3D characterization of printed structures by stylus- and optical-based measurements

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3D characterization of printed structures by stylus- and optical-based measurements

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Abstract

Highly-parallel manufacturing is as revolutionary method for large area devices production with sub-micrometre scale features and/or structured surfaces. Nowadays, many devices are available by these fabrication processes, with the subsequent need to improve either in-line and off-line sampling-based controls. Among others, morphological characterizations and resistance measurements are often used for quality control of printed conductors, which features are simple lines or more complex structures. This study, performed on printed linear conductors deposited on flexible plastic sheets made by roll-to-roll process, exploit stylus and optical profilometers for the 3D surface characterization. A more accurate 3D reconstruction of the surface morphology was achieved by the stylus profiler; starting from these topographical measurements, the calculated resistance of selected lines has been compared to resistance measurements by electrical setup. In this work, morphology and roughness parameters of surfaces are characterized using specialized software tools (Mountains Map and SPIP). Resistance measurements are performed with the aim of identifying correlation between critical sizes/forms and functional features. A good repeatability of parameters together with some drawbacks and limitations due to probe size, shape, type of substrate and sampling time are highligthed. An uncertainty budget is estimated for each of the critical sizes and functional feature of the sample structures under test. Meanwhile, the development of application-oriented material measures to support traceability of quantitative measurements of function-correlated parameters is discussed.

3D characterization, surface topography, resistance measurement, morphology-derived line resistance

1. Introduction

Highly parallel manufacturing methods consist of the rapid production of devices on large surfaces (~ m^2) with high feature resolutions (~ µm) [1]. Rotary screen printing, which is a roll-to-roll process, is part of these techniques and allow to print conductor test patterns onto PET plastic sheets [2]. In the way to see if the samples are well printed, 3D line morphology is reconstructed and compared using by contact and non-contact methods. Finally, resistance measurements performed on the lines are compared with calculated resistance from 3D reconstruction.

2. Topographical measurement

2.1 Optical-based measurement

The instrument in use at INRIM is a Sensofar PLµ 2300 optical imaging profilometer operating in phase-shifting and vertical scanning interferometry, and intensity confocal modes.The sheet analysed is set on a sample holder making use of a vacuum chuck to clamp the substrate. The lines printed on plastic sheets [2] are imaged in confocal mode with an objective 50x. The lines are imaged at different positions and for different lengths. Figure 1 shows a line imaged with an evaluation length of one millimeter. Due to the transparent sheet, only the line itself is imaged, while the void pixels are either from the sheet or some empty local areas of the line.

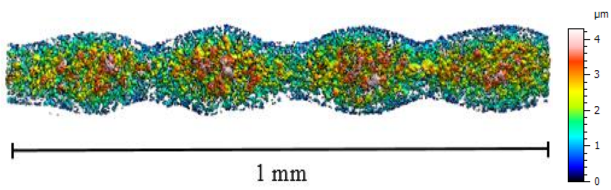

Figure 1. 3D top view of a line as reconstructed by confocal imaging. The void (not measured) pixels from the surface of the transparent sheet and partly from the line are white.

2.2 Stylus-based measurement

The stylus profilometer (Talysurf 2 by Taylor-Hobson) makes use of a 2.5 µm nominal radius tip driven along the x-axis, and a treadmill moving on the y-axis for 3D profiling. The tip draws parallel lines of 6 µm apart in the y-axis. Each line counts 4 000 points in the x-axis. The line to be measured is fixed on a flat surface surface and imaged at different positions. Figure 2 shows a line imaged on an evaluation length of one millimeter.

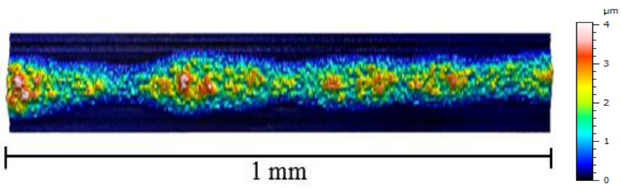

Figure 2. 3D top view of a printed line as reconstructed by stylus profiling.

3. Resistance

3.1 Measurement

The resistance of printed lines was measured by means of a four-wire like setup, which makes use of a moving contact electrode based on a home-modified stylus pick-up. In such a way, the moving electrode approaches the line surface and then moves along the line oriented along the x-axis by the profilometer itself. As shown in Figure 3, a reference electrode tip is placed at one extremity of the line to be measured, while the moving electrode is driven step by step over a given evaluation length. At each step, the value of the resistance is recorded. Data are then analyzed by a linear fit of resistance *vs.* length.

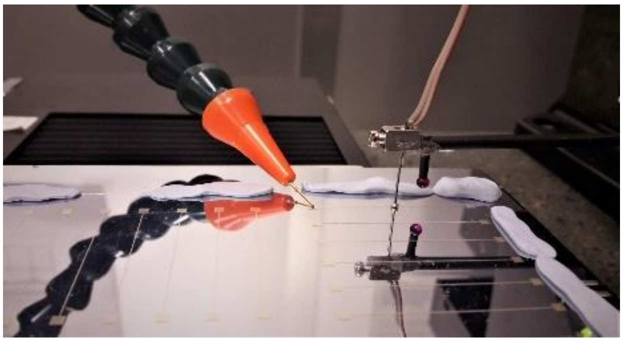

Figure 3. The reference (fixed) electrode (left) and the moving electrode (right).

3.2 Calculation

3D images of the printed lines taken by stylus profiling have been analysed by specialized software tools [3,4] to determine critical sizes of the line cross-section. These are calculated at each longitudinal pixel of its 3D reconstructed topography. As represented in Figure 4, a trapezoidal shape of the line cross-section is assumed [5], by which the cross-section area A is given by the equation (1), where W_f is the base width, t_f is the height and α is the sidewall angle to the horizontal.

$$A = \left(W_f - \frac{t_f}{tg\alpha}\right) t_f \qquad (1)$$

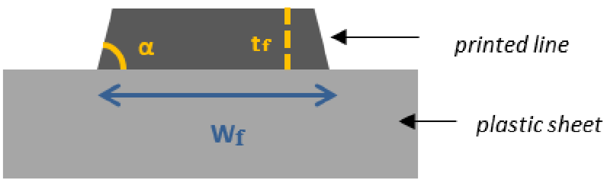

Figure 4. Parameters of the trapezoidal shape of the printed line cross-section, where W_f is the base width, t_f is the height and α is the sidewall angle.

By means of a SPIP tool [4], the number of measured lines, the thickness, the upper width, the lower width, the left slope and the right slope of the one millimeter line cross-section, are calculated. The line resistance can be calculated from the sum of the resistances R_i of the elementary line length dl reported in equation (2), where A_i is the local cross-section area and ρ_f is the given resistivity [2].

$$R_i = \frac{\rho_f}{A_i} \cdot dl \qquad (2)$$

4. Results

Table 1. Comparison between the measured and the calculated resistance of three lines/sheets having different values of resistivity and for 1 mm long measured line.

Line	X	Y	Z
mean width [µm]	1 020	440	160
mean thickness [µm]	9.9	3.6	2.2
mean cross-section area [µm^2]	9 400	1 500	320
relative expanded uncertainty [µm^2]	10 %	30 %	36 %
resistivity [Ω · cm]	$5.5 \cdot 10^{-5}$	$3.9 \cdot 10^{-5}$	$4.1 \cdot 10^{-5}$
calculated resistance [Ω]	0.058	0.265	1.345
relative expanded uncertainty [Ω]	10 %	30 %	36 %
measured resistance [Ω]	0.051	0.214	1.568
relative expanded uncertainty [Ω]	6 %	2 %	4 %

The relevant component of uncertainty is that from the line thickness for the cross-section area, the uncertainty of this last for the calculated resistance, and the repeatability of measurements including probing effects for the measured resistance.

5. Conclusion

3D reconstruction of the morphology of printed line conductors (PLCs) on plastic sheets has been performed with both contact and non-contact methods, *i.e.*, by optical and stylus-based profilers. The stylus tactile method is preferred to the optical confocal measurement, because this latter suffer from high amount of void pixels and does not allow to get a good 3D reconstruction. The pick-up of the stylus profiler has been modified with an electrode probe to directly measure the resistance of the line, which is then compared to the resistance calculated by the reconstructed topography. The larger the resistance the lower the resistance uncertainty. However this statement could be disputed because of the defected lines.

Assuming a trapezoidal shape of the line cross-section seems a good approach to calculate the resistance. Indeed, the results by the measured resistance and the calculated one are really similar. Well-characterized printed lines on plastic sheets may represent application-oriented material measures suitable to support traceability of quantitative measurements of function-correlated parameters and thus allow quality control.

Stylus profiling may be arranged to perform either morphology and line resistance measurements, nevertheless, it is time consuming and tactile effects may occur with a not so hard material, bringing minor surface damages.

Acknowledgments

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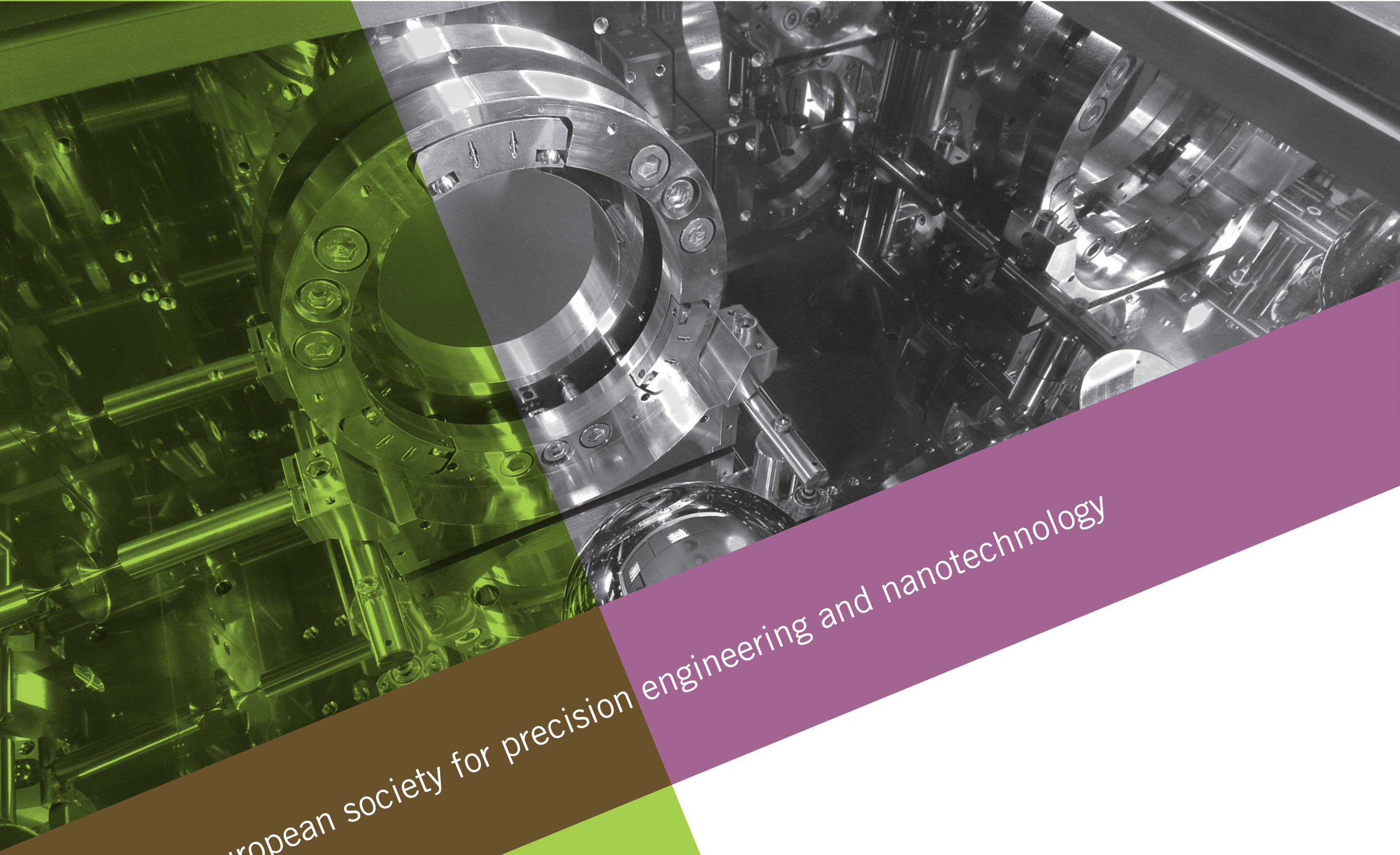

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