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rGO/Mxene Ink for Embedded Sensor in Smart FRP Composites

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1. Introduction

Smart fiber-reinforced polymer (FRP) composite structures have emerged as versatile materials that not only serve as load-bearing components but also as sensing materials to meet safety requirements in a range of applications. While embedded nanocomposite sensors offer improved signal acquisition accuracy and stability for long-term monitoring compared to surface-mounted sensors, matrix cracking or delamination can still occur within composite structures. To address this issue, this study presents the development of conductive reduced graphene oxide/MXene (rGOM) ink and smart composites with embedded sensors that exhibit high sensitivity to mechanical strain, long-term stability, and potential for ultrasonic wave detection highlighting its potential applications in various industries. Further research and development of the rGOM sensor could lead to advancements in the field of smart composite materials, enabling the development of robust and multifunctional structures with enhanced sensing capabilities.

2. Materials and methods

Conductive ink

- Graphene oxide (GO)/MXene was reduced to form a 3D reduced GO (rGO)/MXene hydrogel using L-cysteine. The obtained hydrogels were then redispersed in a solvent to produce reduced GO/MXene (rGOM) ink.

GO rGO rGOM

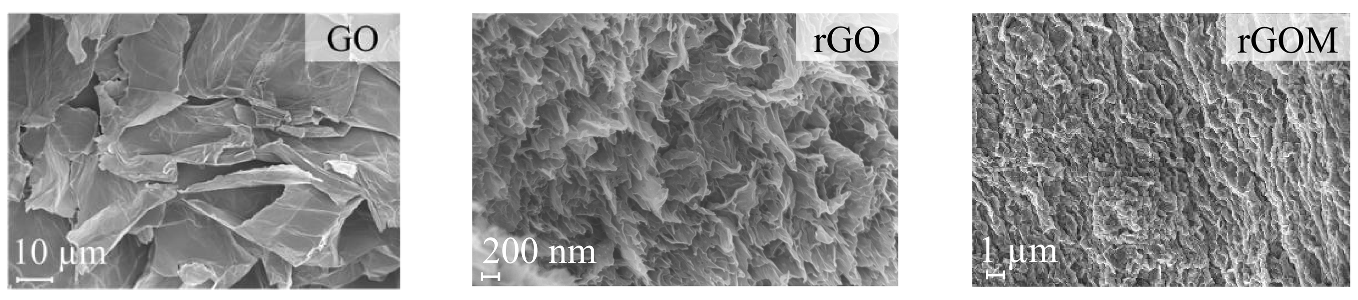
FRP smart composites

- To construct a sensor with a diameter of 10 mm, conductive inks were deposited and dried onto prepreg fabric, and copper wires were attached to the surface of the sensor.

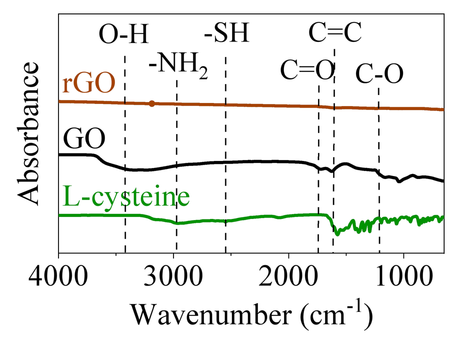
← GF composites
← Sensor layer
← GF composites

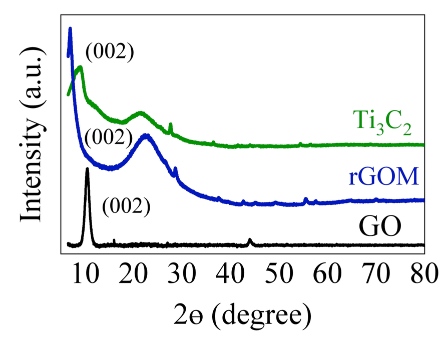
3. Results and discussions

Characterization of the GO nanosheets, hydrogels, and rGOM inks

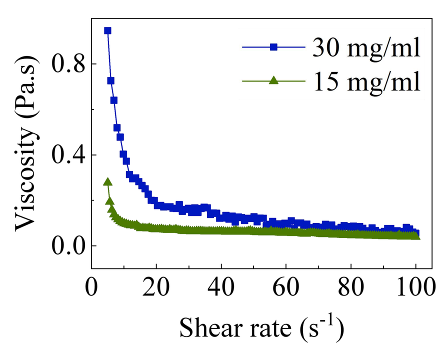


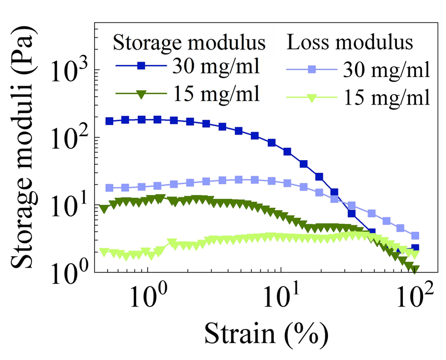
The porous structure was produced by phase separation between water and rGO networks , which occurred as a result of L-cysteine reduction in the GO suspension.





- Oxygen functional groups completely disappeared in rGO
- Show the successful combination of rGO and MXene in rGOM ink





Viscosity

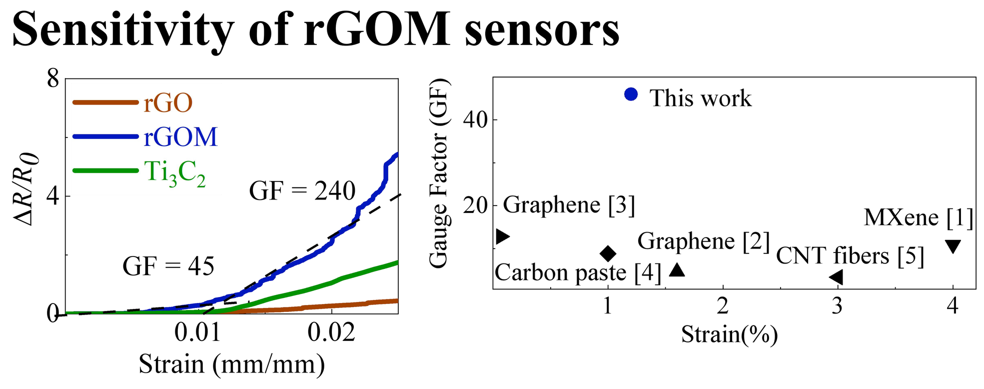
0.9 Pa·s in 30 mg/ml

0.24 Pa·s in 15 mg/ml

Viscoelastic properties (G' and G'')

Both values of 15 mg/ml ink concentration were approximately one order of magnitude lower than those of 30 mg/ml ink concentration.

Sensitivity of rGOM sensors

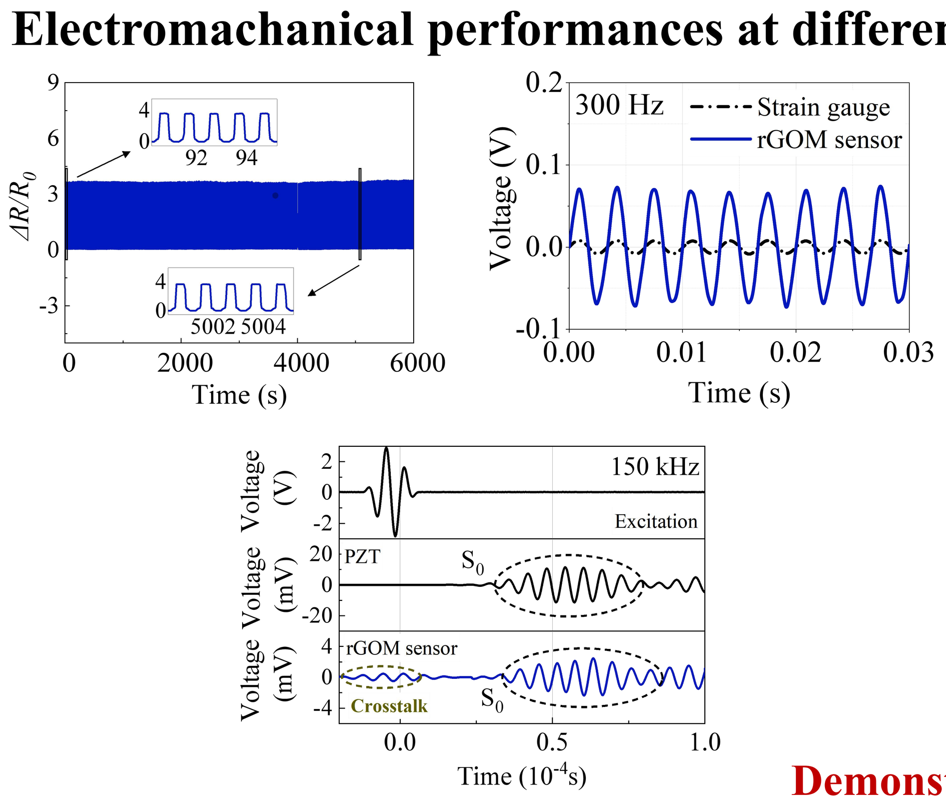


Sensitivity, $GF = (\Delta R/R_0)/\varepsilon$, increased due to changes in contact resistance resulting from two factors:

(1) broken conductivity paths and

(2) increased tunneling effect from adjacent rGOM.

Electromachanical performances at different frequencies



Embedded sensors

At low frequency (1 Hz for 6,000 cycles)

- Demonstrate the reliability and stability

At low-medium frequncy (300 Hz)

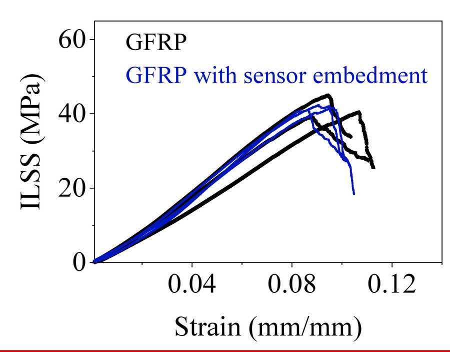
- Exhibit a larger magnitude compared to the stain gauge.
- Show phase differences (due to attachment at different locations).

At high frequncy (150 kHz)

- Exhibit a negligible lag in arrival time compared to the PZT wafer.

Demonstrate high sensitivity and wide-range working conditions

Mechanical properties of FRP laminates with and without sensor embedment



- Demonstrate negligible effects on the mechanical properties of the host FRP laminates.

4. Conclusions

The rGOM sensors, embedded in a prepreg composite prepared using a new polymer-free matrix ink, exhibit excellent sensitivity and successfully maintain the mechanical properties and structural integrity of the host composite structure. The embedded sensors can be fully impregnated with the main prepreg resin, which prevents a mismatch in thermal behavior between the sensor and the main composite. Differences in the coefficient of thermal expansion can lead to cracking and structural deterioration due to temperature changes during use. Therefore, smart FRP composites with embedded sensors made of polymer-free matrix rGOM inks are environmentally friendly and scalable, providing an efficient solution for manufacturing smart prepreg composites in a wide range of applications.

5. Acknowledgements and References

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