Patterning and trimming of thin film strain sensors

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Abstract

Thin film strain sensors are capable of sensing mechanical loads in hostile environments and exhibit large longevity. Laser patterning is a promising approach to overcome existing restriction to 2-D surfaces due to existing manufacturing technologies. In order to fulfil the demand for a cost-efficient manufacturing process, a high throughput is required. At the same time, a high accuracy is required to realize a good signal/noise ratio by interconnection to a Wheatstone bridge. In a typical application the deviation of electric resistance values within a Wheatstone bridge should be better than 0.1 %. This demand is satisfied through a two step process with the processing steps: laser patterning of the sensor layout and equalisation of the electric resitance value through a trimming process. We found an inverse proportional dependency between conductor width and deviation of resistance values within a sensor bridge after laser patterning. The resistor deviation could be decreased up to a factor of 15 by a subsequent trimming procedure. Laser patterning and trimming can be accomplished with the same machining setup. Thus, laser processing is a promising approach for manufacturing of thin film strain sensors on component surfaces with high throughput and a small number of processing steps.

1 Introduction

Metal thin-film strain sensors fulfil longevity and are suitable for monitoring of mechanical loads over the entire lifetime of a component even in harsh environments and at elevated temperatures [1, 2]. They consist of an isolation film (e.g. 5 µm SiO_2) and a sensing film (e.g. 150 nm Nickel/Chromium) which are sputter-deposited directly onto the component’s surface. The sensing film is typically patterned by photolithography in order to realize the sensor geometry. Upon a mechanical load the sensor is strained and its resistance changes due to geometric changes and piezoresistive effects. In order to realize a better signal/noise ratio, single sensor elements are interconnected to measuring circuits, such as a Wheatstone bridge. This requires a tolerance of the resistance of typically better than 0.1%. A trimming procedure is executed after sensor patterning in order to fulfil these tolerance demands.

Laser patterning was identified to be a promising approach to overcome the limitations of photolithographic patterning (no 3-D surfaces and no small batch sizes) by reducing the complexity of the process chain to a 3-D capable direct write process with high throughput [3]. The use of picosecond laser pulses ensures a selective patterning process without damage of the isolation layer below the sensing layer [5]. Due to the short pulse duration, the thermo-mechanical properties of the sensing film are not significantly altered through patterning [4].

2 Experimental

A laser source (Lumera Rapid) emitting pulses with a duration of 15 ps was used for the patterning process. The spot diameter ($1/e^2$) was chosen to be 25 µm. Beam deflection was realised using a galvanometer scanner.

In a first set of experiments the deviation of the resistance dependent on the conductor width was determined. For that purpose, sensor patterns with conductor widths ranging from 13 µm to 73 µm were patterned on a thin film system consisting of approximately 200 nm NiCr(80/20) on an Al_2O_3 layer with a thickness of approximately 10 µm. The coefficient of variation of the resistance values was determined to quantify the deviation of the resistance.

In a second set of experiments, the reproducibility of a trimming process was caracterized. For that purpose, a sensor design which enables trimming through increase of the total sensor length was patterned. The increase of the resistance as a function of the trimming length was analysed.

2 Results & Discussion

2.1 Deviation of the resistance

The variation coefficient decreases with increasing conductor width (Figure 1). This behaviour results from positioning errors of the used machining setup. The variation coefficient is in all cases larger than required for interconnection to a full bridge (0.1%). Consequently, a trimming procedure is required.

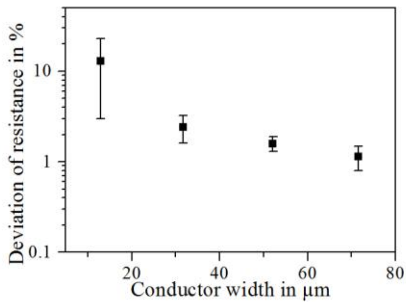

Figure 1: Relative deviation of resistance

2.2 Reproducability of the trimming process

In order to equalise the resistance values within a sensor bridge, the design of the resistors must include an area for trimming. A sensor design, which allows for the increase of the conductor length by iterative laser ablation of small elements was developed (Figure 2). Two trimming sections can be identified: (i) increasing the effective conductor length the same amount as the trimming section (blue area in Figure 2) and (ii) increasing the effective conductor length two times the length of the trimming section (orange area in Figure 2).

The reproducibility of the trimming process was tested by determination of linear fitting functions of the two trimming sections and comparison of maximum difference between fit-function and experimental data (Figure 2). The deviation can be decreased by a factor of at least 15 with one trimming step. Consequently, the limit of 0.1% deviation for interconnection can be reached by one or two trimming steps for conductor widths of 31 µm and larger. The trimming process itself requires only a fraction of the total patterning time.

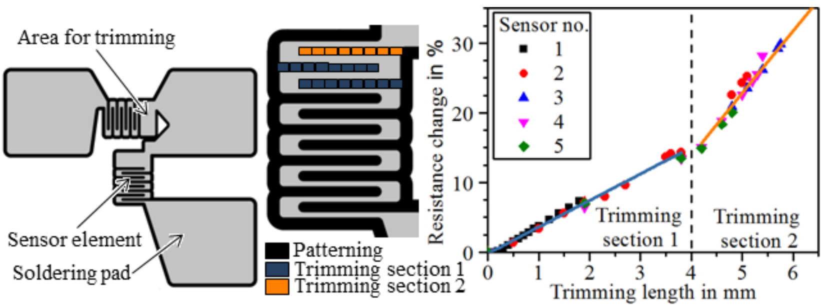

Figure 2: Layout for trimming procedure

3 Conclusion

Thin film strain sensors were patterned by laser ablation. The manufacturing tolerance of laser patterned strain sensors was characterized. It was found that the tolerance of 0.1% for interconnection to a Wheatstone bridge can be achieved by one or two laser trimming steps. Contrary to conventional patterning techniques, such as photolithography, patterning and trimming can be performed with the same machining setup. Therefore, laser patterning promises to be a simple and flexible manufacturing tool for patterning of thin film sensors, e.g. on component surfaces for automotive or medical applications.

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