INTERDIGITATED-TYPE MICROSENSOR TO MEASURE SOLUTION CONCENTRATION

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Abstract. *This work shows the development of a microsensor to measure the concentration of a solution consisting of two dielectric liquids. The sensor is based on interdigitated comb structures prepared using microfabrication techniques. The interdigitated structures were grown by electroplating nickel on an insulator substrate (alumina). The distance (gap) between two opposite electrodes varied from 40 to 100 micrometer. The thickness was around 40 micrometer. The length varied from 800 to 1300 micrometer. In this way, hundreds of parallel micro-capacitors could be formed on an area as small as 1 square centimeter. An impedance analyzer was used to measure electrical properties of the comb structures at frequencies varying from 100Hz to 40MHz. Several liquids have already been tested: water, alcohol, oil, gasoline. The measured capacitance varied from few microFarad (water and alcohol) to several picoFarad (gasoline and cooking oil) at lower frequencies. Sensitivity depended on frequency and type of liquid. This type of microsensor can have several applications in chemical and pharmaceutical industries; for optimal setup of fuel to air rate in car engine; analysis of the quality of oils and fuels; etc.*

Keywords*: solution microsensor, IDT, capacitive microsensor, MEMS*

1. Introduction

Microelectromechanical Systems (MEMS) are becoming very popular nowadays due to numerous applications where they can replace large size sensors with advantage. Moreover, it can also be considered an enabling technology since new applications can be devised. Microsensors have the following advantages compared to large size conventional sensors: occupy reduced space, have low energy consumption, inexpensive, integration with the electronic circuit, etc.

Several types of solution concentration sensors have been reported. One of the most common technique is based on infrared radiation absorption Gillet et al. (2004), Lima et al. (2004). Other methods are based on ultrasound absorption (Kiyoshi, 1998), transmission line (Jenkins et al., 1990; Santos, 2003), inductance variation (Ismail and Shida, 2003), capacitance measurement using interdigitated electrodes (Hofmann et al., 1997; Beckmann et al., 1997).

This work reports the development of an interdigitated type microsensor manufactured using conventional inexpensive microfabrication techniques. The interdigitated electrodes constitute the plates of hundreds of flat capacitors in parallel association. When immersed in a fluid, the gaps between the electrodes are filled with the dielectric fluid. Therefore, the measured capacitance varies with the fluid. If the fluid is a solution of two or more miscible liquids, the measured capacitance will have an intermediary value, proportional to the concentration of the solution.

Possible applications for this microsensor include: verification of the quality of fuel used in cars, fuel concentration in flexible-fuel vehicles, control of several processes in chemical and petrochemical industries, food industries, pharmaceutical industries, etc.

The devised microsensors were modeled and simulated computationally. Then, samples were fabricated using conventional microelectronics techniques. Samples were characterized by microscopy (evaluation of morphology) and by an impedance analyzer.

2. Experimental

The microsensors were modeled using the finite element method, and simulated using ANSYS software. Simulations of electrical potential and electrical field between flat electrodes filled with gasoline were carried out.

Masks of several geometries of interdigitated structures were prepared. Several samples with different sizes were considered. The gap between the electrodes had the same size as the width of the electrodes: between 40 and 100µm. The length of the electrodes varied from 800 to 1300µm. A schematic draft of the mask can be seen in figure 1.

Alumina substrates were used as the base material to fabricate the interdigitated structures of the microsensors. The substrates were covered with a thin layer of sputtered gold.

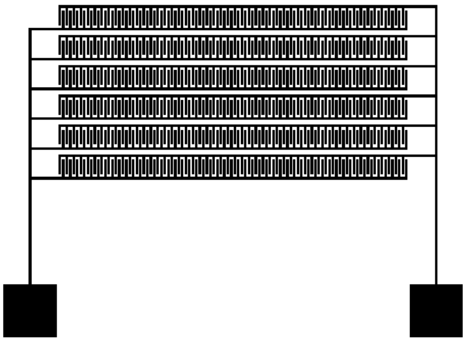

Figure 1. Pattern of interdigitated electrodes typical masks used in this work.

The patterns in the masks were transferred to the substrates covered with photoresist by photolithography. Special photoresists (SU-8 and AZ-4620) were used to achieve high aspect ratio structures in order to increase the capacitor electrodes area, thus improving the sensitivity of the sensor. Then, the substrates were exposed to ultraviolet radiation, and the photoresist was developed.

The interdigitated structures were grown by nickel electroplating. After growth, the photoresist was removed and the gold thin layer underneath nickel structures was etched to avoid short circuit between interdigitated electrodes. The whole deposition process was developed at the Brazilian Synchrotron Light Laboratory (LNLS), and the complete route can be seen in figure 2.

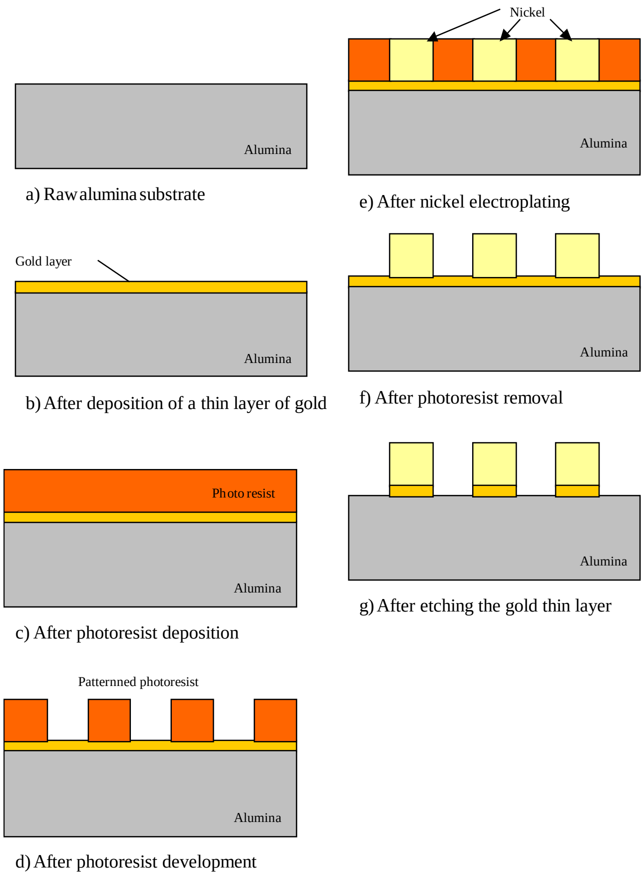

Figure 2. Fabrication route of interdigitated strucutures of the microsensor.

A Dektak3 ST profilometer was used to measure the thickness of the grown nickel. An optical microscope with a CCD camera connected to a microcomputer was used to observe the structures of the fabricated structures.

An HP 4194A impedance analyzer was used to characterize the electrical properties (capacitance, impedance, phase angle, resistance) of the microsensors immersed on several types of liquids.

3. Results

A model including 4 electrodes (2 pairs of electrodes) was prepared using ANSYS software for the Finite Element Method (FEM). The electrodes were modeled as volume blocks 40µm high x 50µm wide x 1000µm long. The gap between the electrodes was 50µm. A medium of permitivity 2 (corresponding to gasoline) was placed around the electrodes. The electrodes were represented as blocks of nickel, fixed (not allowed to displace) to the coordinate system. An electric potential of +2V and –2V was applied. Simulation of electric field around the interdigitated electrodes can be seen in figure 3. This simulation shows the complex but symmetrical form of the electric field for such interdigitated electrodes. The field is much higher around the edges of the electrodes.

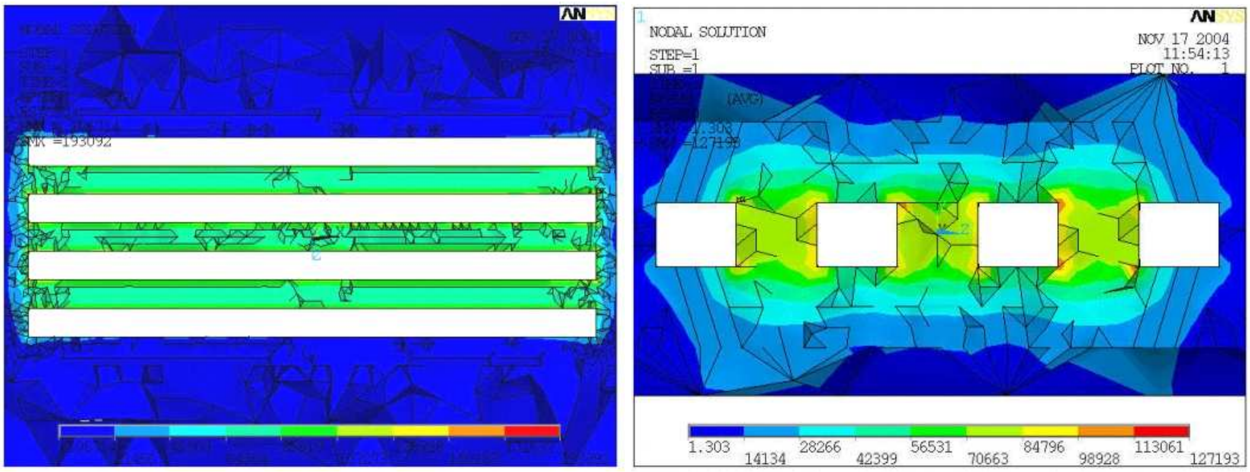

Figure 3. Simulation by FEM of the electric field around the electrodes.

Observation by optical microscopy showed details of the interdigitated structure of the electrodes, figure 4. Since an inexpensive type mask was used, the gap and width of the electrodes is not uniform. However, this imposes no problem in this research because only the total capacitance is measured and used for evaluation of several fuel mixtures. For mass production a better mask must be used.

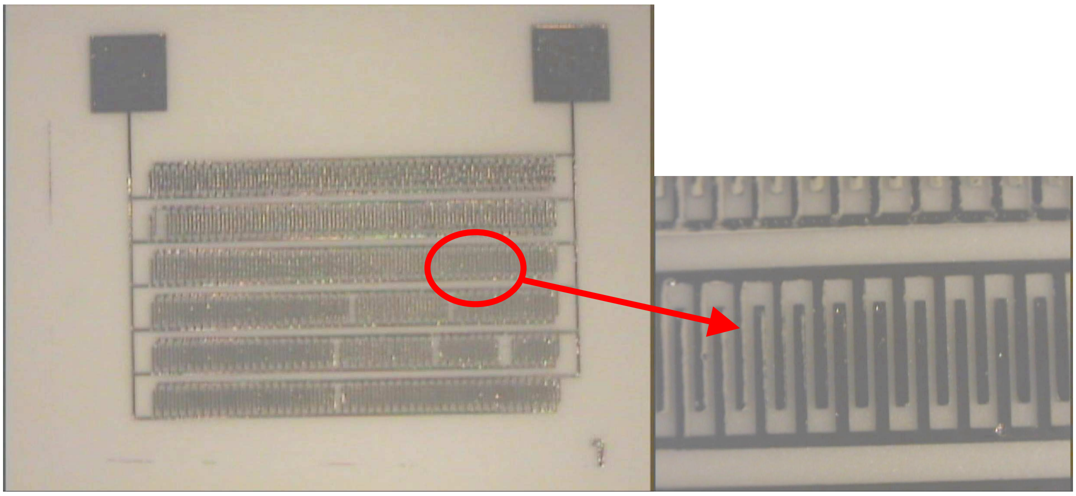

Figure 4. Observation of the structure of the electrodes by optical microscopy.

Tests were carried out with the following fuels: ethanol, common gasoline, Podium gasoline (Petrobras high octane rating type gasoline), and a mixture of Podium gasoline and 14% volume of ethanol. The sensor was immersed in each fuel, and the impedance data were acquisited using an impedance analyzer connected to a microcomputer. Figure 5 shows the capacitance measured as a function of the frequency of the sinusoidal signal used for the measurement. It is very easy to distinguish the different types of fuel due to the good sensitivity of the sensor. Even the mixture of Podium gasoline and 14% volume of ethanol, which represents a type of fuel adulteration commonly found in Brazilian gas stations, could be monitored.

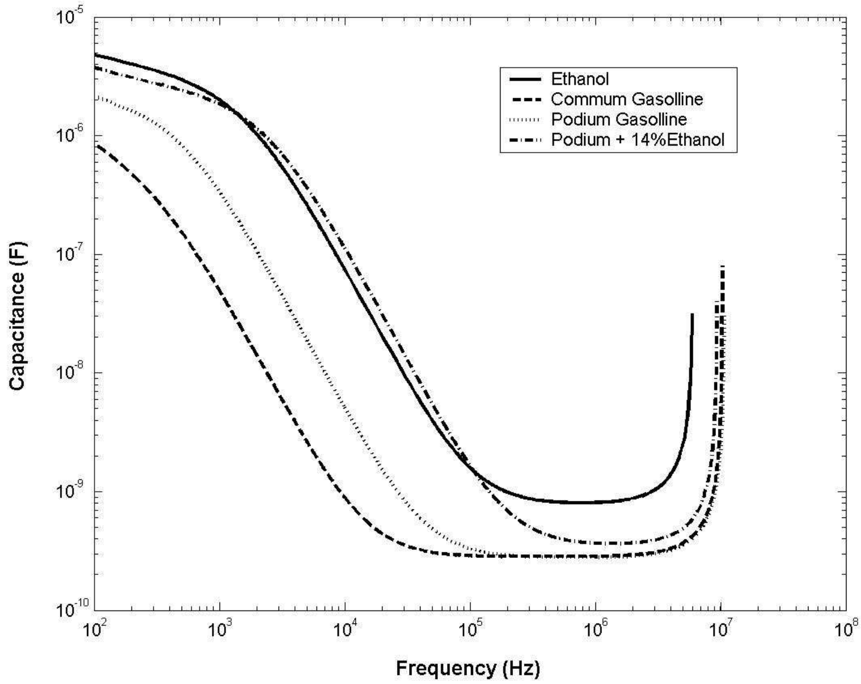

Figure 5. Capacitance curves for several types of fuel measured along the interdigitated structures of the microsensor.

3. Conclusions

These results show that such inexpensive microsensors can be successfully used to distinguish several types of fuels used in Brazil. In addition, it can be used to evaluate lubricants, petrochemical products in refineries, several types of chemicals (specially organic ones), etc. This configuration shows quick response time, can be adapted to harsh environments, and has reduced dimensions.

4. Acknowledgements

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5. References

Beckmann, et al, 1997, “Analysis of complex impedances in CMOS technology for chemical sensor applications”, Sensors and Actuators A, 734-738.

Gillet, B., et al, 2004, “Infrared absorption for measurement of hydrocarbon concentration in fuel/air mixtures (MAST-B-LIQUID)”, Applied Thermal Engineering, 1633–1653.

Hofmann, T., et al, 1997, “Comparison of a conventional with an advanced micromachined flexible-fuel sensor”, Sensors and Actuators A, 319-322.

Ismail, A. B. M., and Shida, K., 1997, “New contactless inductive sensor for the measurement of concentration of an electrolyte solution”, Jpn. J. Appl. Phys., 6558-6561.

Jenkins, S., et al, 1990, “Dielectric measurements on reference liquids using automatic network analysers and calculable geometries”, Meas. Sci. Technol., 691-702.

Kiyoshi Ikeda, 1998, “Ultrasonic liquid-concentration sensor with temperature compensation”, Proceedings of 1998 IEEE International Frequency Control Symposium, 652-659.

Lima, J.A.P., et al, 2004, “Photothermal detection of adulterants in automotive fuels”, Anal. Chem., 114-119.

Santos, E.J.P., 2003, “Determination of ethanol content in gasoline: theory and experiment”, Proceedings of SBMO/IEEE MTT-S IMOC 2003, 349-353.