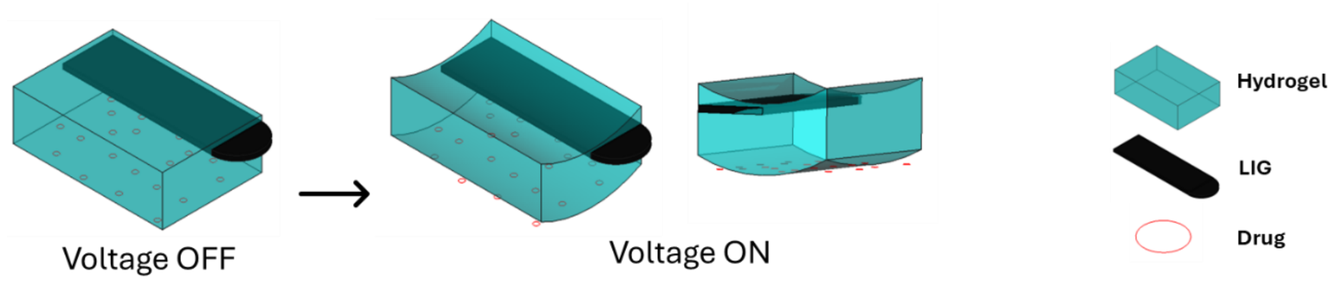
HydroLIG: selective drug delivery via hydrogel/LIG smart actuators

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PNIPAM is a thermoresponsive hydrogel that undergoes a reversible phase change near body temperature, useful in smart material design. Laser-induced graphene (**LIG**) is a flexible, conductive carbon material produced by laser scribing, offering excellent electrical and thermal properties for sensing and actuation applications.



PNIPAM Hydrogels

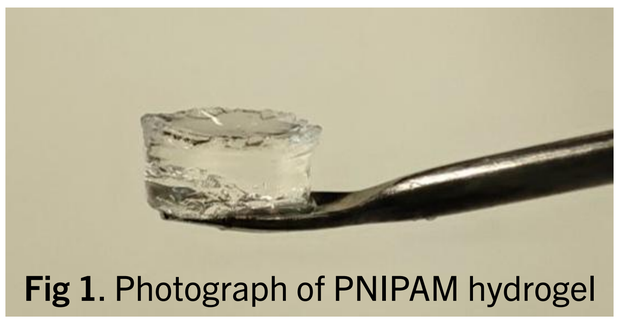


Fig 1. Photograph of PNIPAM hydrogel

Sample	Relative porosity (%)	LCST (°C)
PNIPAM/1BIS	81,6	36,4
PNIPAM/2BIS	54,7	38,1
PNIPAM/4BIS	82,1	36,5

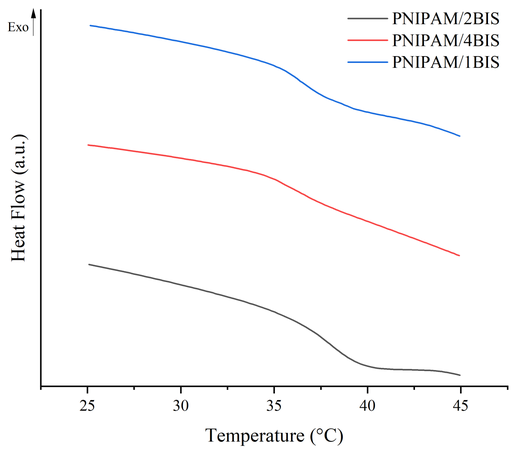


Fig 2. DSC curves of hydrogels samples of varying crosslinker concentrations. LCST is reported as the intermediate T_g.

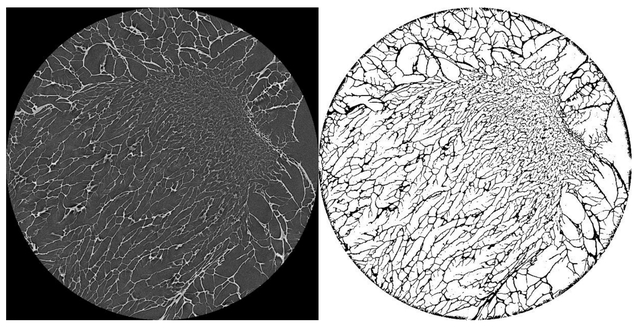


Fig 3. CT scan of PNIPAM/2BIS/1APS hydrogel (left) ROI before porous segmentation. (right) ROI after segmentation.

Laser-induced graphene

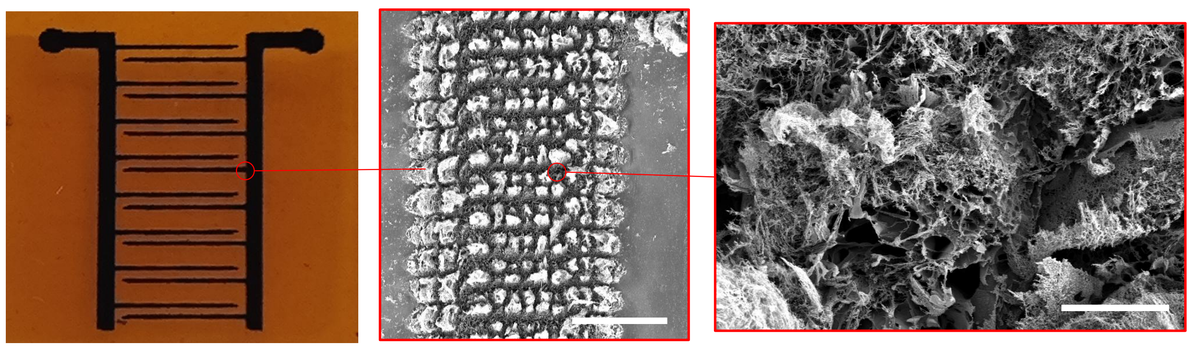


Fig 4. Laser-induced graphene is formed by laser scribing polyimide substrates, where localized pyrolysis converts the surface into a porous network.

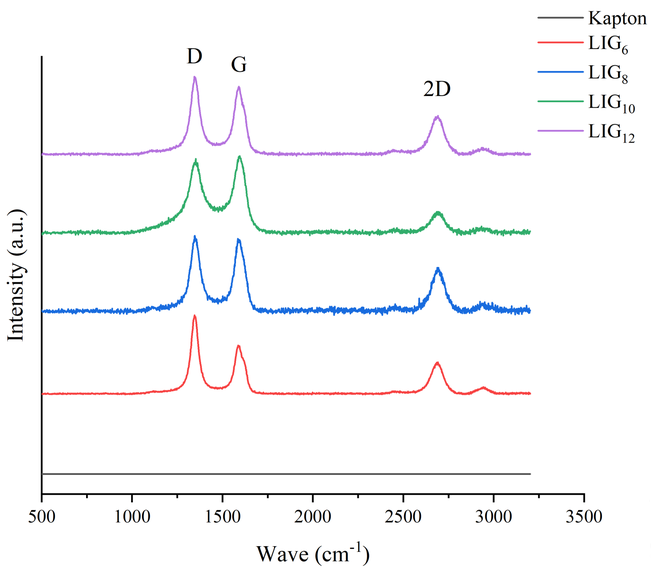


Fig 5. Raman spectroscopy revealed the D, G, and 2D bands. Their intensity variations with laser power indicate changes in graphitic ordering and defect density.

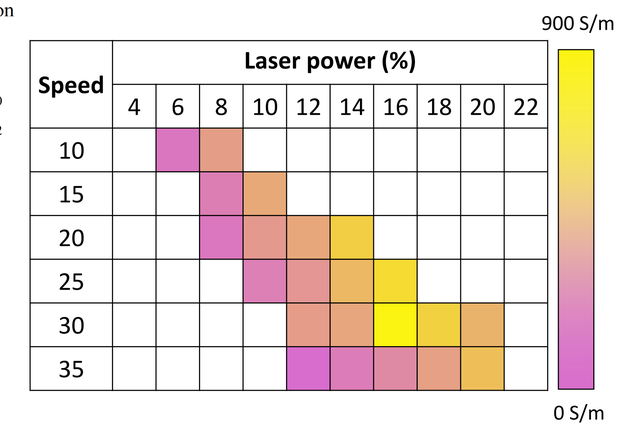


Fig 6. Conductivity mapping showed that electrical performance depended strongly on laser parameters: moderate laser power promoted continuous graphitic pathways and high conductivity, whereas excessive power caused surface ablation and structural damage.

Smart actuators

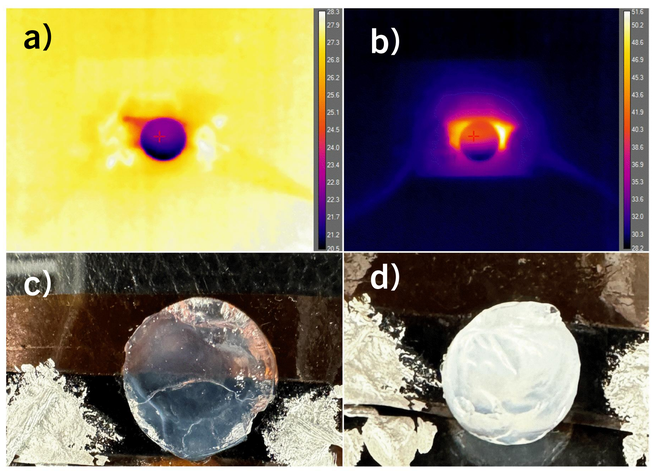
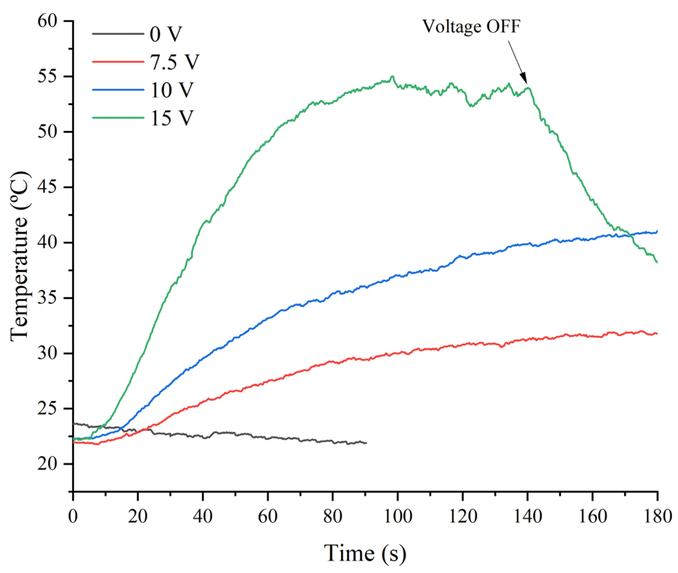


Fig 7. a) Thermal image of hydrogel on LIG electrode when no voltage is applied. b) Thermal image of hydrogel on LIG electrode after 10 V supply. c) Photograph of hydrogel on LIG setup before voltage activation. d) Photograph of hydrogel on LIG setup for temperature recording after voltage difference was applied for 180 s.

Fig 8. Thermal profile of the surface temperature of PNIPAM/2BIS/1APS hydrogel while applying different voltages to the LIG electrode over time. At 15 V after 2.5 min (arrow), voltage was turned off to study the hydrogel cooling kinetics.



Dye delivery system

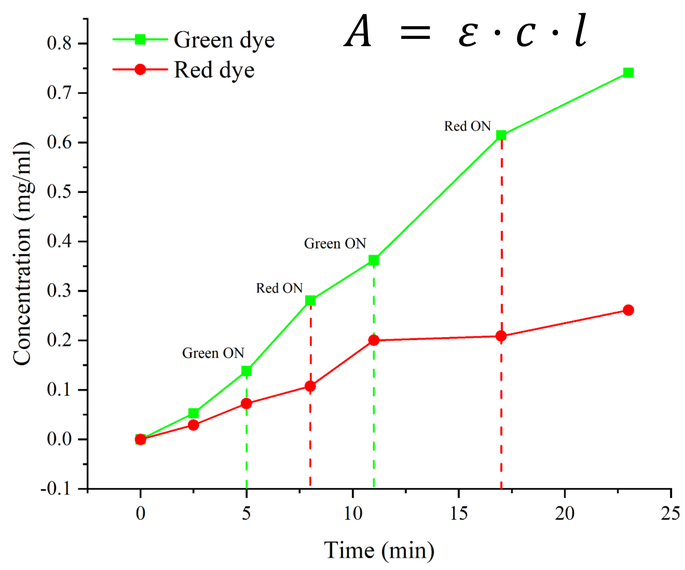


Fig 9. Release profiles from the UV-Vis spectrophotometry of water solution where a red dyed hydrogel and a green dyed hydrogel integrating a LIG electrode were placed. Each curve corresponds to the time at which the solution was collected. Both hydrogels were activated in an offset fashion.

Conclusions

The **HydroLIG** system achieved reversible, voltage-triggered release of a model compound. LIG heating effectively raised the hydrogel temperature above its LCST, confirming **controlled actuation.** These results demonstrate a promising pathway toward **smart wound dressings** and personalized drug delivery in biomedical engineering.

References

[1] Gil, E. S., & Hudson, S. M. Progress in Polymer Science, 2004.
[2] Lin, J. et al. Nature Communications, 2014.

Acknowledgments

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