Polydimethylsiloxane Substrates for passive UHF-RFID Sensors

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***Abstract*— PDMS has previously shown to be a suitable substrate for UHF-RFID strain sensor tags due to their elastomer characteristics. However, PDMS has further properties such as polymer swelling which could be utilized in gas sensing. Macroporous PDMS sponges have been proposed as suitable substrates for passive gas sensors. Porous sponges were fabricated using sugar templates and their absorption capacity was investigated along with standard PDMS elastomers. Possible applications could include food package and air quality monitoring.**

Keywords—Sensors, radio frequency identification (RFID), polydimethysiloxane (PDMS)

I. INTRODUCTION

Passive UHF-RFID (Ultra High Frequency-Radio Frequency Identification) sensing is desirable as it provides a low cost, energy efficient, lightweight and wireless device. Substrates for UH-RFID sensors vary in shape, size, properties and materials. The choice of substrates for UH-RFID sensors depends highly on the application. For example, we have previously described an epidermal passive strain sensor, composed of a flexible antenna (silver Lycra®) mounted onto a stretchable barium titanate loaded PDMS elastomer for assisted living applications (Fig. 1) [1]. PDMS elastomers are highly elastic, inexpensive, properties such as permittivity can be easily altered by ceramic loading and the curing process allows antenna self-adhesion. The PDMS substrate also prevents tag mismatching when placed upon the skin.

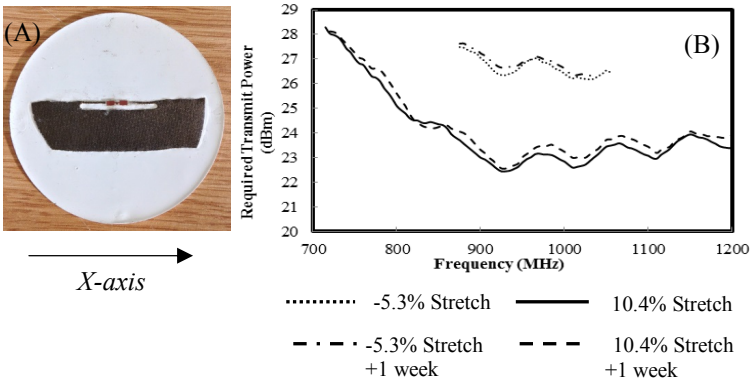

Fig. 1: (A) Image of RFID strain sensor tag (B) Transmitted Power versus frequency graph with x-axis stretching (reproduced from reference [1])

Most recently, we have demonstrated ultra-thin (200µm thickness) PDMS-barium titanate films with good antenna adhesion, allowing for a more wearable UH-RFID strain sensor. A thin film is desirable as these sensors are proposed to offer control of a powered wheelchair through muscle twitches in the face and neck of paraplegic patients.

Variations in the electrical properties of substrates when exposed to different analytes can be exploited as a sensing method. Many gas sensors are based on this method. Gas sensors have a wide range of applications in the automotive, medical and commercial industries. The sensing method stated above has previously utilized metal oxide semiconductors, conducting polymers, non-conducting polymers, carbon nanotubes [2] and moisture absorbing materials. In this research, absorbing materials are proposed for investigation to establish how their volume increase associated with absorption can be applied to passive gas sensing. PDMS (polydimethylsiloxane) showed good promise because of its flexibility, non-toxic nature and swelling ability [3]. Another advantage of PDMS is the ability to tailor surface properties through surface modification. PDMS sponges were chosen as the ideal candidate as they have a porous structure combined with a swellable skeleton. Porous PDMS materials have been previously prepared using sugar, self-assembled colloidal microspheres and emulsion droplets [4]. In this case macroporous PDMS sponges were fabricated using a casting process [5] where sugar templates were used.

II. SUBSTRATE FORMULATION

Synthesis of PDMS elastomers and sponges

PDMS standard elastomers and sponges were formed using viscous liquid PDMS, liquid cross-linker and a catalyst. In this case the PDMS sponges and elastomers were synthesised using a Sn (II) catalyzed condensation reaction. The sugar templates and PDMS standard elastomers were formed in PTFE square molds (length = 2cm, width = 2cm, height = 0.2cm).

Standard PDMS elastomer: Silanol-terminated PDMS, tetraethyl orthosilicate (cross-linker) and tin (II) 2-ethylhexanoate (catalyst) was poured into six PTFE square molds. The elastomer was allowed to cure at room temperature for 2 hours and placed in a 60°C oven overnight.

PDMS sponges: Silanol-terminated PDMS, tetraethyl orthosilicate (cross-linker) and tin (II) 2-ethylhexanoate (catalyst) was poured around a sugar template and left to infiltrate the spaces between the sugar particles via capillary action. After 1 hour the fully saturated sugar template and excess PDMS was removed. The mixture was allowed to cure for 2 hours at room temperature and placed in a 60°C oven overnight. The sugar template was removed by dissolution in a water bath.

III. Results and Discussion

PDMS sponges were synthesised and characterized using Scanning Electron Microscope (SEM) imaging. Fig. 2 shows that both sponges consist of an interconnected three-dimensional framework. Pore sizes up to 342µm were observed when caster sugar templates were used. In comparison, pore sizes up to 867µm were observed when granulated templates were used. Surface area and pore size

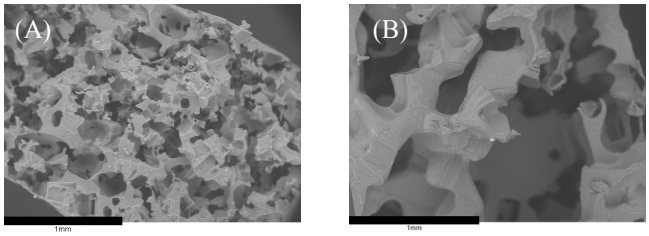

Fig. 2: SEM micrograph of a PDMS sponge prepared using (A) caster sugar template and (B) granulated sugar template

distribution of the sponges will be determined using nitrogen physisorption. SEM micrographs also showed that both the top and bottom surfaces of the sponges were also porous.

The absorption capacity of both PDMS sponges and standard PDMS elastomers were investigated using a range of organic gases. The samples were left for 72 hours in a saturated atmosphere of a particular gas. Table 1 outlines the absorption capacity of PDMS standards and sponges. Standard PDMS shows a large volume % increase for hexane and diethyl ether, as both gases are known to diffuse into PDMS causing what is known as polymer swelling [3]. However, in the presence of methanol gas PDMS showed a very low volume and weight % increase. Due to the polar nature of methanol compared to non-polar PDMS, methanol cannot diffuse into PDMS and cause polymer swelling to the same extent as non-polar gases.

Table 1 suggests that PDMS sponges can also show a large volume % increase using diethyl ether. The swelled PDMS sponge showed no breakages, indicating the interconnected pores do not compromise the materials structural integrity. The standard PDMS elastomer shows a larger volume % increase compared to the PDMS sponge. However, both the PDMS standard and sponge show a similar weight % increase. It could be inferred that the diethyl ether gas is being stored within the pores of the sponge, which would explain why the volume % increase was notably lower than the PDMS standard but the weight % increase was similar.

Table 1: Absorption Capacity

Gas	Sample			
	Standard PDMS		PDMS Sponge*	
	Wt. % increase	*Vol. % increase*	*Wt. % increase*	*Vol. % increase*
Methanol	3.4 ±0.8	2.5 ±0.5	-	-
Hexane	95.0 ±9.7	110.0 ±7.0	-	-
Diethyl ether	173.5 ±21.6	155.0 ±21.9	168.9 ±6.7	124.0 ±5.5

* Sponge formulated using a caster sugar template

In this case the absorption capacity is not improved by a porous structure. However, the absorption rate could be affected. Absorption capacity of PDMS sponges using methanol and hexane will be completed in the immediate future. The gas absorption of both PDMS standard and sponges were also shown to be reversible, as both samples shrink back to their original dimension within 24 hours air exposure. Once methanol and hexane assessments have been carried out on the sponge samples, preliminary RFID measurements will be performed. In the presence of gas, substrate swelling occurs in all three axes (x, y and z) showing a volume change. Therefore, a tag which is designed to respond to substrate swelling in one or more of these three axes is required. We will utilize the silver Lycra® slot antenna we have previously shown [1] as the swelling of the substrate will cause deformation of the antenna slot, leading to tag detuning.

IV. Conclusion

PDMS elastomers were successfully synthesized along with PDMS sponges with varying pore size using a casting technique. Sugar templates have shown to be an easy method of controlling sponge porosity. The introduction of macro pores does not appear to vastly affect the absorption capacity of the original standard PDMS. In our case the absorption capacity of the PDMS sponges was slightly lower than standard PDMS elastomers. However, further investigation using a range of non-polar and polar gases will be completed. Absorption rates of the PDMS sponges will also be compared to standard PDMS elastomers and sensitivity and selectivity will also be examined. In addition to the volume changing behavior of the PDMS materials investigated, an assessment will also be made into the possible permittivity change experienced with absorption.

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