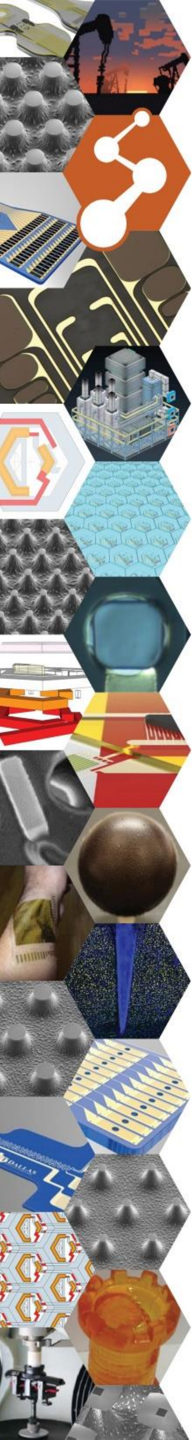


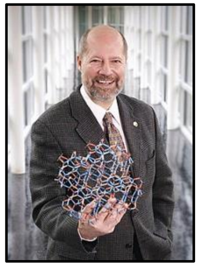
Thiol-based, thermally-conductive adhesives for high power electronics

1969 – Incorporated as UT Dallas

Benjamin Lund[1], Carlos Barrios[1], Mahmoud Hosseini[1,5,9], Xun Han[1], Ali Aliev[5,8], Ray Baughman[5,8], Walter Voit[1-9]

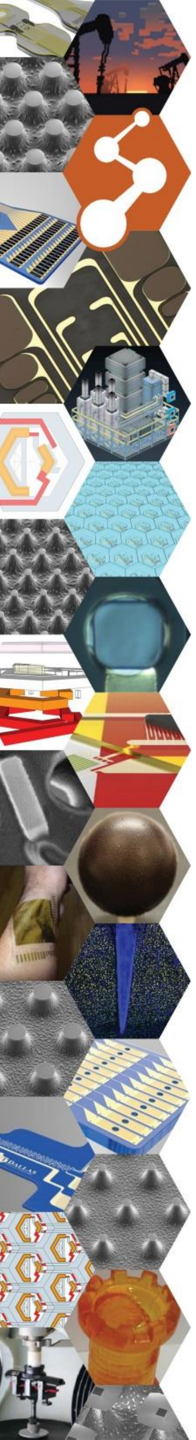




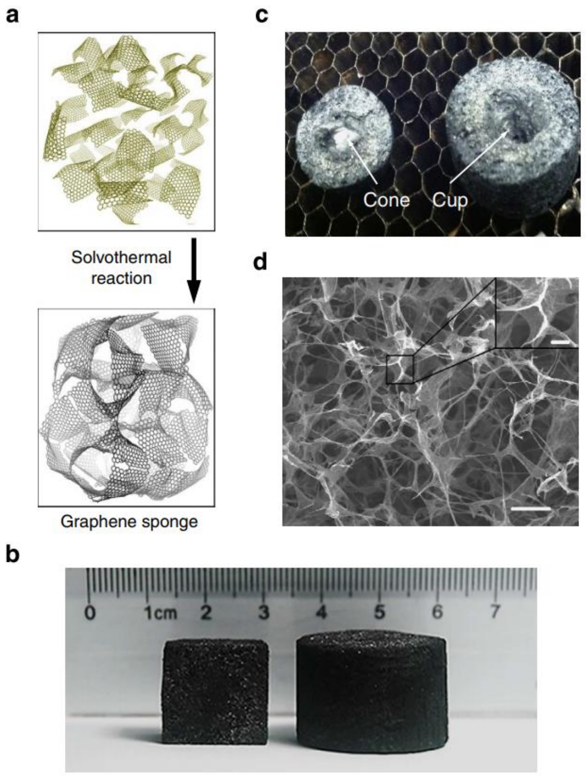

2021 – Fearlessly engineering the future

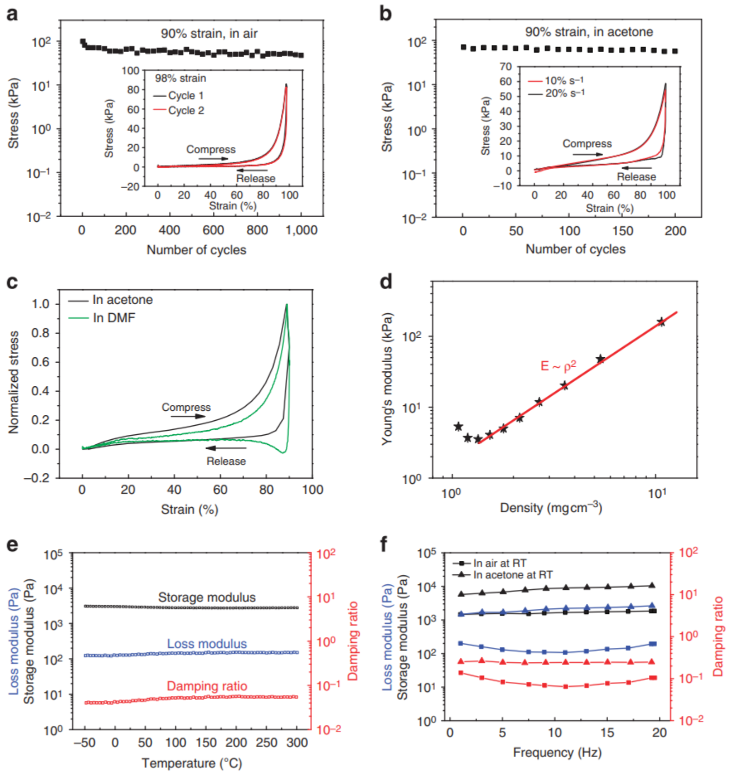
Affiliations: Adaptive3D[1]
UT Dallas - Materials Science and Engineering[2], Mechanical Engineering[3] Bioengineering[4], Chemistry[5], Advanced Polymer Research Lab[6], Texas Biomedical Device Center[7], Alan G. MacDiarmid Nanotech Institute[8], Center for Engineering Innovation[9]

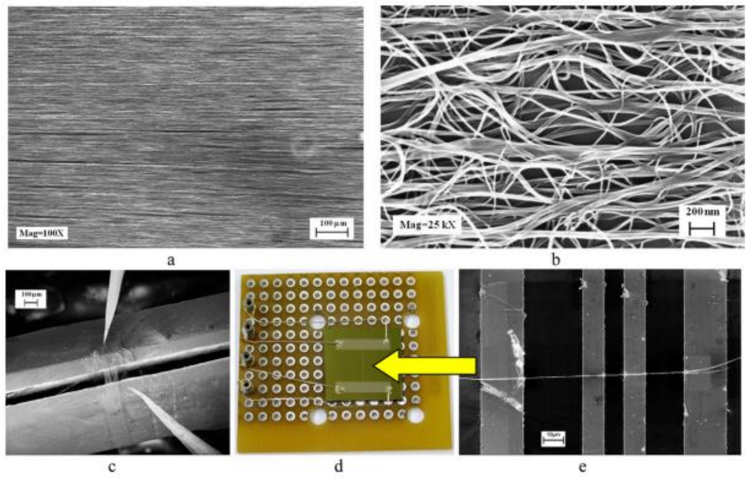


UT Dallas: Graphene Sponges and Multi-Walled Carbon Nanotubes

Well ordered carbon nano-structures possess some of the best reported thermal conductivities. The *Alan G. MacDiarmid Nanotech Institute* at UT Dallas specializes in the design, synthesis and characterization of highly ordered nano-carbon structures.







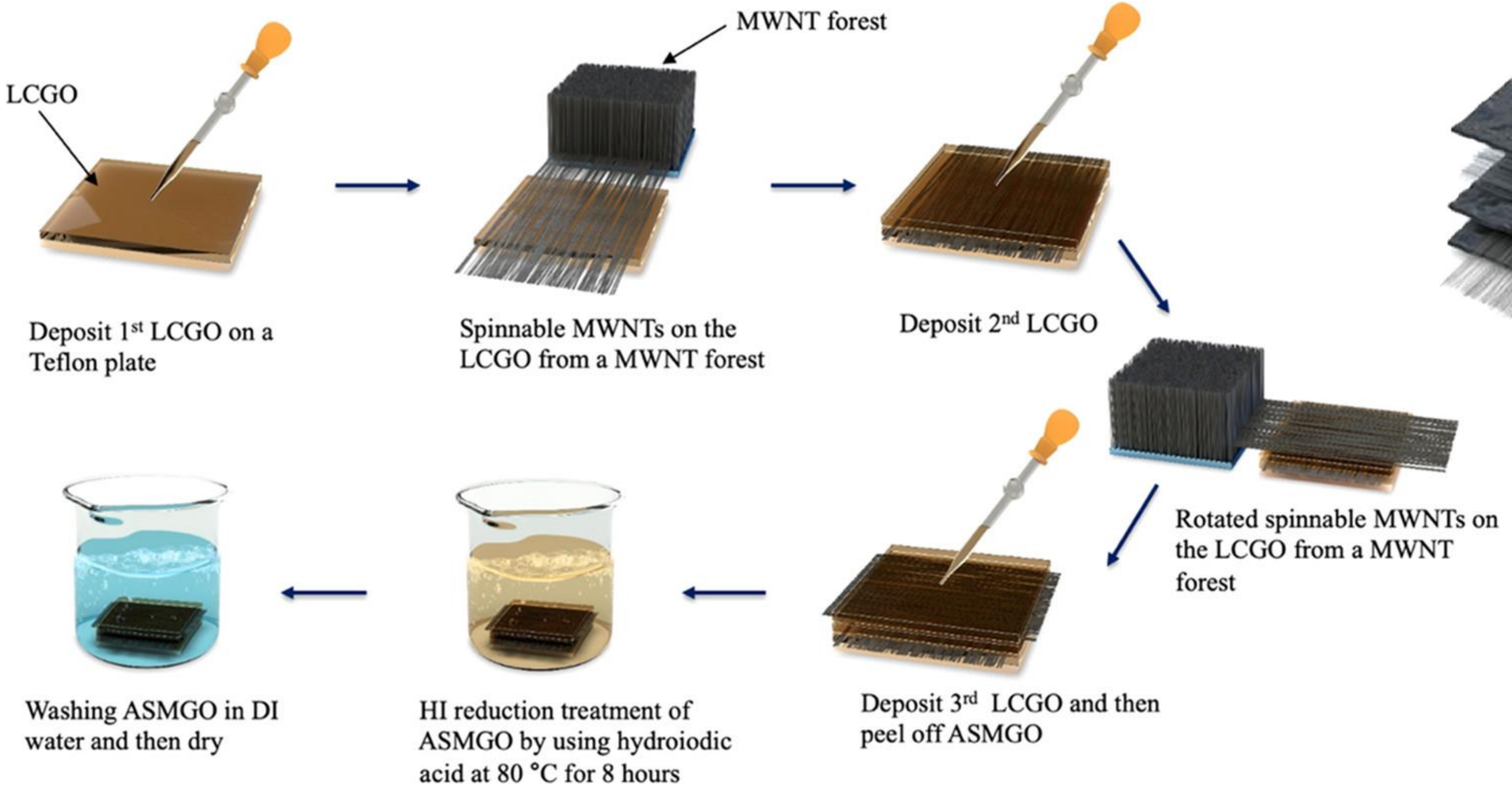
Sample	Thermal conductivity ($W\ m^{-1}\ K^{-1}$)	Thermal diffusivity ($mm^2\ s^{-1}$)	Sheet resistance (Ω/□)
MWNT sheet, ∥	50	45	500
MWNT sheet, ⊥	2.1	8.2	30 000

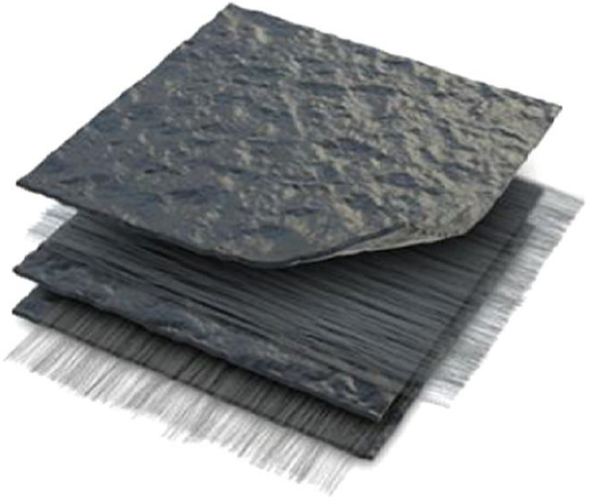
Y. Wu, N. Yi, L. Huang, T. Zhang, S. Fang, H. Chang, A. Aliev, P Chu, Z. Zhang, R Baughman, Y. Chen. **Three-dimensionally bonded spongy graphene material with super compressive elasticity and near-zero Poisson's ratio.** *Nature Communications*, 2015, Vol. 6 Issue 1, Pages 1-9.

A. Aliev, M. Lima, E. Silverman, R. Baughman. **Thermal conductivity of multi-walled carbon nanotube sheets: radiation losses and quenching of phonon modes** *Nanotechnology*, 2009, 21 035709.

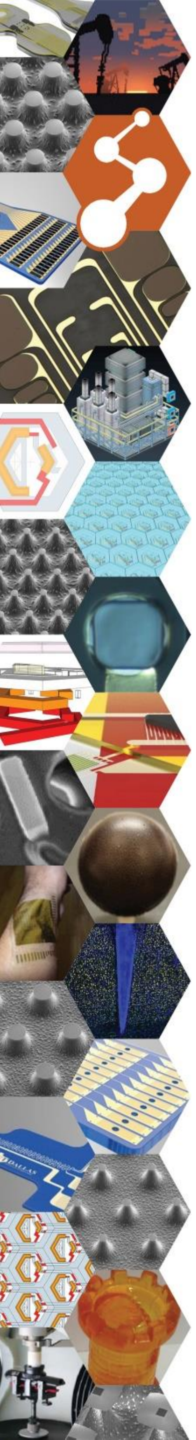
UT Dallas: Bidirectional Core Sandwich Structure of Reduced Graphene Oxide and Spinnable Multiwalled Carbon Nanotubes

Engineering carbon nano-structures enhances electrical and thermal performance in composite materials.



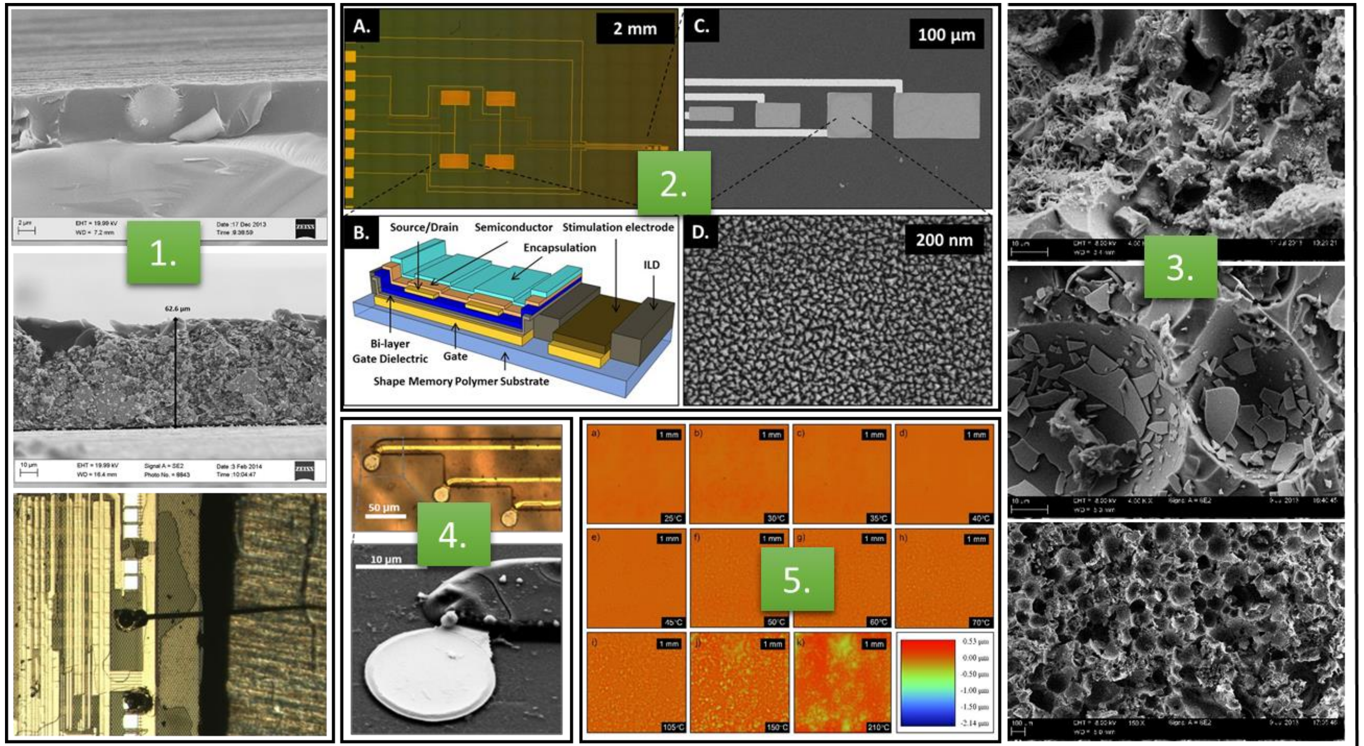


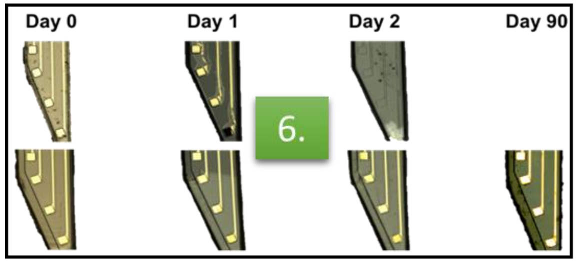
D. Lee, H. Kim, J. Hyeon, J. Moon, B. Kim, J. Jeong, J. Choi, R. Baughman, G. Spinks, G. Wallace, and S. Kim **Bidirectional Core Sandwich Structure of Reduced Graphene Oxide and Spinnable Multiwalled Carbon Nanotubes for Electromagnetic Interference Shielding Effectiveness** ACS Applied Materials & Interfaces 2020, 12, 41, 46883-46891.



UT Dallas: Focused Packaging Efforts in Semiconductor Processing; Thiol based polymer thermosets as substrates for electronics

Thiol-ene polymers exhibit excellent stability and processability for microelectronics. Thiol-ene polymers buffer significant CTE mismatch between substrate and metal traces through stress relaxation and thermo-set nature of the polymer.





Sample	DSC T_g (°C)	DMA T_g (°C)	Density (g/cm^3)	Relative Density (%)	Pore Size (µm)
Control 160C Cure	48 ± 0.2	53 ± 2.4	1.18	100	NA
40% Q-Cel 6019	44 ± 0.2	51 ± 0.6	0.78	66	86 ± 31
50% Q-Cel 6019	49 ± 0.6	54 ± 0.2	0.73	62	99 ± 23
930 DU 120	45 ± 0.1	49 ± 1.4	0.37	31	165 ± 88
XOP-341 130 °C	51 ± 0.3	54 ± 0.3	0.42	35	168 ± 49
XOP-341 160 °C	47 ± 0.8	54 ± 0.5	0.30	25	380 ± 250

1. Tunable Bond Line Thicknesses for Die Attach
Wei, A., R. Reit and W. Voit (2015). Investigating thiol-epoxy composites for semiconductor die attach adhesives. MRS Proceedings, Cambridge Univ. Press.

2. Hafnium Oxide/Polymer Bilayer Dielectrics
Avendano-Bolivar, A., T. Ware, D. Arreaga-Salas, D. Simon and W. Voit (2013). "Mechanical cycling stability of organic thin film transistors on shape memory polymers." Advanced Materials **25**(22): 3095-3099.

3. Controllable Density Packaging via Foams, Particles and Blowing Agents
Ellson, G., M. Di Prima, T. Ware, X. Tang and W. Voit (2015). "Tunable thiol–epoxy shape memory polymer foams." Smart Materials and Structures **24**(5): 055001.

4. Accelerated Aging: 2 billion biphasic charged balanced pulses and resulting package effects
Arreaga-Salas, D. E., A. Avendaño-Bolívar, D. Simon, R. Reit, A. Garcia-Sandoval, R. L. Rennaker and W. Voit (2015). "Integration of High-Charge-Injection-Capacity Electrodes onto Polymer Softening Neural Interfaces." ACS Applied Materials & Interfaces **7**(48): 26614-26623.

5. Evolution of minimal thermal stress above 200°C
Simon, D., T. Ware, R. Marcotte, B. R. Lund, D. W. Smith Jr, M. Di Prima, R. L. Rennaker and W. Voit (2013). "A comparison of polymer substrates for photolithographic processing of flexible bioelectronics." Biomedical Microdevices **15**(6): 925-939.

6. Hydrolytically stable (bottom) and unstable (top) packages for implantable flexible electronics
Reit, R., D. Zamorano, S. Parker, D. Simon, B. Lund, W. Voit and T. H. Ware (2015). "Hydrolytically Stable Thiol–ene Networks for Flexible Bioelectronics." ACS Applied Materials & Interfaces **7**(51): 28673-28681.

Adaptive3D: Commercializing Thiol-based Resins

Technology developed at UT Dallas which enables microelectronics also powers 3D printing. Adaptive 3D is commercializing UT Dallas Technology enabling best-in-class mechanical properties and tunability towards thermal interface materials.

Additive Manufacturing, the scalable cousin of 3D printing, is a technology that creates parts by curing materials.

<u>We sell raw materials</u>, called photo-resins that react (polymerize) when exposed to patterned ultraviolet (UV) light.

1. The elastomers (rubbers) made from our resins are <u>4× tougher</u> than state-of-the-art materials from our leading competitors.
2. Our materials have <u>superior shelf-life</u> so they can be used as one-part (not 2-part) products.
3. Our materials are <u>less sensitive to oxygen</u> than competing resins so we can scale them into manufacturing lines.


Soft Earbuds


Toys


Flow regulators


Springs/Dampers


Bike Grips


Size 4-16 Architected Midsoles


Gun Grips

Better materials properties = better economics.

1. ↑ Toughness = ↑ Performance, ↑ Design Freedom, ↓ Weight, ↓ Cost
2. One-part resin = ↑ Pot-life, ↑ Process, ↑ Consistency, ↑ Quality, ↓ Cost
3. Oxygen insensitivity = ↑ Throughput, ↑ Part Size, ↓ Cost

Better raw materials enable scaled manufacturing.


Chemical Facemasks


Ventilator Valves


Medical Models for Education


Weatherby Recoil Pads

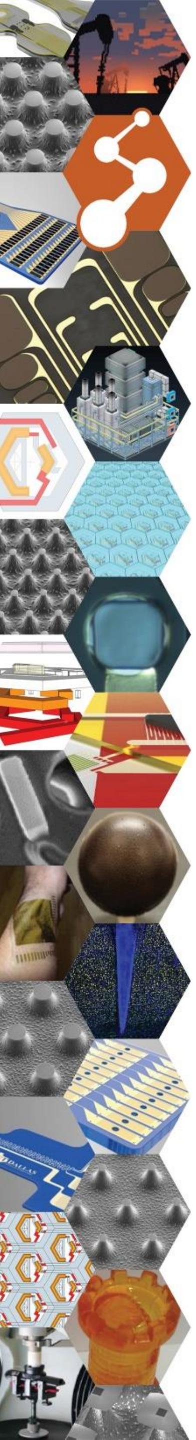

Soft Robotic Grippers


COVID Nasal swabs


O-rings

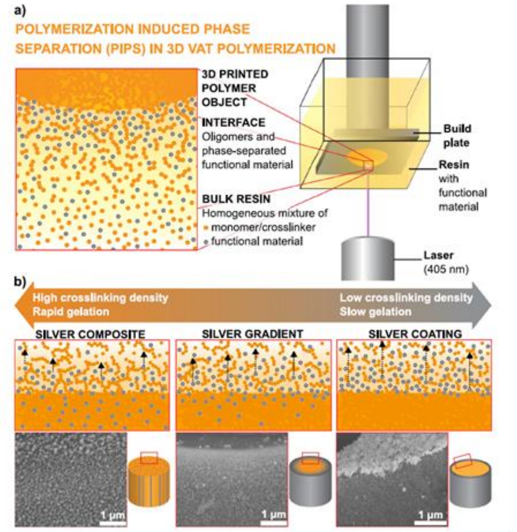
Bushings


Engineered Foams

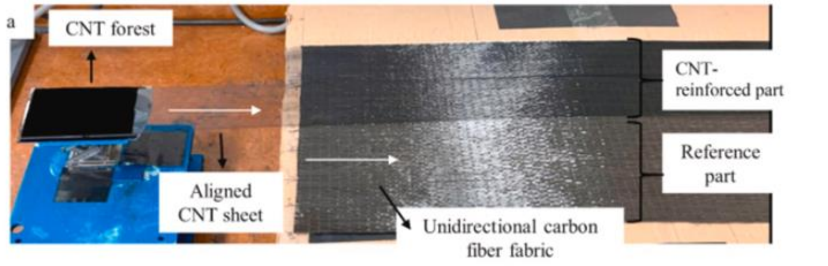


Concept: Thiol-mediated photo-PIPS matrices for carbon nanostructure composites as thermal interface materials

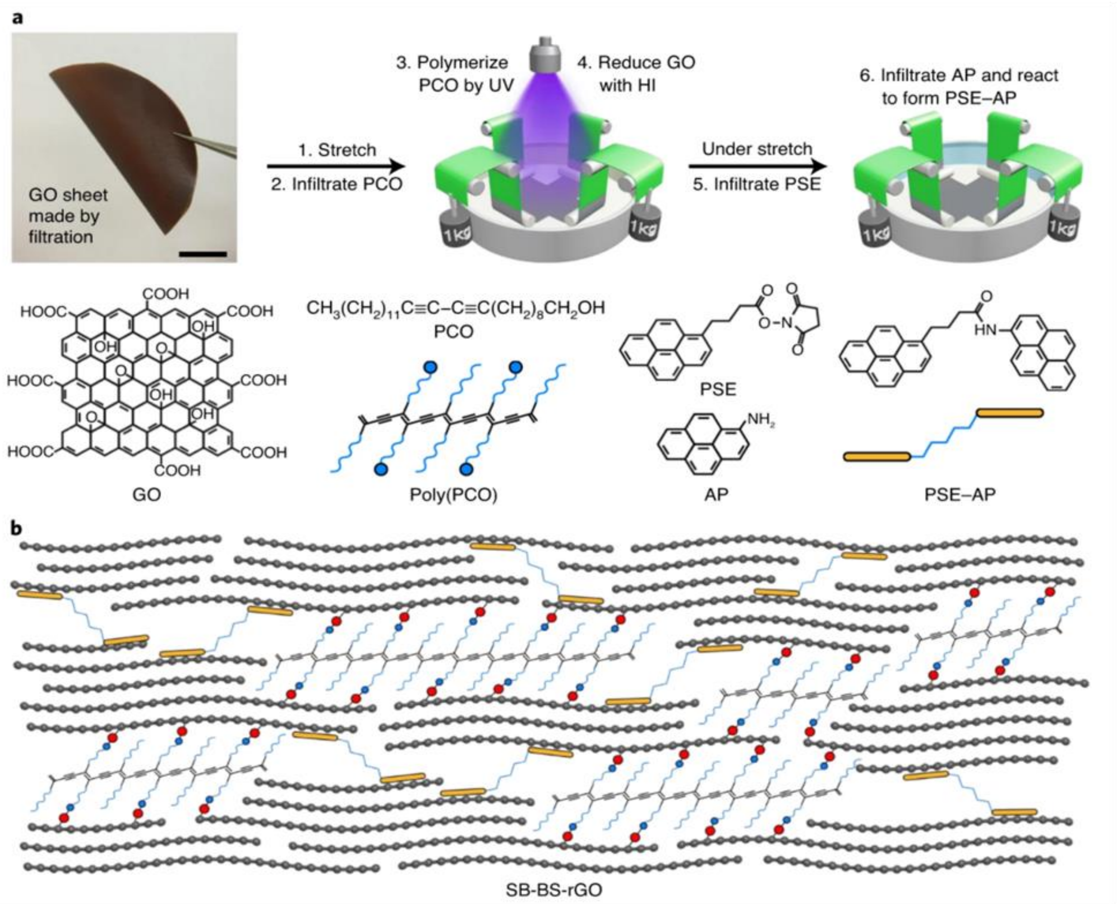
Photo-PIPS technology can enable next generation TIM materials by combining nano-carbon expertise with the micron precision manufacturing enabled by 3D printing. UT Dallas and Adaptive 3D are partnering to develop these materials.



Deore, B., Sampson, K.L., Lacelle, T., Kredentser, N., Lefebvre, J., Young, L.S., Hyland, J., Amaya, R.E., Tanha, J., Malenfant, P.R.L., De Haan, H.W., Paquet, C., 2021. **Direct printing of functional 3D objects using polymerization-induced phase separation.** Nature Communications 12. doi:10.1038/s41467-020-20256-3



P. Koirala, N. van de Werken, H. Lu, R. H. Baughman, R. Ovalle-Robles and M. Tehrani. **Using ultra-thin interlaminar carbon nanotube sheets to enhance the mechanical and electrical properties of carbon fiber reinforced polymer composites.** Composites Part B: Engineering 2021 Vol. 216 Pages 108842



S. Wan, Y. Chen, S. Fang, S. Wang, Z. Xu, L. Jiang, et al. **High-strength scalable graphene sheets by freezing stretch-induced alignment.** Nature Materials 2021