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An Attempt to Prepare Flexible–Strong Conductive Fiber with Bagworm Silk

Conductive Fiber

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ABSTRACT

Bagworm silk is the strongest biofiber to date. In this research, we prepared bagworm silk/polypyrrole composite by oxidative polymerization as an attempt for preparation of flexible–strong textiles. Characters of the composite thus synthesized in this study were evaluated with infrared absorption (IR) spectroscopy, scanning electron microscopy (SEM), electron spin resonance (ESR) and conductivity measurement.

Keywords: Bagworm silk, biomaterial, composite, conductive polymer, fiber

Introduction

Bagworm silk is the strongest biofibers at the present stage. Bagworm silk is consisted of β sheet crystal and amorphous structure for protein. The strength of the bagworm silk is derived from the long length amorphous parts[1,2].

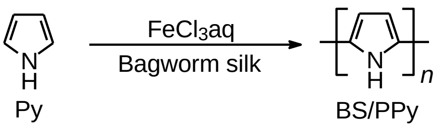
In this research, we attempted to synthesis of flexible–strong conductive fiber with bagworm silk. Polymerization of pyrrole with $FeCl_3$ was carried out on the surface of the bagworm silk fiber.

Experimental

Materials

Bagworm silk fiber was collected from the nest of bagworm obtained in Shizuoka (Japan).

Synthesis



Scheme 1. Synthesis of bagworm silk/polypyrrole composite (BS/PPy).

$FeCl_3$ (20 mg) was dissolved in the water (500 μL). Bagworm silk (0.35 mg) was immersed into the aqueous solution. After 17 h, the bagworm silk containing $FeCl_3$ was placed on a glass plate. Then, pyrrole (10 μL) was added to the bagworm silk. Oxidative polymerization of pyrrole on surface of the silk was carried out with $FeCl_3$. The composite was washed by large volume of water and dried in the ambient atmosphere to obtain the product as a form of black fiber (0.47 mg).

Results and discussion

Molecular Structure

IR spectra for pyrrole (Py) as a monomer, bagworm silk (BS) and bagworm silk/polypyrrole (BS/PPy) were shown in Figure 1. Py shows N–H stretching vibration at 3403 and 3127 cm^{-1}. BS/PPy displays the N–H stretching vibration at 3175 cm^{-1}, indicating successful polymerization of pyrrole on the silk. Furthermore, absorptions derived from amide of protein are observed at ca. 1700 and 1500 cm^{-1}. These results indicate that the product has both characters of PPy and BS.

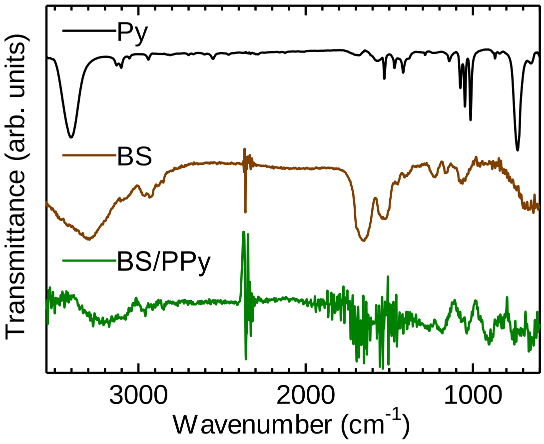


Figure 1. IR spectra for pyrrole (Py), bagworm silk (BS) and BS/PPy.

Surface images

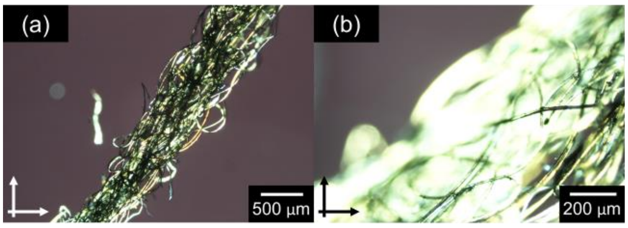


Figure 2. Polarizing optical microscopy (POM) images of BS/PPy. (a): Low magnification. (b): High magnification.

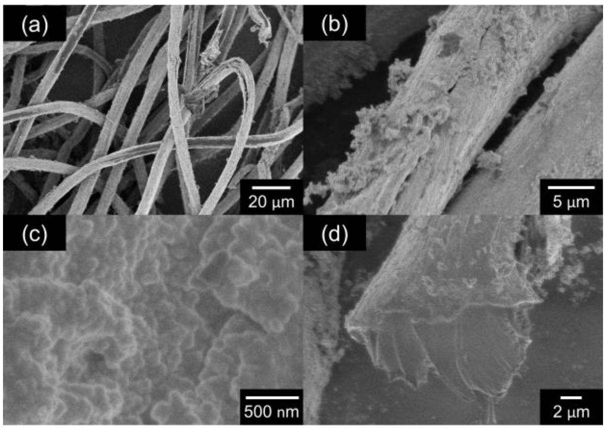


Figure 3. Scanning electron microscopy (SEM) images of BS/PPy. (a): Low magnification. (b,c): High magnification. (d): Cross section.

Figure 2 shows polarizing optical microscopy (POM) images of BS/PPy. Figure 3 displays the SEM images of BS/PPy, indicating PPy is coated on the silk fiber.

Charge carrier and Conductivity

Figure 4 shows the result of electron spin resonance (ESR) spectroscopy measurements of BS and BS/PPy. BS has no ESR signals due to no radicals in the element. Peak width of the ESR signal (ΔH_{pp}) for BS/PPy was 0.527 mT. g value is 2.00388, indicating the charge carrier of BS/PPy is polarons in the polypyrrole chains. Conductivity of the composite was 5.34×10^{-3} S/cm as modarate value.

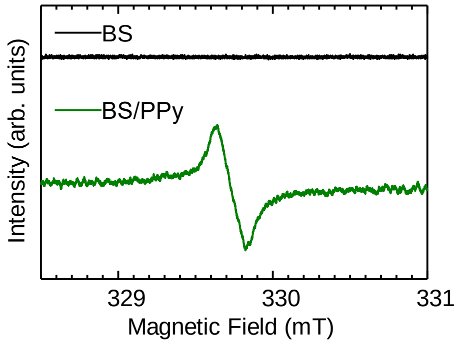


Figure 4. ESR spectra of BS and BS/PPy.

Conclusions and future work

Synthesis of bagworm silk/polypyrrole composite with electrical conductivity was successfully carried out. In the present study, we could employ only small amount of the short length silk fiber for synthesis of the composite. Preparation of the natural/synthetic polymer composite thread with a long length silk fiber to examine mechanical strength is the next subject.

Acknowledgements

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References

[1] Yoshioka, T.; Tsubota, T.; Tashiro, K.; Jouraku, A.; Kameda, T. A Study of the Extraordinarily Strong and Tough Silk Produced by Bagworms. *Nat. Commun.* 2019, 10 (1), 1–11. https://doi.org/10.1038/s41467–019–09350–3.

[2] Tsubota, T.; Yoshioka, T.; Jouraku, A.; Suzuki, T. K.; Yonemura, N.; Yukuhiro, K.; Kameda, T.; Sezutsu, H. Transcriptomic Analysis of the Bagworm Moth Silk Gland Reveals a Number of Silk Genes Conserved within Lepidoptera. *Insect Sci.*, published on 26 June. https://doi.org/10.1111/1744–7917.12846.

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