

Natural Flax Fibres for Sustainable Sensor Applications

Yi Chen¹, Anna de Lena¹, Sansan Shen^{1,3}, Robert Abbel¹, Sofiane Guessama², Kate Parker¹, Xuejun Li³

¹ Bioeconomy Science Institute, Rotorua, 3010, New Zealand

² INRAE, Research Unit BIA UR1268, Rue Geraudiere, Nantes, F-44316, France

³ Department of Electrical and Electronic Engineering, Auckland University of Technology, Auckland, 1010, New Zealand
yi.chen@scionresearch.com

Summary: This study demonstrated the potential of functionalised natural flax fibres for sustainable sensor applications. Flax yarn coated with reduced graphene oxide (rGO) exhibited promising electrical properties for e-textiles application. In contrast, flax fibres coated with conductive polymer, polyaniline (PANI) showed high sensitivity to ammonia, highlighting their potential for seafood freshness monitoring.

Keywords: flax fibre, conductive coating, e-textile, ammonia sensing

Introduction

Electronic textiles (e-textiles) and smart packaging are rapidly emerging as key enabling technologies for product and environmental monitoring, healthcare, and the Internet of Things (IoT). However, these systems are predominantly manufactured using petroleum-derived synthetic materials, raising concerns regarding their environmental impact and end-of-life disposal.

The growing demand for sustainable materials has accelerated the development of bio-based alternatives to conventional petroleum-derived materials used in sensors and electronics. Flax (*Linum usitatissimum*) is one of the world's oldest and most widely cultivated natural bast fibres. It possesses an attractive combination of high specific strength, low density, renewability, and low embodied energy, making it an excellent candidate for sustainable advanced materials [1]. Flax fibres exhibit good flexibility, breathability, and moisture management, which have led to their widespread use in textiles and fibre-reinforced composites. More recently, flax has attracted increasing attention for electronics and sensors, particularly in applications requiring lightweight, flexible, and environmentally friendly substrates, such as wearable electronics and smart packaging [2].

This work investigates the development of functional flax materials using conductive coating strategies based on reduced graphene oxide (rGO) and conductive polymer polyaniline (PANI). Two commercial flax substrates were evaluated for their potential applications in e-textiles and smart packaging demonstrating the versatility of natural fibres for next-generation electronic and sensing technologies.

Materials and methods

For e-textile application, flax yarn supplied by Linificio (Italy) was cut into pieces of 15 cm length and sequentially cleaned with deionised water and isopropanol to remove surface contaminants, followed by drying in an oven at 60 °C for 5 minutes. The pre-cleaned yarns were then fully immersed in a graphene oxide (GO) solution (5 mg/mL) for 1 minute then air-dried at room temperature until completely dry. This dip-coating process was repeated to prepare yarns with different GO loading levels. The GO-coated yarns were placed in an ascorbic acid solution (8 mg/mL) and kept in at 90 °C for 24 hours to reduce GO to reduced graphene oxide (rGO).

For ammonia sensing, New Zealand native flax, harakeke (*Phormium tenax*) fibre sheets were investigated as a sustainable substrate for ammonia gas sensing. Ammonia has been identified as a reliable indicator of seafood freshness. The conductive flax paper-based sensor was fabricated via an in-situ chemical oxidative polymerisation process. Briefly, a pristine flax fibre paper substrate was vertically suspended in 1.0 M HCl aqueous solution. Subsequently, 3.84 mmol of aniline monomer and 5.48 mmol of ammonium persulfate (APS) oxidant were sequentially added to the solution. The in-situ polymerisation reaction was conducted in an ice-water bath (0–5 °C) for 7 hours under mild agitation to facilitate the deposition of PANI onto the flax fibre template. Upon completion, the functionalised paper was rinsed with ethanol and deionised water to eliminate unreacted monomers, oligomers, and residual oxidant. Finally, the composite substrate was dried in an oven at 50 °C overnight, yielding the final sensor substrate.

Results

Scanning electron microscopy (SEM) was employed to investigate the morphology of rGO coated flax yarn (10 coating cycles). As shown in Fig. 1, compared with the uncoated yarn, the GO coating and reduction process generated gaps between individual fibres of yarn, while the deposited rGO sheets assembled into an interconnected three-dimensional network throughout the yarn structure. Rather than coating only the surface of individual fibres, the rGO bridged adjacent fibres and formed conductive pathways across multiple fibre layers. This interconnected architecture is expected to facilitate efficient electron transport, making it well suited for potential e-textile integration applications.

The electrothermal performance of the rGO-coated yarn was further evaluated. Compared with the uncoated yarn, the rGO-coated yarn exhibited a measurable surface temperature increase of $\sim 1.56^\circ\text{C}$ under an applied voltage of 30 V. Infrared thermal imaging also confirmed a uniform heating distribution along the yarn, demonstrating its potential for wearable heating textiles applications.

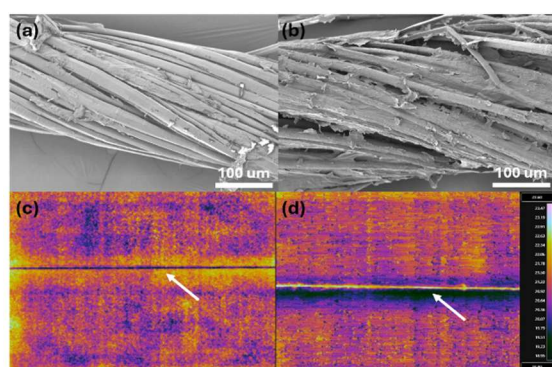


Fig. 1. SEM images of (a) flax yarn, (b) rGO coated yarn (10 times coating cycles), infrared thermal images of flax yarn (c) and rGO coated yarn (d) with applied voltage of 30 V.

PANI coated New Zealand flax fibres were further fabricated for ammonia sensing. The PANI-coated flax fibres exhibited a rougher surface morphology than the uncoated fibres (Fig. 2a and 2b), indicating the successful and uniform deposition of the PANI layer across the fibre surface while preserving the porous fibre structure. Maintaining this porous morphology is advantageous for gas sensing, as it facilitates gas diffusion and interaction with the sensing material. As shown in Fig. 2c, the electrical resistance of the sensor increased upon exposure to ammonia at 80% relative humidity (RH) and 20°C , owing to the dedoping of the protonated PANI chains by ammonia molecules. The sensor exhibited a response of 15.5% at an ammonia concentration as low as 6 ppm, which increased to 193.0% at 70 ppm. These results demonstrate the high

sensitivity of the PANI-coated flax fibres to ammonia and highlight their potential for seafood freshness monitoring.

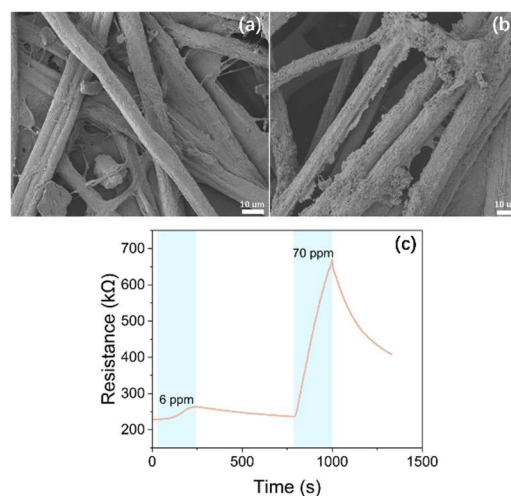


Fig. 2. SEM images of (a) pristine flax sheet, (b) PANI coated flax fibre sheet, (c) ammonia sensing performance of PANI coated flax fibre at 80% relative humidity (RH) and 20°C .

Conclusions

This study demonstrated potential sensor applications of flax fibres through functionalisation. The rGO-coated flax yarn exhibited good rGO coating and electrothermal heating performance, highlighting its potential for wearable heating textiles and e-textile integration applications. In contrast, the PANI-coated New Zealand flax fibres demonstrated good sensitivity towards ammonia, indicating their suitability for ammonia sensing and smart packaging applications, particularly for seafood freshness monitoring.

References

- [1] H. Li, et al, Recent progress in flax fiber-based functional composites, *Advanced Fiber Materials* 4, 171-84 (2022); doi:10.1007/s42765-021-00115-6
- [2] K. Zeng, et al, Design, fabrication and assembly considerations for electronic systems made of fibre devices, *Nature Reviews Materials* 8, 552-561 (2023); doi:10.1038/s41578-023-00573-x

Acknowledgements

This work has received financial support from the UPWEARS project, which is part of the Horizon Europe programme (grant agreement no. 101130741). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HADEA. Neither the European Union nor the granting authority can be held responsible for them. The work was also supported by the Smart Idea Project (No. [AUTX2302](#)) from the Ministry of Business, Innovation & Employment (MBIE), New Zealand.