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Effect of annealing on the performance of nickel thermistor on polyimide substrate

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ABSTRACT

In this study, a nickel thermistor pattern integrated with copper electrodes on polyimide substrate is fabricated by photolithography and magnetron sputtering techniques. The effect of annealing treatment on the performance of the nickel thermistor on polyimide substrate is evaluated. It is found that the performance of nickel thermistor is significantly improved by annealing treatment. The relative change of resistance increases with the increasing annealing temperature and time when the annealing temperature is below 360 °C. The temperature range over which the temperature coefficient of resistance (TCR) remains linear is long when the annealing temperature is 350 °C. The adhesion strength between the nickel thermistor and the polyimide substrate significantly increases after annealing treatment, but decreases when the annealing temperature and time increase. From the experimental results, the appropriate annealing temperature and time are obtained to meet required resistance, TCR, adhesion strength of the nickel thermistor.

1. Introduction

Determination of wall shear stress is essential for understanding the dynamics of fluid flow and controlling near-wall turbulence and flow separation in aerodynamic area [1]. Micro electro mechanical system (MEMS) plays an important role in measuring wall shear stress. The MEMS shear stress sensor is characterized by dimensions in the order of μm. It can be used in micro flow field to minimize flow field interference due to the relatively small size of the sensor dimensions [2,3]. This kind of sensor is featured with fast response, low power consumption, and low cost compared with traditional sensors [4,5].

Flexible MEMS shear stress sensors attract much attention because they can be attached to any surfaces irrespective of their shapes [6–8]. The structures and production processes are simplified compared to sensors of rigid substrate (glass, silicon wafer, *etc.*) [9]. Also the thermal inertia, response time and production cost of the flexible MEMS shear stress sensor are less than those of conventional rigid sensors.

Flexible polyimide film with better heat insulation has been widely used in aviation, navigation, spacecraft, electronic industry, *etc.* [10]. The heat resistance of polyimide enables the film to withstand high temperatures during the sputtering process. The polyimide film has good mechanical properties, which can ensure high mechanical strength of polyimide based MEMS shear stress sensor. Polyimide has been chosen for the substrate of flexible thermal shear stress sensor, due to its excellent mechanical properties, electronic and chemical stability, high radiation resistance, and resistance to high and low temperature [11].

The nickel film has been used as thermistor for polyimide based MEMS shear stress sensor [12,13]. TCR of nickel thermistor can directly affect the sensitivity and response speed of the shear stress sensor. Annealing treatment has been recognized as one of the most effective ways to improve the performance of nickel thermistor [14,15]. However, there is no specific description about influences of annealing treatment on the performance of nickel thermistor such as resistance, TCR, adhesion strength, *etc.*

In this paper, a polyimide based MEMS shear stress sensor with stable reliability and high TCR has been developed. The effect of annealing treatment on the performance of shear stress sensor has been studied. The resistivity and resistances changes of nickel thermistor, TCR, and adhesion strength between the nickel thermistor and polyimide substrate have been investigated after annealing treatment, respectively. In addition, the grain size and morphology of nickel thermistor are examined to explain the resistance changes and TCR.

2. Experimental details

2.1. Manufacture

A flexible shear stress sensor composed of nickel thermistors and copper electrodes, is shown in Fig. 1. The 0.3 μm thick nickel thermistor,

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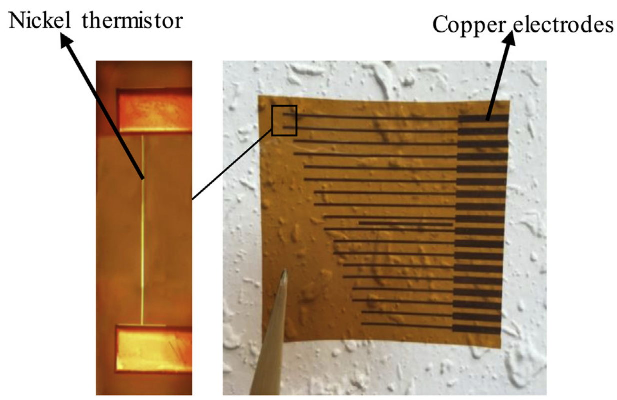

Fig. 1. Flexible shear stress sensor.

whose both ends were stacked with the ends of two parallel copper electrodes, is sputtered on the polyimide substrate.

There are nine nickel thermistors and nine pairs of copper electrode in one flexible shear stress sensor. The width and length of each nickel thermistor are about 10 μm and 2000 μm, respectively. The nine nickel thermistors are properly spaced to avoid mutual thermal interference when working. The width and thickness of copper electrode are approximately 500 μm and 40 μm, respectively. The resistances of the copper wires are all about 0.5 Ω regardless of their length. Because of the low resistance of copper electrodes, their heat dissipation effect on the nickel thermistor is very small. The copper electrodes are overlapped on the two ends of each nickel thermistor so that it can form a good contact when the electric current flows through. The thickness of the polyimide is 75 μm. The glass transition temperature of this polyimide is about 400 °C.

The manufacturing process of the flexible MEMS shear stress sensor is shown in Fig. 2.

In Fig. 2(a), the polyimide substrate is attached to the glass with polyimide glue and ultrasonicated with acetone, alcohol and pure water sequentially to remove the contaminants and grease. After that the polyimide is placed in a drying machine for 15 min at 150 °C to dry the substrate. In Fig. 2(b), reverse photoresist AZ5214 is spun on the polyimide substrate at a speed of 3000 RPM. The photoresist is soft-baked for 60 s at 100 °C then exposed in the exposure machine for 2 s. Next, the photoresist is reverse-baked for 90 s at 120 °C then exposed for 45 s. Finally, the photolithography pattern is transferred to the photoresist. In Fig. 2(c), after soaking in the photoresist developer for 35 s, the pattern appears. In Fig. 2(d), Ni (300 nm thickness) film is sputtered on the substrate with the photoresist pattern. To enhance the adhesion between the Ni film and the polyimide substrate, Cr (2 nm thickness) film is deposited between the Ni film and the polyimide substrate. In Fig. 2(e), the Ni-Cr pattern can be obtained using a lift-off technique. This stage in the manufacturing process represents completion of construction of the Ni thermistor. The fabrication of copper electrodes is describes as flows. In Fig. 2(f), 6 nm thickness Cu film is deposited on the polyimide with Ni thermistors. In order to improve the adhesion strength between the polyimide and the copper film, there is a Ti film with 2 nm thickness as the interlayer. In Fig. 2(g), the positive photoresist AZ4620 is coated on the Cu film. In Fig. 2(h), the patterns are exposed after photoetching. In Fig. 2(i), the 50 μm thickness Cu is electroplated. In Fig. 2(j), the interlayer (Cu (6 nm thickness) and Ti (2 nm thickness) deposited) and the photoresist on them is removing by erosion with H_2SO_4 and HF, so the copper electrodes are made. In Fig. 2(k), the polyimide film with nickel thermistors and copper electrodes are easily released from the supporting glass base. In brief, the nickel resister is made by a lift-off technique and the copper electrode is made by photoetching and electroplating. The Cr or Ti layer makes adhesion between the nickel resister or copper electrode and the substrate much stronger [16]. The dimension of each nickel thermistor is about 2000 × 10 × 0.03 μm.

2.2. Evaluation methods

The fabricated sensors with known resistance are put into a vacuum furnace. The annealing temperature is set at 200, 250, 300, 350, 360, 370, 380, 390 and 400 °C for 2, 4, 6 h, respectively. The highest temperature of annealing treatment is set at 400 °C because the glass transition temperature of the polyimide substrate is about 400 °C. The resistance of different nickel thermistors, which are treated using different annealing temperatures and time, are measured by a digital multimeter after they are removed from the vacuum furnace.

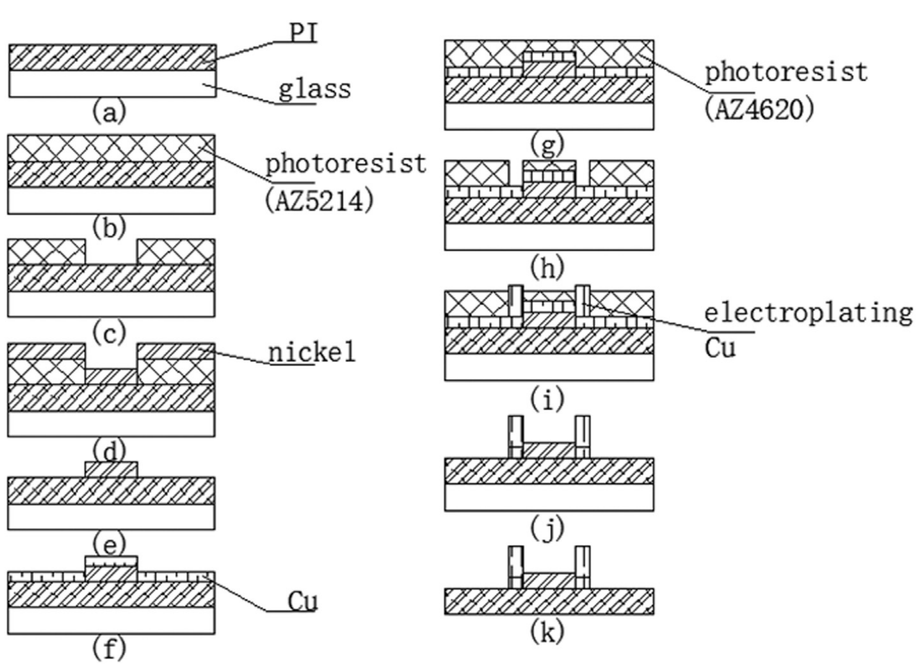

Fig. 2. Manufacturing process of the flexible shear stress sensor (a)Polyimide,(b) coating photoresist,(c)photoetching, (d) Ni-Cr sputtering, (e) stripping, (f) Cu-Ti sputtering, (g) coating photoresist, (h) photoetching and erosion, (i) Cu electroplating, (j) removing photoresist, (k) release from glass.