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SHORT COMMUNICATION

Detection of Landmine Signature using SAW-based Polymer-coated Chemical Sensor

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ABSTRACT

The explosive charge within a landmine is the source for a mixture of chemical vapours that form a distinctive chemical signature indicative of a landmine. The concentrations of these compounds in the air over landmines is extremely low (parts-per-trillion or lower), well below the minimum detection limits of most field-portable chemical sensors. This paper describes a portable surface acoustic wave-based polymer-coated sensor for the detection of hidden explosives. The sensitivity and selectivity of polymer-based sensors depend on several factors including the chemo-selective coating used, the physical properties of the vapour(s) of interest, the selected transducers, and the operating conditions. The polymer-based sensor was calibrated in the laboratory using the explosive vapour generator. The preliminary results indicated that the carbowax 1000 could be a very good chemical interface to sense low levels of chemical signature of explosive material. Response for 50 ppb of TNT vapours was observed to be 400 Hz for an exposure of 2 min.

Keywords: Chemical vapour signature, landmine detection, chemical sensor, polymer-coated sensor, polymer-based sensor, carbowax 1000, explosive material

1. INTRODUCTION

Different types of explosives are utilised as the main charge in anti-personnel and antitank landmines. Almost 80 per cent of the different types of mines manufactured worldwide contain 2-4-6 trinitrotoluene (TNT), or mixture of explosives containing TNT. It is estimated that TNT-containing mines account for 80 per cent to 90 per cent of the total number of landmines deployed[1]. If the landmine is buried under the soil, there is an additional requirement that the TNT vapours be transported to the surface of the ground through the layer of soil covering the landmine. Once soil at the surface of the ground becomes contaminated with the chemical signature of compounds, vapours of these compounds are then slowly released into the air where these can be detected. A growing body of data indicates that explosive vapours do escape from most landmine casings. Moreover, evidence shows that these vapours are present in the air over the landmines. Detection of the chemical vapour signature from the landmines

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through the soil has recently been the focus of a number of experimental and theoretical studies[2]. A study of external contamination, on a number of anti-personnel and antitank landmines, showed 0.5-11 ng/cm^2 of 2,4-DNT and 1.3-83.9 ng/cm^2 of 2,4,6-TNT. Henceforth, one concluded that DNT is the most significant component for detecting buried landmines besides being more stable to environmental degradation[3] as compared to TNT.

A number of techniques are in use for the detection of gaseous chemical species present in the air. One such technique is using surface acoustic wave propagation on a piezoelectric crystal, which is expected to give response to a particular vapour. A surface acoustic wave (SAW) consists of a comb like electrode patterns called inter-digital transducer (IDT) deposited on a piezoelectric substrate with specific cut and orientation. Electrical signal to the input IDT launches SAW which travels along the crystal surface with velocities approx. 10^5 times lower than that of electrical signal after a delay determined by IDT separation and SAW velocity. A SAW device can be imparted sensitivity for a particular chemical species by coating the device surface with a selective adsorbent film. This film provides chemical interface for the adsorption of gaseous species to be detected, and the mass loading due to adsorbed gas molecules result in measurable changes in device characteristics[4]. Using proper adsorbent films, various gases can be detected at very low concentrations; detection limits in the range of ppm and ppb are reported for gases and vapour sensors, and selectivity for the species is also very high[5-6].

SAW devices coated with polymers have been exposed to several vapours including nitro-aromatic compounds and common organic solvents and water vapours. When these devices were exposed to vapours, polymer-coated SAW device sorbs vapours into the polymer film, resulting in perturbation of the SAW propagation velocity. Thus, vapour sorption can be easily monitored as a shift in the resonance frequency of vapour molecules, which affects the selectivity, sensitivity, signal kinetics, and the reversibility of the sensor[7]. In this paper, techniques of polymer coating on a sensor head and response study of SAW-based sensor for explosive vapours have been discussed.

2. EXPERIMENTAL PROCEDURE

The experimental setup involved: (i) electronic configuration, (ii) polymer coating techniques, (iii) TNT vapour generation, and (iv) sensor calibration.

2.1 Electronic Configuration

The sensor assembly comprises two identical SAW oscillators, whose output are mixed, low-pass filtered, amplified, and displayed in a frequency counter. The SAW devices used are commercially available TV IF filters with fundamental response at 37 MHz. The third harmonic of the device has been used for making the oscillators. The group delay of the device is 0.92 |U,s. The untuned insertion[8] losses are in the range 23-25 dB. The sensor head has provision for gas in and out. The circuitry diagram is given in the Fig. 1.

2.2 Polymer Coating Technique

Carbowax 1000 was used as a sensing material. To ensure the smooth surface of chemical interface on the sensor head, the polymer was dissolved in four different solvents, namely acetone, benzene, chloroform, and methanol. The solution was coated on the SAW device by drop coating using a micro syringe. After drying and baking, the surface topography of the coating was observed in the optical microscope. The nominal thickness of the polymer film was about 2 (xm.

2.3 TNT Vapour Generation Unit

A TNT vapour generator was constructed to produce vapour concentrations of explosive TNT that could be used to calibrate the SAW sensor for the detection of low concentration levels. The generator was designed as described by Pella[9], *et al.* The saturated TNT vapours coming out of the generator were diluted to the desired low concentrations using online dilution arrangement provided in the TNT vapour generator. To ensure thorough mixing of the dilution gas and to yield uniform diluted concentration, an impactor was placed in the dilution

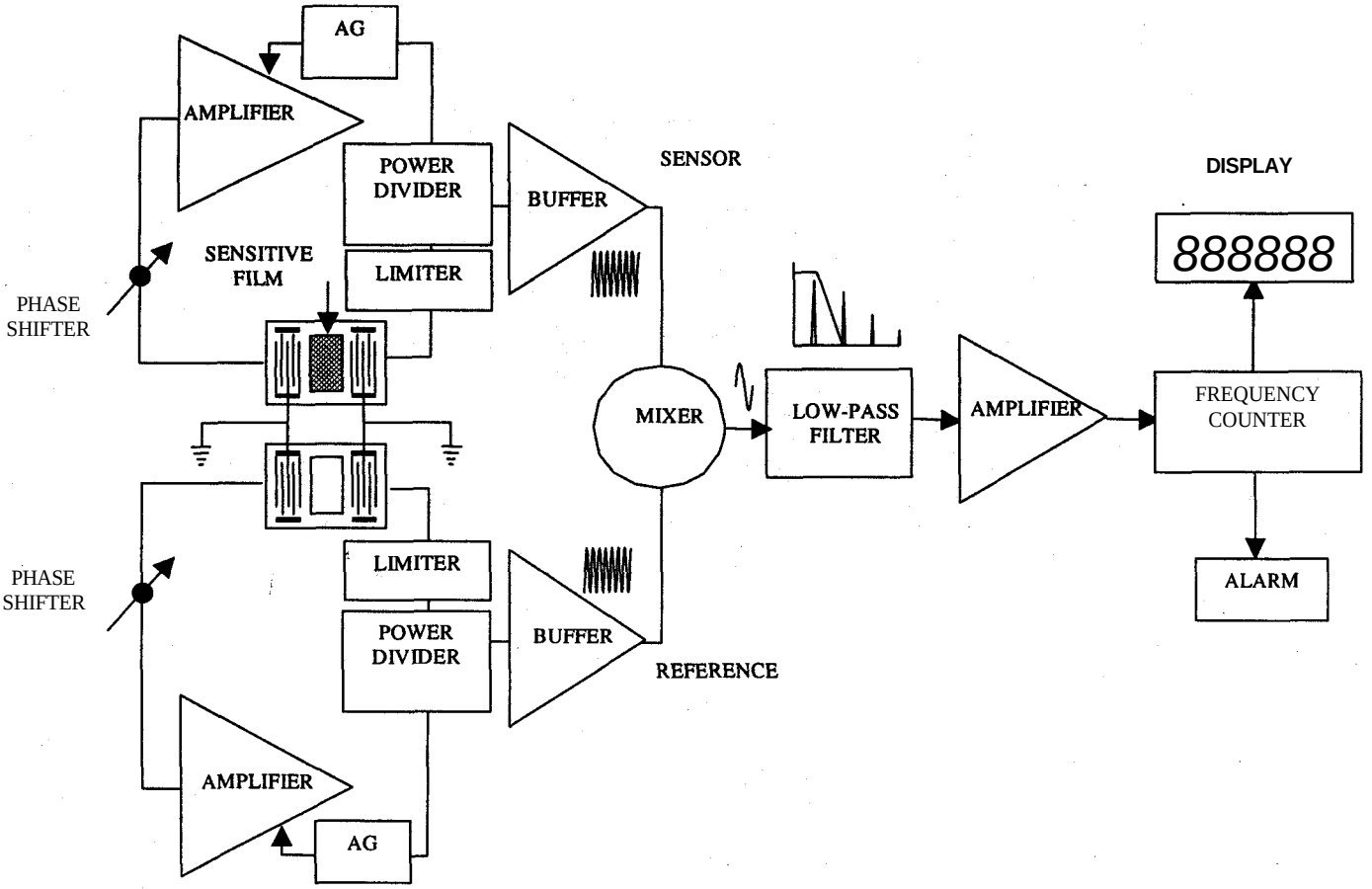

Figure 1. Surface acoustic wave TNT vapour sensor electronic configuration

chamber and also the dual-stage chamber was provided. The stainless tube connection between the outlet of the vapour generator and the sensor head was heated with a heating tape at 45 °C and also the dilution was done in a high precision hot air oven having the accuracy ± 0.01 °C. To ensure thorough mixing of the TNT vapours, a double-stage dilution column with about 5 min residence diffusion time was provided. Adsorbent tube-activated charcoal sampling" and high performance liquid chromatography (HPLC) method[12] were adopted to evaluate this system by measuring the output vapour concentrations. A known volume of saturated TNT vapours were passed through a standard adsorbent tube packed with activated charcoal. The organic vapours were adsorbed on to the activated charcoal. The adsorbed vapours were desorbed using methanol water (4:6) solvent and analysed with HPLC equipped with an ultravioletdetector[13].

2.4 Sensor Calibration Setup

A complete setup of the TNT vapour generation and sensor calibration is shown in the Fig. 2. The setup comprises a gas source, a thermal mass flow controller with an accuracy of ± O.lml/min, a spiral glass column filled with solid support coated with TNT kept in a high precision water bath having a temperature accuracy of ± 0.1°C, a solenoid valve, a resistance temperature derivative and a SAW sensor head coated with carbowax 1000.

3. RESULTS & DISCUSSION

The TNT vapours generated from the vapour generator were standardised before starting the actual calibration work on a sensor. Using the sensor calibration setup, the sensor was calibrated for its response to TNT vapours. The results of the response curve are shown in the Fig. 3. From the results, the following inferences are drawn:

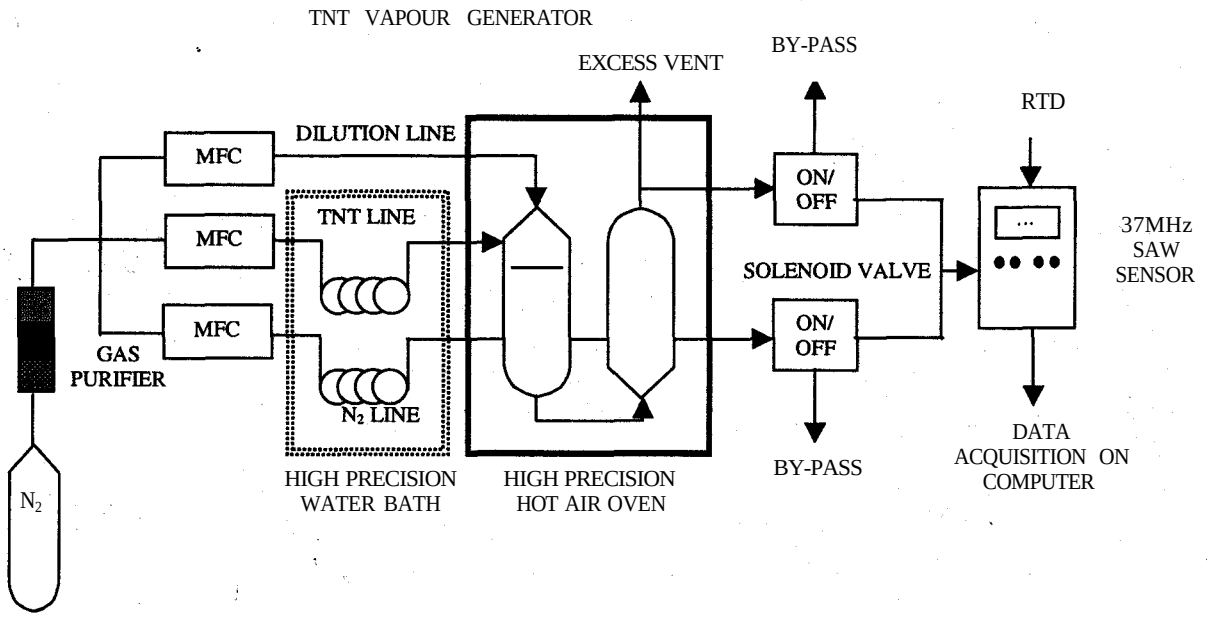

Figure 2. Schematic diagram of TNT vapour generation unit and surface acoustic wave sensor calibration assembly

(a) It is clear that the solvent has to be rightly selected to coat the polymer to ensure the smooth surface of the coating. For the two solvents (benzene and chloroform), a lot of cavities were seen on the surface after processing. The remaining two solvents, namely acetone and methanol gave smooth surfaces. Since acetone is highly volatile than methanol, the later was considered suitable for handling and used for further coating.

(b) Since the solid support coated with TNT vapours was kept in a water bath at the above ambient temperature, there is a possibility of change of temperature in TNT vapours as well as desorbing gas (nitrogen). This has been overcome by keeping nitrogen gasline in similar conditions as shown in the Fig. 2.

(c) The switchover from TNT vapour line to carrier line was automated to reduce the delay, which interferes and gives a false response.

(d) Since the SAW sensor is also sensitive to pressure, the flow of TNT vapour-bearing stream and carrier stream were regulated with an accuracy of ± 0. Iml/min, using calibrated thermal mass flow controller.

(e) The TNT vapours were allowed to pass through the sensor head for 2 min. The response was immediate. However, the prolonged exposure to TNT vapours reduces the signal. Allowing a less exposure time (around 20 s) gives a minimum response. Accordingly, the response of the SAW sensor for 50 ppb of TNT vapours was around 400 Hz in 2 min.

(f) The response of the sensor for other interfering compounds has to be further carried out to ensure selectivity of the sensor coating for the explosive vapours. Adsorption-desorption cycles have to be further improved with the in-built carrier, solenoid valve, etc for field applications.

4. CONCLUSION

The coating technique of polymer on the sensor has been standardised. Methanol has been found to be the best solvent for smooth coating of the carbowax polymer on the sensor head. A single-point calibration of SAW sensor for TNT vapours gave a response of 400 Hz for 50 ppb. The response of the sensor was observed to be 8 Hz (±lHz) per ppb of TNT vapours. The sensor is capable of sensing low levels of TNT vapours.

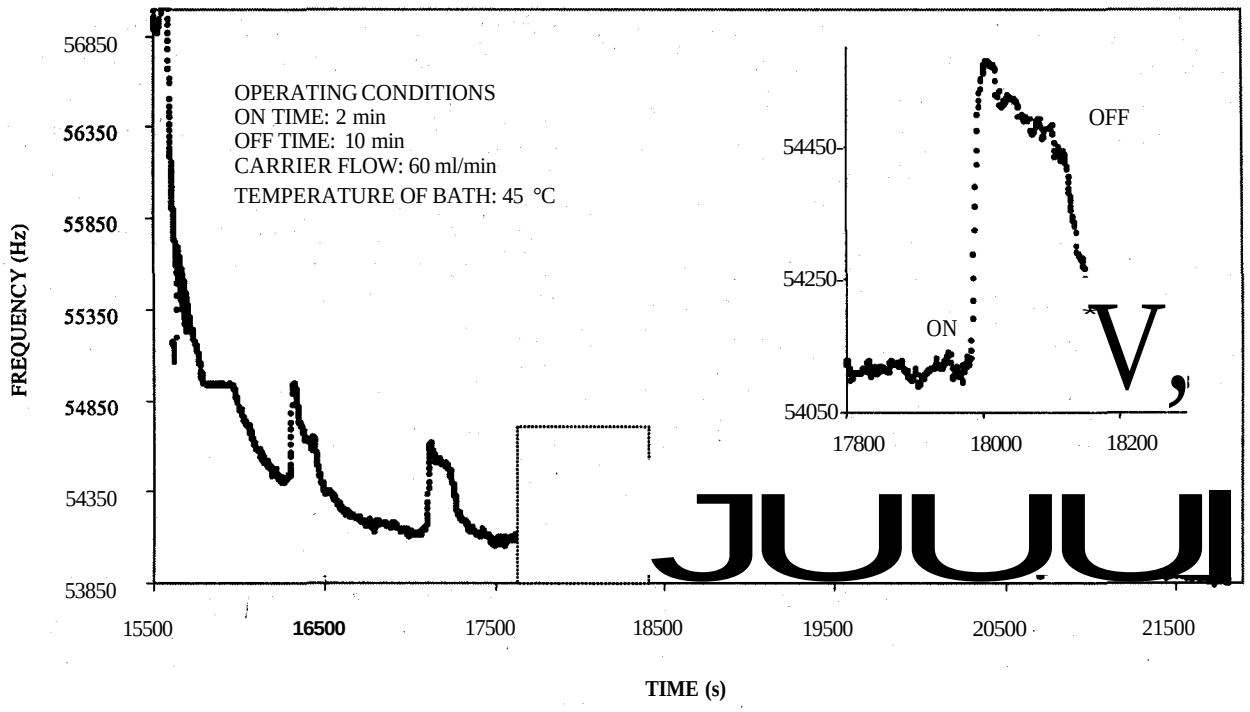

Figure 3. Response of surface acoustic wave sensor (37 MHz) to TNT vapour

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