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Fully Screen-printed Highly Sensitive Strain Gauge with Low TCR

Mani Teja Vijjapu[1], *Manoj Jose*[1], *Jürgen Kosel*[1]
[1]*Sensor Systems Division, Silicon Austria Labs GmbH, Europastraße 12, Villach, 9524 Austria*

Correspondence: mani.vijjapu@silicon-austria.com

Abstract:

Strain gauges are essential in various industrial applications. Commercial strain gauges are developed using Constantan and Karma alloys due to their low temperature sensitivity. Creating alloy inks for printing poses challenges due to high sintering temperatures. Consequently, printed strain gauges (PSGs) are typically made using inks based on silver and carbon. However, the temperature coefficient of resistance (TCR) of these inks is high. In this work, a unique composite was developed using screen-printable ink with silver-coated glass (AgG) particles. The objective of this composite formulation was to increase strain sensitivity while reducing the temperature dependence of the printed strain gauges. The PSGs made with the composite showed a greater gauge factor of 60. Comprehensive characterization of the PSG, including environmental testing, cyclic strain performance, and dynamic strain responsivity, demonstrates the effectiveness and reliability of the developed composite.

Keywords: Printed Strain Gauges, Wearable Technologies, High gauge factor, Composite inks, Printed sensors

Introduction

Strain gauges (SGs) are sensors that convert compressive or tensile strains into electrical signals, usually in the form of variations in capacitance or resistance.[1] They are used where there is need of accurate assessment of force, strain, and torque in mechanically stressed components and in the diagnosis of structural damage.[2] Owing to structural simplicity and ease of electronic reading, resistive SGs are most commonly employed in industrial applications.

The sensitivity of resistive strain gauges is termed as the gauge factor (GF), which is defined as the relative change in the resistance of the strain gauge due to the applied mechanical strain. The gauge factor of commercial strain gauges made of alloys is typically around 2. However, such strain gauges are not suitable for wearable devices, where a high gauge factor and mechanical working range are needed. For instance, detecting human respiration rate requires extremely sensitive strain sensors,[3] and monitoring joint movements necessitates high stretchability.[4] Flexible and Printed technologies can be leveraged to meet the demands of such applications.

PSGs reported are dominantly employed Silver,[5] carbon[6], [7] or Silver/carbon composites,[8] which are susceptible to temperature variations that affect the accuracy of detecting mechanical deformations. Therefore, there is a critical need for PSGs that demonstrate reduced temperature dependence. In pursuit of this objective, a novel composite was developed, comprising a screen-printable non-conductive paste with a polyurethane (PU) matrix blended with AgG microparticles as conductive filler. As anticipated, PSGs made with this composite demonstrated minimal temperature dependence and high gauge factors.

Materials and methods

Tubicoat was utilized as the screen-printable paste. eConduct Glass 352000 – AgG served as the conductive filler. These two components were mixed at a ratio of 1:5 (Wt:Wt) in a speed mixer. The resulting paste, termed PU composite, was then used to print resistive PSGs, as depicted in Fig. 1a. Fig. 1b shows the PSG printed with the PU composite. Mechanical characterization of the PSG was conducted by adhering it to a dog-bone structure using a push-pull tester Zwick Roell, as shown in Fig. 1c. Fig. 1d demonstrates the flexibility of the PSG, and

the microscopic image in Fig. 1e illustrates the AgG particles embedded in the PU matrix.

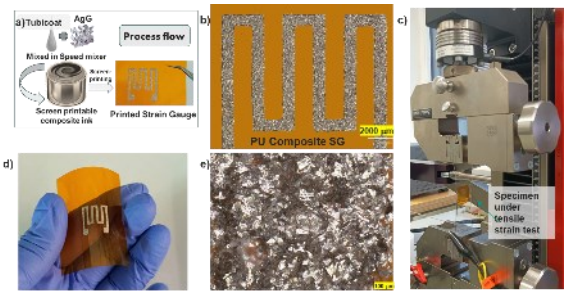

Fig. 1 (a) Printing of resistive PSGs using PU composite paste. (b) Printed PSG with PU composite. (c) Mechanical characterization setup with push-pull tester Zwick Roell. (d) Flexible PSG. (e) Microscopic image showing AgG particles embedded in PU matrix.

Results

The PSGs were tested to assess the thermal dependence in an environmental chamber. The sensor's thermal responsivity is < 0.5% per 10°C increase in temperature, as depicted in Fig. 2a. Compared to printed carbon-based temperature sensors,[9] the PSG exhibits significantly lower temperature dependence. This is attributed to the presence of glass as the core material for the conductive particle, which has a lower thermal expansion coefficient. As a result, there is no physical elongation in the PU composite-based printed trace, unlike nanoparticle inks with the binding matrix, where the interparticle distance increases due to thermal expansion, leading to higher variation.

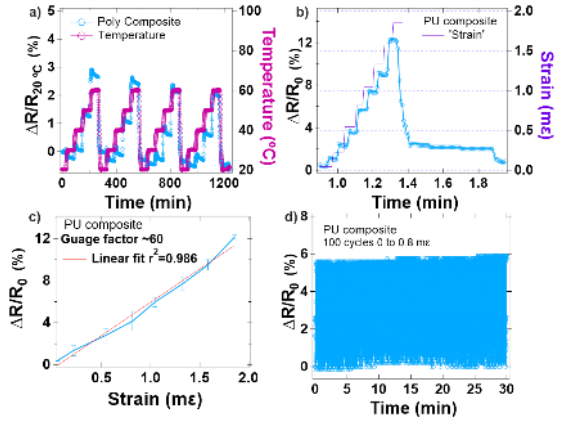

Fig. 2 Performance assessment of PSGs, showcasing temperature response, strain sensitivity, linearity, and repeatability.

Furthermore, the PSGs underwent testing by applying tensile strain up to 0.16%. The response of the PSG is depicted in Fig. 2b, and from the calibration plot (Fig. 2c), it is evident that the response is linear. The gauge factor is estimated to be around 60. The PSGs have demonstrated great repeatability when subjected to multiple stress cycles, as depicted in Fig. 2d. The conduction mechanism in these composite-based conductive traces is predominantly due to the tunneling, where electrons hop from particle to particle. When the interparticle distance increases due to the applied strain, the probability of hopping decreases, resulting in an increase in resistance. Such a high gauge factor is feasible due to this variation in interparticle distance between conductive particles.

In summary, the demonstrated PSGs exhibit significant potential for use across a range of applications, from structural monitoring to wearable technologies.

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