Optical temperature sensing utilizing thermochromic inks – A fully printed approach

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MOTIVATION

Recently, printed electronics technology has generated significant interest in both researchers and industries due to its ability to produce innovative, cost-effective devices on flexible substrates. This work reports on the study of specific thermochromic (TC) inks, which were screen printed on various flexible substrates (PET, and Kapton).
In the context of this project, the possibility of accurately extracting the temperature in a relatively wide field through the optical properties of printed structures was studied.

Temperature sensing has a very wide range of applications; thus, a wide range of temperature sensors have been developed. The most common types of temperature sensing methods are Thermistors, Thermocouples, Semiconductor-Based Sensors etc.

The need for a printed optical flow sensor is defined by its main advantages:

- No need for electronics and input power
- Low cost, high and fast volume production
- Easy integration on various substrates (including curved surfaces),
- Contactless sensing

MATERIALS AND METHODS

A fully printed device was designed and fabricated, that based on a carbon heater. The thermochromic layer was printed on top of the heater, providing the possibility of precise temperature control. The whole structure is entirely made with screen-printed technology and consists of two different ink layers.

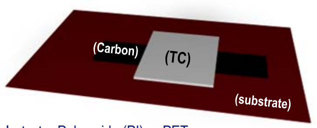
Specifically, the inks that were used in this work are the water based HPR-059 Carbon Black (Carbon content 10 wt%) from Noavacentrix – USA and the water based Thermochromic Screen Printing Ink Black (below 31˚C temp is black and translucent above 31˚C temp) from SFXC (Special FX Creative) - UK.

The devises were implemented on two different substrates, namely Polyamide (PI) film (DuPont Kapton HN, thickness 125μm) and Polyethylene terephthalate film (Polyester, PET, thickness 125μm). All devices were printed using a semi-automatic screen-printing machine (Ever-bright, S-200HFC).

For the thermoelectric characterization, a standard probe-station system was used in combination with a high-precision thermal IR camera (Flir SC655), which was employed to remotely monitor the temperature of the samples and capture thermal photographs.

Initially, the temperature response of the carbon heater was studied, and the induced thermal field was determined as a function of the input applied power. The thermal field was then correlated with the thermochromic ink colour gradations through optical photographs and temperature determination was achieved with a common mobile phone.

To achieve the above-mentioned goal, the processing of the IR photos was implemented with the original FLIR software, while for the optical photos, the ImageJ software (a Java-based image processing program developed at the National Institutes of Health and the Laboratory for Optical and Computational Instrumentation) was used.



Substrate: Polyamide (PI) or PET
Carbon: 1st layer Carbon ink heater (Dimensions: 37.5mm x 8.0mm)
TC: 2nd layer Thermochromic ink (Dimensions: 20.0mm x 15 mm)

Fig. 1 Typical device arrangement.

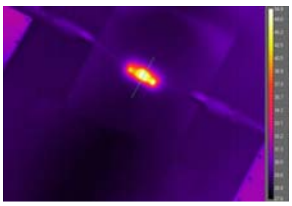


Fig. 2 IR photo with temperature legend.

A correlation of the IR camera photos with the corresponding optical images was performed in order to extract the relation between temperature and differential greyscale levels. As indicated in fig. 2, the temperature distribution in several cross-sectional lines was extracted by the thermal images and a correlation was performed with the corresponding grey-scale distribution that was extracted from the corresponding optical images.

RESULTS

For the thermal characterization of the Carbon heater, two-point probe measurements were implemented, where the same two probes were used for both current application and voltage measurement.
The table and diagram below show the temperature dependence with respect to the input power of a typical device on a Kapton substrate.

Table 1 – Fig.3: Carbon heater temperature dependence with input power

NR	VOLTAGE (Volt)	TEMPERATURE (˚C)	CURRENT (Amperes)	POWER (Watt)
1	0	28.1	0.00000	0.00000
2	5	30.2	0.00111	0.00555
3	8	35.0	0.00178	0.01424
4	10	39.4	0.00223	0.02232
5	12	44.7	0.00268	0.03220
6	14	50.2	0.00313	0.04381
7	16	56.8	0.00357	0.05718
8	17	60.5	0.00380	0.06468

Table 1

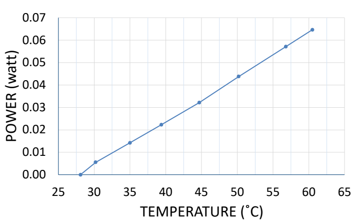


Fig. 3

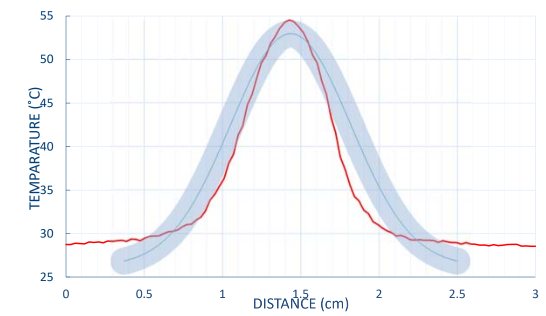


Fig. 4 Correlation between the optical and thermal images (Kapton substrate with 0.054 Watt input power).
The red curve represents the output from the IR camera, while the blue curve represents the mean grey-scale value that was extracted from the optical camera. The shaded area indicates the standard deviation of the grey-scale determination.

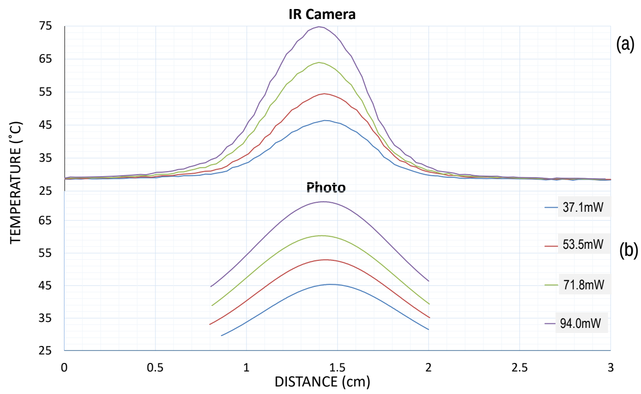


Fig. 5 Comparison of the temperature and grey-scale distribution, as extracted for the thermal (a) and the optical (b) images respectively.

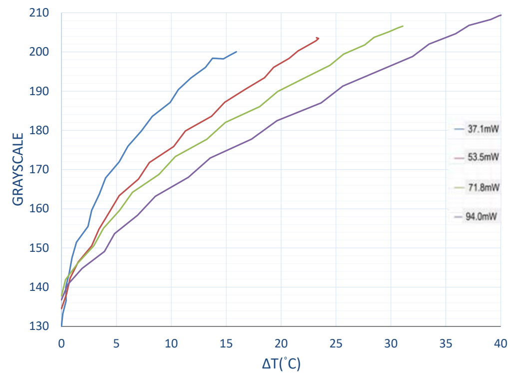


Fig. 6 Diagram T - Gray scale

CONCLUSIONS

The outcomes of this work highlight the potential utilization of TC materials in low-cost and accurate temperature sensing that can be implemented in various applications.

- A fully printed optical temperature sensing device was successfully fabricated and evaluated.
- Two inks were used (carbon ink as a heater and a thermochromic ink as a sensor).
- The temperature field was extracted by an IR camera and successfully correlated to the corresponding optical images, acquired by a regular mobile phone.
- Temperature determination was achieved by using the grey-scale pattern of the optical images.

FUTURE STEPS

- Dynamic measurements in transient flow conditions.
- Use of neural networks to obtain better results under different environmental conditions.