Reduced Graphene Oxide Temperature Sensor for Wearable Mobile Healthcare

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We discovered that inkjet-printed and thermally reduced graphene oxide can be used as micropatternable electronic components for flexible supercapacitors [1] and wearable temperature sensors [2]. For the sensor application, we found that reduced graphene oxide (rGO) exhibits a "strong" NTC behavior which is characterized by significant electrical resistance decrease with slight temperature increase over the temperature of 0 to 150°C [2]. It is important to contrast this NTC behavior of rGO to "weak" positive temperature coefficient (PTC) behaviors observed for more electrically conductive graphitic materials such as graphite, graphene, and carbon nanotubes. We hypothesize that: (1) defect sites present in rGO most likely function as thermally activated traps that influences the long-range hopping of electrons and (2) these defect sites can be engineered to tune its NTC behavior.

For example, results in Figure 1 suggest that etching larger defects cause an increase in temperature sensitivity. Treatment of graphene oxide with concentrated nitric acid is known to controllably enlarge the defects in graphene oxide by oxidative etching. Varying the ratio of nitric acid to rGO (0-10), results in varying average defect sizes between ~2-30 nm as proven by electron microscopy. The resulting etched rGO was tested as a temperature sensing element and calibrated by methods used for commercial thermistors. The resulting devices show increased temperature sensitivity after acid treatment with decreasing sensitivity when a critical defect size is reached.

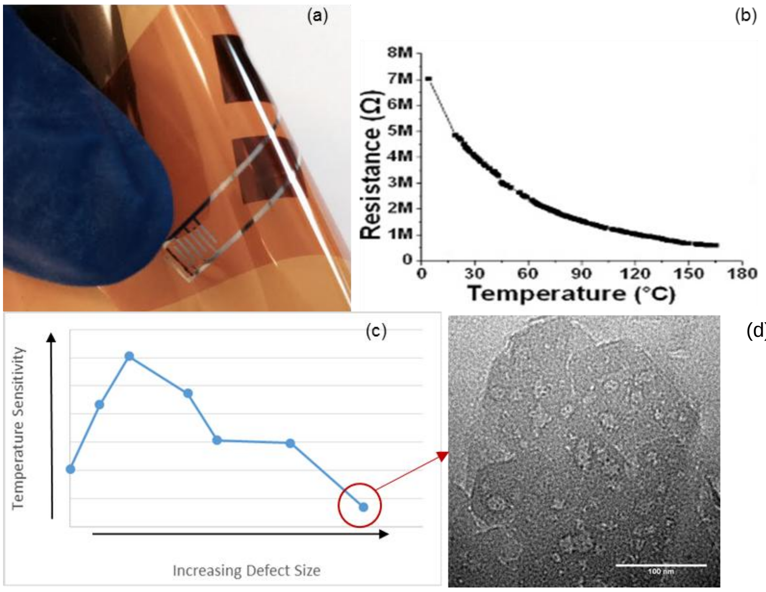

Figure 1: (a) Image of rGO temperature sensor. (b) Representative resistance vs temperature plot indicative of NTC behavior. (c) Etching data demonstrating HNO_3 effect on temperature sensitivity. (d) TEM image of 10:1 HNO_3:rGO ratio with visible 25 nm defects etched into rGO.

We are currently investigating and exploiting this defect-related NTC mechanism as a means of engineering the most conformal, miniaturizable, precise (0.001 °C), responsive (0.1 s) temperature sensor in comparison to all existing contact-based temperature sensors for mobile healthcare applications. The unprecedented sensing properties of rGO are also being utilized to continuously monitor sensitive and rapid skin temperature changes in a wearable format with accuracy and comfort. More importantly, we propose that such temperature information can be used to assess: (1) physiological states (e.g., sleepiness, and nervousness); (2) pathophysiological developments (e.g., hyper- and hypo-thermia for individuals with impaired behavioral thermal regulatory function due to exhaustive physical activities or diseases that affect skin blood flow); and (3) pandemic outbreaks by tracking the movement of populations with high fevers. These mobile health applications would not be possible unless "real" skin temperature changes can be measured using conformal and miniature sensors which can make physically intimate and robust, thermally insulated contacts with the skin surface. Unlike our rGO sensor, all known contact-based sensors are not conformal, and therefore will not be able to measure very sensitive and dynamic "true" temperature changes associated with homeostatic human states and imbalances.

References:

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[2] D Kong, LT Le, Y Li, JL Zunino, W Lee, Langmuir, **28** (2012) 13467.