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Procedia Engineering 25 (2011) 1125 – 1128

Procedia Engineering

www.elsevier.com/locate/procedia

Proc. Eurosensors XXV, September 4-7, 2011, Athens, Greece

Detergents sensing system based on SH-SAW devices

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Abstract

We report on the design and characterization of a novel analytical sensing system for the detection and discrimination of various detergents. Our sensor system could play a key role in the development of more efficient and environmentally-friendly washing machines by enabling the measurement of residual detergents. The sensing device comprises of a dual shear horizontal surface acoustic wave (SH-SAW) resonator device housed in a poly-dimethylsiloxane (PDMS) microfluidic chamber. Unmetalized and electrically shorted device configurations were used to analyze synthetic samples of liquid detergents of different concentrations. The sensor system correctly classified all three detergents without the need for an additional biological or chemical coating.

Electronic tongue; surface acoustic wave; SH-SAW sensor; detergents; principal component analysis

1. Introduction

As a result of increasing environmental awareness, consumers demand “green products” that contribute to a sustainable society and household washing machines are no exception [1]. In recent years, the development of efficient and environmentally friendly washing machines has progressed significantly. The remarkable improvement in pre-wash efficiency had not been possible without the increased use of

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1877-7058 © 2011 Published by Elsevier Ltd.
doi:10.1016/j.proeng.2011.12.277

sensors to control the process parameters of a normal pre-wash cycle. However, consumers can save money and simultaneously reduce environmental impacts by using proper dosing of the pre-wash detergents [2]. This requires consumer education and a change in consumption habits but also devices that enable monitoring and controlling washing cycles.

Household detergent mixtures contain both anionic and nonionic surfactants, therefore, we have studied the aqueous solutions of two anionic surfactants (sodium dodecylbenzenesulfonate (SDBS) and sodium laureth sulphate (SLS)) and one nonionic surfactant (polyoxyethylene (9.5) t-octylphenol (Triton X 100)). Linear alkylbenzene sulfonates are the workhorse of the detergent industry and have good foaming properties [3] while nonionic surfactants are known to be less foaming. Generally, an optimum condition can be achieved by tuning the mixture of anionic and nonionic surfactants to the specific users needs.

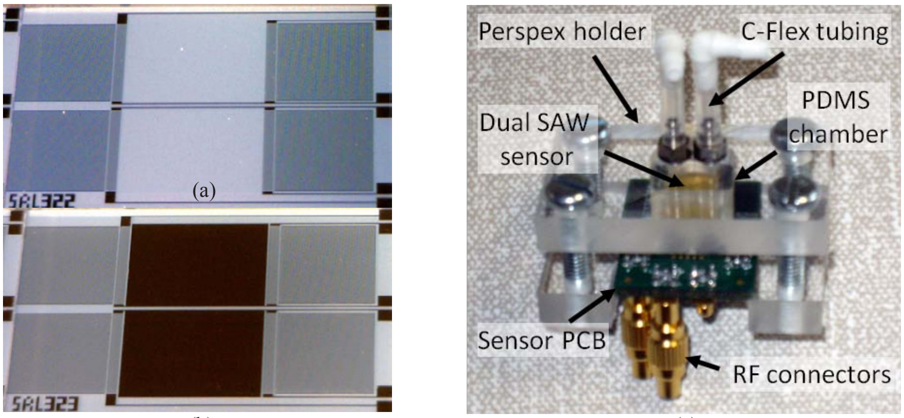
The motivation for the work presented here is the development of a low cost, integrated sensor system that accurately and reliable detects the levels of residual detergents in laundry machines. Such sensors may be used to optimize the control process of rinsing and detergent dispensing in wash cycles and as a result, water is saved and safe levels of residual detergents in the laundry can be maintained. This will enable the production of more eco-friendly washing machines. Efforts have been concentrated towards development of better sensors that can measure residual detergents and even surfactants [1]. Both titration and chromatography systems to supervise the rinse process are difficult to integrate with washing machines, however, other sensor techniques such as electronic tongues [4] or conductivity meters could be viable options. Conductivity meters can give reasonably accurate predictions about detergents, but perform poorly for non-conducting surfactants. Also, the prediction of non-ionic surfactants using an electronic tongue proved difficult [1].

Here we discuss a robust, high sensitivity liquid phase acousto-electric sensing system based on liquid phase surface acoustic wave (SAW) devices developed for the characterization of detergents and surfactants at very low concentrations.

2. Electronic tongue design and fabrication

The sensing elements of the detergent sensing system are surface acoustic wave resonator devices with wavelength of 68 μm that were designed and fabricated using Ti/Au electrodes on a 36°Y-X $LiTaO_3$ substrate. Lithium tantalate was chosen due to its efficient electromechanical coupling constant and comparatively low temperature coefficient. Since the piezoelectric potential associated with the SH-SAW extends into the adjacent liquid, its electrical (e.g. conductivity) and mechanical (e.g. density, viscosity) properties can be characterized by measuring the changes in the propagation characteristics (attenuation and phase) of the surface acoustic wave travelling along the sensor surface. The extent of the penetration of this potential is equal to 0.16 wavelengths [5]. For metalized (i.e. shorted) sensing surfaces, the potential penetration is practically zero. Such devices are only sensitive to the mechanical changes in the adjacent liquid.

Both free and metalized device configurations were implemented to allow the simultaneous measurement of mechanical and electrical properties of liquids. Figure 1 shows an optical micrograph of a free (a) and a shorted (b) dual SAW sensor. A $12\times12\times5$ mm^3 miniature PDMS chamber with a central reservoir volume of ~90 μl was mounted on top of the SAW sensors to contain the liquids under test using Perspex clamps. The complete sensing device setup is shown in Figure 1(c). The attenuation and phase characteristics of both types of SAW devices were measured using an Agilent E50718 network analyzer.



(b) (c)

Fig. 1: Optical micrographs of a free (a) and a metalized (b) 60 MHz dual SAW sensors; and (c) photograph of the SH-SAW sensing device comprising a dual SAW sensors, a PDMS chamber for liquid phase measurements, a Perspex holder and a printed circuit board with radio frequency connectors.

3. Experimental setup

A custom build liquid flow system comprising a micro diaphragm liquid pump, manifold mounted solenoid valves and C-Flex® tubing was used for liquid delivery. The block diagram of the liquid flow system is shown in Fig. 2. The measurements were taken at a controlled temperature (22 ±0.1 ºC) and the test sequence of the samples was randomized to minimize any aging and memory effects. The sensor surfaces were cleaned before each measurement using a wash cycle with the baseline solution.

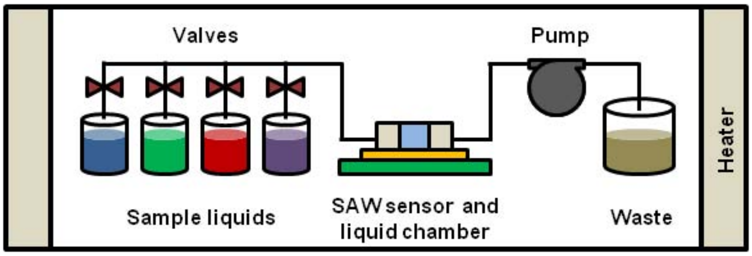


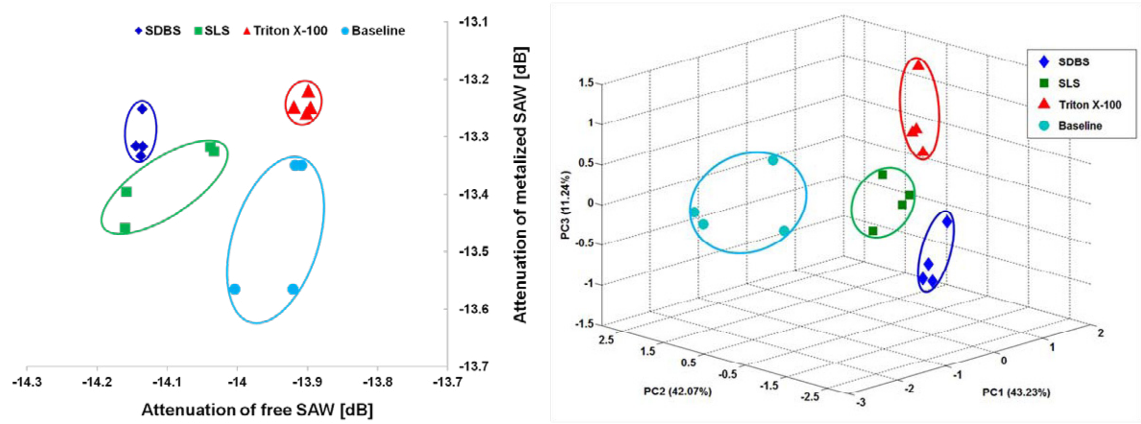
Fig. 2: Schematic diagram of the liquid flow system developed for delivering detergent samples to the surface acoustic wave sensors.

In order to show the system's ability to detect detergents with different electrical charge of the surfactants, anionic (sodium dodecylbenzenesulfonate (SDBS) and sodium laureth sulphate (SLS)) and non-ionic (octylphenol ethylene oxide condensate (Triton X-100)) were tested. Aqueous 100 ppm solutions of SDBS, SLS and Triton X-100 were prepared in a baseline of NaOH and KOH with 65 and 22 ppb concentrations. The baseline solution also served as a reference.

4. Results and discussion

The discrimination of the different liquid samples could be achieved using only two of the four acoustic parameters: the attenuation of the metalized device vs. the attenuation of the free device as shown in Fig. 3(a). Sample separation could be further improved by applying principal components analysis

(PCA), a linear, supervised, nonparametric pattern recognition method (see Fig. 3(b)). The principle components are derived from all four measured sensor characteristics: the attenuation (in dB) and phase difference (in degrees) of the free and the metalized SAW sensors.



(a) (b)

Fig. 3: (a) Attenuation of free SAW [dB] against attenuation of metalized SAW [dB] showing good discrimination of the detergent samples; (b) principal components analysis of the sensor responses to different detergents showing improved separation.

5. Conclusions

A sensing system based on liquid phase surface acoustic wave (SAW) devices has been developed for the characterization of detergents and surfactants at very low concentrations. Results suggest that our SAW-based sensing system can be used effectively to discriminate between different anionic and nonionic detergents.

Acknowledgements

The authors would like to thank F. T. Courtney of Microsensors & Bioelectronics Laboratory at Warwick University for the fabrication of the PDMS devices. J. L. Vivancos acknowledges financial support (PAID-00-10) of the Universidad Politécnica de Valencia for his visit to Warwick University.

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