Facile Fabrication of Flame-retardant Graphene/Sponge Composite for Pressure Sensing and Electromagnetic Interference Shielding

W. G. Teklebrahan[1], Y. T. Park[2]*, and J. I. Song[1]*

[1]Department of Mechanical Engineering, Changwon National University
[2]Department of Mechanical Engineering, Myongji University

Polyurethane foam (PUF)

Unique properties

- ❑ Comfortable
- ❑ Lightweight
- ❑ Good resilience
- ❑ Insulating behaviour

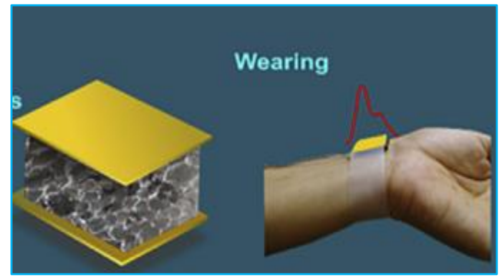
Advanced applications

❑Smart foams (e-foams), i.e., EMI shielding, TENG, piezoresistive, supercapacitors, thermal energy conversion, catalysis, etc.

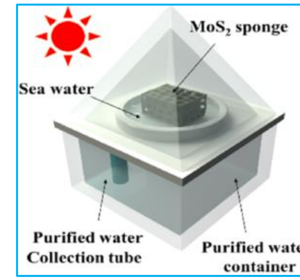
EMI shielding

Advanced applications

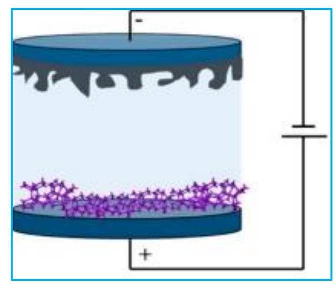
Piezoresistive sensor



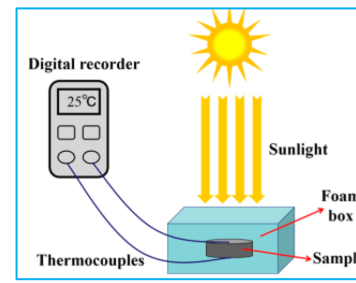
Steam generation



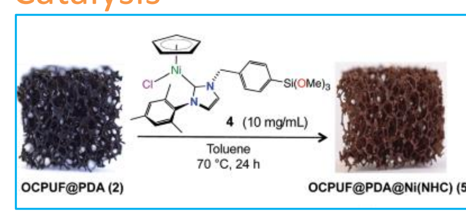
Supercapacitors



Energy conversion



Catalysis



Issues with neat PUF

Highly flammable

- PUF mainly contains C and H
- It is highly porous → swift transfer of heat and fuel during fire hazard

Spreads fire to nearby materials

- Drips flammable molten polymer

Releases toxic and dense smokes

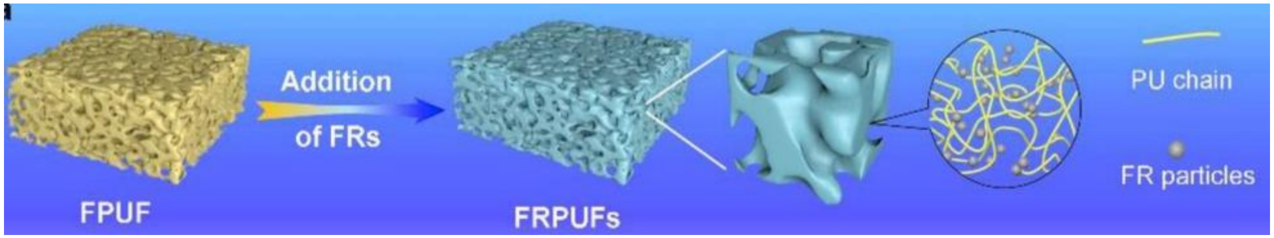
- CO, HCN → deadly within minutes
- Dense smokes makes evacuation and firefighting difficult

Fire risks of consumer products: furniture, cars

Needs modification to lower the flammability and impart functionality

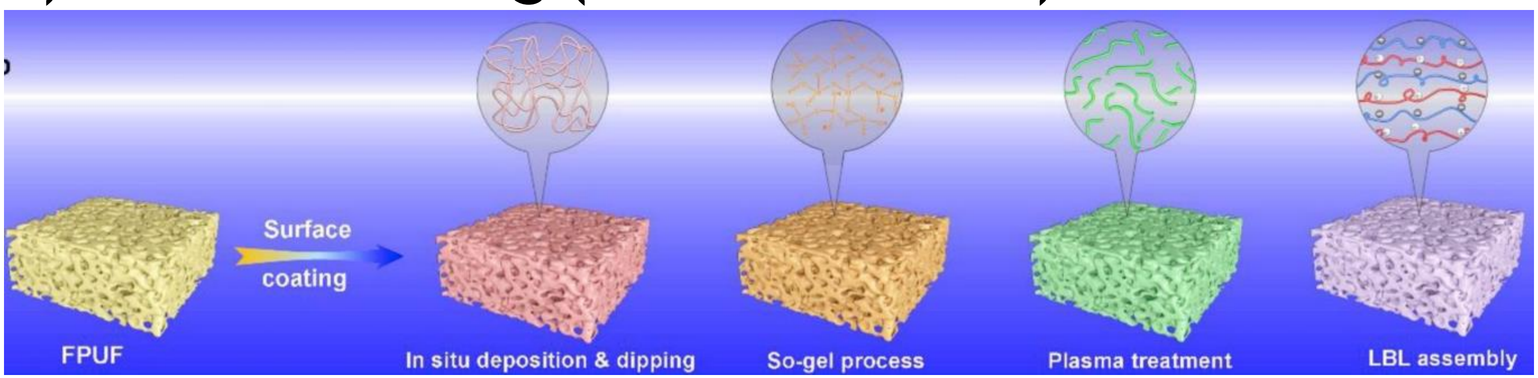
Current strategies

i) Addition of fillers during fabrication



- Needs high loading
- Affects the physical properties of PUF

ii) Surface coating (Post treatment)

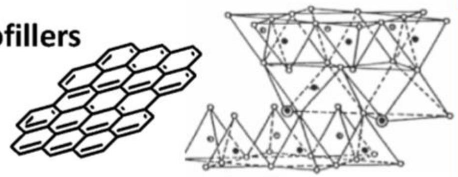


- Modification is on the surface with minimal impact on properties
- Expensive, time-consuming, and tedious due to extensive manual operations

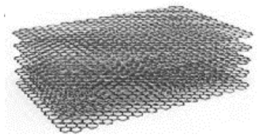
H. Yang et al./Composites Part B 176 (2019) 107185

Research interests

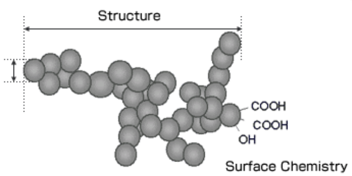
- 2D layered nanofillers
  graphene, clay

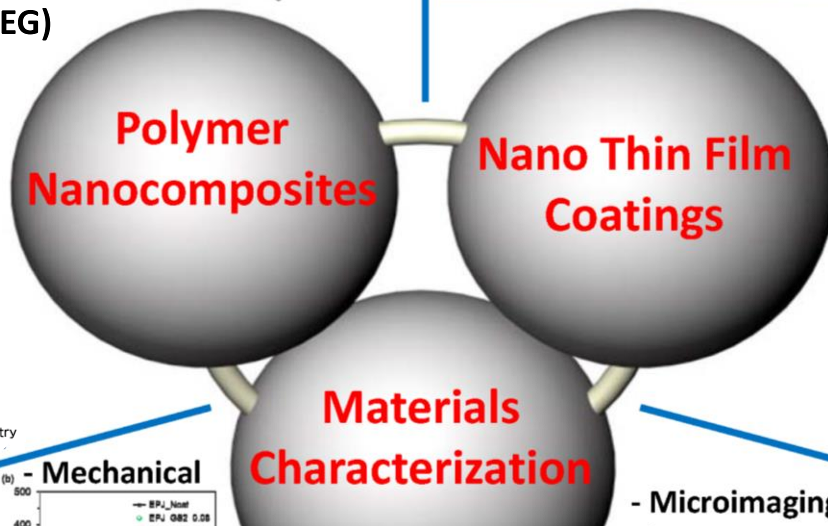


- 3D fillers, graphite (EG)

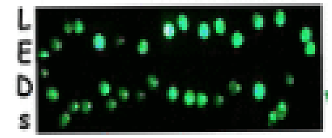


- 0D nanofillers, CB

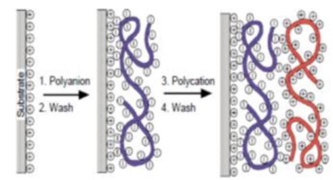




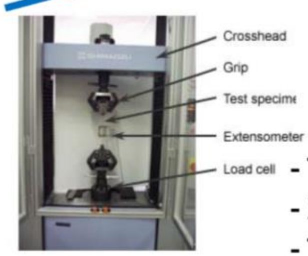
- Multifunctional thin film coating applications

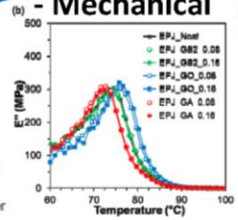


- Layer-by-layer (LbL) self-assembly

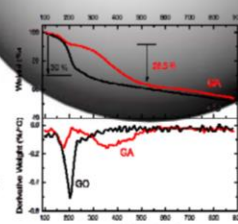


- Mechanical

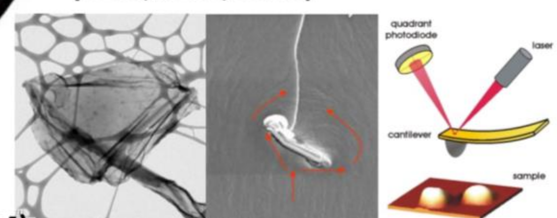




- Thermal (TGA, DSC)
- X-ray (SAXS, XRD)
- Thin film (ellipsometry, UV-vis, FT-IR, QCM)
- Flame retardancy (UL-94, MCC, CC)



- Microimaging
  (TEM, SEM, AFM)



Research interests … cont.

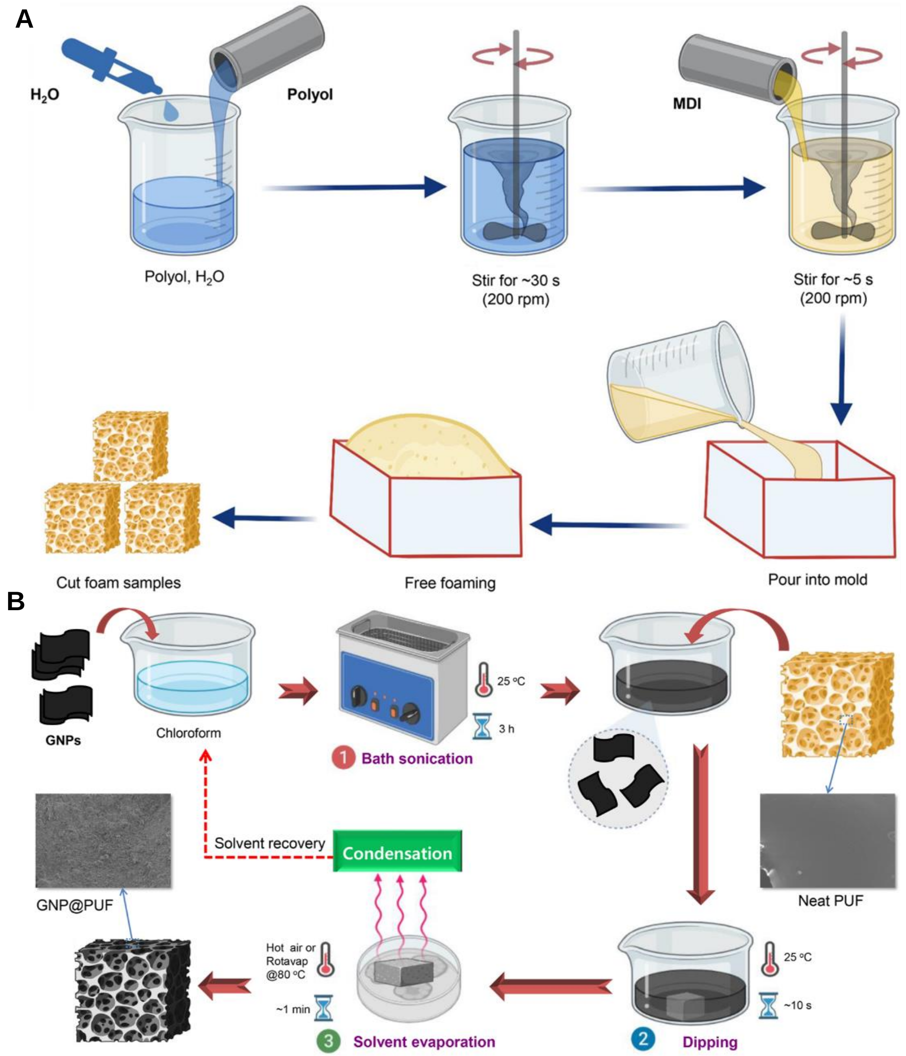
Nanocomposites	Functional coatings	Matrices & filers
PUF/EG/CB/IL[1]	**LbL, PEC, dip-coating[2-4]**	**Matrices: Several biopolymers (CH, AL, PDL, PA)**
• Excellent flame retardancy • Application in energy harvesting • Application in oil-leak sensor	• Improved flame retardancy • Application in pressure sensing and energy • Application in EMI shielding	• Carbon based fillers: expandable graphite (EG), GNP, CB, biomass-derived mesoporous carbon • Clay: montmorillonite (MMT)

Non-flammable **Energy harvesting** **Motion sensing** **EMI shielding**

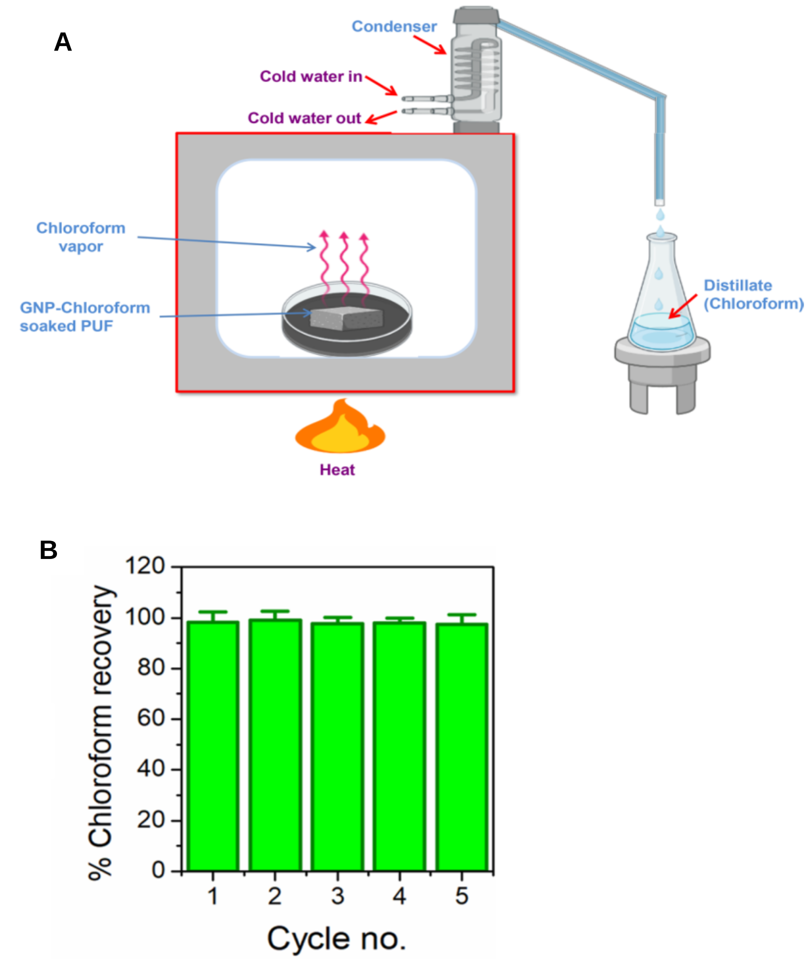
[1] *T. G. Weldemhret et al. /Chemical Engineering Journal 450 (2022) 137982*
[2] *T.G. Weldemhret et al. /Progress in Organic Coatings 161 (2021) 106480*
[3] *T. G. Weldemhret et al. /ACS Appl. Nano Mater. 2022, 5, 9, 12464–12476*
[4] *T. G. Weldemhret et al. /Adv. Mat. Inter. 2023, (in press)*

GNP/PUF composite fabrication process

PUF fabrication (A) and coating process (B)



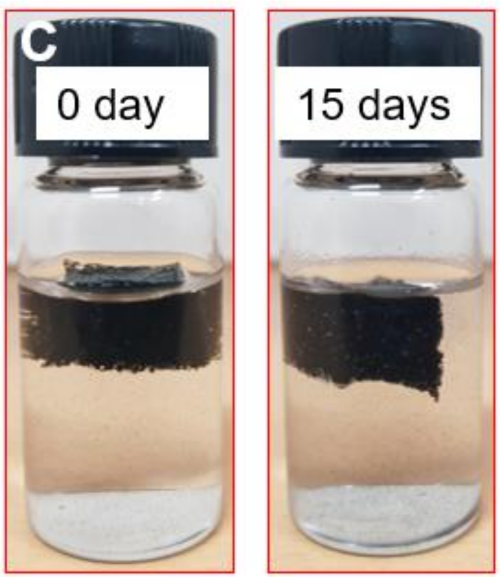
Solvent recycling and recovery (A, B)



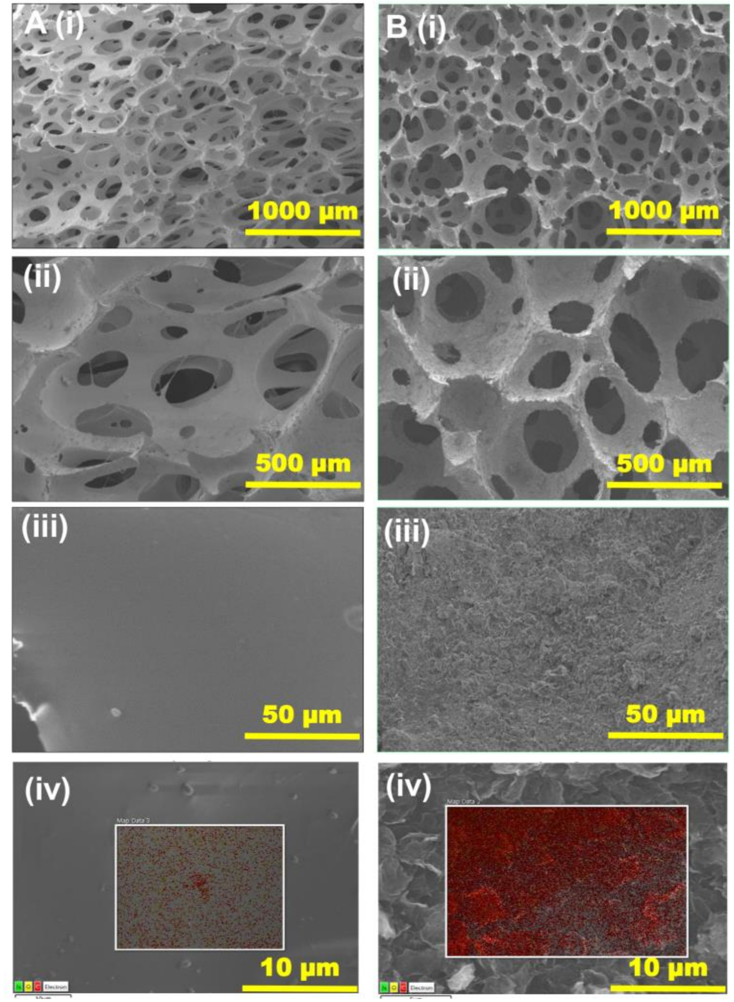
Coating characterization

Digital images of neat and coated PUF

Water stability of the coatings



SEM images of (A) neat and (B) coated PUF



FR properties: MCC and CC tests

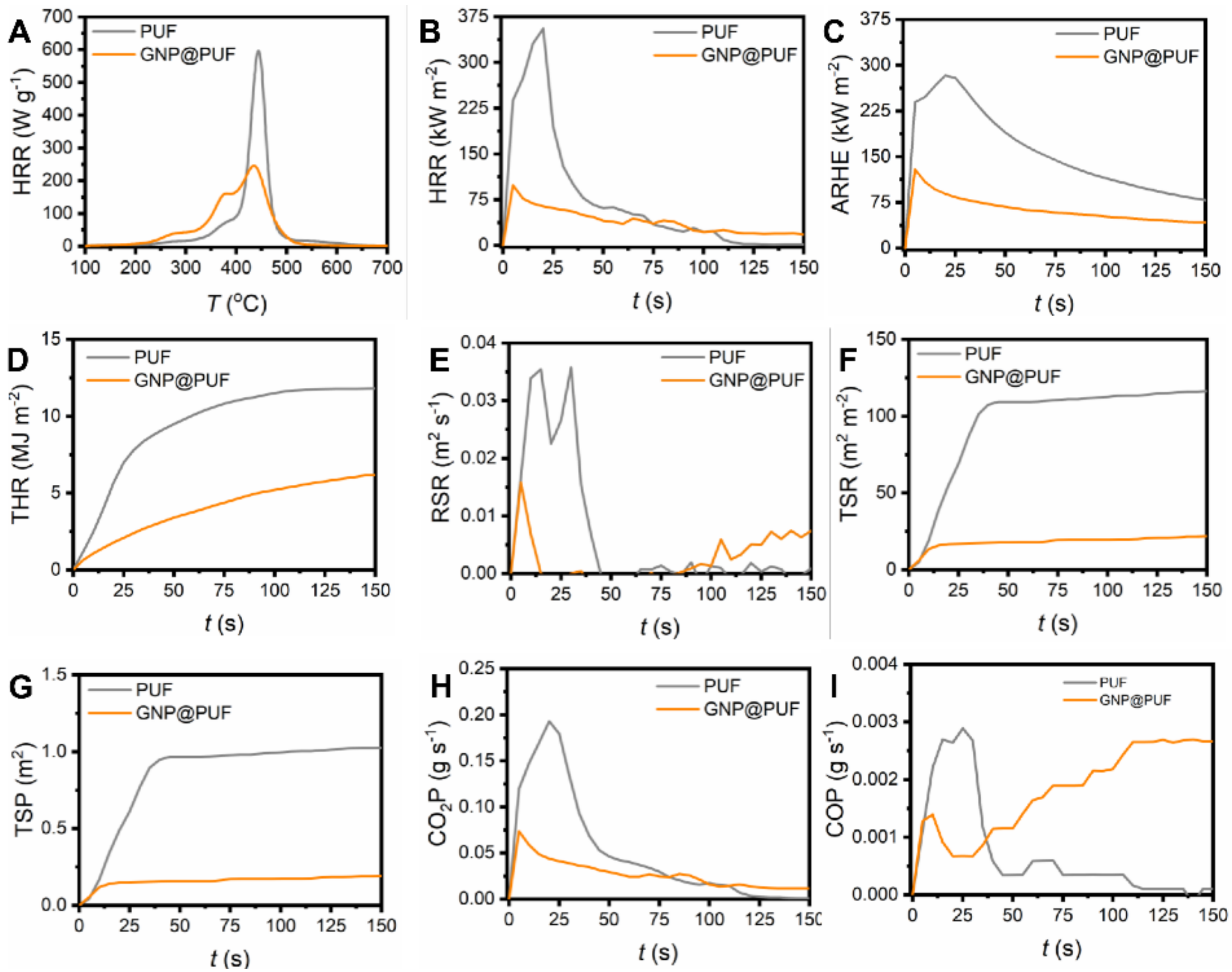
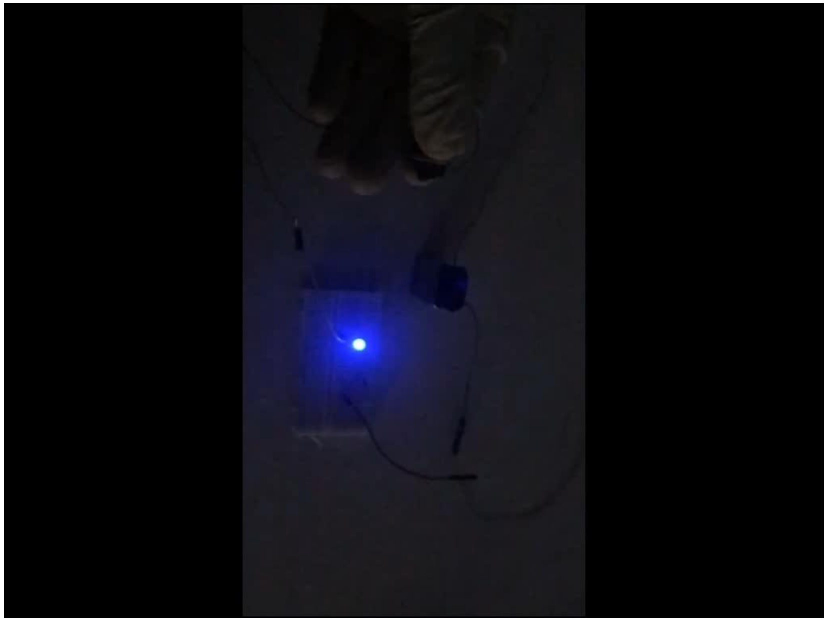
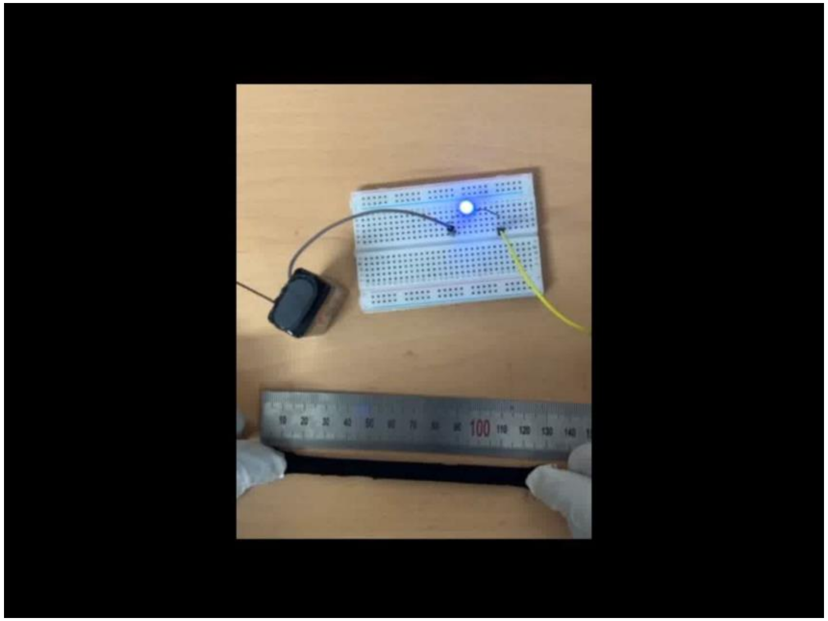


Fig. (A) MCC HRR curve, (B) CC HRR curve, (C) ARHE, (D) THR, I RSR, (F) TSR, (G) TSP, (H) CO2P, and (I) COP. The average value was used for plotting all curves (n = 2).

Piezoresistivity: Qualitative evaluation





Video. A circuit constructed with the GNP@PUF foam, revealing the brightness of LED changes with the compression/stretching and release of the conductive GNP@PUF.

Piezoresistivity: Quantitative evaluation

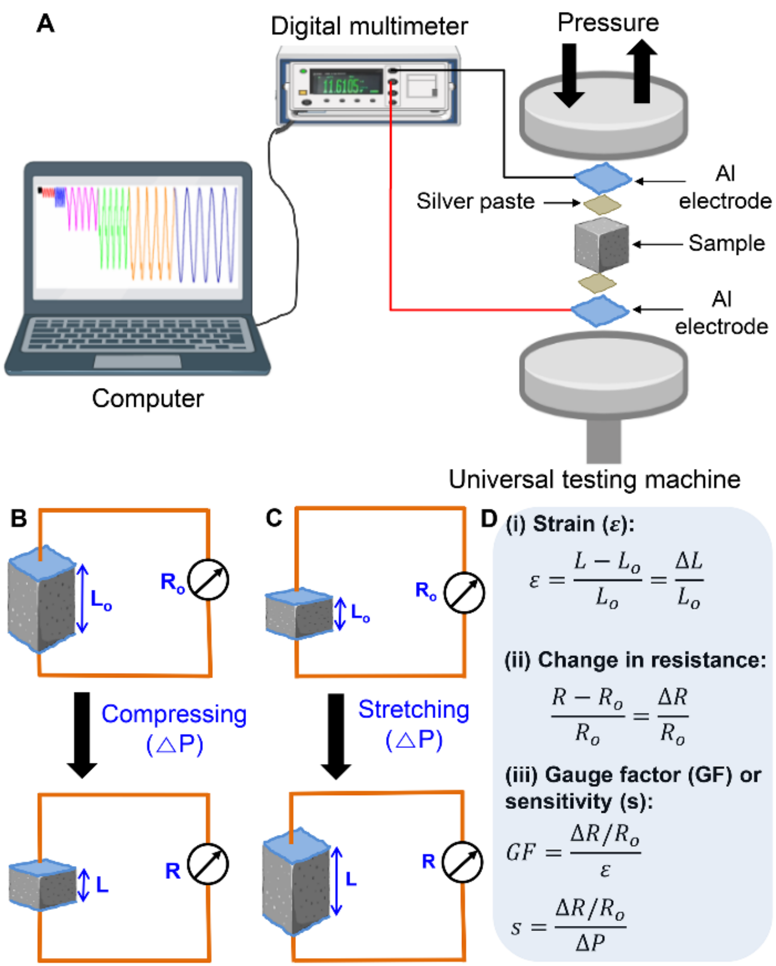


Fig. (A) Experimental setup for the pressure sensor characterization. Schematic showing the circuit diagram of GNP@PUF under (B) compressive and (C) stretching mode. (D) Key performance evaluation

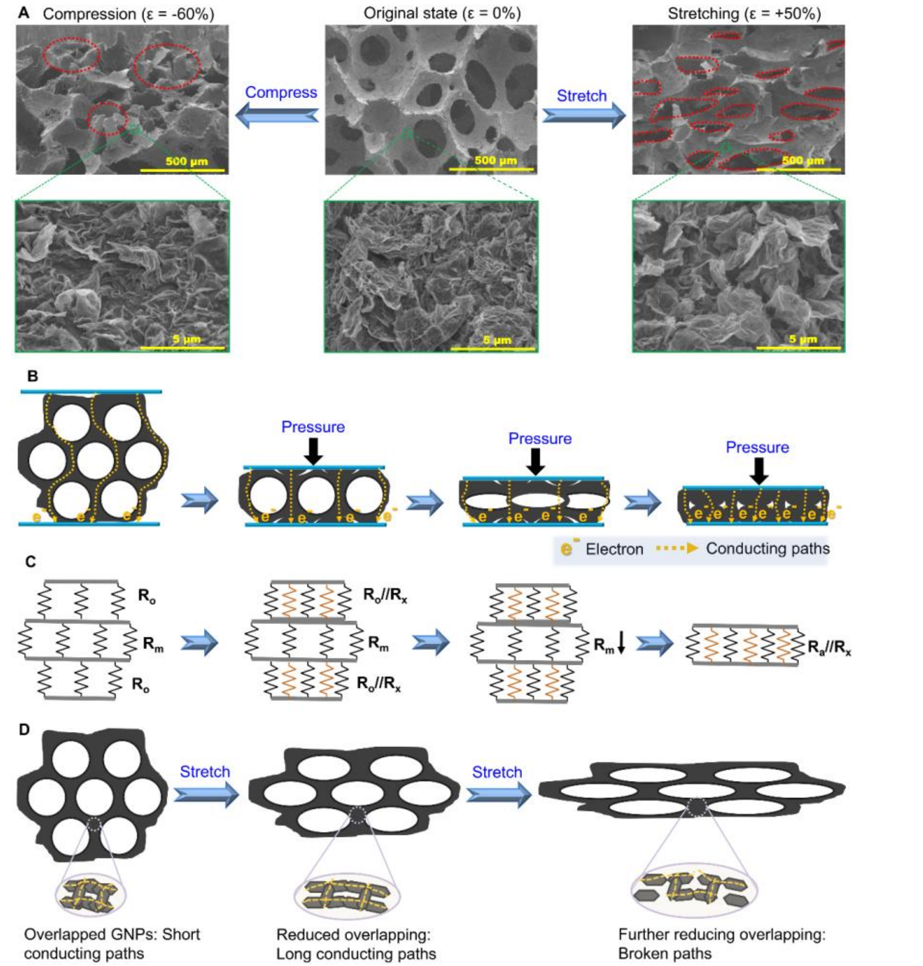


Fig. Schematic illustration of the sensing mechanism of the GNP@PUF sensor under compression and stretching sensing modes.

Sensor characterization

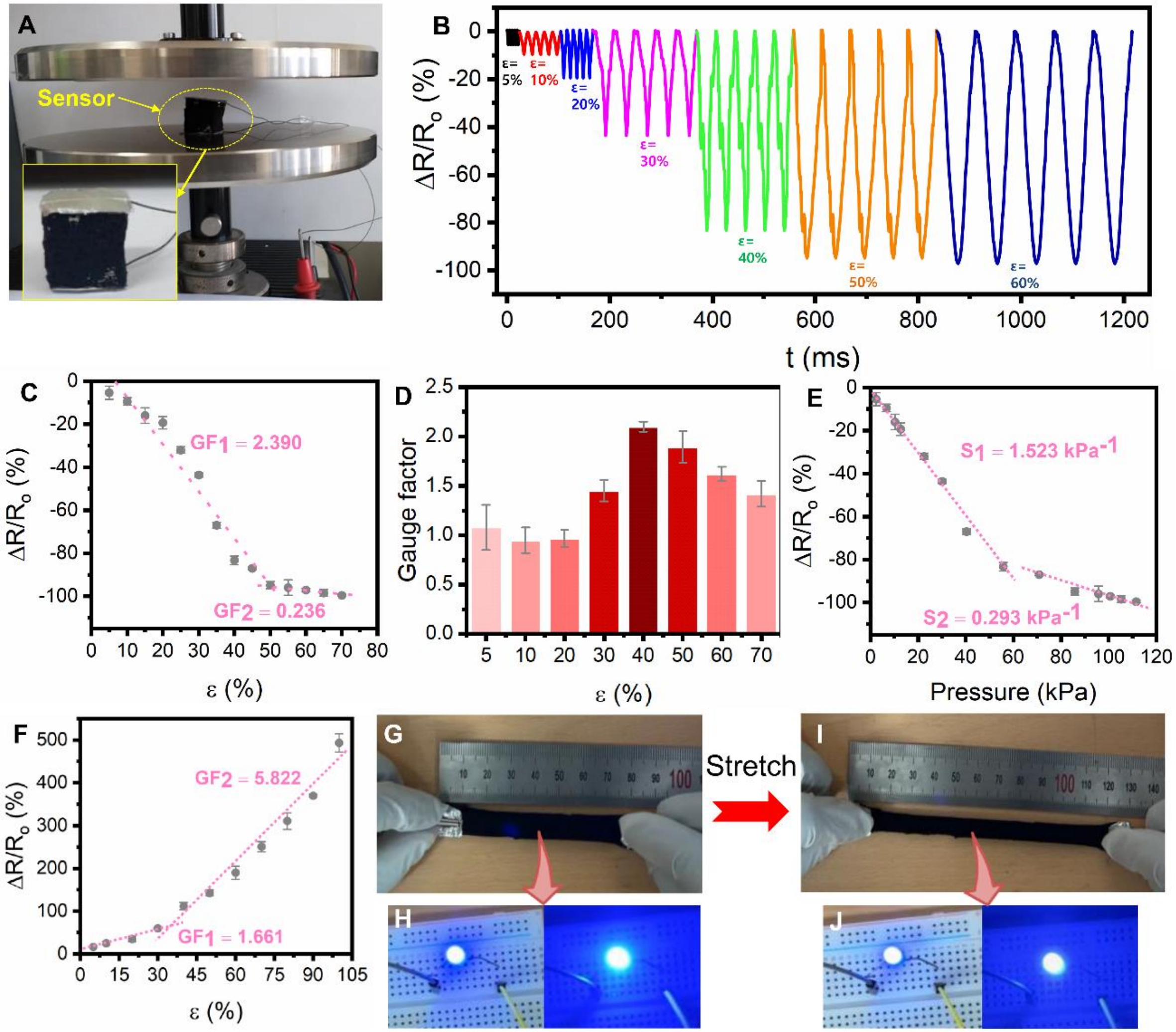


Fig. (A) The GNP@PUF pressure sensor, (B) Sensor response vs. strain, (C) correlation between resistance and strain, (D) calculated gauge factor for different compressive strains, and (E) correlation between resistance and pressure under compressive mode. (F-J) correlation between resistance and strain under stretching mode.

Sensor response time and durability

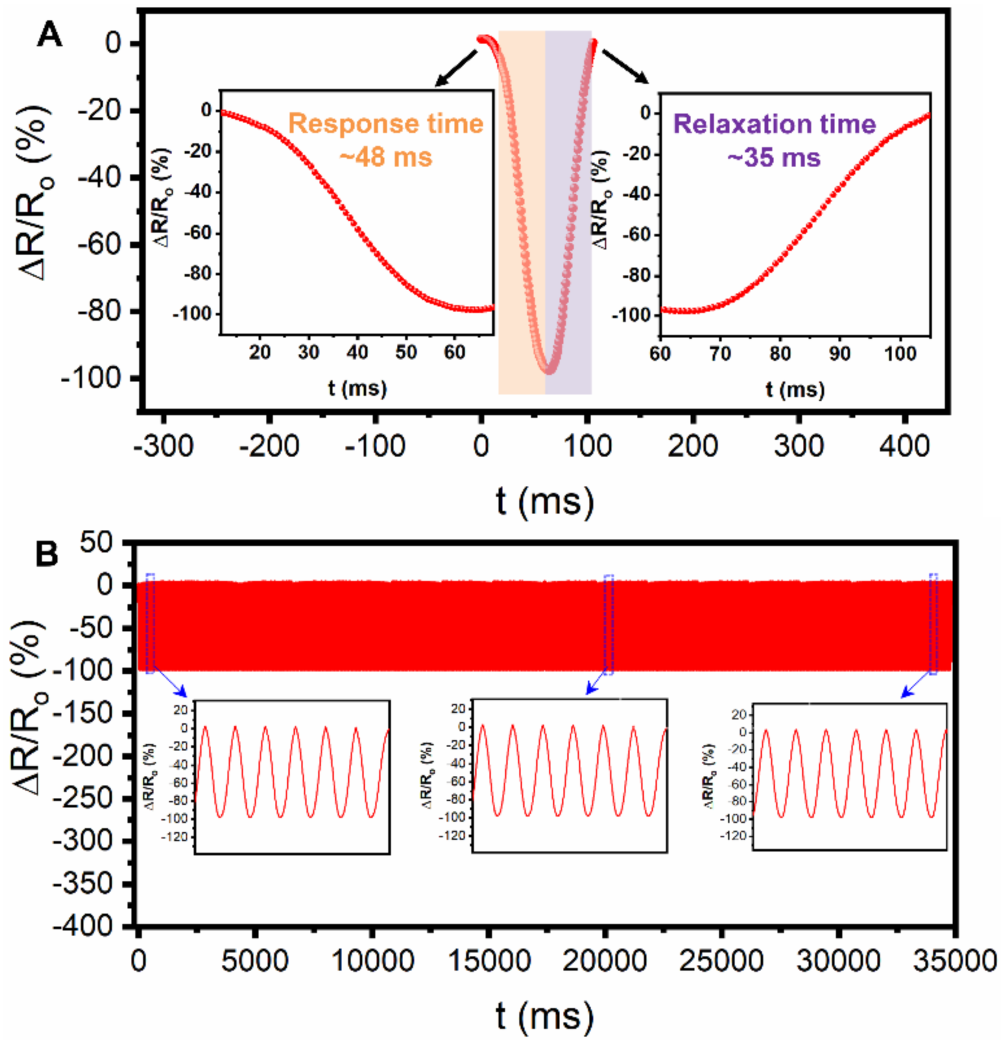


Fig. (A) Response time and (B) stability of the pressure sensor.

Human motion monitoring

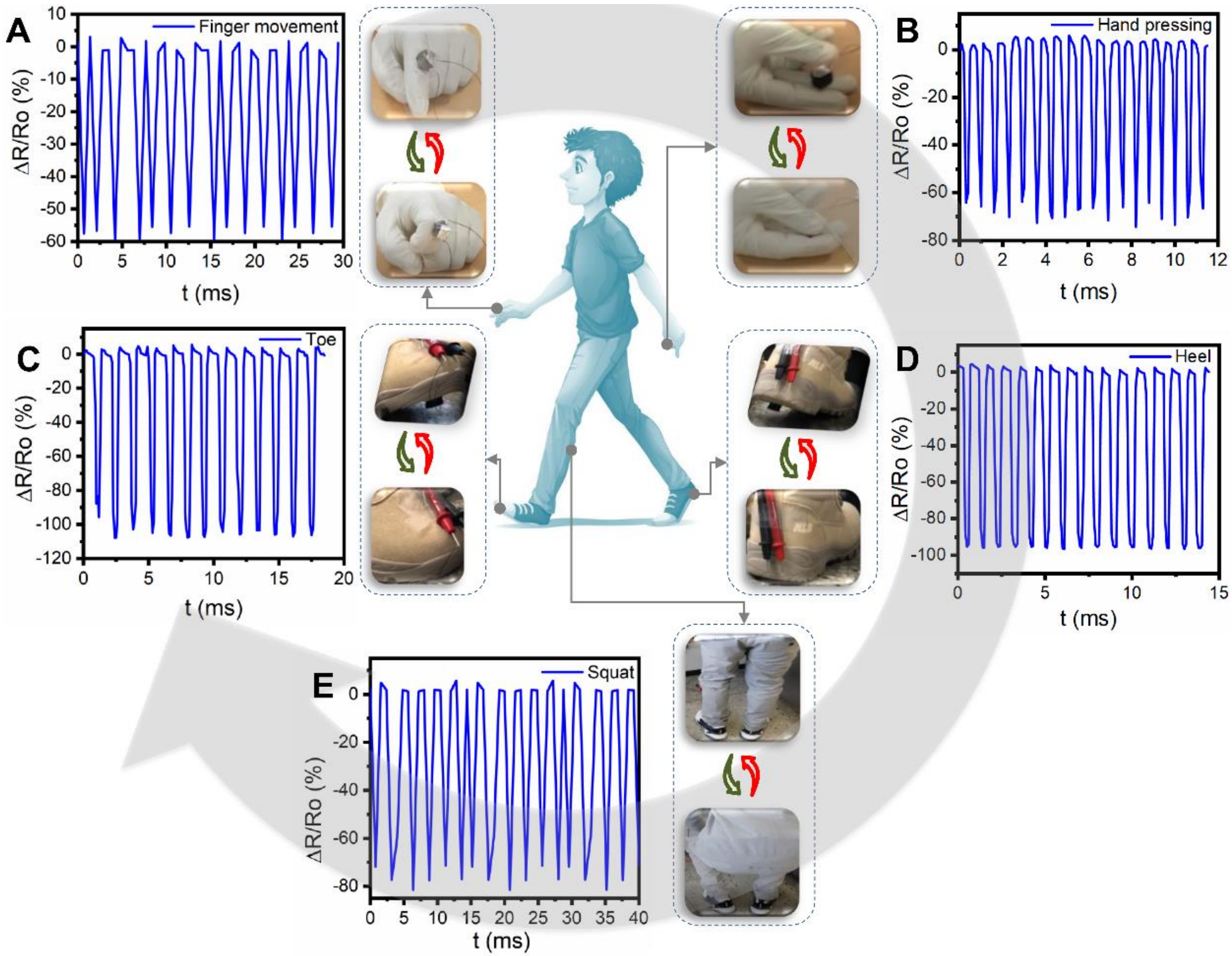
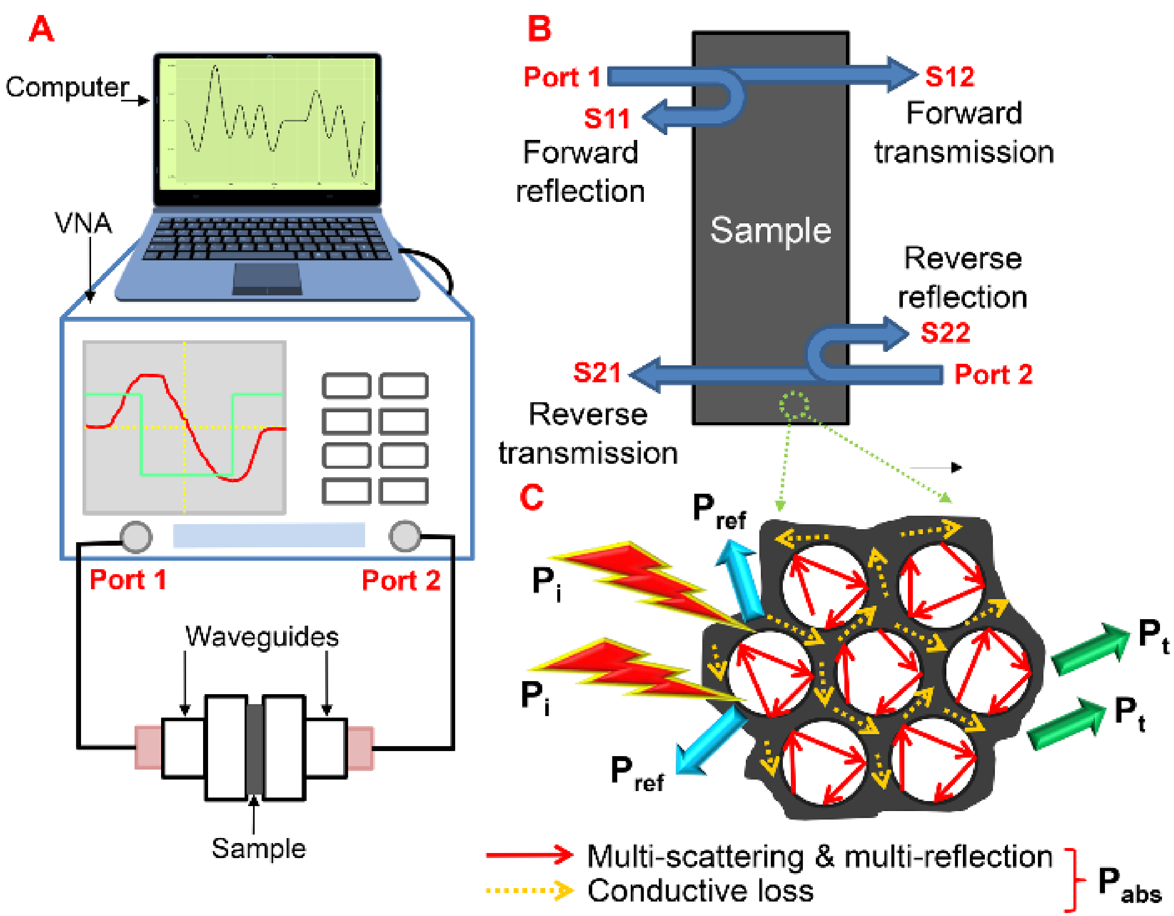


Fig. Monitoring of various human motions using the GNP@PUF sensor.

Application in EMI shielding



D

(i) Coefficients of shielding mechanism

$$R = \frac{P_{ref}}{P_i} = |S_{11}|^2 = |S_{22}|^2$$

$$T = \frac{P_t}{P_i} = |S_{12}|^2 = |S_{21}|^2$$

$$A = \frac{P_{abs}}{P_i} = 1 - R - T$$

(ii) EMI shielding effectiveness (SE)

$$SE_{ref} = -10\log(\frac{1}{1-R})$$

$$SE_{abs} = -10\log(\frac{1-R}{T})$$

$$SE_{total} = 10\log(\frac{P_i}{P_t}) = SE_{ref} + SE_{abs}$$

Fig. (A, B) Experimental setup for EMI shielding measurements: vector network analyzer with the waveguide. (C) EMI shielding mechanism of the foam. (D) Key parameters for evaluating the EMI shielding performance of the foam.

EMI shielding performance

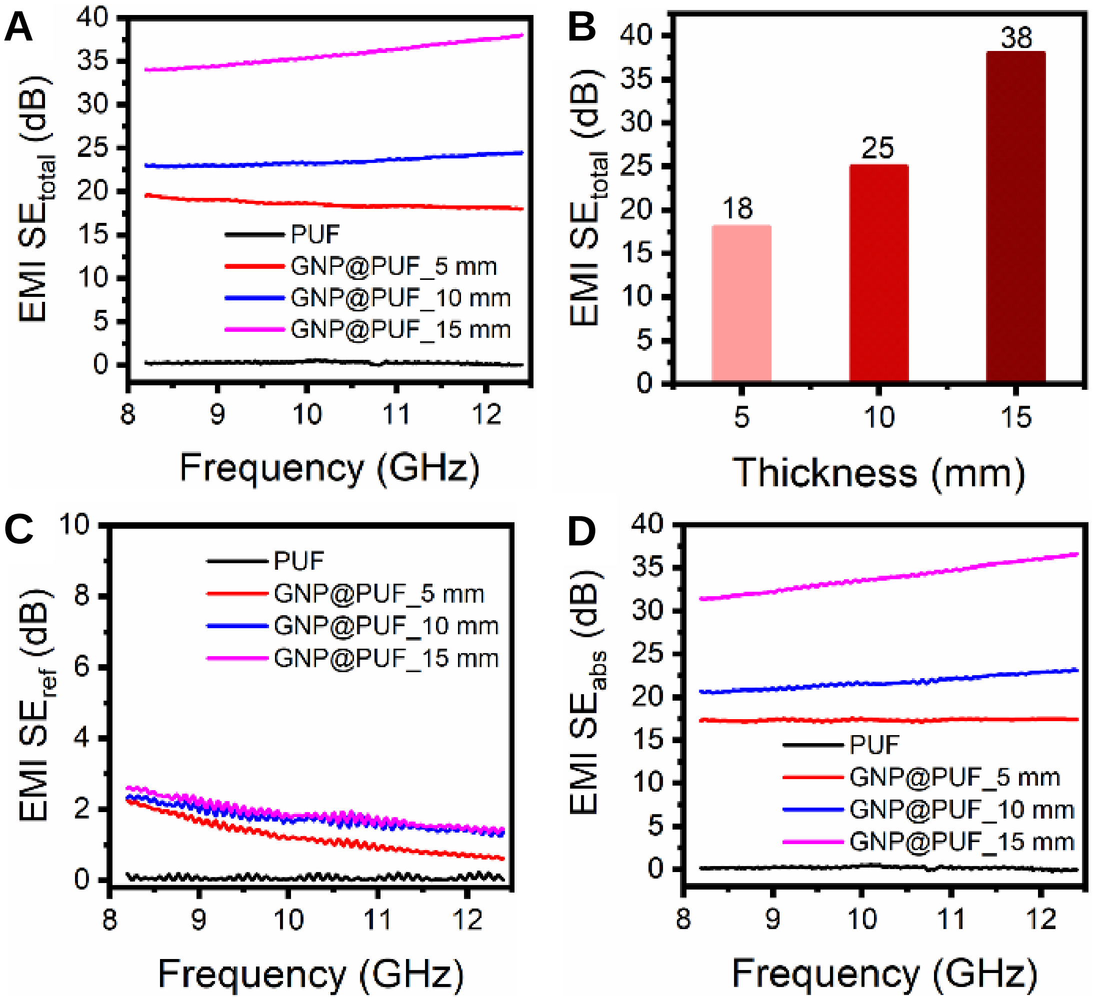
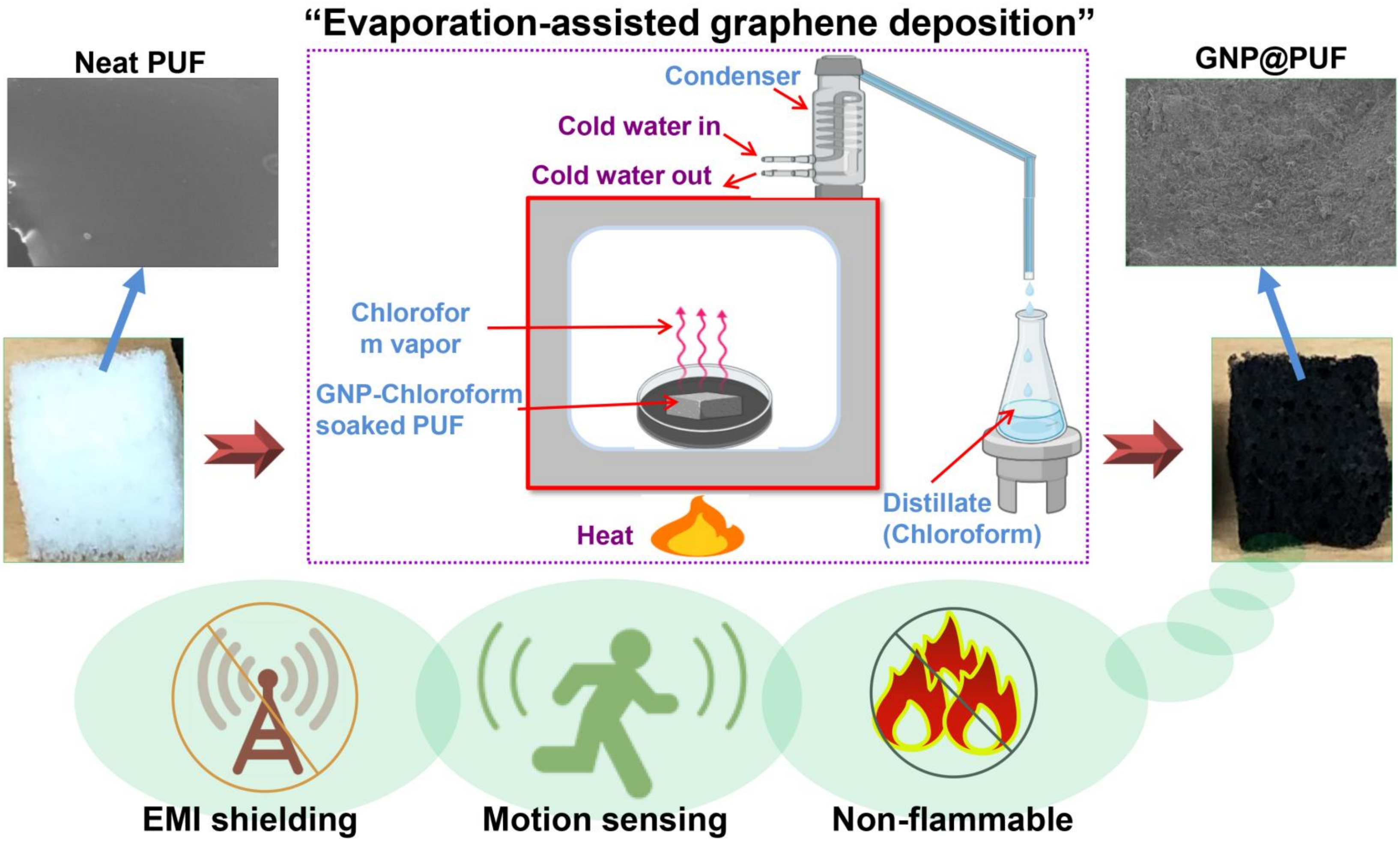


Fig. EMI shielding performance of the foams at a frequency range of 8-12.5 GHz. (A) SE total, (B) effect of thickness, (C) SE reflection, and (D) SE absorption for GNP@PUF.

Conclusions



Acknowledgments

Prof. *Jung-Il Song*
Prof. *Yong Tae Park*
Dr. *M. N. Prabhakar*
Dr. *Dong-Woo Lee*

창원대학교
CHANGWON NATIONAL UNIVERSITY

MYONGJI UNIVERSITY
명지대학교

Funding

NRF National Research Foundation of Korea

Award No. 2021R1I1A1A01057338

Thank you for your attention!