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Investigations on strain behaviour of polymer substrates during a separation process

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Abstract

Magnetic field sensors are used for contact free position detection of machine components for example. Fabricating these sensors on a flexible substrate enables the user to attach the sensor on various surfaces and different installation situations [1].
Within the Collaborated Research Center 653 a modular anisotropic magnetic field sensor on a flexible polymer substrate has been developed. In a next step the sensor should be transferred into an industrial application [2].

Keywords: deformation of flexible substrates; modular magnetic field sensor; Collaborative Research Center 653

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1. Introduction and state of the art

The collaborative research Center 653 broaches the issue of “gentelligent components in their life cycle.” Gentelligent is a word made up of the terms genetic and intelligent and describes a method of how components can inherit their product- and operator data to the next generation of components [3]. Thereby it is necessary to do research of methods that enable to bring in, collect, combine, read out and use information during the life cycle of a device [4]. The experiments made within this subproject deal with an anisotropic magnetic field sensor on a flexible and thin substrate and belong to the category of components which collect information.

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Thin film magnetoresistive sensors are frequently used as for example read heads, mechanical transducers, and magnetic field sensors [5]. The anisotropic magnetic field sensor (AMR sensor) is one of the most important sensors within the group of magnetoresistive sensors. Other effects that can be used in the field of sensor technology to detect an extern magnetic field are the giant magnetoresistance (GMR) effect, the colossal magnetoresistance (CMR) effect and the tunnel magnetoresistance (TMR) effect.

In this subproject the ultimate aim is to integrate the magnetic field sensor into an ABS System in order to detect the rotation speed. Setting up the AMR sensor on a thin and flexible polymer substrate involves as well advantages as challenges. On the one hand the flexible substrate enables the user to attach the sensors to various surfaces and installation situations. Further the flexible substrate can be fabricated much thinner as a solid substrate; only several micrometers thick.

Thin substrates have become essential for the research field of flexible electronics. Several flexible substrates are already used in the field of flexible electronics that vary in their Modulus, their glass transition temperature and their photolithographic process suitability [6]. They are for example applied in flexible conductor boards and silicon chips which are integrated into small portable electronic devices like mobile phones, laptops or clocks. Recently Biomedical engineering has become an application range as well where flexible polymer foils serve as a medium for micro electro mechanic systems. The medical area benefits from the flexible substrates as it can adapt to any surface [4].

Processing a sensor on a flexible polymer substrate brings three major challenges with it: The fabrication of the microsystem on a polymer substrate itself, releasing the polymer based microsystem from its temporary medium and the electrical as well as mechanical contacting of the microsystem.

The investigations described in this paper focuses on the releasing process of the microsystem from its medium.

The standard way of individualizing microsystems, that have been processed on a solid substrate like silicon or ceramic is to separate them by abrasive cutting where diamond coated saw blades cut through the material. If the microsystem is build up on a flexible polymer a simpler and less energy intensive cutting process can be chosen in order to cut through the polymer. The disadvantage when building up a microsystem directly on a flexible and thin substrate is its difficult handling due to the low stiffness of the polymer complicating thin film processes like photolithography, electroplating or vacuum deposition. The here used innovative way of fabricating a sensor is to deposit the polymer on a solid silicon substrate before building up the microsystem on it. When the system is processed completely the silicon is only partly removed. The remaining silicon grid is still functioning as a supporting medium and simultaneously exposing the microsystem on the polymer substrate that can be removed without having to saw through the solid silicon.

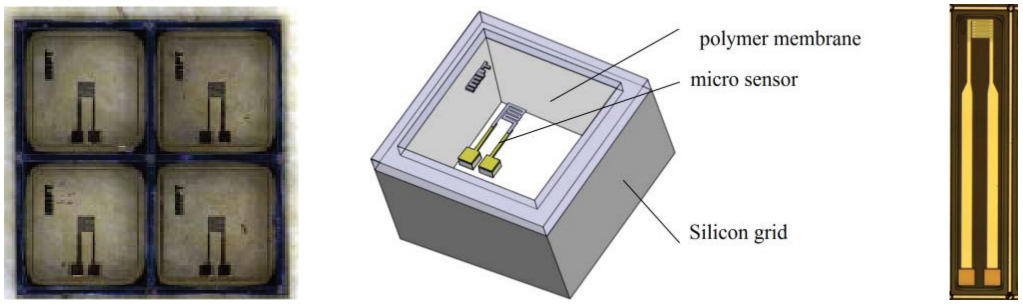
The here described concept provides to separate the sensors from their assemblage with a stamping tool, that has a planar tip of the size of a single sensor. This separation process will cause a strain of the flexible substrate and the sensor layers respectively. It is necessary to analyze this releasing process in order to identify the occurring strains and decide if the strain is causing any damage of the microsystem or the polymer substrate respectively.

2. Sensor Design

The anisotropic magnetic field sensor is fabricated on a polymer resist which is spin coated in a liquid form on a 4 inch silicon or silicon dioxide wafer and structured by photolithography in order to create spaces, in which contact pads can be grown galvanic. Afterwards the polymer layer is cured in a hard bake process at 350°C for one hour. The substrate becomes thereby stabile towards temperatures of up to 350°C as well. The sensor layers are deposited onto the polymer membrane consisting of the meander containing the functional layer (permalloy), the contact pads and the feed lines which are made out of copper. In a next step a second polymer film is spin coated on top and cured as well at the same temperature. The silicon substrate is partly removed in a deep reactive ion etching process. This process is a key element in the fabrication of these sensors, as it creates very straight flanks and therefore realizes a high aspect ratio.

Accordingly a silicon grid with web thicknesses of only 200 µm remains exposing the membrane's backside as well as the contact pads [2]. As the silicon is removed, the polymer layer undertakes the task of serving as a substrate and as an isolating layer.

To separate the sensors a simple stamping tool can be used, without applying high forces. The ejected sensor elements have a quadratic form with an edge length of 1 mm. An image of four sensor elements and a technical drawing of a single sensor element on a silicon grid are shown in fig. 1a and fig. 1b. Alternatively we designed the sensor with dimensions of 1x5 mm^2 as shown in fig. 1c.



(a) (b) (c)

Fig. 1. (a) Image of four sensor elements in the wafer composite. (b) A technical drawing depicts one sensor element on a silicon grid. The front side is directed to the viewer. The backside has been removed. (c) An alternative design of the AMR sensor.

The production method stays the same for both types; only the photolytic masks have been changed. The thickness of one sensor element without the silicon grid remains below 15 µm. Due to its space saving set-up and its simple production method, this sensor type is predestinated for being transferred into an industrial application. Therefore, a reliable packaging and assembling method has to be designed.

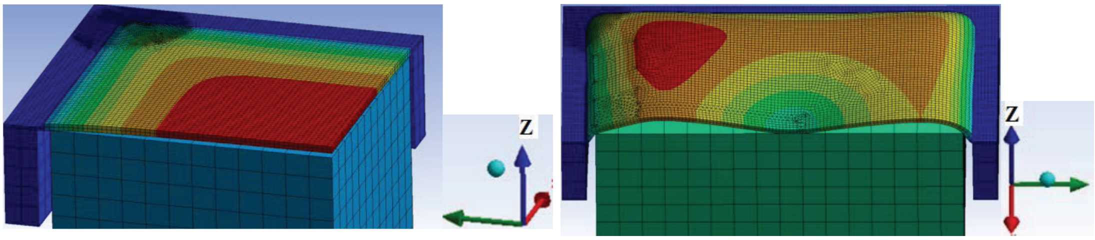
The primary issue was to analyze and optimize the separation process of a single sensor element out of the wafer. First of all we simulated the separation process in Ansys©. In addition to the simulation we used a white light interferometer to detect the deformation that occurred during the actual releasing process, as a reference to the simulation results.

3. Simulation of the Separation Process

To analyze the separation process in advance, the process has been simulated with an implicit solver in Ansys© V14.5. The simulation is quasi static, which means no inertia is taken into account. The polymer's crosslinking is simulated with "solid shell" elements. These elements have five integration points in the direction of the polymer's thickness. The geometry of a single sensor element including the silicon grid was designed in Solid Works©. It is assumed that a solid connection exists between membrane and silicon. Furthermore the silicon grid is assumed to be fixed. The ejection tool's material is chosen to be steel. It has a square planar tip with an edge length of 0.9 mm. The frictional coefficient µ between polymer membrane and tool amounted 0.1. All materials are simulated as linearly elastic.

The simulation calculates the deformation of the sensor element and the membrane that occurs as soon as the tool contacts the sensor from its backside and moves upwards 6 µm in the positive direction of the z-axis. Fig. 2 shows the simulated deformation of the sensor element. For better visualization the picture shows a cross section of the sensor element and the tool. In addition the deformation is depicted five times enlarged. The degree of deformation is demonstrated by a color grading from blue indicating no deformation to red indicating a maximum deformation.

As long as the membrane is simulated together with the sensor layers, the sensor element is deformed non-uniformly as illustrated in fig 2b. The maximum deformation of 16 µm occurs in the upper left corner causing a wave shaped deformation. It is interesting that the simulation shows a uniform deformation with a maximum of 9 µm in the centre, in case the simulation only considers the polymer layers under the same strain conditions (fig.2a). Hence, the sensor layers are causing this particular deformation.



(a) (b)

Fig. 2. The simulation shows the deformation of the membrane without the sensor elements (a) and with the sensor elements (b) when a planar steel tool has been moved 6 µm along the positive z axis deforming the polymer membrane. In (b) the contact pads can be seen on the left side of the membrane. The feed cable and the meander are located in the center.

As the feed lines and the meander are very thin (200 nm and 50 nm), it can be assumed, that these layers have no significant influence on the specific deformation behavior of the whole sensor element. The contact pads, which are embedded inside the lower membrane and reach into the upper membrane as well with a total height of 10 µm, as depicted in fig. 3, most probably shift the polymer membrane causing the specific deformation.

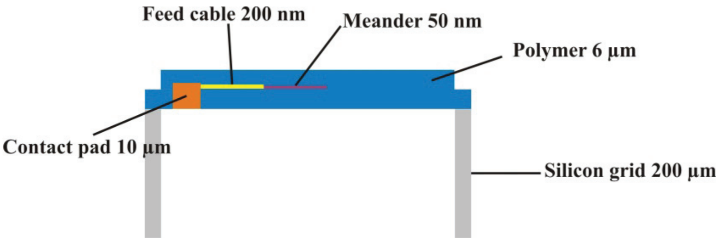


Fig. 3. Schematic side view of a single sensor element while it is still connected to the silicon grid. The thicknesses of all layers are labelled.

The simulation results are of particular importance for the sensor layers. To ensure the functionality of the sensor the permalloy layer of the meander must not be damaged by plastic deformation. When the sensor layer is stretched during the separation process, the permalloy layer is deformed elastic until the tensile strength of σ_t =0.24 GPa is reached [7]. If the permalloy layer is elongated further, plastic deformation takes place. Therefore it is necessary to calculate the elongation at which the tensile strength is reached. Permalloy has a Young´s Modulus of E=113 GPa and a tensile strength of σ_t =0.24 GPa [7,8]. With $\sigma = E * \varepsilon$, ε being the elongation, we can calculate the elongation corresponding with the tensile strength. As the elongation is defined as $\varepsilon = \Delta L/L_0$ we can calculate the maximum change in length before plastic deformation takes place.

In our specific case the meander's loop is 20 µm long in vertical direction. With $\varepsilon = \Delta L/L_0$ we assert that an elongation ΔL of 0.04 µm leads to plastic deformation in the permalloy layer and must be prevented.

4. Investigation on the Membrane's Stress Behavior by White Light Interferometry

4.1. Set-Up

Following test set-up has been designed in order to examine the process of releasing the sensor element from the grid: The Wafer is clutched between two clamp rings and placed above an ejecting tool. Inside the clamp rings two pins are integrated that allow adjusting the wafer with its flat at the pins. The clamp rings are screwed on four 75 mm long poles that realize the necessary distance between wafer and ejecting tool. The tool is placed on top of three micro meter screws placed above each other allowing a three dimensional movement of the tool. The ejecting tool has a planar surface and a height of 1mm, the same dimensions as used in the simulation. The tool is easily exchangeable, as it is screwed on top of the micrometer screw. The poles are attached onto the base plate, too. The whole set-up, as shown in fig. 4 is placed underneath a white light interferometer to detect the deformation during the releasing process of the sensor element.

The white light interferometry is a contact less optical measurement. It uses interferences of white light, which allows to create a three dimensional picture of a reflecting surface.

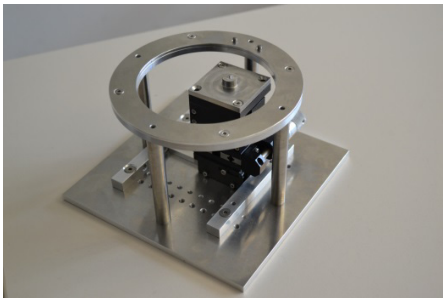
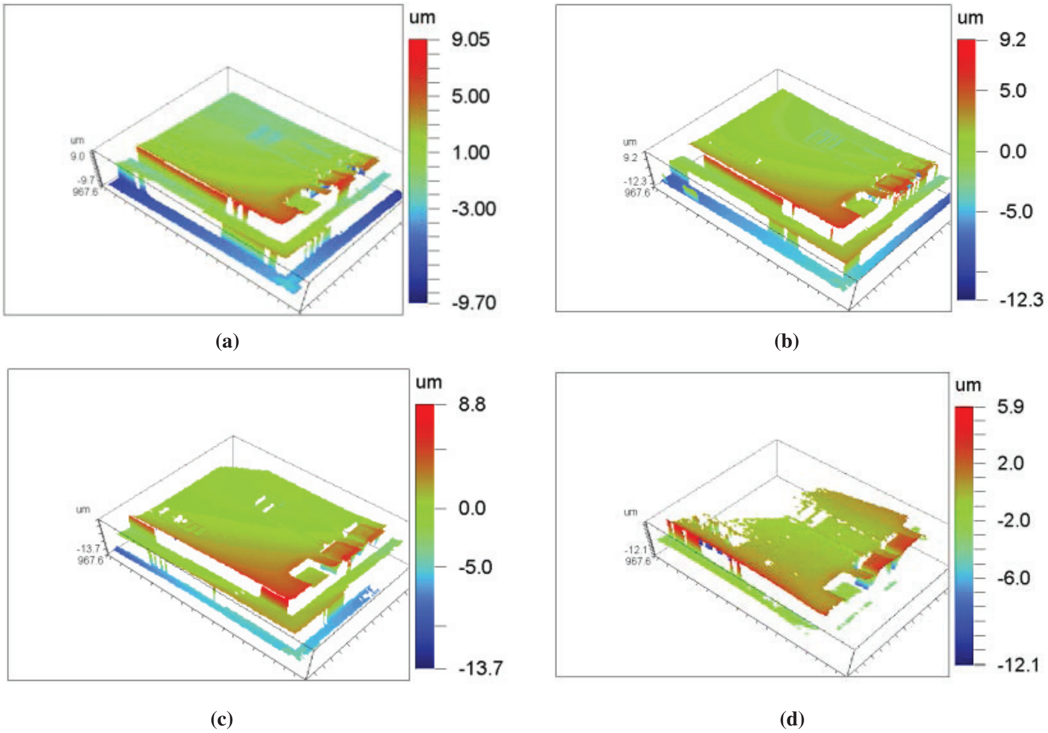


Fig. 4. Set-up for ejecting the membrane from the wafer composite. Here no wafer is included.

4.2. Experimental Procedure and Results

The wafer is fixed inside the set-up, the backside facing towards the tool, the same way as shown in the simulation. The micrometer screws in the direction of x and y-axis enable a precise placement of the tool directly underneath one sensor element. The tool is moved upwards via the micrometer screw in the direction of z until the sensor element has left the focus of the microscope, which is caused by the tool contacting the membrane. The picture is refocused and the measurement starts.



(a) (b) (c) (d)

Fig. 5. Pictures taken with the white light interferometer during the separation process. (a) picture taken after tool contacted membrane und moved upwards for 250 µm. (b) picture taken after tool moved 500 µm (c) picture taken after tool moved 750 µm (d) picture taken after tool moved 1000 µm.

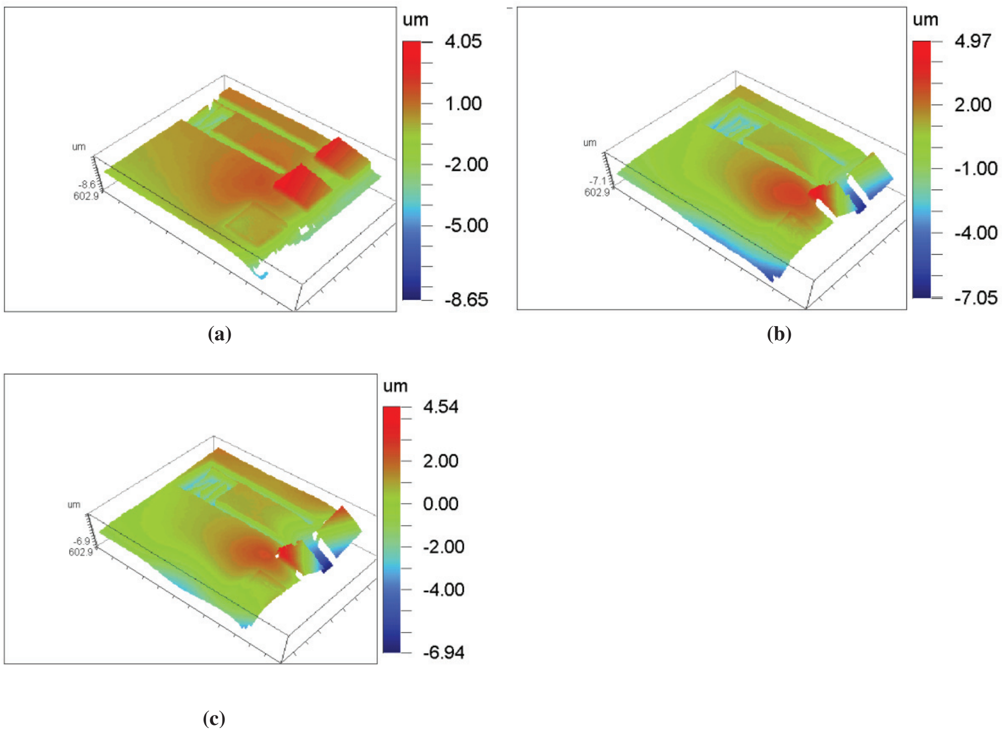
After that a picture is taken every time the tool has been moved upwards for additional 250 µm. The three dimensional pictures in fig.5 illustrate the deformation detected by the white light interferometer. The graphics in fig.5 show three levels. The lowest level shows the silicon grid followed by two polymer membranes above.

The contact pads, feed lines and the meander structure are visualized as well. The white regions between the different height levels are a result of the steep edges that are not reflecting the white light. On the right side of each picture is a color scale. The scale division varies with each picture coloring the lowest point measured in dark blue and the highest point in red.

Although the micrometer screw is moved 250 µm from one picture to another, the membrane itself does not deform strongly. The difference in height, measured from the silicon grid to the top of the upper membrane, rises only 3 µm while the tool is moved 250 µm upwards (picture a to b) and hardly changes after the tool moved 250 µm further (b to c). The forth measurement could not deliver a suitable result anymore. A further movement of the tool of 50 µm disconnects the membrane from the silicon.

The difference between the distance the tool was moved and the elongation of the membrane can be explained by the fact that the wafer is fixed only at the outer circumference and the polymer membrane is strained very firmly. The tool causes an upside movement of the whole wafer during the separation process. A wave shaped deformation as shown in the simulation could not be proofed by this measurement.

The aim of the experiment is to realize the simulated conditions as exact as possible. That is why firstly the wafer was placed above the stamping tool with the backside facing towards the tool.



(a) **(b)**

(c)

Fig. 6. Pictures taken with the white light interferometer during the separation process. The wafer's front side faces towards the tool. (a) picture taken after tool contacted membrane. (b) picture taken after tool moved 250 µm (c) picture taken after tool moved 500 µm

However this leads to a strong upwards movement of the whole wafer during the separation process, which does not match with the assumption made in the simulation, that the wafer grid is fixed. Therefore we repeated the measurement with the wafer's front side facing towards the tool. The results are shown in fig. 6.

The pictures in fig. 6 do not show both polymer layers, because it shows the sensor element from the back side. In fig. 6a the tool has contacted the polymer layer only. When the tool is moving upwards for 250 µm (picture b) and further 250 µm (picture c) the main deformation takes place above the inner contact pad, as it had been expected from the simulations' results. A further movement of the tool of 60 µm releases the polymer from the wafer grid. It can be seen that the release of the sensor element takes place much earlier when the tool contacts the sensor element from the other side.

As a final experimental result fig. 7 shows a picture taken by a light microscope showing a cutout of the remaining grid, after the microsystems have been removed in the above describes way. It could be observed regularly that the polymer substrate cracks preferential above the contact pads. This is the area where most of the strain occurs according to the simulation and the measurements made with the white light interferometer.

Fig. 7. Remaining silicon grid after the microsystems has been released.

5. Summary and discussion

Fabricating a sensor onto thin and flexible substrates means higher deformation of the microsystem during the separation process as on a solid substrate like silicon, in case the sensor is separated by stamping rather than by cutting. The way of how this particular AMR sensor and the polymer which is carrying it are deformed could be shown via simulation as well as experimental results. Both simulation and measurements with the white light interferometer have shown an increased strain of the microsystem near the contact pads. In order to adapt the conditions for the simulation and the experiments even further, the experimental set-up should change the way of how to fix the wafer. The current set-up provides a fixation of the wafer only at its outer are whereas the simulation calculates with a completely fixed silicon grid. It would be possible to replace the outer clamp ring with a solid piece with only one small opening of several square millimeters. In that way the whole silicon grid would be fixed better and an upside movement of the complete wafer as it occurred during the here made separation process would be avoided.

An important conclusion that can be drawn from the results is that no critical deformation of the meander layer takes place by the chosen separation process. This is important to know as any damages in the meander layer would hinder the measurement. In order to measure the magnetic field, the change in the meander's resistance is determined. Structural changes could falsify the results.

Anyway the major strain occurs in the polymer near the area where the contact pads are embedded that can cause the polymer to crack in exact that place. Due to this disadvantage it must be said, that these results show that the current way of releasing the microsystem has to be improved before if it can be transferred into an industrial application. Changes in the tool's geometry and material could be the next investigation. It would be interesting to know how the polymer behaves when the stamping tool' material becomes softer for example. A change in geometry could change the separation process perhaps, if the tool's tip is no longer formed planar but has an inclined profile. In that way the polymer would be rather cut out of the grid than pushed.

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