Development and Fabrication of Modular Micro Sensors on Flexible Polymer Foils

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Summary: A concept for the fabrication of modular micro sensors on flexible substrate materials is presented in this paper. This paper describes the development and fabrication of modular eddy current micro sensors on a 7 µm thick polymer layer. The modular eddy current micro sensors are fabricated on a standard Si wafer due to handling purposes during the sensor fabrication process. Initial investigations concentrated on the proof of principle of applying a deep reactive-ion etching (DRIE) process to remove the Si wafer in parts. The DRIE process was used to structure Si frames, which serve as a carrier for the modular eddy current micro sensors. To evaluate the fabricated eddy current micro sensors on a flexible polymer foil, electrical resistance measurements were accomplished. Furthermore, the micro sensors were tested in a temperature shock test chamber to proof the long-term stability of the micro systems.

Keywords: Magnetic Micro Sensors, Modular Sensor Concept, Flexible Polymer Foils, Eddy Current Sensor

1. Introduction

A new approach for the development and fabrication of micro sensors is pursued within the Collaborative Research Center (SFB) 653, which is funded by the German Research Center (DFG). To come up with genetically intelligent (”gentelligent”) machine tools or components, various micro sensors were developed to gather user and maintenance data as well as recycling relevant information throughout the whole life cycle of the components [1]. A family of modular magnetic micro sensors covering force, strain, and magnetic property measurements has been developed so far [2, 3].

In contrast to existing micro electro-mechanical systems (MEMS) fabricated on rigid Si substrates, this paper describes the development and fabrication of an eddy current micro sensor using a flexible polymer as substrate material. One of the main benefits of this approach is the less complex system integration later on. The application of thin flexible polymer substrates makes wafer thinning processes unnecessary, in general used at the end of the MEMS fabrication to reduce the thickness of the Si wafer [4]. By using a thin polymer foil as substrate material, film thicknesses less then 10 µm can be achieved. The presented eddy current micro sensor is fabricated on a 7 µm thick polymer foil. The design of this micro sensor system depicts Figure 1.

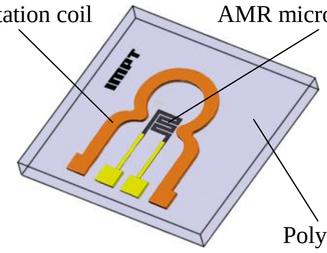

Figure 1. Design of the modular eddy current micro sensor fabricated on a flexible polymer substrate .

The modular eddy current sensor consists of two parts, a single-turn excitation coil and an anisotropic magneto-resistance (AMR) sensor. The excitation coil is fed with an alternating current, which generates a magnetic field around this coil. Eddy currents are induced in an electrically conducting probe and create an electromagnetic field. This field counteracts with the magnetic field generated by the excitation coil. The sensing axis of the AMR sensor is in plane with the surface of the probe and detects the total magnetic field generated by the excitation coil and the eddy currents induced in a defect-free specimen. In case of a defect (e.g. a crack) the output signal of the sensor changes caused by the disturbance of the eddy current flow path [5].

For the fabrication of modular micro sensors on flexible polymer substrates, investigations on releasing techniques are essential, since it must be possible to release the sensors at the end of the fabrication process [6]. The modular micro sensors are fabricated on standard Si wafers due to handling purposes during the sensor fabrication process. Initial investigations concentrated on the proof of principle of applying a deep reactive-ion etching (DRIE) process to remove the Si wafer in parts. The DRIE process was used to structure Si frames, which serve as a carrier for the modular eddy current micro sensors. In comparison to other micro systems fabricated on polymer foils, the application of structured Si frames presents a new approach [7]. To evaluate the fabricated modular eddy current micro sensors on polymer foils, electrical resistance measurements were accomplished. Furthermore, the micro sensors were tested under different temperature conditions using a temperature shock test chamber to proof the long-term stability of the micro systems.

2. Fabrication Concept

The modular eddy current micro sensors are fabricated in thin-film technology. Due to handling purposes during the micro sensor fabrication, rigid Si substrates are still required as carriers. To enable a release of the eddy current micro sensors at the end of the fabrication process, a DRIE process is used to structure a Si frame, which serves as a carrier for the micro systems. Due to the flexible characteristics of the polymer foil tensions can lead to a warping of the micro sensor system. In order to work against the warping and to prevent damages of the micro sensors, a carrier frame is structured out of the Si substrate. Figure 2 depicts the design of the modular eddy current micro sensor mounted on a Si frame.

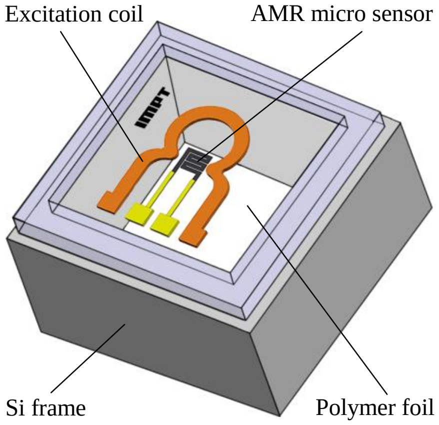

Figure 2. Design of the eddy current micro sensor fabricated on a flexible substrate and mounted on a Si frame.

The Si carrier frame also simplifies the handling and the application of the micro sensors at the place of installation later on. The eddy current micro sensor can be released by die cutting from the Si frame.

3. Micro Sensor Fabrication

The modular eddy current micro sensors were fabricated on a 4 inch Si wafer. Figure 3 shows the fabrication sequence for the modular magnetic field micro sensors.

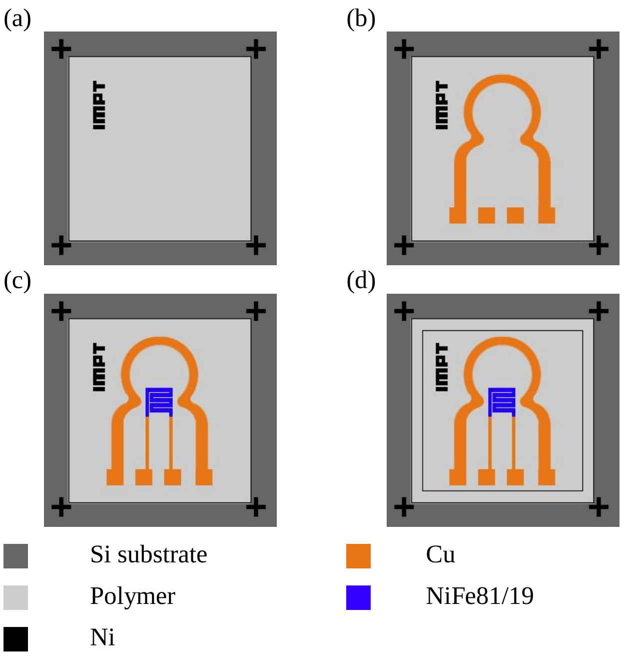

Figure 3. Fabrication sequence of a modular eddy current micro sensor fabricated on a polymer foil.

In the first step, a polymer layer was deposited on a Si substrate by spin-coating. Afterwards, the modular micro sensor was fabricated directly on this polymer layer. In the next step, a Cr adhesion layer was sputter deposited, followed by an Au layer deposition serving as a conductive seed layer for the electroplating process of the alignment marks and the logo of the Institute for Micro Production Technology (IMPT) (Fig. 3a). To pattern the micro molds for electroplating, a positive photoresist was used. Then, the Ni alignment marks were electroplated. Subsequently, the photoresist was stripped. In the next step, the micro molds for the contact pads and the excitation coil were created. For depositing both, the micro molds were filled up with electroplated Cu (Fig. 3b). A removal of the seed layer was required to inhibit short circuits. This was executed by Ion Beam Etching (IBE). For the fabrication of the electrical connections and the meander-like structure of the AMR sensor, micro molds were patterned again using a positive photoresist. Afterwards, a 100 nm thick Cu layer was deposited for the electrical connections, followed by a 50 nm thick NiFe81/19 layer for the meander-shaped structure (Fig. 3c). Both layers were fabricated by sputter deposition. The functional layers of the micro eddy current sensor were embedded in a second polymer layer (Fig. 3d). After fabricating the micro sensors the back side of the Si substrate was structured by the DRIE process. Figure 4 depicts micrographs of an eddy current micro sensor fabricated on a flexible polymer foil before (Fig. 4a) and after the release of the Si frame by die cutting (Fig. 4b).

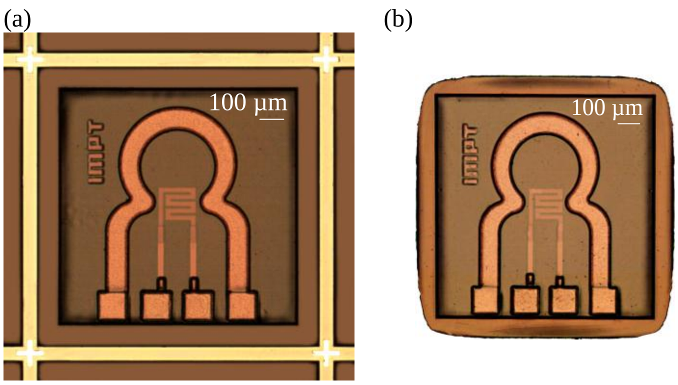

Figure 4. Micrographs of a completed modular eddy current micro sensor: (a) before and (b) after the release of the Si frame.

4. Experimental Results

To evaluate the fabricated eddy current micro sensors on a flexible polymer foil, electrical resistance measurements were accomplished with the AMR sensor element. The aim of these investigations was to characterize the electrical resistance R of the AMR sensors fabricated on a flexible polymer foil. The electrical resistance signals of these sensors were subsequently compared with electrical resistance measurements of identical AMR sensor elements fabricated on a Si substrate. These AMR sensors served as reference. This comparison was carried out to evaluate the influence of the substrate material on the characteristics of the AMR sensor. For the evaluation 40 micro sensors fabricated on a flexible polymer foil and 40 AMR sensors fabricated on a Si substrate were investigated. The arithmetical mean of the electrical resistance measured for both sensors types are shown in Table 1. The measurement results show a marginal effect of the substrate material on the electrical resistance of the investigated AMR sensors. The arithmetical mean of the electrical resistance of the micro sensors fabricated on a polymer foil is 451.3 Ω. Compared to the micro sensors fabricated on a Si substrate, an electrical resistance of 461.7 Ω was measured. The difference between the measurement results can be explained by the different reflections index of the used substrate materials. The reflection index has an essential influence on the results of the photolithography processes.

Table 1. Investigation on the electrical resistance for micro sensors fabricated on flexible polymer foils and on a Si substrate.

Number of measurements: 40, conducted for each type of AMR micro sensor	Micro sensors fabricated on a polymer foil	Micro sensors fabricated on a Si substrate
Arithmetical mean of the electrical resistance *R* [Ω]	451.3	461.7
Standard deviation of the electrical resistance *R* [Ω]	5.7	5.5

Furthermore, the eddy current micro sensors were tested in a temperature shock test chamber to proof the long-term stability of the micro systems. This evaluation was carried out according to the military specification standards (Mil-Std) 883 condition F of the United States. The temperature conditions of this test standard are shown in Table 2.

Table 2. Temperature conditions of the military specification standards MIL 883 condition F to proof the long-term stability of the micro systems.

	Test cycles	Temperature conditions	
MIL F	100	-72 °C Soak time: 20 min	+183 °C Soak time: 20 min
	Maximal time for the temperature change from cold to hot or hot to cold: 10 s		

To proof the sensor function of the AMR sensor elements the electrical resistance was measured after 100 test cycles. Table 3 depicts the results of the electrical resistance measurements of 5 investigated micro systems tested under these temperature conditions.

Table 3. Evaluation of the long-term stability of the completed eddy current micro sensors.

Number of test cycles	Electrical resistance *R* [Ω] of the investigated micro sensor systems				
	System 1	System 2	System 3	System 4	System 5
0	453.2	458.5	451.2	448.9	453.5
100	456.4	457.6	452.9	447.5	455.9
	Error of the measuring instrument: ± 0.8 %				

The measurement results of the AMR sensor elements show a minor deviation of the electrical resistance in comparison to the initial values. This effect can be explained by the error of the applied measuring instrument, because no modifications could be observed by the optical inspection of the micro sensor systems

5. Summary

This paper demonstrates the successful fabrication of modular eddy current micro sensors on a flexible polymer foil. For the fabrication of these micro sensors, investigations were conducted to form a Si frame, which serves as a carrier for the micro systems fabricated on a flexible polymer foil. A DRIE process was used to structure this Si frame. After the fabrication process electrical resistance measurements were accomplished to evaluate the micro sensors fabricated on a flexible polymer foil. These measurements were subsequently compared with electrical resistance measurements of reference AMR sensors fabricated on a Si substrate. The measurement results show a marginal effect of the substrate material on the electrical resistance of the investigated micro sensors. Furthermore, the eddy current micro sensors were tested in a temperature shock test chamber to proof the long-term stability of the micro systems. For this evaluation the micro sensors were tested according to the Mil-Std 883 condition F. The measurement results of this investigation show that the modular eddy current micro sensors fabricated on a flexible polymer foil are able to stand the military specification standards.

Acknowledgements

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