is verified by a reduction in circuit output (event 5) that overwhelms the upward thermal signal evident in event 1. Post-deflagration reference pulses of 25 volts resulted in spikes similar to the one seen in event 1.

The occurrence of deflagration was inferred from three consistent observations. First, the cantilever returns to its pre-test resonance frequency after deflagration, suggesting that all of the adsorbed material has been lost. Second, a specific voltage (corresponding to a threshold, or deflagration-point, temperature) is necessary to cause deflagration. Third, the measurement of heat added to the cantilever during deflagration shows that the reaction is exothermic, ruling o[illegible] such as melting [illegible]on.

Our [illegible]e deflagration [illegible]9×10^{11} molecul[illegible]he shift in cantil[illegible]f detection is t[illegible]ed version[9] of t[illegible]ometry technolo[illegible]ecurity. Calculati[illegible]n limit could be improved by up to three orders of magnitude by using optimized cantilevers.

An explosive-detection technique based on deflagration is advantageous, because deflagration is a characteristic property of these substances. Other potentially interfering but non-explosive substances tested — including water, acetone, ethyl alcohol and gasoline — all desorbed in our system before the voltage pulse was applied. In the absence of a voltage pulse, desorption of nanogram quantities of deposited TNT takes tens of minutes; comparable amounts of water or alcohol desorb in seconds.

Other explosive molecules can be detected by this method and differentiated by their compound-specific deflagration points and desorption times (results not shown). Our technique could also be used in conjunction with coated-cantilever chemical-sensing arrays[5], in which the arrays serve as an initial indicator, and positive readings are verified by deflagration on an uncoated cantilever.

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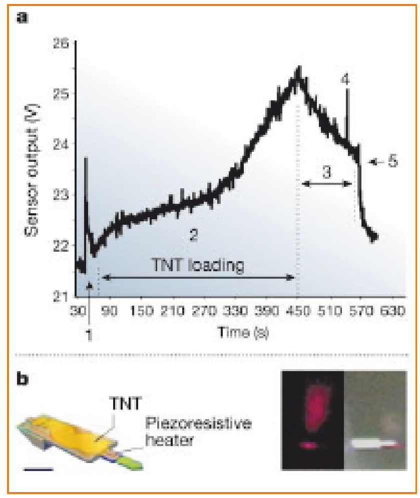

Figure 1 Deflagration and detection of trinitrotoluene (TNT). **a**, Sensor output plotted against time. During event 1 (numbered arrow) of the test, a 25-volt reference pulse is sent to the piezoresistor before TNT loading begins; sensor output returns quickly to almost its pre-pulse value. In event 2, TNT is gradually loaded onto the cantilever and the resonance frequency decreases, causing the sensor output to increase. After loading, the TNT begins to desorb (event 3) and a 5-volt pulse (event 4) is insufficient to heat the explosive on the cantilever to its deflagration point. However, a 25-volt pulse is sufficient to cause deflagration (event 5). **b**, Left, diagram of the microcantilever, showing the integrated piezoelectric sensor, piezoresistive heater, and TNT loaded on the cantilever surface. Scale bar, 100 μm. Right, deflagration is confirmed in magnified high-speed video images; the smoke plume is visible, particularly when illuminated by red laser light.

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