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Vacuum-Packaged Resonant Microsensor for Photoacoustic Detection of Glucose in a Gelatin-based Tissue Model

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Abstract

This paper describes the fabrication, and testing of a highly sensitive resonant microsensor for photoacoustic detection. The microsensor employs a cantilever structure as a sensing element which is fabricated with an SOI (Silicon on Insulator) wafer using standard microfabrication technology. High sensitivity is achieved by packaging the microsensor in a high vacuum environment with a getter to achieve a high Q-factor. The fabricated microsensor was then applied for photoacoustic detection of aqueous glucose solutions in physiological range embedded in gelatin samples. High power near infrared pulse laser diode with 1550nm wavelength was used to make optical excitations in the samples and the resulting optoacoustic signals were recorded by monitoring the resonator vibrations. The experimental results reveal that the microsensor response is highly sensitive to glucose concentrations.

1. Introduction

The conventional technique of photoacoustic detection makes use of a gas-microphone detector which senses the thermal waves in the gas medium of the sample being irradiated with pulsed optical beam. For condensed samples this technique offers poor sensitivity because of low transmission coefficient for an acoustic wave going through solid-gas interface of the sample [1]. While certain designs have the potential to greatly reduce these limitations; however, their sensitivity is still inferior to overcome the challenges of required performance and resolution of photoacoustic detection for condensed materials [2]. Several authors have used piezoelectric detection in photoacoustic experiments of condensed materials [3]. Piezoelectric transducers offer advantage of good acoustic impedance matching for photoacoustic detection in liquids and solids over gas-microphones. Still the use of piezoelectric transducers is not free from complications. If the samples are not properly acoustically matched with the piezoelectric material, a substantial part of acoustic energy will be reflected at the sample-detector interface resulting in poor resolution and sensitivity. Furthermore, the piezoelectric transducers are very sensitive to scattered light signals entering the transducer from light windows and walls [5]. To address these issues associated with the conventional methods we propose and demonstrate the use of a vacuum packaged microcantilever based resonant sensor for photoacoustic detection of samples of biological interest such as α D-glucose. The fabricated microsensor was applied for the photoacoustic detection of various concentrations of aqueous glucose solutions in gelatin-based tissue models and the results of experimental investigation are reported.

2. Microsensor Design and Fabrication

The microsensor is based on hermetically packaged Si micro-cantilevers, thereby avoiding the problems of viscous damping which normally degrade the performance of resonant type microsensors. By matching the frequency of laser excitation with the resonance frequency of the resonator, the detection sensitivity can be improved. Based on this concept, the resonator elements are designed with desirable resonance characteristics for photoacoustic signal detection. The microsensor is coupled with the gelatin tissue sample via a glass stage. The acoustic pulse is directly detected by the microsensor without involving any transmission of the signal across solid-gas interface as is the case with the gas-microphone detection. Thus a good acoustic impedance matching is realized for improved detection sensitivity. In this work the pulsed excitation frequency was kept under 3 kHz, therefore the resonant microsensor was designed with resonance frequency below 3 kHz. The resonator part of the microsensor was fabricated using the process flow as shown in Figure 1.

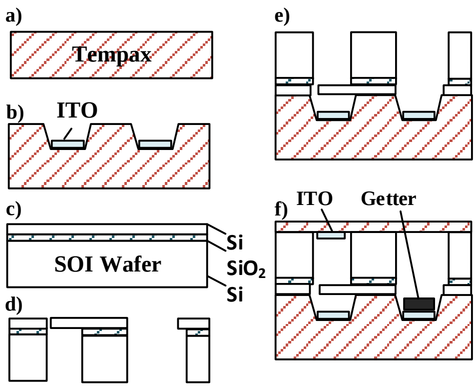

Fig 1. Fabrication Process of hermetically sealed photoacoustic sensors.

A silicon on insulator (SOI) wafer composed of device, buried SiO_2 and handling layers with thicknesses of 7 µm, 1 µm and 300 µm, respectively, is the starting material for cantilever resonator elements. The top device layer and the handling layer of the wafer were etched by Deep Reactive Ion Etching (DRIE). Sandblast process was used to make cavities in the

Tempax glass. A thin Indium Tin Oxide (ITO) layer of 100 nm thickness was deposited on the top and bottom glass covers to prevent the electrostatic pull-in damage to the resonator structures during the anodic bonding process. The first anodic bonding process was carried out at atmospheric conditions. Finally, the resonators were vacuum packaged with a ST 787 strip getter from SAES Getters S.p.A. Figure 2 shows the optical micrographs of the fabricated device.

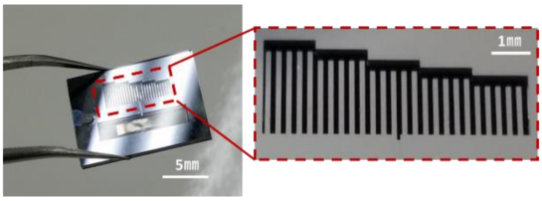

Fig 2. Fabricated Packaged Microsensor

A laser vibrometer setup was used to measure the frequency response of the fabricated microsensor, which shows a resonance peak at 2.4 kHz and a quality factor of approximately 5900.

2. Experimentation

Samples of different aqueous glucose concentrations were mixed with gelatin powder in 1.7:1.5 mass ratio respectively, to form sample tissue models. The schematic of experimental setup is shown in Figure 3. The microsensor is firmly fixed to a glass stage with a solidified glue. Optical excitations in the samples were made using near infrared (NIR) pulsed laser diode with wavelengths of 1550 nm. The trigger signal to the laser diode is supplied by a function synthesizer.

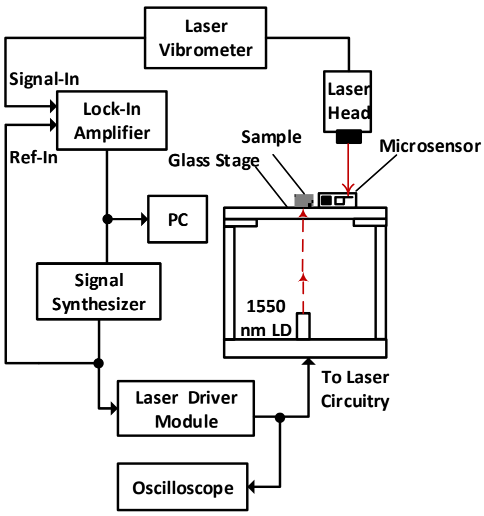

Fig 3. Experimental Setup

For all measurements the laser pulse width was kept at 150 ns and the response of the microsensor was recorded through a laser vibrometer by sweeping the pulse repetition rate of the laser trigger signal around the resonance frequency of the microsensor. Experimental results have been depicted in Figure 4. The resonance frequency of the microsensor slightly shifts due to temperature variations.

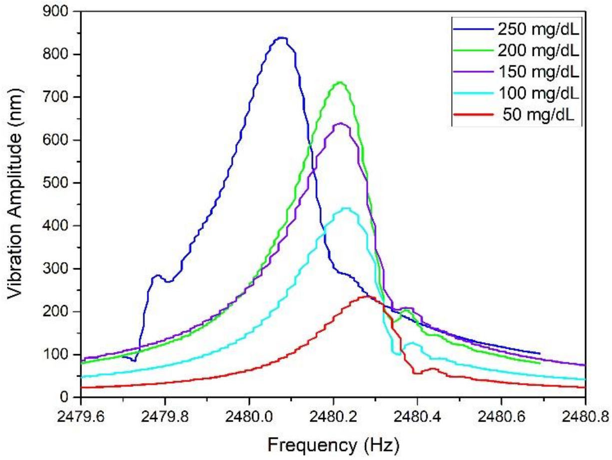

Fig 4. Photoacoustic signal from various aqueous glucose concentrations in gelatin tissue model

The vibration amplitudes of the microcantilever at the resonance frequency of the packaged resonator, which correspond to photoacoustic signal, have been plotted as shown in Figure 5. It can be seen that the sensor response linearly increases with the increasing concentrations of glucose in the gelatin tissue model.

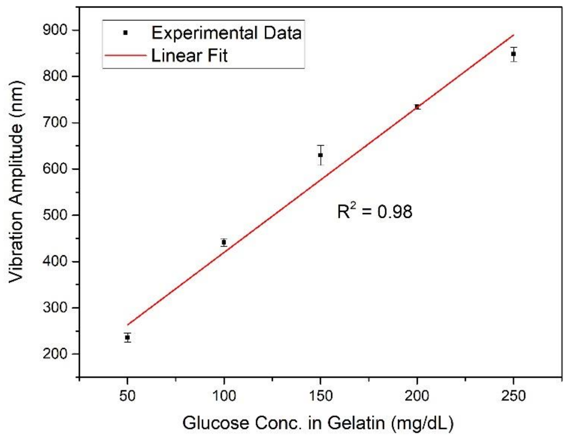

Fig 5. Maximum photoacoustic signal at the resonance frequency of the microsensor for various glucose concentrations in gelatin

3. Conclusions

In this work we have developed a vacuum packaged resonant microsensor for photoacoustic detection. The fabricated device was applied to photoacoustic signal detection from various glucose concentrations in gelatin-based in vivo tissue model. Experimental results show a linear relationship between the sensor response and glucose concentrations.

References

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