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Electrolytic tilt sensor fabricated by using electroplating process

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ABSTRACT

This paper proposes new electrolytic tilt sensor fabricated by MEMS process especially using electroplating process to form vertical electrodes each of which is connected to planar electrode. Comparing with conventional electrolytic tilt sensors having difficulty in manufacturing in small size, the present tilt sensor can be manufactured in small size, particularly in very small height, having comparable performance, thus resulting in mass production possible, while still having a variety of manufacturing in higher height which is possible using electroplating process. In order to perform the electroplating process, an assembly of SU-8 polymer and PDMS was used as electroplating mold, former not being removed to form outer wall of sensor cavity but latter being removed to make a cavity in which electrolytic solution is contained. The nonzero null output voltage offset has minimum value in the range of 100–800 Hz of the frequency of alternating input voltage source. Analytically derived equation and experiments to examine how the sensor cavity size affects the performances confirmed that smaller the cavity diameter D, the smaller sensitivity but larger angle range. Compared to commercial electrolytic tilt sensor products, the fabricated tilt sensor has comparable performances such as angle range of about $\pm 40^\circ$, especially linear range of about $\pm 10^\circ$, sensitivity of 4.4 V/$^\circ$ in case of V_{in} = 1 V (rms), and resolution of 0.5 arc min.

1. Introduction

Tilt sensors are widely used in fields such as alignment of machinery, attitude-control systems of vehicles, cellular phone, robot and entertainment. There are many operational principles of tilt sensor: optically detecting of the movement of liquid in the filed of gravity; using the change of resistance or impedance of variable resistor; or using the change of capacitance and so on [1–10].

A tilt sensor using the method of optically detecting the movement of air bubble according to tilt angle was introduced [2]. This sensor made possible for the angle range to be up to $\pm 180^\circ$. However, there is disadvantage of complex structure which needs additional light source and angular position detector (APD). It was introduced a tilt sensor which detects the capacitance change according to tilt angle [4]. This type of tilt sensor has advantage of good stability and resolution, however, has disadvantage of temperature and humidity dependency.

Recently, researches using MEMS technology for tilt sensors fabrication have been performed [7–10]. Using MEMS technology has the advantages of easy fabrication, mass production, low cost and easy assembly with circuit. Oh introduced a tilt sensor using mercury drop which has a role for media for electrodes connection and moves downward according to tilting [7]. This sensor has advantages due to MEMS technology, however, has also disadvantages of having split phenomena and noise sensitive characteristic. Kang and Jung has realized a tilt sensor based on electrolytic solution filled in anisotropically KOH etched Si cavity [9,10]. The cavity has the depth of at most 300–400 μm so that it has difficulty in injection of electrolyte and has surface tension effect which may influences on liquid movement.

In this paper, a MEMS-based electrolytic tilt sensor with highly electroplated Ni electrodes, which reduces surface tension effect, has been proposed and fabricated.

2. Design

The MEMS-based electrolytic tilt sensor reported in this paper has about 500 μm deep cavity which is formed surrounded by SU-8 housing layer which is formed on a glass substrate, as schematically shown in Fig. 1. Separated four Cu/Au layers and vertically highly electroplated four Ni rods each of which are connected to Cu/Au layer, respectively form four electrodes which give a functionality of tilting angle detection. After sealing the cavity by PDMS plate, electrolytic solution is injected into the cavity.

Fig. 2 shows the operational principle of electrolytic tilt sensor in which the conductivity between two electrodes 'a' and 'b' is proportional to the length of the electrodes immersed in the electrolytic solution. For example, when the tilt sensor is inclined as in the state of Fig. 2(b) after the leveled stated as in Fig. 2(a), the electrode 'a' will be more immersed whereas the electrode 'b' will be less immersed,

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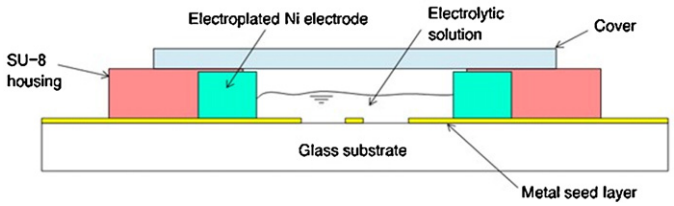

Fig. 1. Schematic view of electrolytic tilt sensor structure.

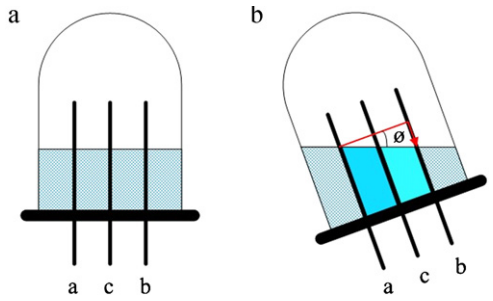

Fig. 2. Working principle of electrolytic tilt sensor: (a) before tilt, (b) in the state of tilt.

which results in larger conductivity between electrodes 'a' and 'c' than that between electrodes 'b' and 'c' [11].

3. Fabrication

The fabrication process of the proposed electrolytic tilt sensor is described in Fig. 3. Firstly (a) 2000 Å/300 Å of Au/Cr seed layer is deposited on a glass wafer using E-beam evaporation, and then lithography is performed on the Au/Cr seed layer to form electrically separated four planar electrodes (b) a negative photoresist of SU-8 is thickly spin coated about 500 μm which is then UV irradiated, and (c) a portion which is not UV irradiated is removed by SU-8 developer to form a cavity and also a portion of electroplating mold. Independently (1) SU-8 is thickly spin coated about 500–600 μm on a Si wafer and then is UV irradiated, (2) the portion which is not UV irradiated is then removed by SU-8 developer to form a cylindrical cavity, (3) PDMS is cast into the cavity and then cured, and (4) the cured PDMS is peeled off the Si wafer. Then (d) the PDMS peeled off in the process (4) is inserted in the middle of the cavity formed in the process (c) to form an electroplating mold together with the portion of SU-8 electroplating mold, (e) Ni is electroplated about less than 500 μm from the electrically separated four Au/Cr seed layers which was formed in the process (a) to form vertical electrodes all of which are connected to each planar electrodes,

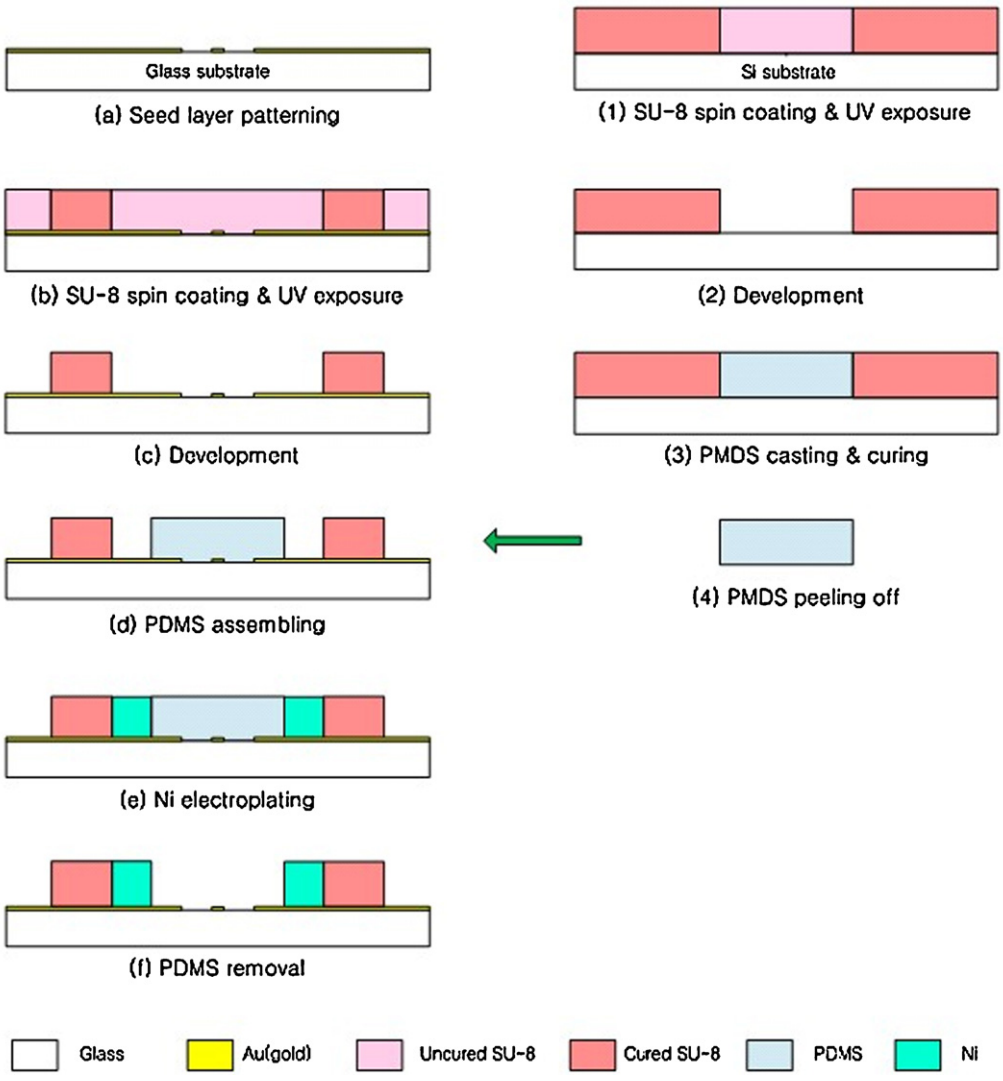

Fig. 3. Fabrication process using SU-8 electroplating mold combined with PDMS.