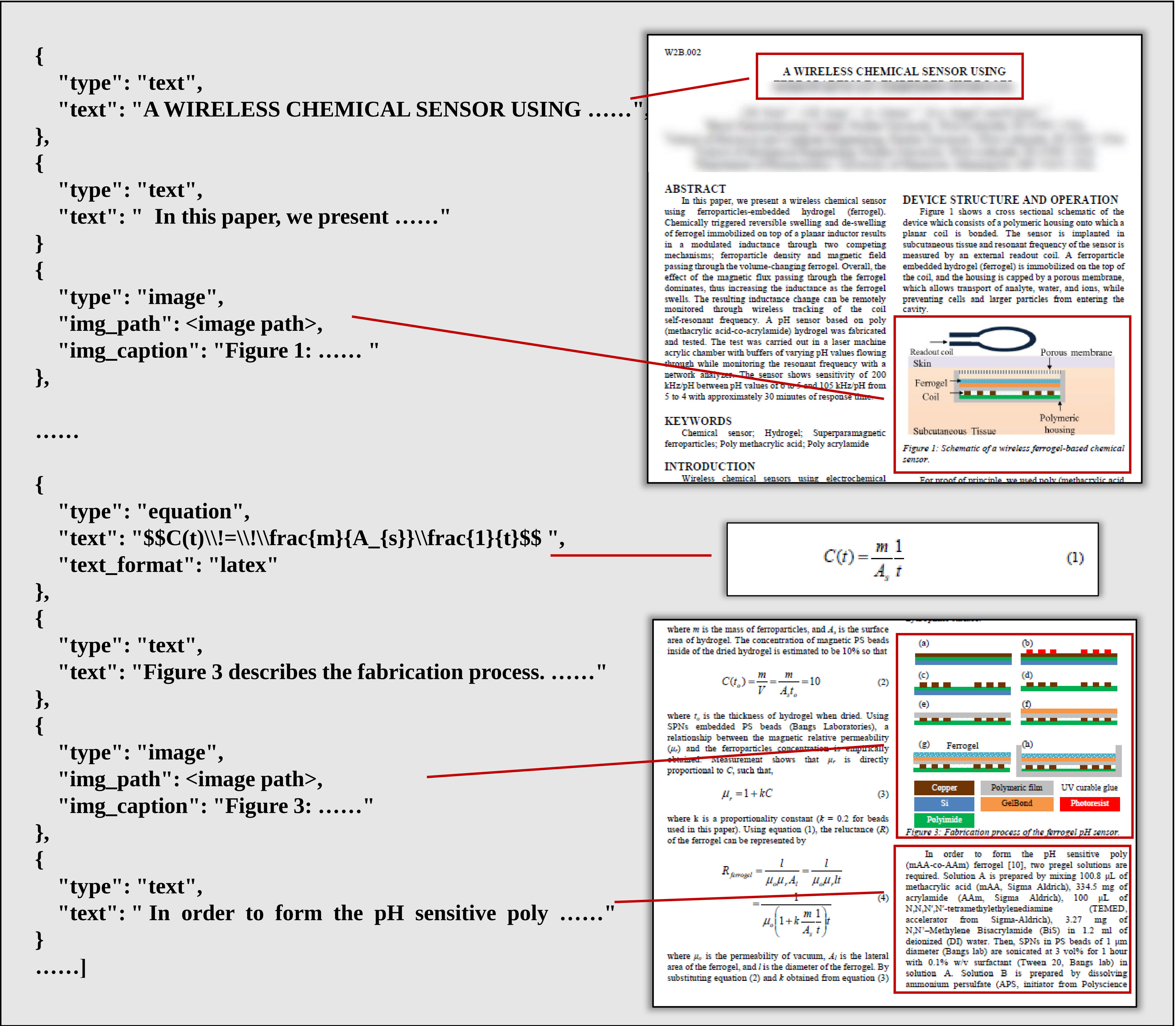
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A WIRELESS CHEMICAL SENSOR USING
ABSTRACT
In this paper, we present a wireless chemical sensor using ferroparticles-embedded hydrogel (ferrogel). Chemically triggered reversible swelling and de-swelling of ferrogel immobilized on top of a planar inductor results in a modulated inductance through two competing mechanisms; ferroparticle density and magnetic field passing through the volume-changing ferrogel. Overall, the effect of the magnetic flux passing through the ferrogel dominates, thus increasing the inductance as the ferrogel swells. The resulting inductance change can be remotely monitored through wireless tracking of the coil self-resonant frequency. A pH sensor based on poly (methacrylic acid-co-acrylamide) hydrogel was fabricated and tested. The test was carried out in a laser machine acrylic chamber with buffers of varying pH values flowing through while monitoring the resonant frequency with a network analyzer. The sensor shows sensitivity of 200 kHz/pH between pH values of 6 to 5 and 105 kHz/pH from 5 to 4 with approximately 30 minutes of response time.
KEYWORDS
Chemical sensor; Hydrogel; Superparamagnetic ferroparticles; Poly methacrylic acid; Poly acrylamide
INTRODUCTION
Wireless chemical sensors using electrochemical
DEVICE STRUCTURE AND OPERATION
Figure 1 shows a cross sectional schematic of the device which consists of a polymeric housing onto which a planar coil is bonded. The sensor is implanted in subcutaneous tissue and resonant frequency of the sensor is measured by an external readout coil. A ferroparticle embedded hydrogel (ferrogel) is immobilized on the top of the coil, and the housing is capped by a porous membrane, which allows transport of analyte, water, and ions, while preventing cells and larger particles from entering the cavity.
Readout coil
Porous membrane
Skin
Ferrogel
Coil
Polymeric housing
Subcutaneous Tissue
Figure 1: Schematic of a wireless ferrogel-based chemical sensor.
For proof of principle, we used poly (methacrylic acid
$C(t)=\frac{m}{A_s}\frac{1}{t}$ (1)
where m is the mass of ferroparticles, and A_s is the surface area of hydrogel. The concentration of magnetic PS beads inside of the dried hydrogel is estimated to be 10% so that
$C(t_o)=\frac{m}{V}=\frac{m}{A_s t_o}=10$ (2)
where t_o is the thickness of hydrogel when dried. Using SPNs embedded PS beads (Bangs Laboratories), a relationship between the magnetic relative permeability (μ_r) and the ferroparticles concentration is empirically obtained. Measurement shows that μ_r is directly proportional to C, such that,
$\mu_r=1+kC$ (3)
where k is a proportionality constant (k = 0.2 for beads used in this paper). Using equation (1), the reluctance (R) of the ferrogel can be represented by
$R_{ferrogel}=\frac{l}{\mu_o\mu_r A_l}=\frac{l}{\mu_o\mu_r lt}=\frac{1}{\mu_o\left(1+k\frac{m}{A_s}\frac{1}{t}\right)t}$ (4)
where μ_o is the permeability of vacuum, A_l is the lateral area of the ferrogel, and l is the diameter of the ferrogel. By substituting equation (2) and k obtained from equation (3)
(a) (b) (c) (d) (e) (f) (g) Ferrogel (h)
Copper
Polymeric film
UV curable glue
Si
GelBond
Photoresist
Polyimide
Figure 3: Fabrication process of the ferrogel pH sensor.
In order to form the pH sensitive poly (mAA-co-AAm) ferrogel [10], two pregel solutions are required. Solution A is prepared by mixing 100.8 µL of methacrylic acid (mAA, Sigma Aldrich), 334.5 mg of acrylamide (AAm, Sigma Aldrich), 100 µL of N,N,N',N'-tetramethylethylenediamine (TEMED, accelerator from Sigma-Aldrich), 3.27 mg of N,N'–Methylene Bisacrylamide (BiS) in 1.2 ml of deionized (DI) water. Then, SPNs in PS beads of 1 µm diameter (Bangs lab) are sonicated at 3 vol% for 1 hour with 0.1% w/v surfactant (Tween 20, Bangs lab) in solution A. Solution B is prepared by dissolving ammonium persulfate (APS, initiator from Polyscience