DESIGNING A THERMOELECTRIC GENERATOR FOR MILITARY APPLICATIONS

Project Reference No.: *47S_BE_4006*

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Keywords:

Wearable thermoelectric generator, Carbon fabric, Molybdenum disulfide (MoS2), Seebeck Coefficient, Electrical Conductivity

Introduction:

The availability of dependable power sources is critical in modern warfare when operations are often carried out in isolated or hazardous environments. Conventional power sources provide logistical difficulties and have limited operational capabilities since they frequently depend on fossil fuels or heavy batteries. As a result, thermoelectric generators, or TEGs, have become a viable substitute that can transform waste heat from a variety of sources into electrical power that is useful. The purpose of this project is to investigate the development and use of thermoelectric generators especially intended for use in military settings. These generators have the potential to significantly improve military forces' operational readiness and sustainability by offering a consistent and renewable power supply in a variety of settings. But the major factors that need to be considered in building the TEGs are rigidity, breathability, mobility, and efficiency of the device. These generators need to be lightweight and portable for simple deployment. Furthermore, it is essential to maximize energy conversion efficiency to make the most use of the heat sources that are already accessible and reduce the need for external fuel or battery replenishment. This project focuses on several TEG design issues such as material selection for the thermoelectric devices, device shape optimization, integration with heat sources etc. And system-level factors, such as power management and interaction with current military infrastructure, will also be considered. This work aims to improve the energy independence and operational effectiveness of military forces globally by utilizing advancements in thermoelectric technology and customizing solutions to fit the specific requirements of military operations [1]. Additionally, these thermoelectric generators (TEGs) are divided into two categories: bulk TEGs and flexible TEGs. Flexible TEG modules are used in wearable electronics and can produce power from the human body for self-sustainability. These modules have a high thermoelectric performance at room temperature. Remarkably, the Seebeck effect may produce enough energy to power an electrical generator because humans possess an inherent thermoregulation mechanism that allows them to maintain distinct body temperatures at various locations as shown in Figure 1.

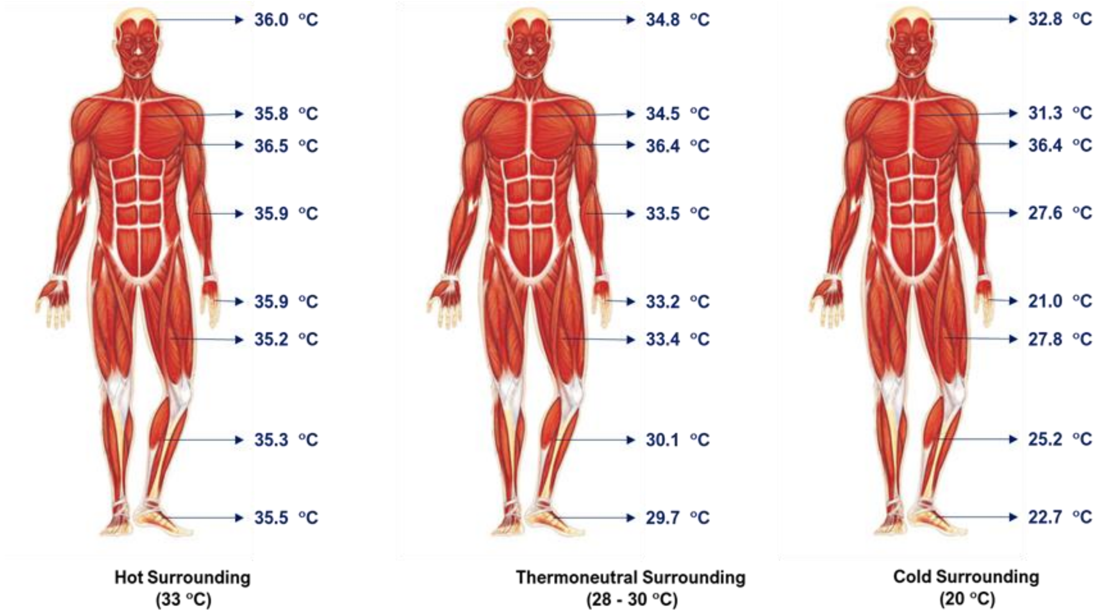

Figure 1 Body temperatures at various parts of the body [2]

Objectives:

- To synthesis MoS2 on carbon fabric.
- To study the role of thermoelectric material on the carbon fabric.
- To design and fabricate the flexible thermoelectric generator.
- To studying the output voltage of the fabricated device.

Methodology:

1. Citric acid ($C_6H_8O_7$): Citric acid may be used as a complexing agent or a pH modifier in solution-based synthesis methods to prepare the thermoelectric material.
2. Sodium hydroxide (NaOH): Sodium hydroxide can be utilized as a base to adjust the pH of solutions during material synthesis or to clean substrates before deposition processes.
3. Triton X-100 ($C_{14}H_{22}O(C_2H_4O)_n$): Triton X-100, being a surfactant, may aid in the dispersion of nanoparticles or improve the wetting properties of the solution during coating processes onto substrates like carbon fabric.
4. Hydrochloric acid (HCl): Hydrochloric acid may be employed for cleaning purposes, etching surfaces, or adjusting the pH of solutions during material synthesis.
5. Thiourea (CSN_2H_4): Thiourea could serve as a sulfur source in the synthesis of certain thermoelectric materials or as a complexing agent.

6. Hexa ammonium hepta molybdate tetrahydrate ($(NH_4)_6MoO_7•4H_2O$): This compound likely acts as a precursor for molybdenum-based thermoelectric materials, providing the necessary molybdenum ions in the synthesis process.
7. Copper(II) nitrate hexahydrate ($Cu(NO_3)_2•6H_2O$): Copper nitrate may serve as a precursor for copper-based thermoelectric materials, contributing copper ions to the synthesis process.
8. Ethanol (C_2H_5OH): Ethanol may be used as a solvent for dissolving precursors or for cleaning substrates before deposition processes. Carbon fabric: Carbon fabric serves as the substrate onto which the thermoelectric material is deposited, providing a flexible and conductive base for the wearable thermoelectric generator.

Synthesis:

- The MoS_2 nanosheets grown on carbon fabric were synthesized via a straightforward hydrothermal method, as illustrated in Figure1.
- Initially, the fabric underwent a cleaning process using citric acid, Triton X100, and NaOH in 100 mL of DI water at 100 °C for 2 hours.
- Subsequently, the fabric was rinsed with DI water and ethanol, then dried at 100 °C for 12 hours.
- Following this, the fabric was functionalized with hydrochloric acid to ensure homogeneous hydroxyl group formation on its surface.
- In the synthesis process, 4.5 g of CSN_2H_4 was dissolved in 72 mL of DI water and stirred for 1 hour. Then, 2.5 g of $(NH_4)_6Mo_7O_{24}·4H_2O$ was added and stirred for an additional hour.
- The resulting solution was then transferred to a stainless steel autoclave, with a carbon fabric adhered to a glass substrate at a 45° angle, and maintained at 180 °C for 24 hours.
- The obtained samples were subjected to sonication with ethanol and DI water multiple times to eliminate any unwanted residuals from the fabric, followed by drying at 60 °C for 12 hours and the resulting sample was denoted as CM0.

Fabrication:

- The sample cut into several strips (2 cm X 0.5 cm) as p-type material and copper wire was used as n-type material.
- Copper tape was used to interconnect the n and p-types legs as shown in Figure 2.
- Further the output voltage has been measured.

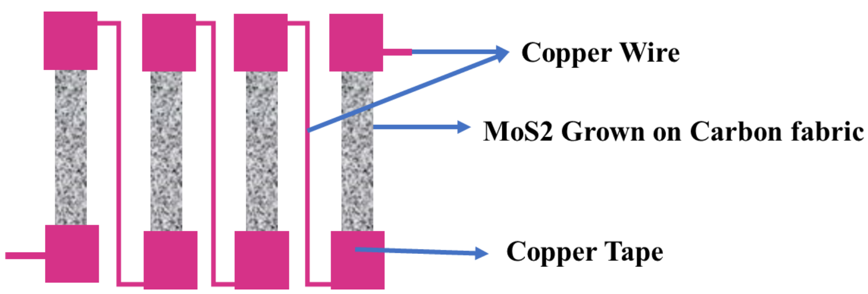

Figure2: Designing fabric TE device.

Conclusion:

1. XRD Analysis:

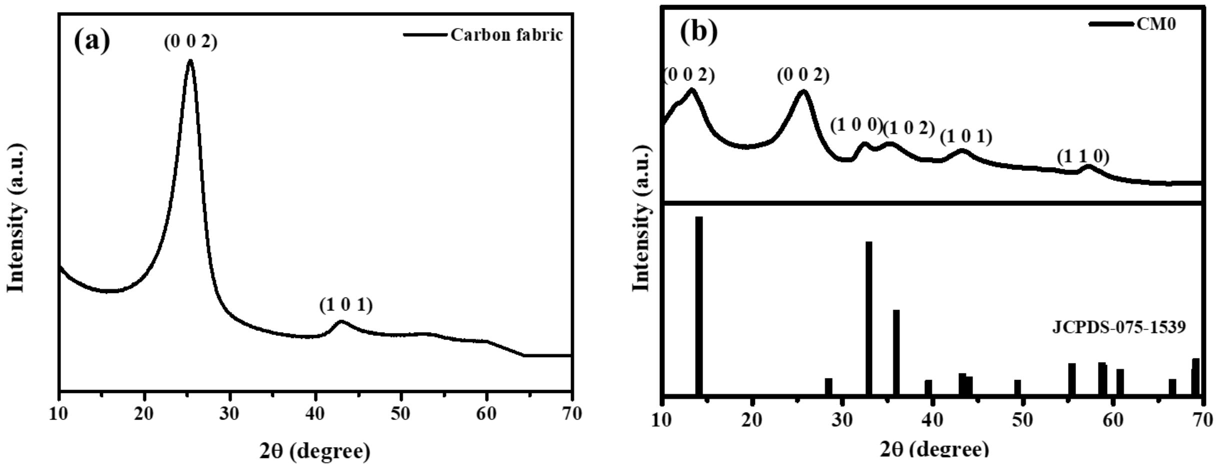

Figure 3 shows the XRD patterns of pure carbon fabric and MoS2 grown carbon fabric.

A flexible non-destructive analytical method for examining the phase composition, crystal structure, and orientation of powder, solid, and liquid samples is called X-ray diffraction (XRD). The figure 3a. illustrates the XRD patterns of pure carbon fabric and Figure 3b. illustrates the XRD patterns of MoS2 grown on carbon fabric. The peak at 2θ = 25.4° corresponds to the graphitic carbon and the peak at 43.3° corresponds to the impurities of the pure carbon fabric as shown in figure 3a. The peak at 13.13°, 32.23°, 35.28°, and 57.27° corresponding to (0 0 2), (1 0 1), (1 0 2), and (1 1 0) planes of the hexagonal MoS2 phase. And this was well matched with JCPDS card no. 01-075-1539 as shown in figure 3b. The MoS2/carbon fabric sample exhibits additional peaks at 25.6° and 43.6° attributed to CF, and a change in the peak postion of (002) plane was observed (25.4° to 25.6°) in the pattern owing to the interaction (Mo–O–C and S–C) between the MoS2 and the carbon fabric. This implies that the surface of the carbon fabric and the generated MoS2 are chemically bonded. After growth of MoS2 on carbon fabric, MoS2 and Carbon peaks were retained and no additional peaks were formed, this confirms the growth of pure MoS2 on carbon fabric.

2. FESEM Analysis:

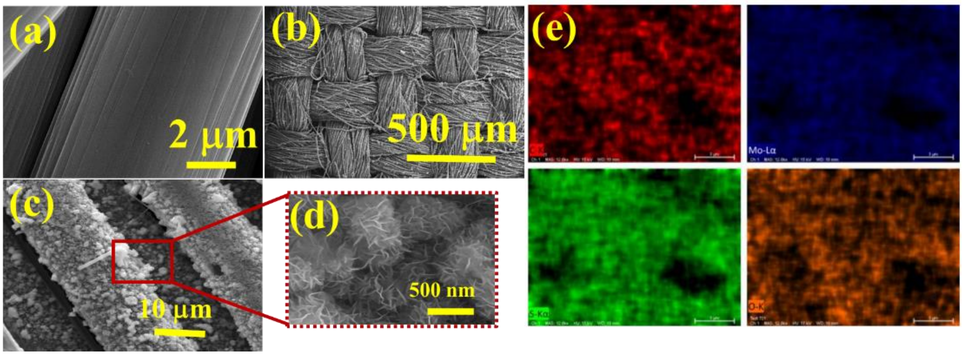

Figure 4 (a-d) shows the FESEM analysis of pure carbon fabric and MoS2 grown on carbon fabric and (e) elemental mapping.

Field emission scanning electron microscopy (FE-SEM) is a cutting-edge technique utilised to study the materials' microstructure. FESEM was utilized to analyse the surface morphology and elemental distribution of MoS2. Figure 4(a-d) presents both lower- and higher-magnification HR-SEM micrographs of pure carbon fabric and MoS2 grown on carbon fabric, revealing a uniform and dense MoS2 layer on the carbon fabric. Specifically, Figure 4(b-d) illustrates the flower-like morphology of MoS2 grown on carbon fabric, composed of interwoven nanosheets. The analysis confirms the uniform growth of MoS2 on the carbon fabric, with energy-dispersive X-ray spectroscopy (EDS) mapping (Figure 4(e)) revealing that Mo and S atoms cover the carbon fabric surface. This indicates uniform MoS2 growth on the carbon fabric, with no observable cracks, demonstrating strong adherence between the carbon fabric and MoS2.

3. Thermoelectric analysis:

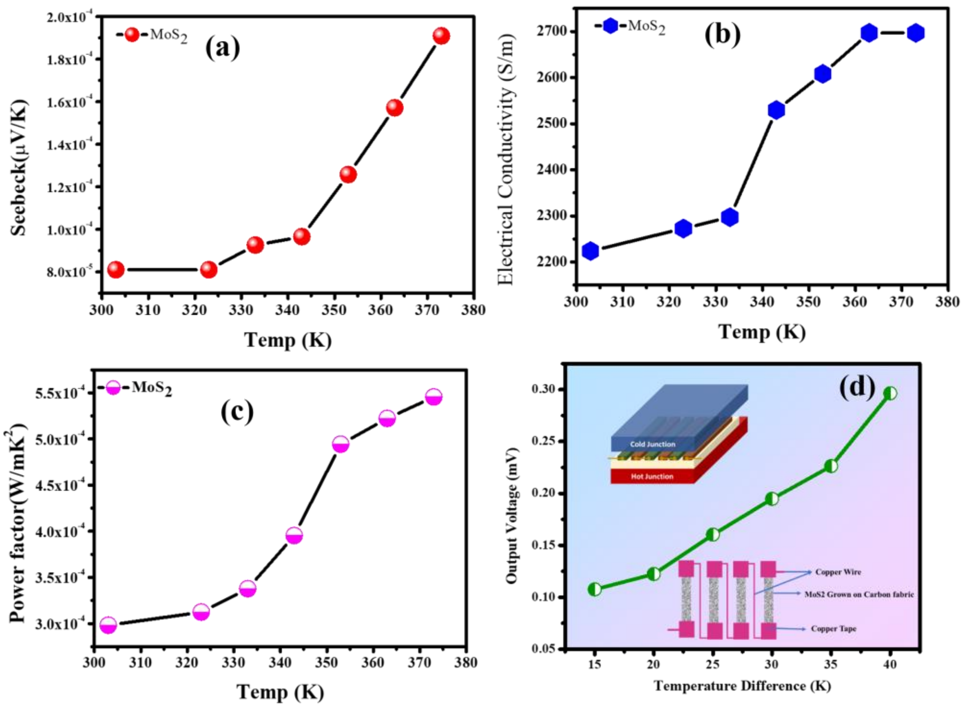

Figure 5(a) Seebeck analysis, (b) electrical conductivity analysis, (c) power factor and (d) Device analysis

The Seebeck coefficient provides a qualitative measure of the asymmetric charge distribution around the Fermi level. In Figure 5a, the Seebeck coefficient of MoS2 grown on carbon fabric was measured across a temperature range of 303 to 373 K. Throughout this temperature range, the Seebeck coefficient values for MoS2 grown on carbon fabric remained positive, indicating that holes are the dominant charge carriers. Furthermore, as the temperature increased, the Seebeck coefficient of MoS2 grown on carbon fabric also increased, suggesting a decrease in charge carrier concentration. At 373 K, the Seebeck coefficient reached its maximum value of 1.91x10-4 mV/K.

Figure 5b depicts the electrical conductivity of MoS2 grown on carbon fabric. The analysis reveals a trend of increasing electrical conductivity with rising temperature, indicative of the semiconducting behaviour exhibited by the sample. Specifically, the electrical conductivity of the MoS2/carbon fabric sample was measured at 2223 S/m at 303 K and increased to 2697 S/m at 373 K.

The thermoelectric power factor of the samples was determined by calculating the product of the square of the Seebeck coefficient and the electrical conductivity (PF = S^2 * σ), as illustrated in Figure 5c. It was observed that the power factor increased with rising temperature, mirroring the trend seen in the electrical conductivity. The highest power factor, reaching 5.45x10-4 nW/m·K2, was attained at 373 K for MoS2 grown on carbon fabric.

A thermopile comprising MoS2 grown on carbon fabric as the p-type material and copper wire as the n-type material was constructed. The MoS2 grown on carbon fabric was cut into several strips measuring 5 cm x 0.5 cm. These strips were then connected to copper wire using copper tape to ensure a robust connection, as depicted in Figure 5d. One side of the assembled device was exposed to heat (hot side), while the opposite end was kept at a lower temperature (cold side). Initially, with no temperature gradient, the output voltage remained close to zero. As the temperature difference between the hot and cold sides increased, the output voltage gradually rose. In Figure 5d, it can be observed that with a temperature difference of 40 K, the output voltage reached approximately 0.30 mV.

Scope for future work:

As a part of my future work, We tend to synthesis n-type MoS2 grown on carbon fabric for fabricating wearable thermoelectric generator.

- Synthesize p and n-type materials using the hydrothermal method.
- Integrate the p and n-type materials with carbon fabric and cut them into 5 cm x 0.5 cm size pieces, referred to as the p-type TE leg and n-type TE leg, respectively.
- Use Cu foil, cotton thread, or Ag thread to create connections between the p and n-type materials, ensuring secure electrical contact.
- Measure the voltage output of the fabricated device by placing it on the human body, simulating real-world wearable conditions.