Optical Temperature Detection, Utilizing Screen-Printed Thermochromic Inks

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INTRODUCTION

Printed electronics is a rapidly growing field, that has recently attracted great interest from both research and industry, as it offers the possibility of manufacturing cost-effective innovative devices on flexible substrates.

Thermochromic inks (TCs), belong to the category of chromogenics and exhibit reversible or irreversible alterations in colour, when exposed to temperature variations.

MATERIALS

In this work, the thermal and optical behaviour of two TC screenprint samples, printed on **PET (Polyethylene Terephthalate/PET, thickness 125μm, Goodfellow) and Polyimide (PI) (Kapton® HN Film, thickness 125μm, Goodfellow)** substrates, is studied**.**

The inks employed, are the **Thermochromic Screen Printing Ink Black 47 °C by SFXC and the water based HPR-059 Carbon Black (Carbon content 10 wt%)**, serving as the heater for the temperature control of the TC element.

The samples were fabricated via the **semi-automatic screen-printing machine (Ever-bright, S-200HFC)** and subsequently cured via the **Heating & Dry Heat Sterilization Oven (NUVE FN400).**

The element's dimensions are 32×3mm and 17.5×13mm for carbon and TC, respectively **(Fig. 1a,Fig. 1b)**.

Figure 1: Internal Heating at 60 °C of the Black TC samples with 47 °C critical temperature on **a)** PET substrate, **b)** Polyimide substrate.

METHODS

The main objective of this study is to establish a correlation between the thermal and optical fields of the TC samples. To conduct the analysis, controlled heating was applied through the carbon element of each sample, via the probe station.

Two distinct scenarios were applied:
1. A **wide temperature range** (50 – 70 °C)
2. A **narrow temperature range** close to the critical temperature(40 – 52 °C).

The correlation between the thermal and optical field was established through a High precision Thermal IR Camera - FLIR SC655 and a high resolution camera, respectively.

Thermal data processing was conducted via FLIR SC655 software, which correlates the temperature with the pixels in the selected area of interest in each TC sample.

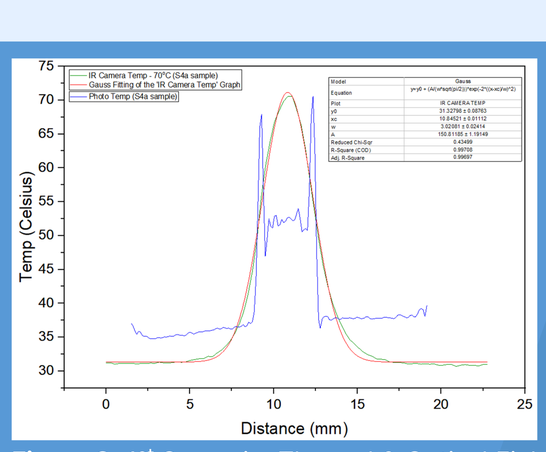
The ImageJ software was employed to extract the grayscale data from the images captured by a high-resolution camera, focusing on the same area of interest on each TC sample.

In the resulting graphs, the temperature distribution across the selected width area of the Thermochromic (TC) element, derived from both the IR camera and the high-resolution camera, is presented as a function of distance.

RESULTS

In the thermal-optical correlation graphs of the **1st scenario**, the amplitude between the two spikes is attributed to the transparency of the TC element, when exposed to temperatures significantly above its 47 °C critical temperature **(Fig. 2)**. This feature, along with the transparent PET substrate, reveals everything that lies beyond the area of the underlying black carbon material.

In the **2nd scenario**, at 43 °C the Thermochromic (TC) element has initiated its transparent transition **(Fig. 3, Table 1)**.In this scenario, all graphs exhibited a similar pattern **(Fig. 4)**. Further heating of the TC element beyond 52 °C, causes its area of transparency to surpass that of the carbon material beneath it, similarly to the 1st scenario.



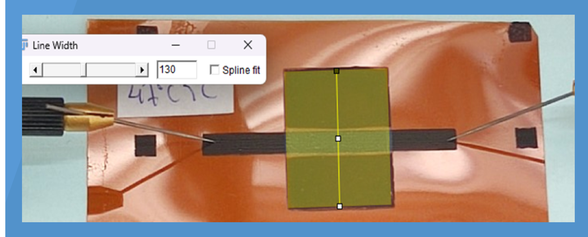
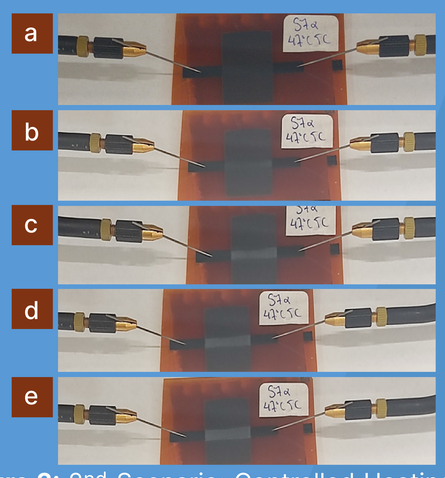


Figure 2: 1st Scenario: Thermal & Optical Field Correlation Graph of the TC sample on Kapton substrate with Gaussian Fittings, for 70 °C heater temperature.



Black TC (47 °C) on Kapton Substrate	
Temperature (°C)	Power (°W)
40	0.219
43	0.294
46	0.384
49	0.451
52	0.522

Table 1: Powers applied to get the desired temperatures of the 2nd Scenario.

Figure 3: 2nd Scenario: Controlled Heating phases: **a)** 40 °C, **b)** 43 °C, **c)** 46 °C, **d)** 49 °C, **e)** 52 °C.

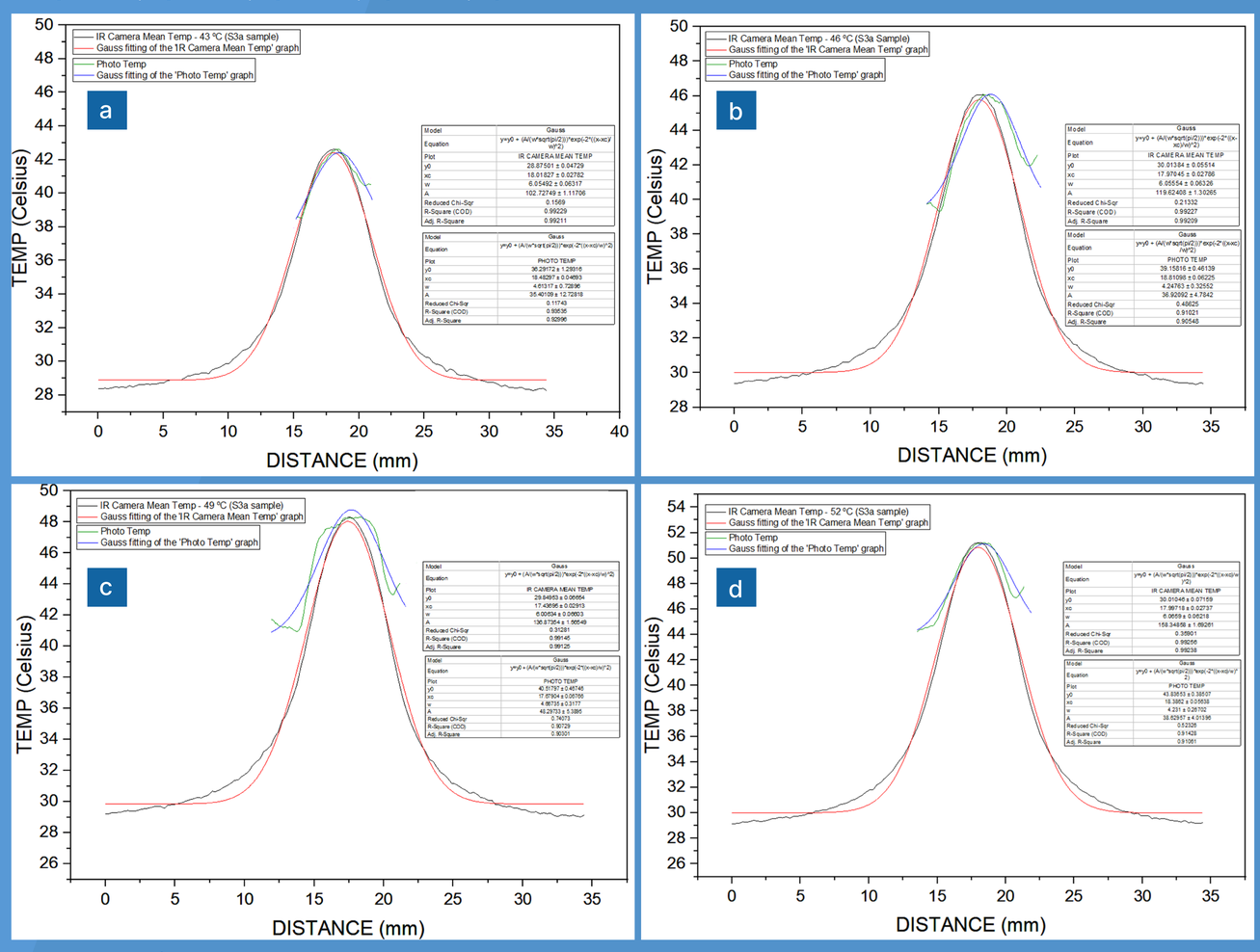


Figure 4: 2nd Scenario: Thermal & Optical Field Correlation Graph of the TC sample on PET substrate with Gaussian Fittings, for **a)** 43 °C, **b)** 46 °C, **c)** 49 °C, **d)** 52 °C heater temperatures.

CONCLUSIONS & FUTURE WORK

- A fully printed optical temperature sensing device, including a carbon ink acting as a heater for the thermochromic sensor was successfully fabricated, via screen-printing technology.
- The temperature field was extracted by an IR camera and was successfully correlated to the corresponding grey-scale pattern of the optical images, acquired by a high-resolution camera .
- This study facilitates the implementation of a surface's thermal mapping, allowing for the identification of the areas that are warmer or cooler than normal.
- Additional measurements could be conducted, regarding the dynamic behaviour of the fabricated samples.
- Use of neural networks to obtain better results under different environmental conditions.