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Ultra-High Sensitivity LC Resonant Pressure Sensor Based on a Microstructured Ionogel Dielectric Layer

Chia-Yu Cho and Yao-Joe Yang*
National Taiwan University, Taipei, TAIWAN

*Corresponding Author: chiayucho@mems.me.ntu.edu.tw

Summary:

This study introduces a highly sensitive ionogel-based wireless pressure sensor, incorporating an inductor coil and a parallel-plate capacitor for pressure detection. A microstructured ionogel film was employed as the dielectric layer on the capacitor which significantly enhances the sensor performance. This effective improvement is largely due to the ultra-high capacitance generated by electron double layers at the interface between the ionogel film and the electrode. The sensitivity of the proposed device was recorded at 0.023 mmHg^{-1}, making it roughly 50 times more sensitive than similar capacitive devices without the ionogel film.

Keywords: pressure sensor, ionogel, electron double layer, LC resonator, phase-dip technique.

Background, Motivation an Objective

In recent years, the advancement of flexible pressure sensors for biomedical applications has garnered substantial interest [1]. The sensors of the capacitive type enjoy widespread popularity due to its simple design and straightforward manufacturing process. In [2], the use of a polyurethane ionogel as the dielectric in capacitive sensing systems was proposed to boost the device efficiency. Such improvement is chiefly due to the creation of electron double layers (EDLs) at the dielectric-electrode interface, which effectively elevates the capacitance, and in turn, the sensitivity of the sensors [3]. In this work, we propose a highly sensitive ionogel-based pressure sensor that incorporates an LC resonator for the passive power and signal transmission. Furthermore, this sensitivity enhancement substantially improves the device resolution.

Description of the New Method or System

Figure 1(a) shows the sensor layout with its components monolithically implemented on a flexible substrate, while Figure 1(b) illustrates the device configuration when folded to form a capacitor structure. The device consists of an electro-plated copper inductor, a pair of capacitor electrodes, and a microstructured ionogel film sandwiched between the capacitor electrodes. The surface of the ionogel film features numerous grooves, enabling it to accommodate buckled protrusions under external compression. Thus, the compressibility of the film is significantly improved due to its microstructured fillable surface. Figure 1(c) illustrates the sensing principle of the proposed device. The fabrication process of the device is detailed in Figure 2. The planar coil was realized by the conventional micromachining techniques, as depicted in Figures 2(a) to 2(f). A photodefinable PDMS prepolymer was spin-coated on the coil layer, and an ionogel film was placed in the PDMS cavities (Figures. 2(g)-2(j)). Note that the ionogel film was prepared using the similar technique using a sand paper [4]. Then, the LC tank layer was separated from the glass substrate (Figure 2(l)). Finally, the layer was folded to form a capacitor structure. Figure 3 shows the SEM image of the microstructured ionogel film. Figure 4 presents images of the assembled device, and a device folded and attached to curved surfaces.

Results

Figure 5 displays the setup used for characterizing the proposed device. Figure 6 illustrates the measured impedance phase at various pressures ranging from 0 to 225 mmHg. With no external pressure, the resonance frequency is approximately 406 MHz. As pressure increases, the total inductance rises, resulting in a decrease in the resonant frequency. Figure 7 shows the normalized resonant frequencies. The device with the ionogel film showed a sensitivity of 0.023 mmHg^{-1} for pressures ranging from 0-30 mmHg, and 0.00042 mmHg^{-1} for pressures ranging from 30-225 mmHg. These results show that the utilization of ionogel film significantly improved the device sensitivity.

Illustrations, Graphs, and Photographs

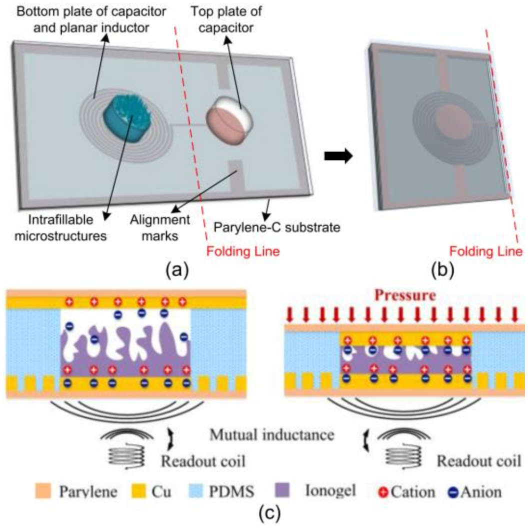

Fig. 1. The Schematic of the proposed device.

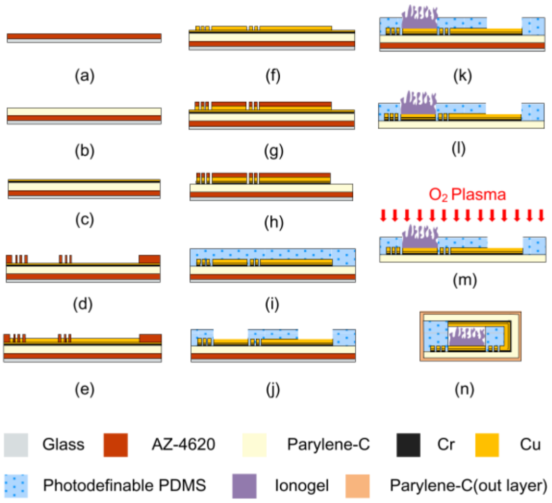

Figure 2: The fabrication process of the proposed device.

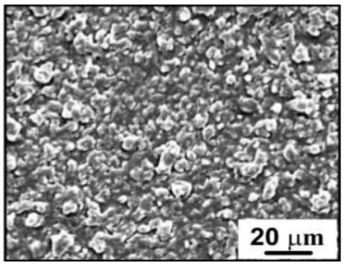

Figure 3: SEM pictures of microstructured ionogel films.

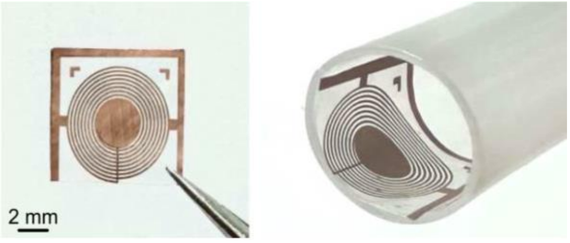

Figure 4: (a) The fabricated results. (b) The pressure sensor attached on curved surfaces.

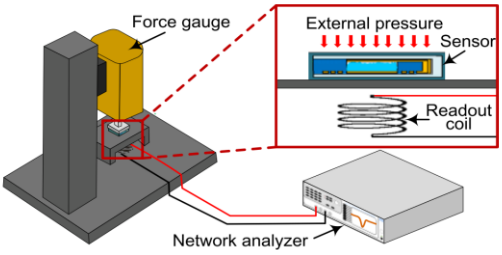

Figure 5: Schematic of pressure sensor test measurement setup.

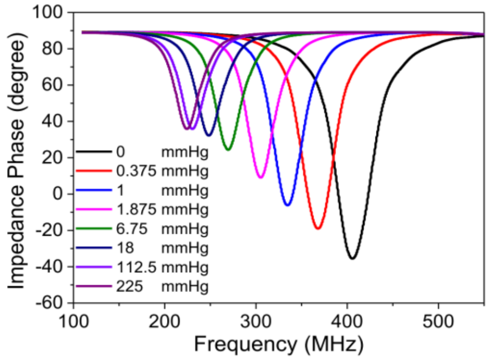

Figure 6: The measured impedance phase as a function of frequency for several applied pressures.

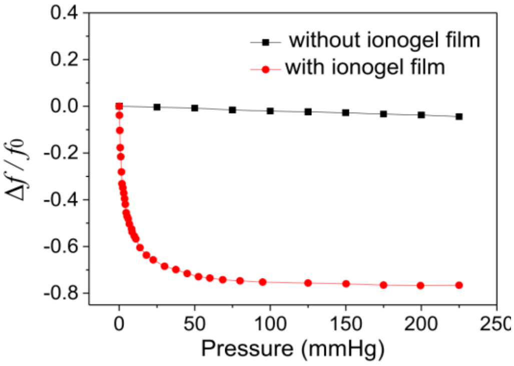

Figure 7: The normalized measured resonant frequencies vs. applied pressures.

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