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## Sensitivity, reliability, precision and accuracy

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# Membrane Based Surface-Stress Sensors: Sensitivity, Reliability, Precision and Accuracy

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Surface stress based measurement is a relatively new mechanism in biological and chemical sensing. When a clamped plate is used as the sensing component in such a measurement, it provides an isolation between the sensing and detection surfaces. Therefore, it allows for using capacitive readout techniques, particularly in liquid environments.

Although a micro-plate with a fully clamped contour is not very sensitive to surface stress changes [1, 2], the ratio of functionalized area to the whole surface of the plate plays a key role in increasing its sensitivity. By optimizing this ratio, the sensitivity of a plate-shape sensor can be increased at least to 22 % of that of an equivalent cantilever shape sensor. In addition, due to lower mechanical compliance of the clamped plates, the thermo-mechanical noise is less influential [3].

Apart from the sensitivity and signal to noise ratio, there are some other parameters which have to be considered when evaluating the suitability of a sensor such as linearity, repeatability, accuracy and precision.

In general, in bological detections, the poor surface coverage of target molecules on the functionalized area due to contamination of the surface or poor adhesion, might result in a low accuracy and precison [4-6]. It is assumed that if the surface coverage is uniformly dispersed, the surface stress induced by the adsorption exhibits a non-linear dependence on the surface coverage, and it steeply increases when the coverage is near saturation [7, 8]. However, at low concentration of target molecules, or when the target molecules or proteins are large, the distribution of the coverage might be randomly dispersed or just accumulated in one area [9]. In which case, the surface coverage is not as uniform, and the theoretical model will not provide an accurate estimate of the concentration. Although this problem can be tackled with using parallel cantileveres, still a higher reliability of individual sensing components is favourable.

In this study, we aim to study the effect of shape and position of the agglomeration of target molecules on the ultimate response of these types of sensors. We show that by optimizing the size of the functionalized area, in addition to achieving the beter sensitivity, the performance of the sensor with respect to accuracy and precision can be improved. For this purpose, a simplified model of a capacitive surface stress sensor was considered.

The model of the sensor consists of a circular silicon plate of radius $R_s$, fixed on all sides. A part of the plate surface is coated with a thin gold layer of radius $R_f$ which is functionalized with probe molecules. The other side of the plate is coated with a very thin layer of a metal as the electrode. The plate is suspended over an electrode for capacitance measurements. This conceptual design is graphically shown in Figure 1.

The sensor was modeled in the commercially available finite element software COMSOL. In application, the adsorption of target molecules on the functionalized area will create a change in the surface stress on the gold film. In the model, the surface layer with the adsorbed molecules is mimicked with a membrane attached to the gold film (Figure 1-b). The change in the surface stress leads to deflection of the plate and the electrode. The change in capacitance between the two electrodes is calculated as the output signal.

The shape of the membrane mimicking the surface layer is controlled with a parametrized function. The parameters in this function are changed randomly to statistically study the effect of different shapes of the agglomeration of molecules on the output signal.

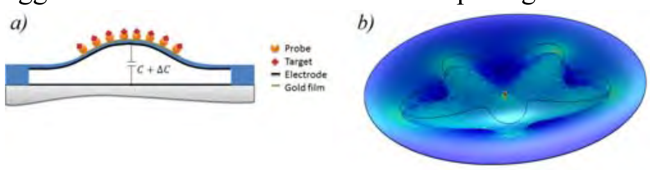


*Figure 1) a) The schematic of the surface-stress-based sensor with a plate as the sensing component b) The random shape of agglomeration of molecules modeled in COMSOL*

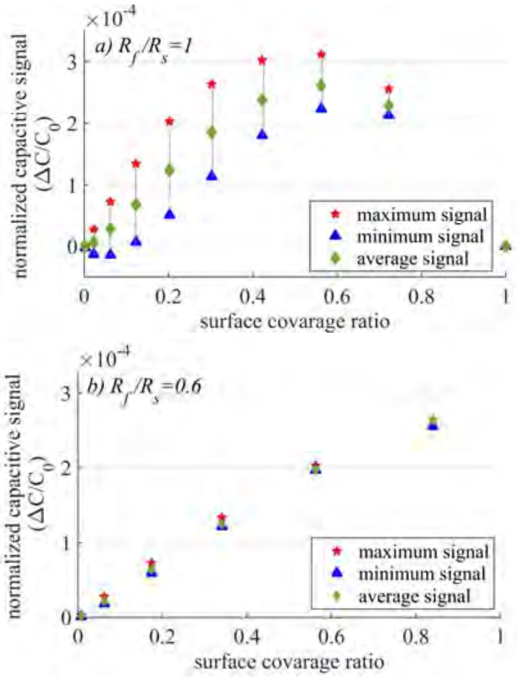


*Figure 2) The output signal for a)* $R_f/R_s = 1$ *and b)*$R_f/R_s = 0.75$ *due to eccentricity of agglomeration of molecules*

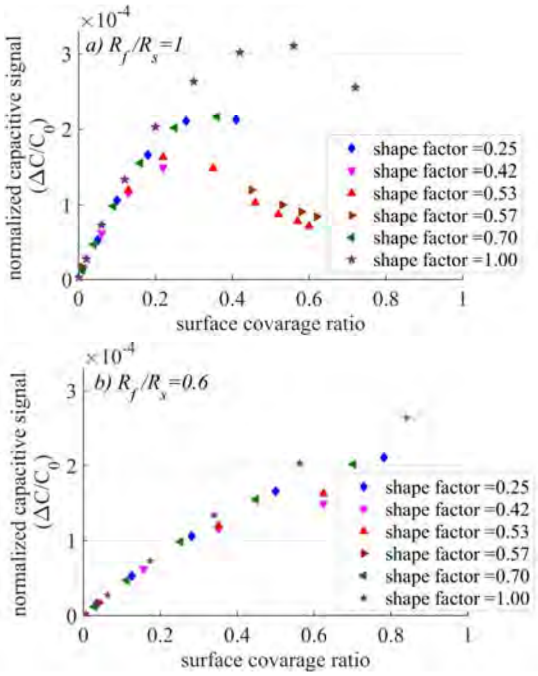


*Figure 3) The output signal for a)* $R_f/R_s = 1$ *and* $R_f/R_s = 0.75$ *due to shape factor of agglomeration of molecules*

The simulations were repeated for two different sizes of the functionalized area. As a result of these simulations, two shape factors of eccentricity and circularity of the agglomeration of molecules were found to be the most influential on the output signal of the sensors. Dispersity (or porosity) of the agglomerations was the third most important factor.

Figure 2 shows the range of the capacitive signal induced with different surface coverage ratio. This range is caused by different eccentricity of the aggregation of molecules. For any coverage ratio, the maximum signal occurs if the aggregation of molecules is concentric with the functionalized area. The range of the output signal is proportional to inverse of precision, and can be significantly decreased by reducing the size of the functionalized area. Figure 3 shows the normalized output signal of for different circularities of the shape of the agglomerations versus the coverage ratio of molecules, where their eccentricity in all is almost zero. The dependency on the shape of the adsorption appears mostly in larger aggregation areas which can also be limited with decreasing the size of the functionalized area.

As a result of this study, we found that by decreasing the size of the functionalized area, not only the sensitivity of the surface stress sensors can be optimized, but also, the linearity, accuracy and precision of the system can be significantly improved. Consequently, the overall reliability of the system can be increased.

[1] Carlen, E. T., Weinberg, M. S., Dube, C. E., Zapata, A. M., and Borenstein, J. T., 2006, "Micromachined silicon plates for sensing molecular interactions," Applied physics letters, 89(17), p. 173123.

[2] Cha, M., et al., 2008, "Biomolecular detection with a thin membrane transducer," Lab chip, 8(6), pp. 932-937.

[3] Carlen, E. T., Weinberg, M. S., Zapata, A. M., and Borenstein, J. T., 2008, "A micromachined surface stress sensor with electronic readout," Review of scientific instruments, 79(1), p. 015106.

[4] Tsouti, V., et al., 2012, "Evaluation of capacitive surface stress biosensors," Microelectronic Engineering, 90, pp. 37-39.

[5] Moulin, A., O'shea, S., and Welland, M., 2000, "Microcantilever-based biosensors," Ultramicroscopy, 82(1), pp. 23-31.

[6] Tabard-Cossa, et al., 2007, "Microcantilever-based sensors: effect of morphology, adhesion, and cleanliness of the sensing surface on surface stress," Analytical chemistry, 79(21), pp. 8136-8143.

[7] Tamayo, J., Kosaka, P. M., Ruz, J. J., San Paulo, A., and Calleja, M., 2013, "Biosensors based on nanomechanical systems," Chemical Society Reviews, 42(3), pp. 1287-1311.

[8] Sushko, M. L., Harding, J. H., Shluger, A. L., McKendry, R. A., and Watari, M., 2008, "Physics of nanomechanical biosensing on cantilever arrays," Advanced Materials, 20(20), pp. 3848-3853.

[9] Tian, J., Bai, Y., Tang, X., Sang, S., and Wang, F., 2016, "A capacitive surface stress biosensor for CSFV detection," Microelectronic Engineering.