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# Water Transfer Printing of Silver Ink-based Temperature Sensors

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**Summary:**

This paper presents a reliable emerging technology to fabricate lightweight and conformal electronics on 3-D complex shapes and various materials, including everyday life objects. The novel technology consists in screen-printing of silver ink onto water soluble film. Next, a water transfer printing method is used to allow the substrate-free transfer of the screen-printed patterns. This process exhibits electrical functions similar to conventional screen-printing ones, enabling the fabrication of a highly sensitive and reproducible temperature sensors.

**Keywords:** Water Transfer Printing, Screen-printing, Silver Ink, Temperature Sensors.

## Background, Motivation and Objective

The novel form of electronics is marked by the growth of innovative technologies aimed at making electronic more conformal, lightweight, connected and user-friendly, thereby opening up exciting new possibilities and applications in various aspects of everyday life [1], [2]. The main objective is to push back the limits of traditional 2-D electronic design by proposing to integrate electronic devices onto complex 3-D shapes, such as sensors, whose effectiveness is enhanced by bringing them closer to the object being monitored [3].

## Description of the Method

Such an innovative technology is water transfer printing (WTP) [4]. It ensures the free-transfer of a highly sensitive temperature sensors to 3-D materials without any alteration of the device features, opening up many perspectives for the future of 3-D lightweight electronic.

## Results

WTP process is a process commonly used in the industry to apply decorative patterns or designs onto three-dimensional surfaces. It is used since our pioneering work in 2017 [2] to transfer electronics from polyvinyl alcohol (PVA) substrate to arbitrary and daily live objects as shown in Fig.1. Firstly, sensor is screen-printed on PVA, which is then dried and cured to remove solvents and obtain optimum resistivity. Afterward, the PVA is gently deposited at the water surface to be dissolved, allowing electronic patterns to float. At last, a 3-D object is dipped through the floating patterns, resulting electronic active layer fixed conformally to the object surface.

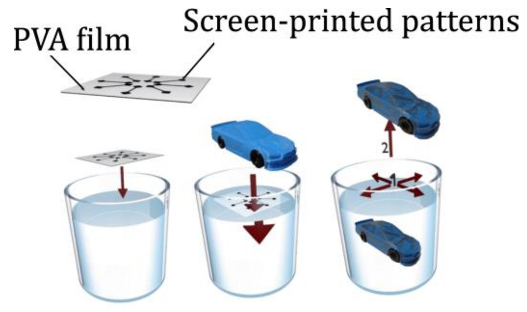


*Fig. 1. WTP Process.*

Our previous works already show the high degree of conformality as the technology is a substrate-free transfer [2], it's also important to note that this method does not affect the electrical performances of sensors as show in Fig.2. Indeed, sensors fabricated by WTP or directly screen printed on PET substrate highlight the same electrical behavior.

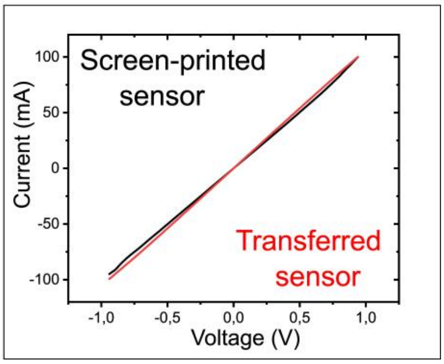


*Fig. 2. I=f(V) characterization of a silver ink-based sensor after and before its transfer using WTP.*

Basically, temperature sensor is an electronic device designed to measure and control the temperature of an object or a system. That's why the closer the sensor is to the object, the more accurate the measurement will be, which is guaranteed by our process. The resistance variation as function of temperature of a transferred silver ink-based temperature sensor is showed in Fig.3 shows. Indeed, the electrical response of the sensor is reproducible over more than four hours cycling.

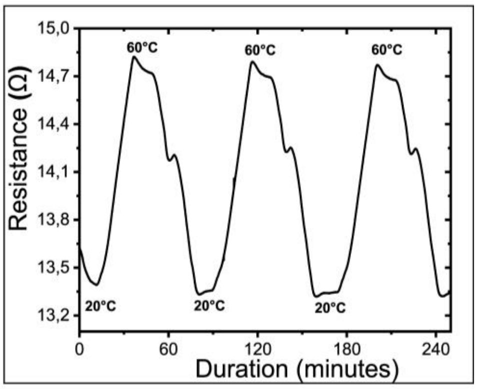


*Fig. 3. Resistance variation as function of temperature of a silver ink-based temperature sensor.*

Observing the graph, it's obvious that the resistance of the sensor decreases as the temperature decreases. This follows the classical behavior of metallic materials. Moreover, transferred silver ink-based sensor shows high sensitivity to temperature with 0.08 Ω/°C and 0.25%/°C. Note that, authors assume that the transferred silver sensors have been compared to screen-printed ones, demonstrating similar behavior, performance, and sensitivity. This is already confirmed by the I-V characterization shown in Fig.2

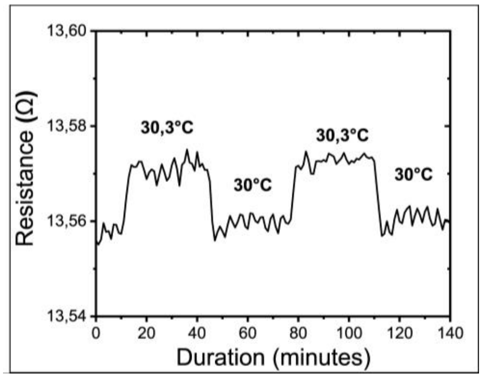


*Fig. 4. Minimal variation of temperature detected by the silver ink-based temperature sensor.*

The Fig.4 shows the smallest temperature variation that transferred sensor can reliably detect and measure without applying any mathematic complex treatment. This result proves the high efficiency and accuracy of the sensor, enabling it to distinguish a minimal temperature change of 0.3°C, despite background noise and fluctuations. Temperature sensors are placed in locations where temperature needs to be monitored, such as industrial environments, air conditioning systems, and medical laboratories.

In these application areas, various levels of humidity are defined, between [40% RH: 60% RH], an environment is considered as optimal, and between [60% RH: 100%RH], it's considered very humid. Fig.5 shows the impact of humidity on the transferred temperature sensor described previously. The result highlights that the sensor is not sensitive to humidity (either for optimal humidity or excessive one), regardless of the temperature value. This is ensuring the normal behaviour and stability of the transferred temperature sensor in all desired installation environments, disregarding humidity effect.

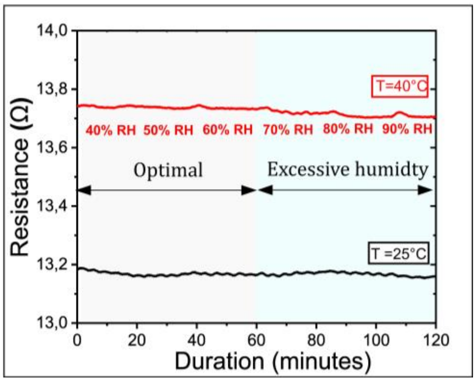


*Fig. 5. Resistance variation of silver ink-based sensor as function of relative humidity ratio (%RH) at 25°C, and 40°C.*

## Conclusion

The WTP process surpasses the limits of traditional electronics manufacturing by enabling the integration of temperature sensors onto all complex objects, regardless of their shapes, while obviously maintaining the same performance as conventional screen-printed sensors.

## References


[1] M. Harnois, F. Garcia-Castro, G. Herry, O. De Sagazan, et F. Le Bihan, « Eco-designed Conformable Inorganic Electronics to Improve the End of Life of Smart Objects: Sensor Processing and Applications », *ACS Appl. Electron. Mater.*, vol. 2, nº 2, p. 563-570, févr. 2020, doi: 10.1021/acsaelm.9b00807.

[2] B. Le Borgne, O. De Sagazan, S. Crand, E. Jacques, et M. Harnois, « Conformal Electronics Wrapped Around Daily Life Objects Using an Original Method: Water Transfer Printing », *ACS Appl. Mater. Interfaces*, vol. 9, nº 35, p. 29424-29429, sept. 2017, doi: 10.1021/acsami.7b07327.

[3] R. Selmi, J.-C. Fustec, M. Harnois, et F. L. Bihan, « Organic and Metallic Sensors on Complex 3-D Object Using an Original Method: Water Transfer Printing », *IEEE Sens. Lett.*, vol. 7, nº 9, p. 1-4, sept. 2023, doi: 10.1109/LSENS.2023.3301845.

[4] Harnois, Maxime, Jacques Emmanuel, and Brice Le Borgne., "Solvent transfer printing method." U.S. Patent No. 11,345,184. 31 May 2022.