

Ultrathin Wearable Thermochromic Tattoo-Based Skin Sensor

Katrin Unger¹, Rudolf Heer¹, Paulina Piller¹
¹ Silicon Austria Labs GmbH, 8010 Graz, Austria
 paulina.piller@silicon-austria.com

Summary:

Continuous, non-invasive skin temperature monitoring is essential for healthcare and sports applications. We present an ultrathin, skin-conformal thermochromic temporary tattoo sensor. Its flexible, permeable structure enables intimate skin contact and high wearing comfort. The sensor, based on tattoo paper functionalized with a leuco-dye layer, exhibits a thickness of $(1.7 \pm 0.2) \mu\text{m}$ and changes color from purple to pink at $(27.2 \pm 0.5) ^\circ\text{C}$, enabling the detection of abnormal skin temperatures associated with impaired perfusion.

Keywords: Ultrathin Temporary Tattoo-Based Sensor, Wearable Thermochromic Sensor, Leuco Dye, Colorimetric Sensing, Skin Temperature Sensing

Background, Motivation and Objective

Human skin serves not only as a protective and sensory organ but also as a crucial interface for thermal exchange with the environment. Spatial variations in skin surface temperature provide valuable diagnostic information for pathological conditions such as vascular disorders, inflammation, and cancer. Infrared thermography is a widely used non-invasive technique for mapping skin temperature. However, it is limited by motion artifacts, sensitivity to measurement geometry, and restricted accuracy in detecting small or localized abnormalities. [1]

To overcome these limitations, alternative approaches based on wearable thin-film sensors have been developed, employing electronic and/or colorimetric readout mechanisms. [2-3] These systems typically consist of flexible substrates combined with thermosensitive materials and must be designed to minimize thermal interference with the skin. Achieving ultrathin architecture is essential to ensure accurate measurements and maintain soft, conformal contact with the epidermis during natural movement. While electronic sensors can reach sub-micron thicknesses, reported colorimetric devices are generally thicker, and ultrathin implementations remain scarce despite their inherent advantages, such as battery-free operation. [4-5]

Temporary tattoo substrates provide a promising platform for transferring ultrathin sensors on the skin. These systems enable intimate skin contact through a simple transfer process and have

already been applied in electrochemical and electrophysiological sensing. [6-7] Building on this concept, they offer significant potential for the development of minimally invasive, conformal skin temperature sensors.

Description of the New System

In this work, a temporary tattoo paper substrate is utilized to realize an ultrathin thermochromic skin sensor with a total thickness below $2 \mu\text{m}$. This represents a significant reduction compared to previously reported colorimetric wearable sensors, which typically exhibit thicknesses in the tens of micrometers to millimeter range. By functionalizing commercially available tattoo paper with a thin layer of thermochromic leuco dye, the presented system constitutes, to the best of our knowledge, the thinnest colorimetric on-skin temperature sensor reported to date.

Leuco dyes exhibit reversible switching between colorless and colored state in response to external stimuli such as temperature, light, or pH. Their thermochromic behavior enables straightforward, power-free temperature sensing and has previously been exploited in wearable systems. However, their implementation in ultrathin, tattoo-based platforms has not yet been demonstrated at this thickness scale. [8]

The proposed approach advances the state of the art by combining sub- $2 \mu\text{m}$ thickness, conformal tattoo transfer, and battery-free colorimetric sensing in a single platform. This enables minimally invasive, highly compliant skin sensors

with reduced thermal interference and improved adaptability to natural skin motion.

Results

A thin leuco dye layer was successfully deposited onto temporary tattoo paper, which appears macroscopically homogeneous and retains full transferability onto skin, enabling reliable transfer and yielding an ultrathin, mechanically compliant system with strong conformity to skin microtopography (Figure 1).

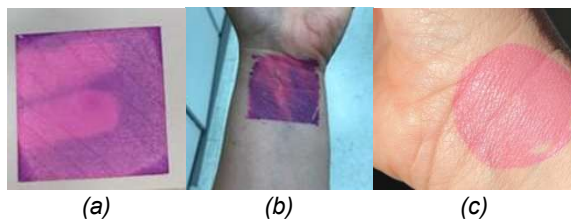


Fig. 1. (a) As-prepared tattoo sensor showing a localized area of temperature change upon exposure to a fingertip. (b) Applied tattoo sensor on a cooled arm, showing localized color change induced by underlying arterial heating. (c) Tattoo sensor applied conformally on skin.

Thickness analysis via optical and laser confocal microscopy reveals a transfer layer thickness of (610 ± 50) nm and a total sensor thickness of (1.7 ± 0.2) μ m. This is significantly thinner than previously reported colorimetric skin sensors (~ 40 μ m [5]), representing an approximate 20-fold reduction and enabling improved skin conformity and reduced thermal interference.

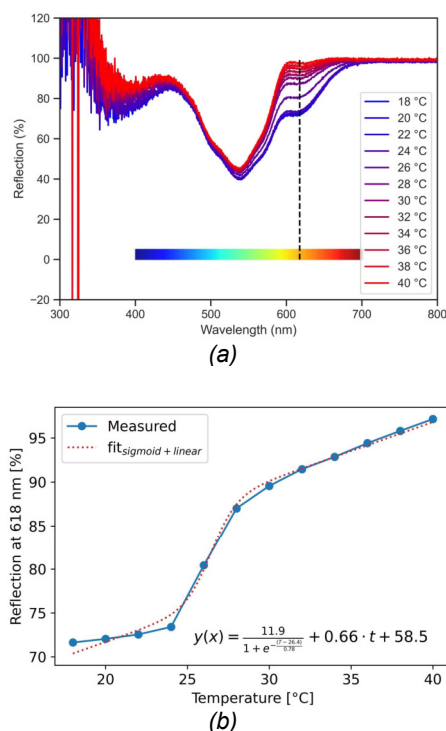


Fig. 2. (a) Reflection spectra of the sensor at temperatures between 18 – 40 °C. (b) Reflection at 618 nm of the sensor in relation to the temperature.

Optical measurements show temperature-dependent changes between 18 – 40 °C, with a characteristic decrease in absorption at 618 nm upon heating (Figure 2a). The reflectivity at this wavelength increases from 64 % to 87 %, following a sigmoidal trend corresponding to the thermochromic transition of the leuco dye. A transition temperature of $T_c = (26.4 \pm 0.3)$ °C is determined (Figure 2b).

The sensor exhibits a fully reversible thermochromic response over multiple temperature cycles, changing from purple to pink upon heating above the defined transition temperature, confirming the switching behavior of the leuco dye. This stable and repeatable performance demonstrates the feasibility of an ultrathin, conformal, and reliable colorimetric skin temperature sensor based on temporary tattoo substrates for non-invasive, real-time skin temperature monitoring and related thermally responsive applications.

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