IMPEDANCE BASED MICROPARTICLE COUNTER ON AN INTERDIGITATED ELECTRODE (IDE) SURFACE WITH SINGLE-BEAD SENSITIVITY

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ABSTRACT

An interdigitated electrode (IDE) array-based impedance sensor is developed for microparticle detection. The IDE is fabricated by photolithography, Ti/Au deposition, and dielectric deposition. With this microfabricated IDE array, we demonstrated a highly portable impedance sensing system with frequency analyzing circuits, DAQ, and LabVIEW. With samples containing various microparticle concentrations, impedance values are measured. As the number of microparticles increases, magnitudes of impedance decrease due to current blockage. By obtaining a series of differential magnitudes which are adjusted by a background signal, we found that these differential magnitudes exponentially increase due to the increasing number of microparticles. From these results, number of microparticles on the IDE surface can be precisely counted with a single microparticle resolution. This platform can be extended to use for label-free single particle detection enabling various biological and chemical analyses.

KEYWORDS: Label-free detection, Interdigitated electrode array, Impedance, particle counter

INTRODUCTION

One approach to implementing bioassays in a small and inexpensive method which is to use a microparticle as a label. These microparticle labels enable an electronic biosensor system rather than optically avoiding the need for optical components and enabling integration with standard electronics. Several types of microparticle detectors have been developed including Giant Magnetoresistance sensors, inductors, and Hall-effect sensors, for detecting magnetic beads [1, 2]. Most sensors have focused on the magnetic beads, since they have unique electromagnetic properties, which are compatible with electronic biosensors. However, these sensors involve several intensive fabrication processes and require an external magnet or an internal magnetization system for polarization of each bead. On the contrary, a polymeric microparticle has better stability, inexpensive, and an easy-fabrication process. However, the detection of the microparticle on an electronic sensor has not been well explored to be able to use for various bioassays. In this work, we demonstrate how an interdigitated impedance sensor can be used to measure the number of polymeric microparticles on the surface over a wide range of frequencies.

Figure 1: Fabrication process (1) wafer cleaning with acetone, IPA, and DI water. (2) Photoresist coating on glass. (3) UV exposure on coated sample. (4) Developing process of photoresist. (5) Formation of adhesion layer (Ti) and Au electrode by using e-beam evaporation. (6) Lift-off process with acetone, IPA, and DI water. (7) Formation of passivation layer (Si₃N₄) by using PECVD.
The IDE array was fabricated on a glass wafer, which consists of 8 IDEs. Each IDE contains 10 µm in finger width and space [3]. In detail, 7 fabrication steps shown in Figure 1 were followed: Photolithography process (from step 1 to 4), deposition of titanium (Ti) and gold (Au) electrode (from step 5 to 6), and 10 nm Si₃N₄ passivation layer formation (step 7). To perform experiments using liquid samples, microchannels were fabricated using soft-lithography and integrated on the IDE array.

To acquire impedance plots, we developed a custom-made impedance analyzer, which consists of an Au IDE array, impedance analyzer, DAQ, and LabVIEW program shown in Figure 2. Before performing an actual experiment, overall functions of this platform were measured with various pH buffer solutions. After finishing these characterization steps, a counting microparticle was performed on the IDE array. To monitor the impedance change by the microparticles, a 40 µm polystyrene (PS) microparticles (poly-science Inc.) mixed in phosphate buffer saline solutions were prepared as shown in Figure 3A.

RESULTS AND DISCUSSION

We evaluated the overall impedance change with various number of PS microparticles. Figure 3A presents photographs of various microparticles on the IDE sensor. After adding various microparticle concentrations on the IDE array, both magnitude and phase shift of impedance were measured from input frequencies (11 kHz to 91 kHz). In these measurements, we investigate significant decrease of magnitude as decreasing number of the microparticles. Furthermore, Figure 3B shows an adjusted plot showing absolute magnitude differences from a background value. This differential plot provides a standard curve to determine the number of microparticles on the IDE sensor with single particle sensitivity. Essentially, the background impedance value without any microparticles is tightly related to the conductivity of a buffer solution. When PS microparticles cover on the IDE array, the PS microparticles can block the current flow between electrodes due to extremely low electrical conductivity of the PS microparticles. This current blockage decreases overall magnitude of each input frequency [4].

Figure 3: Impedance measurements of 6 different number of beads over the signal range 11 kHz to 91 kHz. As increasing bead coverage on the sensor surface, differential impedance values were increased at low frequency range.
magnitude differences decrease as increase input frequencies. This phenomenon can be confirmed by performing further experiments with various sized, shape, and material properties of particles. By studying the effect of these variables, this proposed particle counting method opens up a new methodology on micro-nanoparticle based biomolecule detection without any expensive metal or fluorescence materials. In addition, this IDE platform can be integrated with a proper fluidic manipulator which can perform sample processes such as metering, reacting, washing steps facilitating an automated bioassay.

CONCLUSION

In this work, we demonstrated the IDE impedance sensor enabling determination of number of PS microparticles without any labels. In this system, magnitudes decreased significantly at low frequency input with minimal phase shift. By determining the differential magnitudes on each microparticle samples, we can quantify the number of microparticles in the buffer solution with single-bead sensitivity. Currently, we are studying the effect of microparticle sizes and its materials on this impedance biosensor to define an ideal microparticle for maximizing the sensitivity of bioassay. The innovative impedance sensing technique eliminates the need for specialized optical equipment and complicated fabrication processes, which provide a miniaturized and affordable platform for point-of-care testing.

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REFERENCES


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