Next-generation nanocomposite strain sensors

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Strain Sensors

While strain sensors are the best approach to contact mode monitoring[1], it is difficult to find a compromise between their elasticity and sensitivity[2]. These devices accurately **detect deformation**, triggering a **shift on its resistivity**. The fractional resistance change is related to the mechanical strain by the **Gauge Factor** (GF):

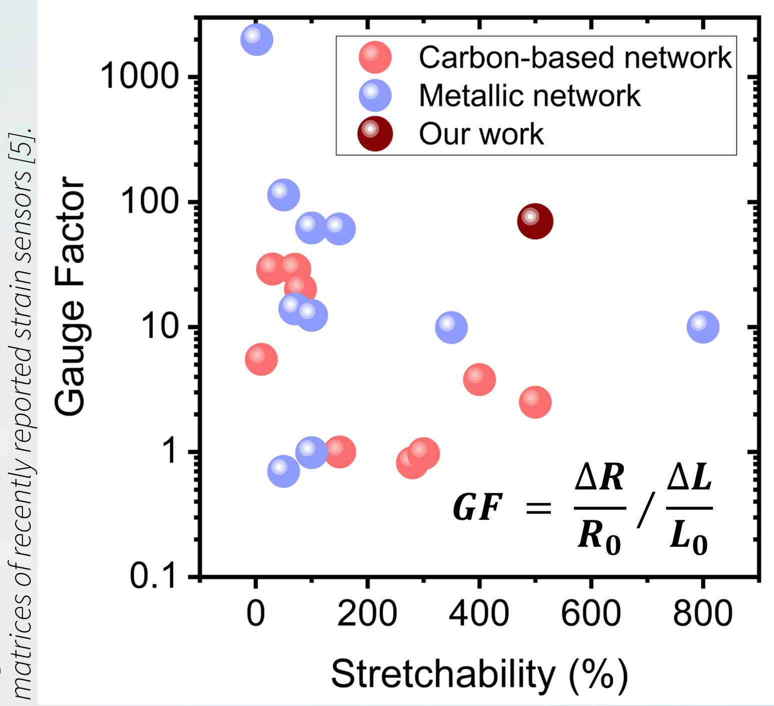


Fig. 1. Results of different combinations of fillers and matrices of recently reported strain sensors [5].

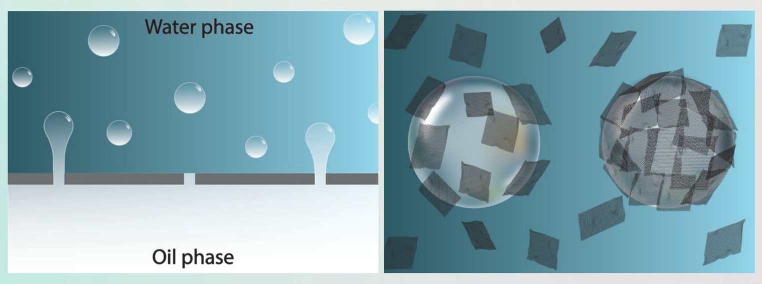


Fig. 2. Fabrication of graphene-coated silicone droplets.

The **optimal choice** of functional **nanoscale fillers**[3–6] and **elastic matrix**[2–6] (*Fig. 1*) makes the sensor easily tuneable according to the application and target[4]. In collaboration with NASA, I'm utilising liquid-exfoliated graphene nanosheets and commercially-available silicones to develop the next generation of nanocomposite strain sensors[3] (*Fig. 2*), yielding excellent electro-mechanical properties with a robust exponential response to applied strain.

Experimental

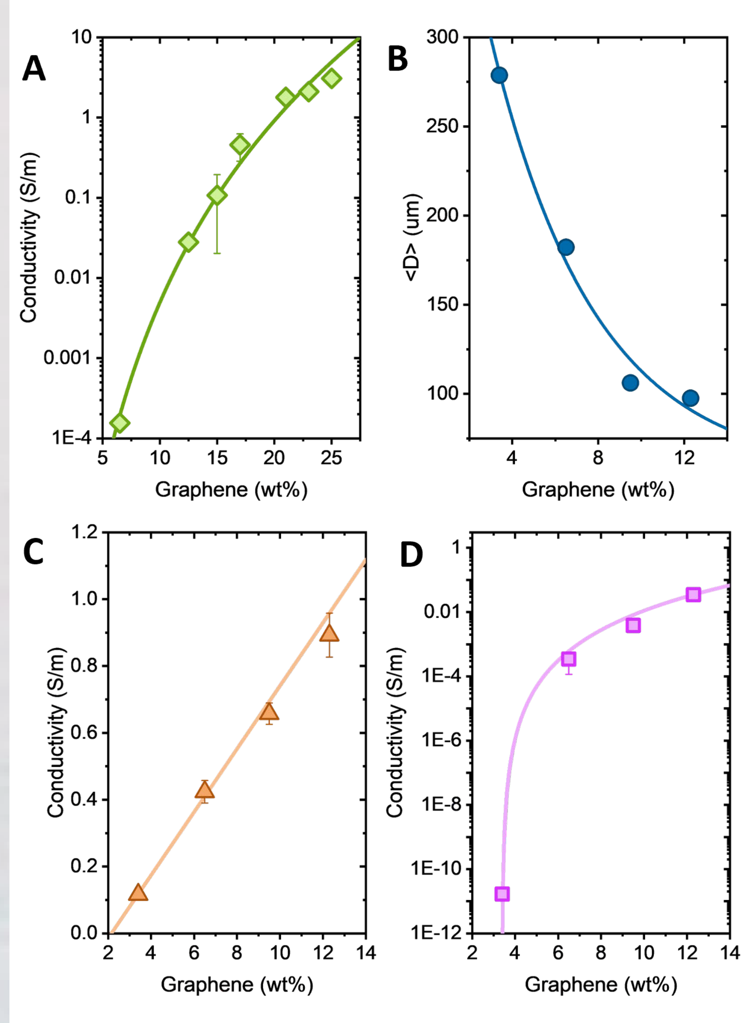


Fig. 3. Plots of the influence of graphene % on A) the conductivity of the matrix, B) the G-Balls diameter, C) the conductivity of the G-Balls, D) G-Balls on the conductivity of the filler.

The **sensor properties** (conductivity, G-Balls diameter, etc.) are **easily tuneable** by changing the graphene content (*Fig. 3*), allowing to choose the most suitable diameter. In a nutshell, the **conductivity increases** with the **graphene concentration**, however it introduces **stiffness** into the matrix.

As can be seen *Fig. 4*, the sensor is very versatile and can be **easily attached to substrates** of different nature (skin, nylon, Kevlar, metal, glass, etc.).

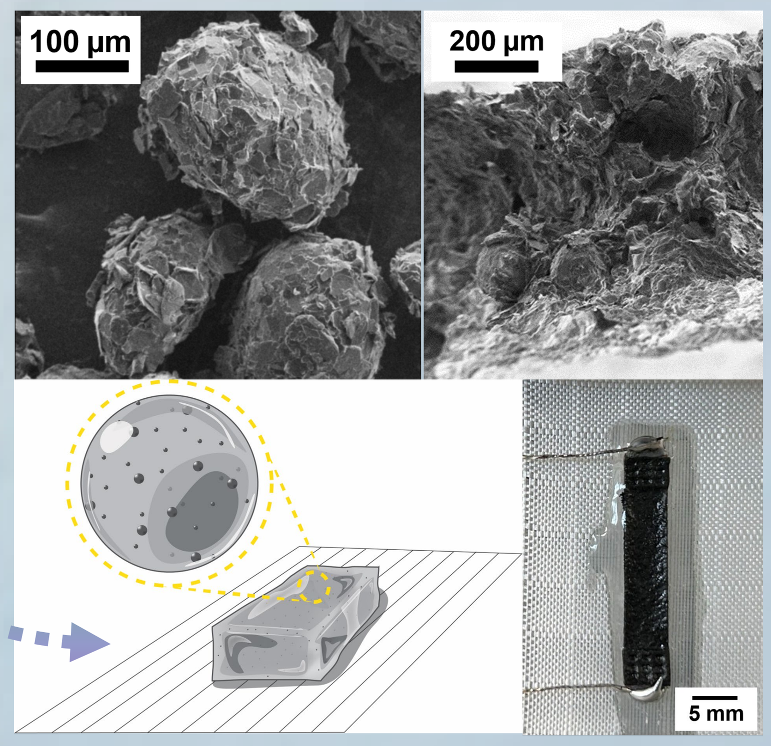
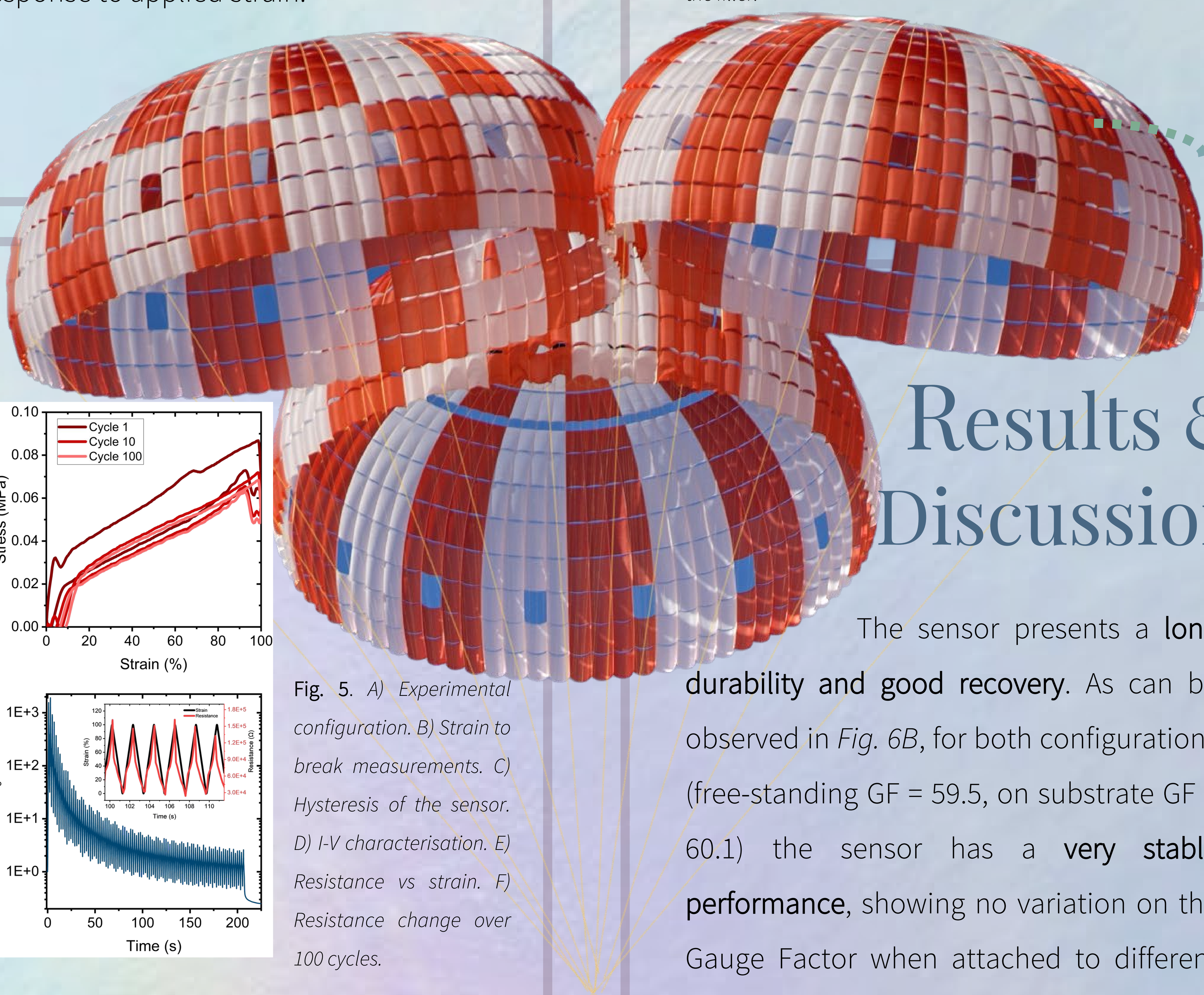


Fig. 4. Sensor SEM images and casting process and set up.



Research Aims

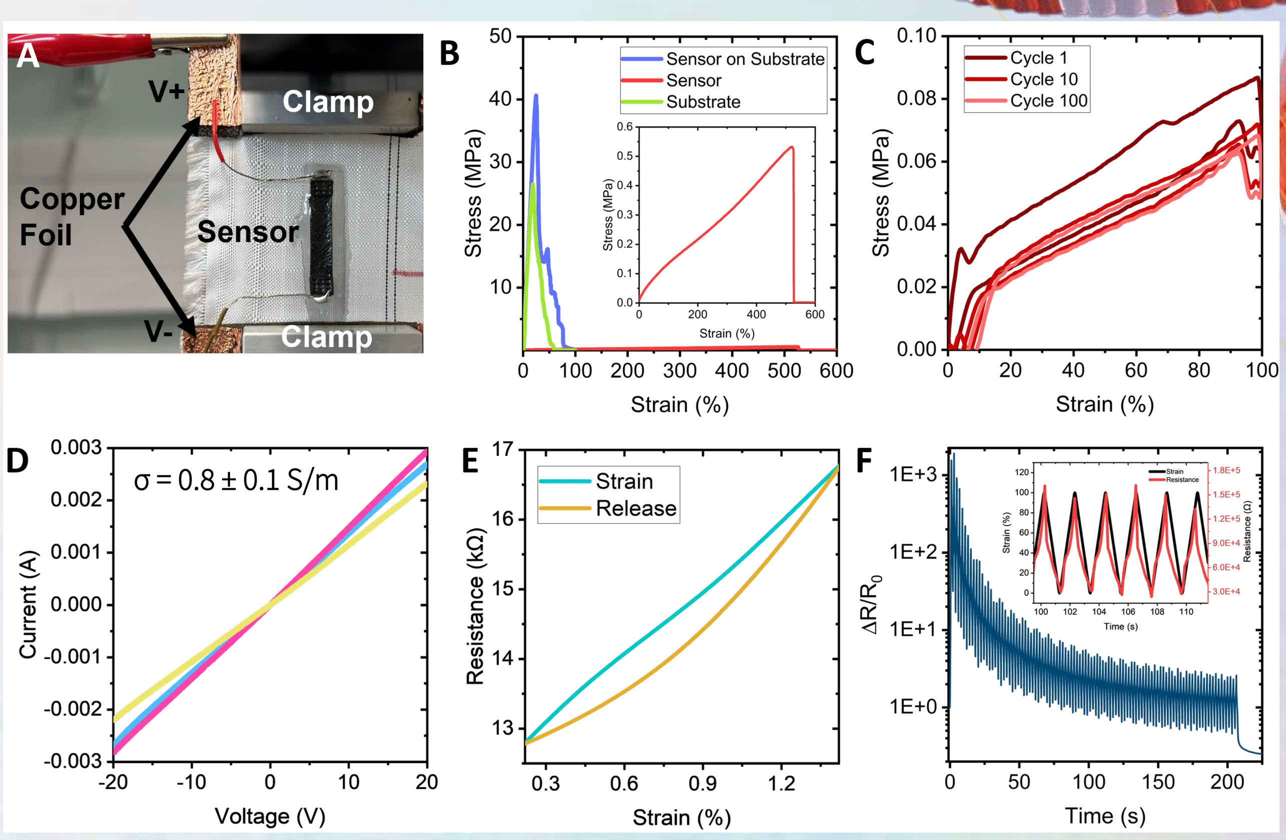


Fig. 5. A) Experimental configuration. B) Strain to break measurements. C) Hysteresis of the sensor. D) I-V characterisation. E) Resistance vs strain. F) Resistance change over 100 cycles.

We've observed no obvious damage after more than 500 cycles up to 100% strain and at a strain rate of 100% per second. Mechanical hysteresis is shown to decrease with increasing cycle number (almost identical in cycle 10 – 100). The sensor exhibits good ohmic conductivity. For the single, high strain rate strain to break measurement a well-defined exponential response is observed up to 160% strain, featuring a high R/R_0 of 2×10^5 (*Fig. 5*). One of the aims of the project is to **integrate** and **attach** the sensor to **surfaces of diverse nature.** Here we've attached it to a nylon fabric that works as a parachute (*Fig. 6A*) canopy material provided by NASA.

Results & Discussion

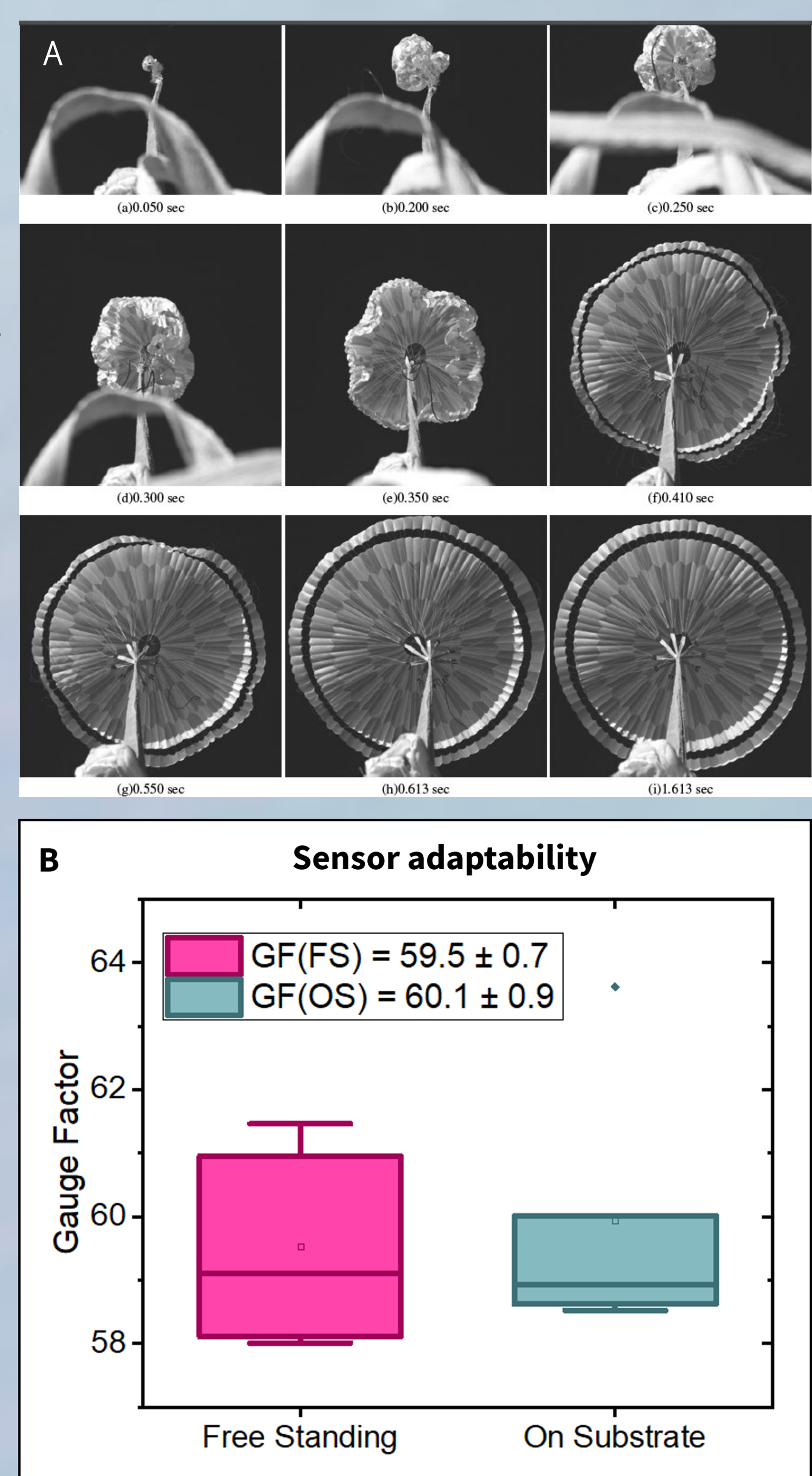
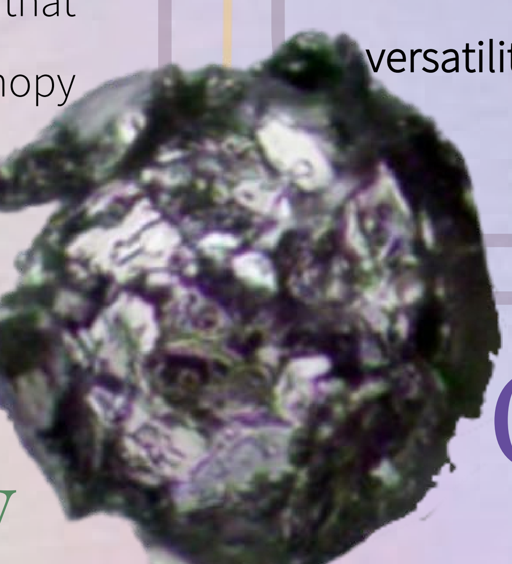


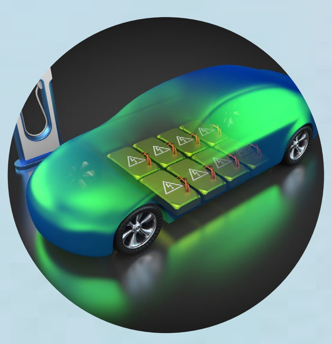
Fig. 6. A) NASA images of a canopy deployment. A) Free Standing sensor and Sensor on Canopy Gauge Factor up to 1000 cycles.

The sensor presents a **long durability** and **good recovery**. As can be observed in *Fig. 6B*, for both configurations (free-standing GF = 59.5, on substrate GF = 60.1) the sensor has a **very stable performance**, showing no variation on the Gauge Factor when attached to different substrates, and no variability over 1000 cycles. The sensor presents **good attachment and behaviour**, and when comparing the Gauge Factor of both cases, it is remarkable that the substrate barely affect its value, showing **reliability** and **versatility**.



Applications & Sustainability

Monitoring of the loads experienced by wind turbine blades during operation and their deterioration (**fatigue** testing).



Strain is a **critical parameter** to determine the state of lithium-ion batteries, as it is an **efficiency** and **safety** indicator[7].

Strain sensors have a **broad range** of health-related applications: **breathing**, **pulse**, **swallowing** and **joint** movements detection.

Conclusions

- ➢ We've developed an **innovative**, **adaptable** and **integrable** strain sensor made in Sussex.
- ➢ The sensor presents **high sensitivity** and **good mechanical properties**, making it competitive with the sensors in the literature.
- ➢ The versatility of the sensor makes it useful for **health**, **aerospace** and **sustainability applications**.

References

[1] N. Lu, C. Lu, S. Yang, and J. Rogers, Advanced Functional Materials 22(19), 4044–4050 (2012).
[2] C. Zhang, D. Liao, Y. Wang, P. Xie, M. Li, L. Zhou, Y. Chen, and H. Liu, Ceramics International 49(5), 8121–8131 (2023).
[3] M. O'Mara, S. Ogilvie, M. Large, A. Amorim Graf, A. Sehnal, P. Lynch, J. Salvage, I. Jurewicz, A. King, and A. Dalton, Advanced Functional Materials, (2020).
[4] A. del Bosque, X.F. Sánchez-Romate, A. Gómez, M. Sánchez, and A. Ureña, Sensors and Actuators A: Physical 353, 114249 (2023).
[5] M. Amjadi, K.-U. Kyung, I. Park, and M. Sitti, Advanced Functional Materials 26(11), 1678–1698 (2016).
[6] M. Amjadi, A. Pichitpajongkit, S. Lee, S. Ryu, and I. Park, ACS Nano 8(5), 5154–5163 (2014).
[7] J. Peng, X. Zhou, S. Jia, Y. Jin, S. Xu, J. Chen, Journal of Power Sources 433, 226692 (2019).

Graphics by Raquel Cano-Cordero. Thanks to NASA for providing the images for Fig. 6A.

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