IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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To cite this article: H Hardianto *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **459** 012012

Seebeck coefficient of thermopile made of nickel-coated carbon fiber

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Abstract. A textile-based thermopile has been fabricated by etching the nickel layer of a nickel coated carbon fiber (NiCF) selectively to form a series of CF-NiCF junctions along the NiCF. The pristine NiCF was inserted into the polyester woven fabric manually. Each half part of the float yarns was covered with Lurapret® D579 dropwise to form a 36-pair CF-NiCF thermopile. After drying in the oven, the sample was etched in the etching solution, then rinsed with water and air dried. The Seebeck coefficient resulting from 36-pair CF-NiCF thermopile is 93.04 μV/K. This proofs that creating a flexible thermoelectric generator from a conductive textile yarn is possible.

1. Introduction

Thermoelectric has attracted a lot of attention because of its considerable potential to be utilized as a renewable and sustainable energy source. Since 2001, research on harvesting and converting heat into electrical energy in a wearable thermoelectric generator has been conducted [1]. Recently, a number of studies on the thermoelectric generator (TEG) by way of harvesting body heat have been reported [2–6] but the TEG they used were made of inflexible materials and non-textile materials. Some papers reported the energy harvesting of the human body using different structures of textile-based TEG [7–9], however, none of these studies used the thermopile principle made from a single yarn.

According to our previous finding, Nickel-coated Carbon Fiber (NiCF) and Carbon Fiber (CF) are good candidates for fabricating a textile-based thermoelectric generator because they can be inserted into a fabric structure [10]. In this paper, we try to utilize the NiCF as a starting material and convert it into a textile-based thermopile. The objective of this work is to fabricate a textile-based TEG from a single yarn i.e. NiCF in a textile fabric by means of the etching process to form a series of CF-NiCF junctions in order to obtain a thermopile and study its Seebeck coefficient. In this paper, the term NiCF corresponds to Nickel-coated Carbon Fiber in the form of multifilament yarn.

2. Experimental

In this experiment, NiCF yarn from Toho Tenax Germany GmbH (Tenax®-J HTS40 A23 12K 1420tex MC) was used. The thickness of the nickel is around 0.25 µm [11]. The textile-based TEG was prepared by manually inserting the NiCF yarn into a polyester fabric by means of a needle to form a pattern as shown in Figure 1. Each row was circa 8 cm in length and each float of the yarns was around 1 cm. The distance between the rows was 1 cm.

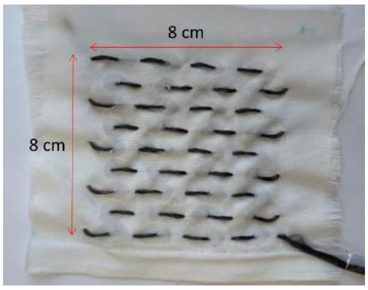

Figure 1. A textile thermopile sample having 36 pairs of CF-NiCF junction.

Then, this NiCF was covered with a polymer called Lurapret® D579 dropwise on the half part of the float yarns on top and bottom sides of the fabric as shown in Figure 2. Next, the sample was dried in the oven at 130°C for 15 minutes. Then, the etching process was performed according to the literature [10] where the sample was dipped in 10% H_2O_2 + 37% HCl (1:1) for 30 minutes without heating, rinsed with running water and air dried for 24 hours (minimum) before use. This process allows the etching chemical to remove the nickel selectively from the NiCF where the nickel was not covered with Lurapret® D579. In this way, a textile-based TEG from a single yarn containing CF-NiCF junctions was obtained.

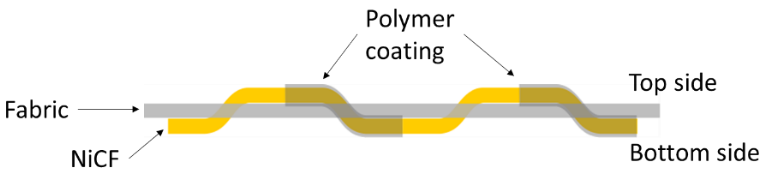

Figure 2. Illustration of the covered and uncovered area of NiCF with polymer before etching.

Microscope images were taken with an Olympus SZX10 stereomicroscope equipped with ToupView camera control software. Voltage measurement was performed by placing the sample on a hot plate and placing a cooling fan on the sample. The output voltage of the sample was measured with a nanovoltmeter NV 724 at different ΔT of hot and cold sides. Measurement of hot and cold temperatures was done with a Fluke 54 II B digital thermometer. From the gradient of the voltage and temperature difference graph, the Seebeck coefficient was obtained.

3. Results and discussion

In this paper, we aim at fabricating a textile-based thermopile from NiCF filaments by removing the nickel layer of NiCF at specific zones by an etching technique. Some zones were covered with a polymer called Lurapret® D579 before the etching process. As a result, only nickel in the area where there is no polymer on its surface would have a contact with the etching chemical forming an intermittent pattern of CF-NiCF along the yarn.

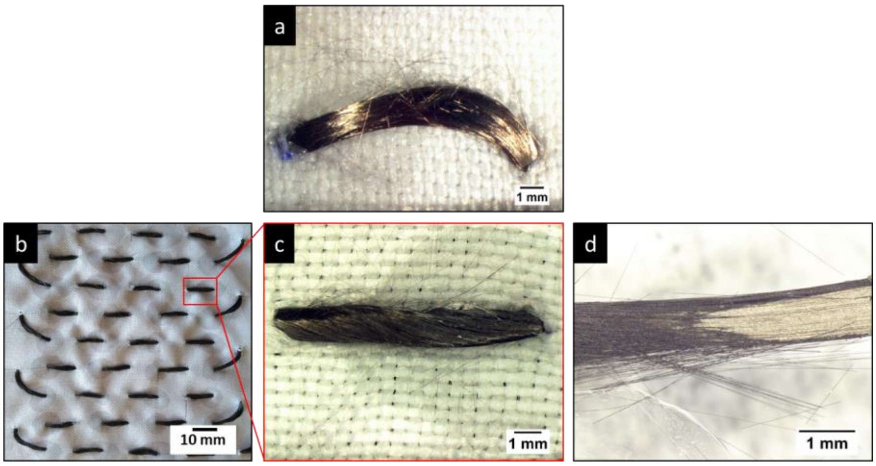

Figure 3. Microscope images of NiCF yarn samples in the fabric: (a) before and (b)-(d) after etching. Image (c) is the magnification image of the selected area from image (b).

Figure 3 shows microscope images of NiCF yarn samples in a polyester fabric before and after the etching process. It is clear that the NiCF yarn colour is brown before etching (Figure 3a) and it becomes black after etching process (Figure 3b-3d). Since the original colour of carbon fiber is black, it is observed that after the etching process the yarn changes to black indicating the nickel has been removed from the surface of carbon fiber. In Figure 3b and 3c, the polymers Lurapret D579 added dropwise on the sample are also observed; each in an oval shape and is seen darker than the normal colour of the polyester fabric. Theoretically, the nickel on the surface of the carbon fiber beneath the Lurapret D579 polymer will remain brown if it is not removed by the etching chemical. Unfortunately, from the image (b) and (c), we cannot observe clearly the colour difference between the covered and uncovered part of the yarn after the etching process. Due to that issue, a sample of the floated yarn was cut so that the inner part of the filaments bundle was revealed as shown in image (d). From this image, it is obvious that there are two different colours i.e. black and pale brown which confirm that the nickel in the area covered with the polymer still remains there.

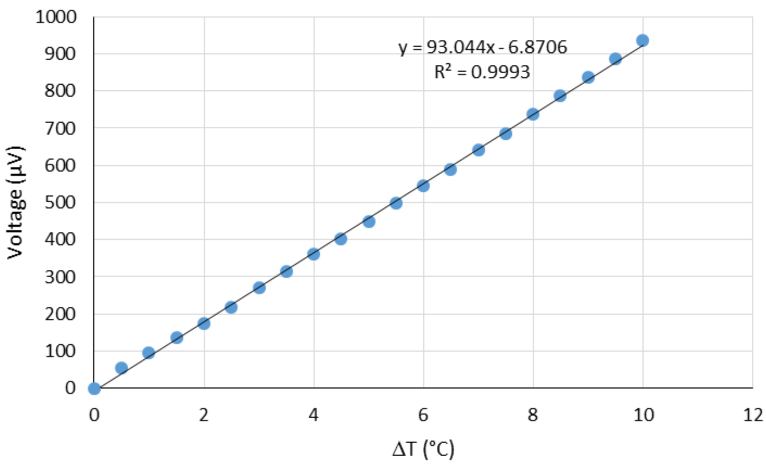

Figure 4. Graph of voltage versus temperature difference from 36-pair CF-NiCF junction after the etching process.

The Seebeck coefficient resulting from 36-pair CF-NiCF thermopile is 93.04 µV/K as presented in Figure 4. The result is lower than the theoretical calculation i.e. 648 µV/K as the single thermocouple from CF-NiCF was found to be around 18 µV/K [12]. This indicates the junctions are not at full potential when constructed as given.

4. Conclusion

In this work, a 36-pair CF-NiCF thermopile from single NiCF yarn has been fabricated using the etching technique and can generate a Seebeck coefficient of 93.04 μV/K. This proofs that it is possible to create a flexible thermoelectric generator from a conductive textile yarn. However, the results were still far from the theoretical maximum.

5. Acknowledgements

Mr. Hardianto gratefully acknowledges the Indonesia Endowment Fund for Education (LPDP) for making this work possible by financially supporting the research activities.

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