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Assessment of Graphene for Heat Flux Sensor

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Abstract: ***Graphene is synthesized on a lab scale by a reduction approach and used to create a graphene-based heat flux sensor. An oil bath approach is used for the calibration of the sensor to find its sensitivity and temperature coefficient of resistance. The graphene sensor proved useful in measuring thermal changes as it performed well in detecting both temperature and heat flow. Graphene measured temperature and heat flow with effectiveness. Resistance and temperature show a strong linear connection in the graphene sensor. The temperature coefficient of resistance is found to be 0.0013/ ⁰C. Fabricated graphene sensor is sensitive to 0.715 Ω/ ⁰C. The sensor is appropriate for use in heat flux detecting applications since it demonstrated consistent resistance variations under heat load.***

Keywords: Heat flux sensor, Graphene, RTD, TCR, Sensitivity

1. Introduction

A small layer of thermally sensitive material, such as platinum or silver, is deposited over thermally insulating material, like Quartz and Macor, to create a thin film-based heat flux sensor, which is an RTD (Resistance Temperature Detector). Thermally sensitive materials have essentially linear increment in resistance as temperature rises. The surface temperature and hence the heat flux may be predicted with the help of this feature. Because platinum behaves more linearly with temperature than other materials and is inert, it is a substance that is commonly used in heat flux sensors. Because silver paint adheres well to most substrates, it is commonly employed as a medium for preserving electrical connections.

Because of its characteristics, graphene is a promising option for sensing applications. Numerous sensing applications make use of it. Many research studies employ the grapheme for temperature sensing. A body temperature sensor utilizing laser-induced graphene (LIG) was presented by H. Kun et al.[1] . This sensor is renowned for its inexpensive, easy-to-produce, and excellent accuracy. In comparison to conventional thermal resistance sensors, it is simpler to manufacture and use. With a linear relationship between resistance and temperature, the LIG sensor monitors temperatures in the human body range of 30°C to 40°C with a good accuracy of ±0.15°C.

A wearable temperature sensor with extreme sensitivity was made by J. Yang et al.[2] utilizing graphene nanowalls (GNWs) in conjunction with polydimethylsiloxane (PDMS). The polymer-assisted transfer process used in the fabrication of the sensor makes it biocompatible, inexpensive, and simple to assemble. Three times greater than traditional sensors, its high positive TCR is 0.214/ ⁰C. The stretchability and heat sensitivity of GNWs as well as the high expansion coefficient of PDMS are the causes of this high sensitivity. Real-time body temperature monitoring, quick response/recovery, and long-term stability make this sensor ideal for human-machine interface systems and customized healthcare.

A reduced graphene oxide (rGO) temperature sensor was reported by G. Khurana et al. [3]. It was created by drop casting a GO solution onto platinum inter-digital electrodes, then reducing it using hydrazine vapor and annealing. The sensor, which is characterized by Raman spectroscopy and X-ray diffraction, exhibits an exponential reduction in resistance as temperature increases from 100 to 400 K. The rGO sensor works well for temperature sensing applications because of its high sensitivity, stability, and repeatability.

A novel technique for producing temperature sensor arrays was reported by V. Kedambaimoole et al. [4]. It involved screen printing a sheet of graphene-nickel (Ni) nanocomposite over a flexible printed circuit board (PCB). This economical method guarantees consistent film thickness. The sensor array exhibits Negative Temperature Coefficient (NTC) behavior, measuring temperature differences through changes in resistance, with a sensing thickness of around 50 µm. With a temperature coefficient of resistance TCR of -2.635 $\times 10^{-3}$/ ⁰C and a sensitivity of 2.455 Ω/ ⁰C, the resistance falls as the temperature rises. Body temperature sensors that are wearable and readily integrated into electronic devices can be produced in large quantities. Graphene is used for temperature sensing in many other studies [5–7].

Graphene finds usage in numerous other fields. A flexible, inexpensive ammonia sensor utilizing multilayered graphene on filter paper which is reduced from graphene oxide with glucose was reported by R. Ghosh et al. [8]. It has repeatable performance, detecting ammonia at as little as 430 ppb and operating consistently in both bending and flat configurations throughout values between 400 and 4000 ppm. A low-cost, reagent-free E. Coli sensor built with graphene on a flexible acetate substrate was reported by P. Basu et al. [9] . Gold electrodes create a two-terminal capacitor by growing graphene on copper foil by chemical vapour deposition (CVD) and then transferring it to acetate. Changes in impedance with E. Coli concentration are measured using impedance spectroscopy. E. coli is bound by residual methyl groups on graphene, which increases hole doping and reduces graphene resistance. 60% sensitivity is reached by the sensor at 4.5 × 10^7 cfu/ml. In another study by V. Kedambaimoole et al. [10], reduced graphene oxide was used as the sensing layer. This study is a demonstration of a flexible proximity sensor that displayed great electrostatic potential sensitivity for object proximity detection. It is clear from the literature review that reduced graphene is utilized in a wide range of applications, including gas and temperature sensors. However, heat flux sensing applications do not employ it. The use of graphene for heat flux sensing applications is the focus of this work.

2. Synthesis of graphene

One layer of carbon atoms organized in a two-dimensional honeycomb lattice is known as graphene. It serves as the fundamental component of other carbon allotropes. Each carbon atom in graphene is joined to three other carbon atoms to form a hexagonal structure. In terms of weight, graphene is about 100 times stronger than steel, but it is also extraordinarily light. Graphene is a far better electrical conductor than a lot of conventional conductive materials. Its high electron mobility allows electrons to move through material at a very fast speed. It is also an effective heat conductor due to its high thermal conductivity. Graphene is extremely flexible and can be bent or stretched without breaking, even though it is very strong.

Because of its extraordinary qualities, graphene is a highly studied substance with a broad variety of possible uses in several industries. There are numerous uses for graphene. Because of its exceptional electrical conductivity, it is utilized in transistors, sensors, and other electronic equipment. It is used to increase the energy storage capacity of batteries and supercapacitors. It is added to materials to increase their elasticity and strength. It might be helpful for biosensors, medication delivery systems, and other medicinal uses.

Numerous techniques exist for synthesizing graphene, each with pros and cons [11,12]. Depending on the desired graphene characteristics and the required manufacturing scale, each graphene synthesis technique has a specific set of applications. Research keeps developing new strategies and refining existing ones to produce graphene in a more scalable and effective manner. The current technique uses chemical reduction of graphene oxide to create graphene in a lab setting. Further information regarding this technique can be discovered in the literature.

3. Fabrication of heat flux sensor

As shown in Fig. 1, the substrate, sensing thin film, and connecting thin film are the essential parts of a heat flux sensor (HFS). Substrates for HFS construction can be built of Pyrex, Quartz, or Macor, whereas platinum and nickel are usually used to make the sensing thin film [13]. Electrical connections are implemented with silver thin sheets. A quartz rod measuring 10 mm in diameter and 20 mm in depth was used as the substrate material for this investigation. Sandpapers with grit sizes of 400, 1000, and 2000 are used in succession to polish the substrate material. The substrates are cleaned with acetone after polishing. Lastly, the substrates are dried for 20 minutes at 50° to 60°C.

Graphene is initially mixed in the necessary amount of solvent to create a paste. A thin layer of this paste is applied to the substrate's top surface. Enough attention is paid to preserving the film's consistent thickness. The thickness, according to the device, is approximately 100µm. The substrates are immediately dried under a high-power heating lamp for 20 minutes to ensure the film is entirely dry and to remove any chemical reagents. Annealing the painted surfaces in a microcontroller-based muffle furnace relieves thermal strains and stabilizes the calibration parameters (TCR and sensitivity). Over time, the temperature is raised progressively to 350°C for 1 hour at a constant heating rate, followed by natural cooling overnight to avoid crack formation.

Making electrical connections is the next stage of the fabrication process. Paint with a silver base is utilized for this purpose. The substrates' rounded surfaces are covered in two silver thin coatings on opposing sides. To offset the effects of gravity, these films are formed in a single stroke when the substrates are horizontal, guaranteeing a sufficient amount of material for efficient conduction. The length of the films is kept at roughly half the depth of the substrates. The films are also made extremely thick. The overlap between the silver thin films and graphene is kept to a minimum. After 30 minutes of annealing at 300°C in a microcontroller-based muffle furnace, the substrates are left to cool to ambient temperature overnight. The copper wires that are insulated are utilized for electrical connections. To provide structural integrity, Teflon tape is used to insulate the soldered junctions where the wires are meticulously soldered to the silver thin sheets. The manufactured end heat flux sensor is shown in Fig.2.

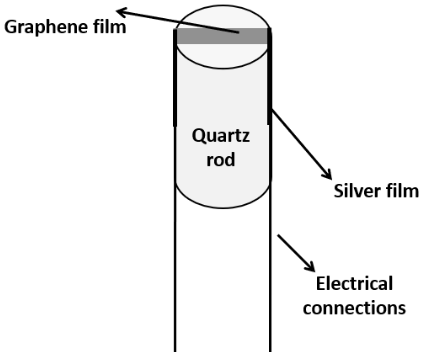

Figure 1: Schematic of heat flux sensor

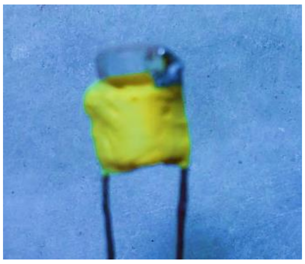

Figure 2: Fabricated heat flux sensor

4. Assessment of sensor

4.1 Oil bath calibration

Oil bath calibration is a technique used to calibrate temperature measurement devices, such as thermometers, thermocouples, and resistance temperature detectors (RTDs). This method involves immersing the device to be calibrated in a bath filled with oil that is heated to a precise and stable temperature[14]. The manufactured heat flux sensor is calibrated to determine performance metrics like sensitivity and TCR. The following formula describes the relationship between resistance and temperature change:

$$R(T) = R_0 [1+\beta (T-T_0)]$$

Here,
$R(T)$ = Resistance at temperature T
R_0 = Resistance at ambient temperature T_0
β = Temperature coefficient of resistance

As seen in Fig. 3, it is seen that the heat flux sensor's resistance lowers with temperature. This is because graphene has a negative TCR. The sensitivity is found to be 0.715 Ω/°C. It is discovered that the current sensor's TCR value is 0.0013 /°C as described by Fig.4.

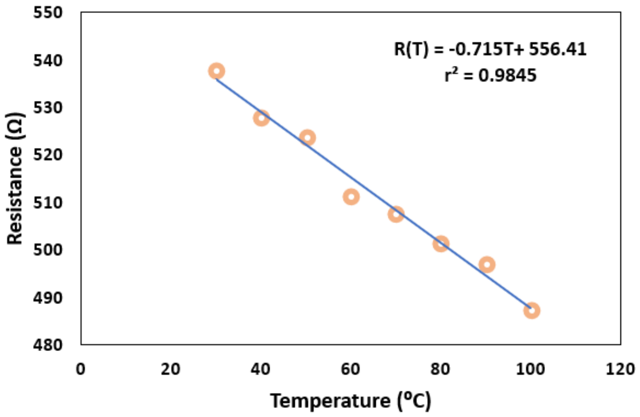

Figure 3: Variation of resistance with temperature

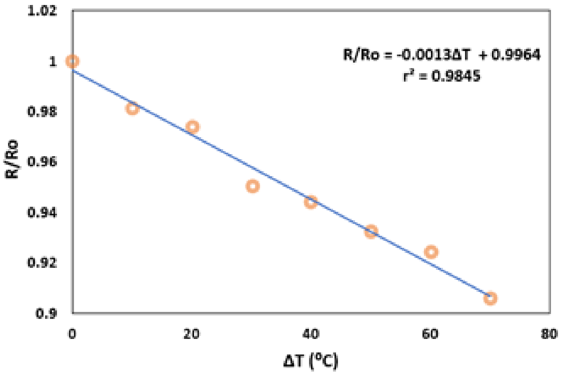

Figure 4: Estimation of TCR

4.2 Sensor testing under heat load

The literature has information on a number of heat flux testing methods, including the conduction, convection, and radiation approaches. The approach of using radiation or LASER is a commonly recognized and employed method. Fig. 5 provides details of the LASER configuration employed in this investigation. The coherent light that the LASER machine emits is made possible by spatial coherence, which also helps the laser maintain focus, making testing more simpler. For testing purposes, a monochromatic LASER with a defined wattage is utilized. The testing is conducted for 4 seconds. The LASER is switched on and off every 1 second to check the sensitivity of the sensor toward heat load. The resistance change in the sensor is shown in Fig.6.It is observed that the graphene heat flux sensor is very sensitive toward heat load. A total of 3 experiments are conducted under the same conditions. It is claimed that the graphene sensor has good repeatability as shown in Fig. 6.

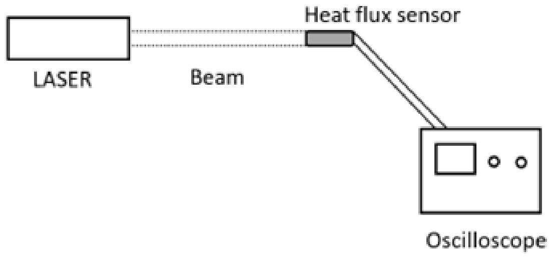

Figure 5: Heat flux testing setup

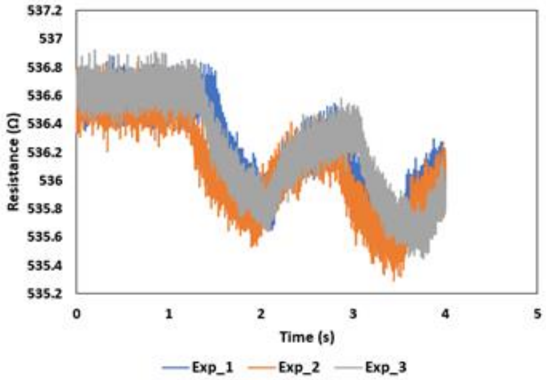

Figure 6: Variation of senor resistance under heat load

5. Conclusions

A laboratory-scale graphene-based heat flux sensor is created. Using a reduction process, graphene is synthesized at the laboratory scale. The TCR of the sensor is determined using the oil bath calibration procedure. The crucial findings are

- The ability of graphene to sense temperature and heat flow is good.
- There is a nice linear relationship between resistance and temperature in the graphene-based heat flux sensor.
- The TCR of the graphene heat flux sensor is found to be 0.0013 /°C.
- The sensitivity of the graphene heat flux sensor is found to be 0.715 Ω/°C.
- The graphene heat flux sensor has good repeatability.
- The graphene heat flux sensor showed good resistance change under the heat load conditions. Hence, it can be used for heat flux sensing applications.

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