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Chemical Vapor Detecting Passive RFID Tag

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***Abstract*—A Radio Frequency Identification (RFID) Tag is designed for threshold detection of certain chemical vapors. The vapor presence is signaled to the reader by a digital alert and communication between the tag and reader is not interrupted. The detection mechanism comprises an inkjet printed conducting track on an elastomer that swells in response to vapor exposure. The expanded track breaks and triggers a tamper detection circuit integrated into the RFID tag transponder chip**

Keywords—passive RFID, Vapor sensing

I. INTRODUCTION

Ultra High Frequency (UHF) RFID tags were conceived as a wireless technology for tracking applications [1, 2]. More recently, the technology has been investigated as a cost effective and low energy method to realize passive sensing in food packaging, or for environment and health monitoring [3–7]. The siloxane based elastomer Polydimethylsiloxane (PDMS) was used to enable RFID sensing of vapours as reported in [8] where the swelling of a tile of PDMS displaced the feed network of an RFID tag antenna and altered the amount of backscattered power in comparison to a calibrated transmit power. An alternative threshold vapour level sensing method was reported in [9] where the tag antenna matching network was inkjet printed onto a PDMS substrate. The elastomer swelling on exposure to vapour disrupted the printed conducting tracks and disconnected the antenna from the RFID transponder chip, thus signalling an event to the reader. In both cases, the PDMS was found to respond to diethyl ether, dichloromethane (DCM), and acetone vapours and the detection was repeatable. This letter summarizes the results of an investigation of a low-cost passive chemical vapour threshold alarm detector using a PDMS block with an inkjet printed conductive loop as the sensing mechanism in conjunction with a tamper detect circuit incorporated into a RFID transponder chip. The swelling properties of the PDMS substrate during exposure lead to changes in the conductivity of the printed track. The loop is connected between the pins of the RFID tamper detect circuit which produces an alert when the resistance between the pins increases. The benefit of using this approach is that the tag remains in contact with the reader and sends a signal bit when the vapour threshold is crossed. The techniques in [8] and [9] rely on a progressive, or an abrupt, loss of communication between the reader and tag and are therefore challenging to calibrate and make failsafe.

II. RFID TAG AND SENSOR DESIGN

The sensing mechanism of the reported tag uses the swelling properties of PDMS elastomer in combination with a printed conducting track. As the PDMS expands, the integrity of the printed track is compromised and the end-to-end resistance increases. At some point, the track resistance passes a threshold where it appears as open circuit when connected to the terminals of a ‘circuit break’ tamper detecting RFID chip.

A 80 mm × 60 mm end loaded dipole antenna with an inductive feed loop was etched on a 0.8 mm thick FR4 fiberglass circuit board, Fig. 1. FR4 was chosen for the tag substrate as it is not affected by exposure to the target chemical solvents. The RFID transponder was a NXP UCODE G2iL+ chip, which incorporates a tamper detection circuit triggered by a resistance value above 2 MΩ between 2 pins. The tamper event signal is stored in the transponder memory and can be accessed by the remote reader. The tag read range is around 6 m in the EU and US bands (865-868 and 902-928 MHz respectively). A number of PDMS elastomer tiles (20 × 20 × 2 mm^3) were moulded and conducting tracks were printed onto the top surfaces using a silver nanoparticle dispersion ink following previously published methods [9], Fig. 2. Four PMDS samples were used for each vapour. The average terminal resistance of the tracks was found to be around 20 Ω.

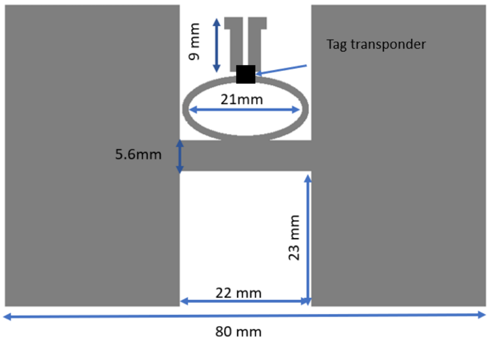

Fig. 1. Vapor Sensing Tag Design

To enable the tag PCB to be reused for different PDMS tiles, the elastomer was held in place by a polymer strap and pressure contact was made between the printed track terminals and the tamper circuit pads on the circuit board.

Fig. 2. Inkjet Printed Conductive Loop on PDMS Block

III. MEASUREMENTS AND RESULTS

The assembled tag was placed into a well-sealed glass desiccator, as shown in Fig. 3. 50 cm^3 of the chosen solvent was injected into the base underneath the tag. The desiccator was placed 30 cm above the reader antenna such that the reader and tag antenna beams aligned. During the exposure, the transponder memory status was monitored using the Voyantic Tagformance Pro RFID system. The time taken for the memory status to change from on to off is referred to as OFF time, in seconds. This is the time that takes the inkjet printed loop to break, due to the swelling of the PDMS substrate, and raise the terminal resistance from 20 Ω to an open circuit well above 2 MΩ . Once the memory status changed, the solvent at the base of the desiccator was removed and the lid left open to monitor the time taken for the tag memory status to reverse back to its original state. This time is referred to as ON time. For each of the chosen solvents, the process was repeated for 5 more complete cycles. The dc point to point resistance of the inkjet printed loop was also measured after a time equivalent to the exposure time +10 minutes. Figs. 4(a) and (b) compare the sensor memory status time change when it is exposed to DCM, diethyl ether and acetone solvents.

Fig. 4(a), shows the tags to be most responsive to DCM followed by diethyl ether and acetone with responses typically taking several minutes. After 2 cycles of exposure, the DCM and diethyl ether responses become similar while the response time remains longer for acetone. The recovery times after exposure remain consistent (less than 30 s) until cycle 5 when the DCM exposed tags require longer periods to reset the threshold signal, Fig. 4(b). In Fig. 4(c), the recovered loop terminal resistances are observed to remain stable near 20 Ω for DCM and acetone, though the loops exposed to ether exhibit higher resistances from the second exposure. This does not affect the response or recovery times as the 20 to 70 Ω values are << 20 MΩ where threshold switching occurs. It should be noted that although the tag response was repeatable, 50% of the printed loops failed after the fourth cycle and this means the statistical significance is diminished for the recovery time of DCM and the loop resistance of diethyl ether after repeated exposure.

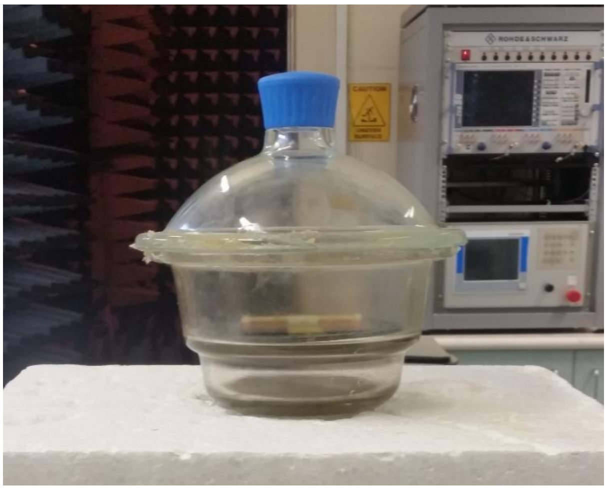

Fig. 3. RFID Tag with PDMS loop inside desiccator during measurements

IV. CONCLUSION

The use of threshold detection for DCM, ether and acetone vapour levels has been demonstrated using the swelling properties of PDMS elastomer which broke the conductivity of an inkjet printed track. Threshold detection through a tamper detect circuit removes the uncertainties associated with individual track resistance values and simplifies calibration. While responses were measured for a number of tags over 6 cycles, the significant failure rate after 3 cycles means that in practice, tags are likely to be replaced after they have been triggered. The simplicity and low cost of the tags can make this viable. Possible applications could include manufacturing process environments where accidental release of solvent vapour should be monitored appropriately.

ACKNOWLEDGMENT

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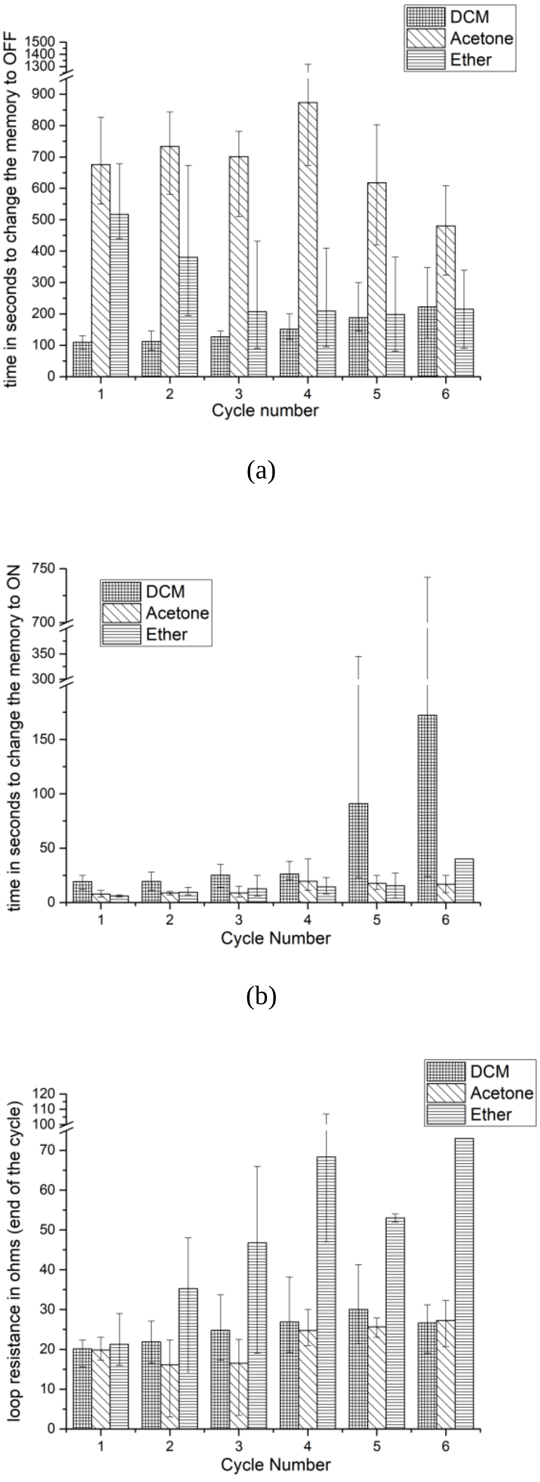

(a)

(b)

(c)

Fig. 4. RFID sensor response to different chemical vapors per cycle: (a) average time to detect vapor (OFF time), (b) recovery time (ON time), and (c) point to point average