Wireless graphene-enabled wearable temperature sensor

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Abstract. E-textile is an emerging technology which takes the advantages of material science, electronic engineering and wireless communications. We present a pilot study on smart textile system. Our study aims at developing a graphene temperature sensor and its interfacing with a commercial wireless sensor node providing the graphene sensor with processing and wireless communication capabilities. Flexible planar structure sensor was fabricated using CVD-processed single-layer graphene following its transfer to the polyvinyl chloride substrate by hot lamination method. For calibrating the graphene temperature sensor we connect it in series with a calibrated resistor and to the calibrated power source (battery). Afterwards we measure the sensor resistance via the analogue-to-digital converter of wireless sensor node, process the data and send it to the user over wireless channel.

1. Introduction

Temperature is an alarm physical parameter [1] of the human body that plays a key informative role in the diagnosis and monitoring of the health condition [2][3][4]. Continuous temperature detection of the most vulnerable patients such as new-borns, disabled, and elderly people provides urgent disease diagnosis and thereby confers timely adequate medical treatment [5]. Recent achievements in the development of the temperature sensors demonstrate a variety of resistance temperature detectors with high accuracy, fast response, and good stability [6][7][8][9]. However, these sensors are still sophisticated by own features, namely inflexibility, bulkiness, fragility, and an inability of attaching to the skin in inaccessible curvilinear places. Placement of the sensor and the presence of wires lead to discomfort, interrupt patients’ sleeping or movement, destroy natural communication of new-borns with parents and causes a pain while releasing the sticky sensor [10]. It can be improved by the development of flexible wearable temperature sensors on lightweight and bendable substrate integrated with wireless communication concept [11] on the basis of a low energy-consumption microprocessor in the scope of Internet of Things (IoT) [12][13].

Graphene, due to its excellent mechanical and electrical properties [14], has been demonstrated as an appropriate temperature sensitive material [15], which can be easily adapted to any surface providing flexibility and durability of fabricated devices. Graphene electrode sheet resistance is highly sensitive to the changes of the temperature. Furthermore, graphene electrical resistivity, or consequently conductivity, can be accurately tailored by means of chemical functionalisation of its surface [16][17]. Graphene possesses antibacterial properties [18] and its biocompatibility with human tissue [19] which is very important in healthcare applications.
2. Synthesis of graphene and sensor fabrication

Herein, we used single-layer graphene (SLG) which was synthesised by a catalytic chemical vapor deposition (CVD) method. We employed 25 \( \mu m \) thick copper foil as a catalyst (Alfa Aesar item 13382) for graphene growth. The copper foil was placed inside a quartz chamber with a diameter of 3 cm. The synthesis process was carried out under vacuum in the \( H_2 \) (100 sccm) and \( CH_4 \) (10 sccm) atmosphere applying 1035 °C for 1 minute (see Figure 1). After the terminating the graphene growth, samples were cooled down to room temperature. For the flexible sensor fabrication, SLG was transferred to the polyvinyl chloride (PVC) using a hot lamination technique with a temperature of about 120 °C [20]. The obtained PVC/graphene/copper samples were then dipped in a 1 M \( FeCl_2 \) aqueous solution for etching copper. Final PVC/graphene membranes were cleaned in deionized water and blow-dried with \( N_2 \) gas.

The graphitization fingerprint and the presence of defects (see Figure 2) were determined by Raman spectroscopy (Renishaw Raman Microscope; with 40× microscope objectives, 10 s integration time and 532 nm excitation wavelength).

3. Results

For conducting temperature measurements and sending them to the user over a wireless channel we designed an experimental testbed (see Figure 3a) based on WaspMote by Libelium evaluation board. WaspMote communicates with the user’s smartphone via Bluetooth Low Energy (BLE), \( RF \) transmitter, and the smartphone transmits the measured temperature values to an online
Figure 3: (a) Schematic diagram of experimental testbed and (b) sensor resistance change over temperature.

Internet service, e.g., via Wi-Fi. We tested the quality of BLE channel within 0.5 - 10 m distance. For this evaluation we used Received Signal Strength Indicator (RSSI) metric which demonstrated that the signal quality degrades from -59 dBm at 0.5 m to -95 dBm at 10 m in direct line-of-sight condition.

The voltage drop across the sensor’s resistance (1-layer graphene sensor) was measured via the 10-bit analog-to-digital converter (ADC) of WaspMote microcontroller unit (MCU). Sensor’s temperature is calculated from the resistance value, $R_{sensor}$, using the calibration curve based on the experimental data as it is shown in Figure 3b. Measured data were transmitted to Thingspeak cloud service over Wi-Fi channel using http GET method with 1 Hz frequency.

4. Conclusions
In summary, the study presented an approach to develop a graphene temperature sensor over the wireless communication-assisted platform. The single-layer graphene was synthesized by catalytic chemical vapor deposition method and its graphitization fingerprint was confirmed using Raman spectroscopy. The sensor was prepared by the coatings of as-synthesized graphene over flexible polyvinyl chloride films employing the hot-lamination technique. The sensor’s performance test was based on the resistance analyses versus temperature (20–70°C) via the analogue-to-digital converter of the wireless sensor node, process the data, and then transfer it to the user over the wireless channel. The sensing phenomenon of the single-layer graphene-based sensor is demonstrated by rising the conductivity with increasing the external temperature. Further improvement of graphene structure or sensor design can lead to an enhanced response in the range of human body temperature and thus to advanced sensing devices suitable for healthcare.

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