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WIRELESS PRESSURE SENSOR FOR SMART STENT APPLICATION

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ABSTRACT

In this research, we describe the design and fabrication of a wireless pressure sensor for smart stent applications. The pressure sensor employs SU-8 polymer as a structural material and it has3.13×3.16mm^{2}in a dimension. The proposed sensor consists of an inductive coil and a capacitive plate. The operation principle is exactly same as the concept of a RFID except the use of a variable capacitor. A micromachined inductor is serially connected with a pressure variable MEMS capacitor, which forms an LC resonance circuit. The resonance frequency of the fabricated pressure sensors is characterized by employing an external coil antenna. There resonance characteristics as a function applied pressure is also evaluated using a network analyzer and a home-made measurement system. Furthermore, the fabricated pressure sensor is integrated with a commercial stent and the feasibility of the smart stent was evaluated using small animals.

KEYWORDS: Smart stent, Pressure sensor, L-C circuit, SU-8, Wireless sensing

INTRODUCTION

Hardening of blood vessels known as “Atherosclerosis” is a type of disease which cause blockage in the arterial wall due to the deposition of plaque. To treat partially blocked arteries a minimal invasive procedure of stent implant is followed in most of the cases which is known as percutaneous transluminal coronary angioplasty (PTCA). Commercial stents are mainly composed of tubular bodies fabricated by utilizing stainless steel or shape memory alloy material to reopen the blocked blood vessel. More than 1.5 million patients with coronary artery block age receive stent per year. Even though PTCA procedure is an effective treatment of atherosclerosis, but about 30-40% patients suffer from a complication known as restenosis within 6 months.

Here, we aim to design an L-C resonant pressure sensor in a way that the stent can continuously monitor blood pressure inside the coronary artery having stent implant in order to improve the real time monitoring of stent and early detection of restenosis. The vessel containing stent if re-narrowed by restenosis will prevent the blood flow inside the artery. The reduction in the blood flow inside narrowed artery will cause a change in blood flow per unit area which will appear as a pressure drop. This physical phenomenon is possible to measure as a change in pressure by using an L-C pressure sensor. For this purpose, the pressure sensor should have the following features 1) it should be smaller than the stent to be inserted within the artery 2) it should have appropriate size and thickness so as not to interfere with the flow of blood 3) should be able to measure a small change in blood pressure inside the coronary artery, and 4) sensor should be fabricated by utilizing biocompatible material. Figure 1 shows the concept of the pressure sensing with L-C elements and optical images of fabricated pressure sensors. Calculated inductance and capacitance values are about 839nH and 69pF, respectively.

$$C = kE_0 \frac{A}{d} \quad L_s = K_1 \pi_0 \frac{n^2 d_{avg}}{1 + K_2 \rho} \quad f_s = \frac{1}{2\pi \sqrt{L_s C_s}} \quad (1)$$

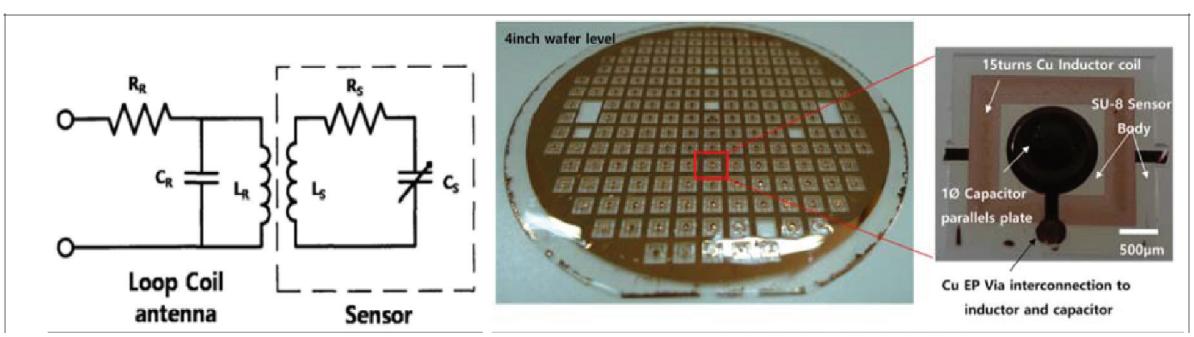

Figure 1: Block diagram of L-C resonating sensor. Resonance frequencies were shifting following to the capacitance change of the sensor(Left), Fabricated wireless pressure sensors on a 4 inch wafer(right)

EXPERIMENTAL

Wireless pressure sensor shaving a dimension of 3 × 3 mm^2 are fabricated by combination of a surface micromachining and an electroplating process. First, a thin SU-8 layer employed as a structure material for sensors is patterned on an oxidized silicon wafer with 100 mm in a diameter. The thickness of the bottom SU-8 layer is about 10 μm. A Cu layer with 15 μm in a thickness is deposited on the thin SU-8 layer using an electroplating technique. The metal layer is defined to form a rectangular coil of inductor and a bottom electrode of a capacitor, respectively. And then, these Cu structures are electrically isolated using an additional SU-8 layer. 10 μm thick photoresist (AZ 4562) used as a sacrificial layer is selectively pattered on the Cu bottom electrode. Next, a top electrode made by a thin Au layer is patterned on the sacrificial PR layer. Finally, the sensor structures were released from the substrate by removing the oxide layer with a BHF solution and the sacrificial layer with acetone.

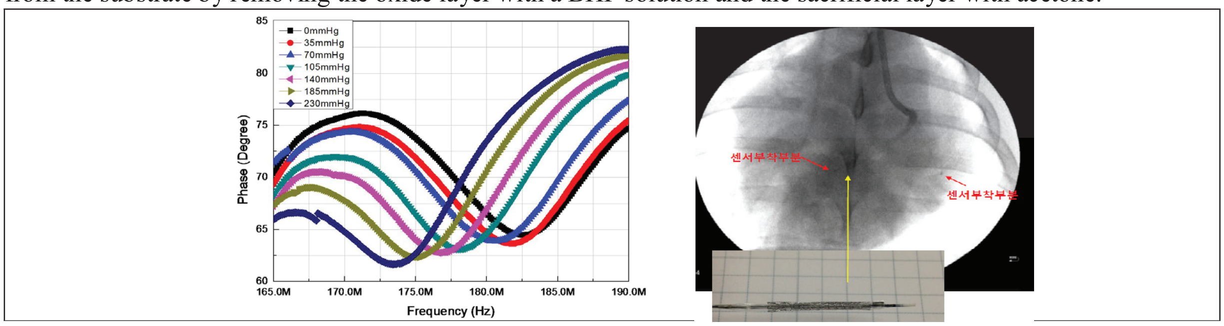

Figure 2: Measurement results. Left: phase and frequency change as a function of applied pressure, Right: long-term stability test (biocompatibility)

RESULTS AND DISCUSSION

The wireless pressure sensor is installed in a hand-made chamber and the resonance characteristics of the fabricated pressure sensor are evaluated using an external antenna and a network analyzer(Agilent 4395A). The expected resonance frequency of the wireless pressure sensor is about 200MHz which is calculated using the equation (1). However, the measured resonance frequency is in a range from 170 to 185MHz.This slight change in resonance characteristics is due to the small difference of dimensions between designed and fabricated devices, especially for the values of inductors and capacitors. A gap distance off fabricated capacitors is smaller than that of the designed value (10 μm) and the thickness (15 μm) of fabricated inductors was not uniform. Outside of the coil is much thicker than that of the inside. As shown in Fig. 2 (left), the resonance frequency of the fabricated sensor is wirelessly measured as a function of applied pressure. Figure 2 (middle) shows the frequency characteristics as a function of a gap between a pressure sensor and an external antenna. As the experiment results, the sensitivity of the pressure sensor is about 0.43MHz/mmHg. The maximum distance is limited as 2mm, however, this can be improved by the optimization of an external antenna.

CONCLUSION

A wireless pressure sensor based on a photosensitive polymer has been proposed to effectively monitor the blood pressure in a coronary artery. A prototype of the pressure sensor is fabricated using a biocompatible material and surface micromaching technologies. Basic experiments of the fabricated pressure sensor are successfully carried out using a home-made measurements system. The fabricated sensor has been combined with a commercial stent for wireless monitoring of blood pressure. The fabricated smart stents are placed in an inside of animal coronary artery to monitor the long-term reliability as shown in Figure 2 (right). We expect that the proposed pressure sensor combined with stents can effectively monitor the pressure difference of blood inside the human coronary artery.

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