Project 1 – Piezoresistive effects in nanocrystalline carbonic films and their application as foil strain gauges (PIEZOCARB)

Stage IV-1: Functional laboratory testing in accordance with the requirements of industrial applications.

For this phase of the project, a direct comparison was accomplished between commercial foil strain gauges, which utilize a metallic thin film for piezoresistive sensing, and in-house build strain gauges based on a nanocrystalline graphite (NCG) film as the piezoresistive element.

For this purpose, linear foil strain gauges developed by Hottinger Baldwin Messtechnik GmbH were purchased. The configuration of the respective sensors (series Y, model LY1) is schematically represented in Figure 1. The piezoresistive metallic film consists of a 5 µm thick constantan (copper–nickel alloy) film, which is patterned on a 50 µm thick polyimide foil.

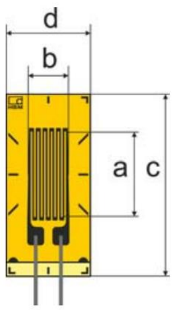

Figure 1: HBM linear foil strain gauge, series Y, model LY1

The LY1 foil strain gauges were glued with epoxy resin onto 125 µm thick Kapton foils of 6 cm in length and subjected to elongation tests along the *c* axis (Figure 1) with the MultiTest 2.5-i (Mecmesin, UK) equipment. The samples underwent an initial 200 elongation-relaxation cycles, after which the electrical resistance was measured during one cycle, over an elongation distance of 0.5 mm. The gauge factor (GF), which is the proportionality factor between the relative variation of the electrical resistance $\left(\frac{\Delta R}{R_0}\right)$ and the relative applied mechanical strain $\left(\varepsilon = \frac{\Delta l}{l_0}\right)$, was then computed according to Equation 1:

$$GF = \frac{\frac{\Delta R}{R_0}}{\varepsilon} = \frac{R - R_0}{R_0} \cdot \frac{l_0}{l - l_0}, \quad (1)$$

where R is the electrical resistance measured at an elongated length l, R_0 is the electrical resistance in the relaxed state $(l = l_0)$ and l_0 is the length in the relaxed state. Figure 2 shows the electrical resistance's variation with respect to the mechanical elongation, the calculated gauge factor being GF = 0.76.

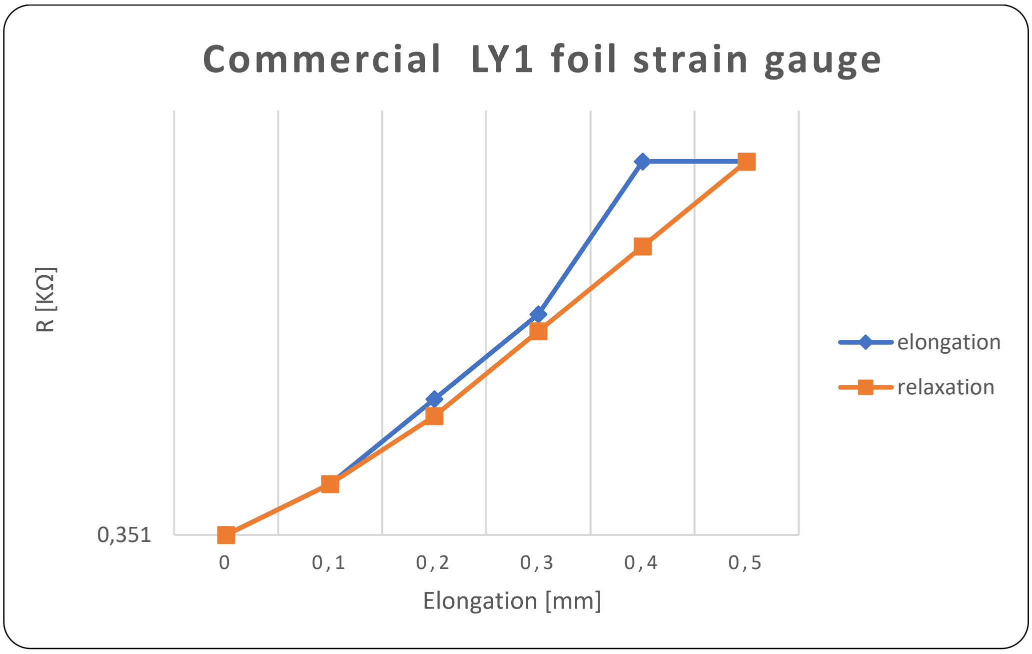

Figure 2: Electrical resistance as a function of mechanical elongation. Calculated gauge factor is GF = 0.76

For the functionality testing of the NCG thin films as piezoresistive elements, foil strain gauges were fabricated according to the technological workflow presented in report no. 3:

- NCG thin films were synthesized at approx. 900 °C on 35 µm thick copper (Cu) foils;
- NCG / Cu samples of an area of 1 cm x 2 cm were glued on a 125 µm thick Kapton foil of 6 cm in length with epoxy resin;
- The central area of the Cu foil was etched in iron trichloride ($FeCl_3$), while its extremities were masked to be later used as electrical contact pads.

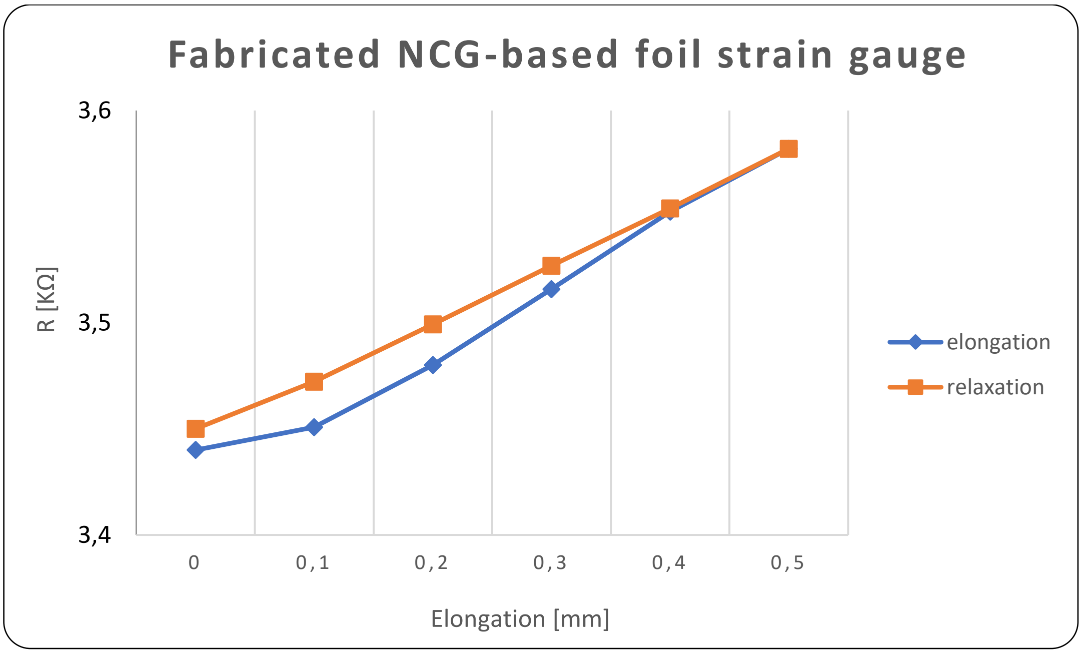

Figure 4: Electrical resistance as a function of mechanical elongation. Calculated gauge factor is GF = 4.13

There is a certain inconsistency observed for the measurements on the five fabricated foil strain gauges: the initial electrical resistance varied from 1.5 kΩ to 3.5 kΩ and the GF varied from 4 to 7 between the individual foil strain gauges. The respective variation between the different fabricated samples can be caused by multiple factors that may rely both on the fabrication process and on the NCG storage conditions. Also, it must be specified that during the development of the aforementioned samples, they were not encapsulated, thus making the NCG films susceptible to humidity which can directly influence the electrical resistance and implicitly the gauge factor.