ENERGY HARVESTER MADE OF TAIWAN LOCAL NEPHILA PILIPES SPIDER SILK

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ABSTRACT

Many researches reveal that proteins have the property of piezoelectricity. Therefore, the study presents the concept of energy harvester made of natural spider silk. Moreover, with high density of protein, spider silk can produce more strong and stable piezoelectric property through the polarization technology. The major ampullate gland of native Nephila pilipes was chosen as the silk source in this study, and it was examined by Flourier transform infrared spectroscopy (FTIR), and electrical testing. FTIR reveals the polarized silk increases significantly at the peak of 1610 cm^{-1} to 1660 cm^{-1}. It means that polarized silk has better α-helix and β-sheet arrangement than non-polarized ones. The result of the electrical testing shows that the output voltage of polarized silk has 3.485 times higher than that of non-polarized silks. Thus, Taiwan local Nephila pilipes spider silks show great potential in energy harvester due to its piezoelectricity.

KEYWORDS

energy harvester, piezoelectricity, FTIR, spider silk

INTRODUCTION

Batteries were more common and essential in our life, but the disadvantages of batteries, such as the finite energy, limited life, and chemical pollution, make themselves inconvenient. Hence, device made of piezoelectric materials is a good choice since it generated electricity by itself. Due to piezoelectric effect, piezoelectric materials generate electricity as they occur deformation. Moreover, vibration is everywhere in our life, such as arm swing, feet walking. It means good use of vibration on piezoelectric materials is an effective way to generate electricity without any difficulties [1-2]. The piezoelectricity and related properties in biological materials were first proved in 1941 by Martin [3]. Then Fukada found the piezoelectricity effect in wood, bone, and DNA in 1955 [4]. Therefore, protein was proved as a piezoelectricity material. Piezoelectricity was the linear coupling between mechanical strain and electric charge, which also depended on crystal structure and polar orientation [5]. Spider silk was found not only made of protein but also a natural piezoelectricity material. Spider silk was one of the most mystical natural substances on earth which was more durable and elastic. Because of its extraordinary properties on mechanical strength and elasticity, there were many applications on spider silk. However, the studies of spider silk in energy harvester were very few. Hence, this study focused on piezoelectric effect of spider silk, and the results were reported in the following sections.

EXPERIMENTAL METHOD

In this study, the major ampullate gland of native *Nephila pilipes* was chosen as the experimental samples. Through the forced-silking equipment, the spider silk was collected at the reeling speed of 1.56 m/min, as shown in Figure 1. The spider was held in position by pins. Then, the hand-made reel was used to collect spider silk.

To analysis the piezoelectric effect of this spider silk, its directional piezoelectric effect and reverse piezoelectric effect was examined by beating test. The beating test controlled by direct current (DC) motor caused the sample deformation, while the sample was fixed on a flexible polyethylene terephthalate (PET) with the ends connected to the copper foil electrode pairs, as shown in Figure 2. In order to show the piezoelectric d_{33} mode, the direction of the spider silk was perpendicular to the direction of the electrode. When the sample was applied a stress, the spider silk produced strain along the axial direction. Since the sample was deformed continuously by beating, the deformed energy was converted into electricity power. With the piezoelectric d_{33} mode, the alternating voltage produced by the sample can convert into current.

The reverse piezoelectric effect was that electricity power converted into deformed energy. Thus, the sample was tested to observe the deformation with an external electric field. In addition, spider silk got better structure to generate electricity after polarizing by high voltage. And flourier transform infrared spectroscopy (FTIR) was used to compare the change of spider silk structure with non-polarized and polarized. Flourier transform infrared spectroscopy used Michelson interferometer to get interferogram. The interferogram was calculated from the computer and processed by Fourier transform. Finally, the infrared spectrum was obtained. The characteristic and wavenumber of the absorption peak in the infrared spectrum can be used to identify the molecular structure.

The study added KBr powder to non-polarized and polarized spider silk, respectively. Then, the powder was pressurized into a tablet with oil hydraulic press and put into the instrument for measurement. The energy absorption of spider silk was measured by infrared light penetration tablet.

EXPERIMENTAL RESULTS

According to the reverse piezoelectric effect, deformation of the samples was observed with an applied external electric field (12 kV/mm), as shown in Figure 3. The beating test shows that the spider silk converts deformed energy into electric energy including voltage value and current value. The non-polarized had 13.4 mV of open circuit voltage and 70.6 nA of loading current as the strain rate was 0.02/s, as shown in Figure 4. The polarized had 46.7 mV of open circuit voltage and 105 nA of loading current as the strain rate was also 0.02/s, as shown in Figure 5. As a result, by polarizing the spider silk, the peak voltage value rose up from 13.4 mV to 46.7 mV, and the peak current value rose up from 70.6 nA to 105 nA. Thus, the polarized silk's voltage and current were 3.485 times and 1.516 times, respectively, higher than the non-polarized ones. In addition, FTIR reveals the polarized silk increased significantly at the peak of 1385 cm^{-1}. It illustrates that the polarized silk has better crystal arrangement than the non-polarized ones. With previous data, they all shows spider silk had piezoelectric effect, and polarized one had better consequent as shown in Figure 6.

Figure 6 displayed FTIR spectra (4000~400 cm^{-1}) of the spider silk which was recorded at room temperature. These spectra were analyzed by using the second derivative method. According to the previously published [7-8]. The spectrum around 1600~1700 cm^{-1} characterizes the C=O stretching vibration of the amide I. The secondary structures of the spider silk consist of aggregated strand at 1610 cm^{-1}, parallel -sheet at 1620 cm^{-1}, 1630 cm^{-1} and 1695 cm^{-1}, random coil at 1641 cm^{-1} and 1651 cm^{-1}, -helix at 1651 cm^{-1} and 1659 cm^{-1}, and turn at 1668 cm^{-1}, 1673 cm^{-1} and 1682 cm^{-1} based on the curve-fit data using the second derivative method. The second derivative curve of the amide I spectrum is used to determine the positions of de-convoluted peaks. The result showed the polarized spider silk had about 3% raised in α-helix wavelength than non-polarized spider silk in 1600~1700 cm^{-1}, while α-helix is the main piezoelectric property in protein. Thus, it was proven that spider silk increases its piezoelectric effect after the polarization process.

CONCLUSIONS

The study innovatively explores natural spider silk as energy harvester. The electricity of spider silk has been improved after polarizing process. By flourier transform infrared spectroscopy, the phenomenon of -helix and -sheet in spider silk structures was observed which means that silk has better arrangement after polarizing process. Spider silks show great potential in energy harvester due to its piezoelectricity.

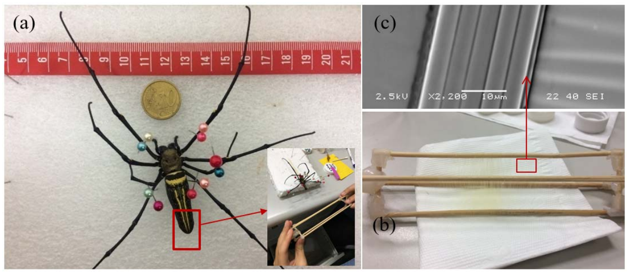
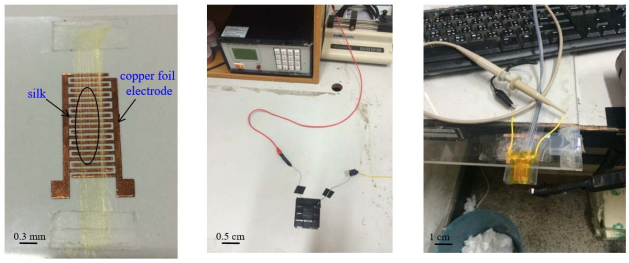


Figure 1: Taiwan local Nephila pilipes spider, (a) image of Taiwan local Nephila pilipes spider, (b) the forced-silking equipment, (c) SEM of the spider silks.



(a) sample (b) sample in polar process (c) testing process

Figure 2: View of experimental equipment, (a) testing sample on electrode, (b) sample under polarization process, (c) the electrical testing process.

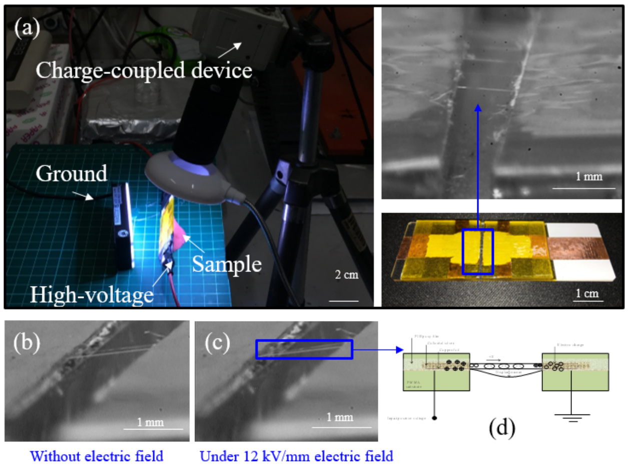


Figure 3: View of testing sample and its reverse piezoelectricity effect, (a) View of testing sample, (b) The spider silk without electric field, (c) The spider silk under 12 kV/mm electric field (d) Illustration of reverse piezoelectricity effect.

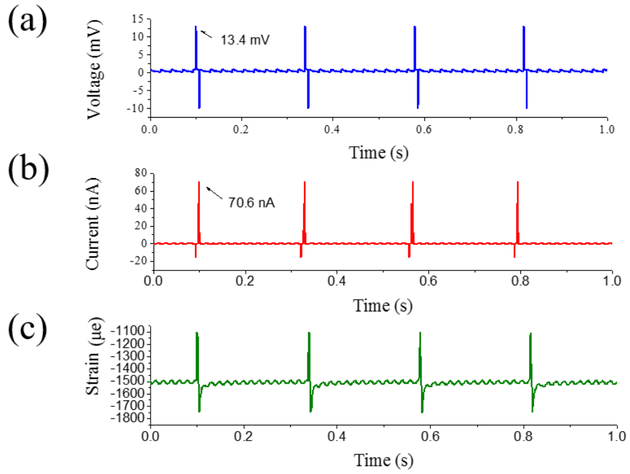


Figure 4: Result of the non-polarized silk electrical testing, (a) output diagram of open circuit voltage value, (b) output diagram of loading current value, (c) output diagram of strain value (the strain rate was 0.02 1/s).

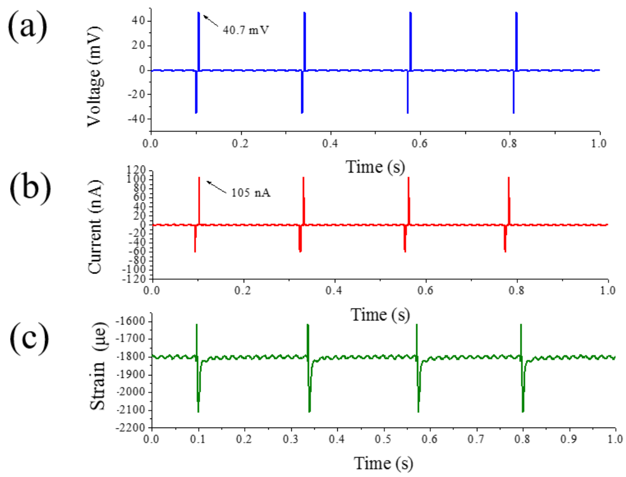


Figure 5: Result of the polarized silk electrical testing, (a) output diagram of open circuit voltage value, (b) output diagram of loading current value, (c) output diagram of strain value (the strain rate was 0.02 1/s).

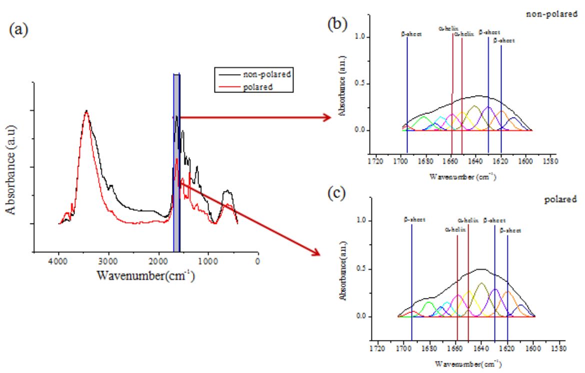


Figure 6: (a) Result of FTIR, (b)The result of non-polarized spider silk' FTIR in 1600~1700 cm^{-1}, (c)The result of polarized spider silk FTIR in 1600~1700 cm^{-1}.

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