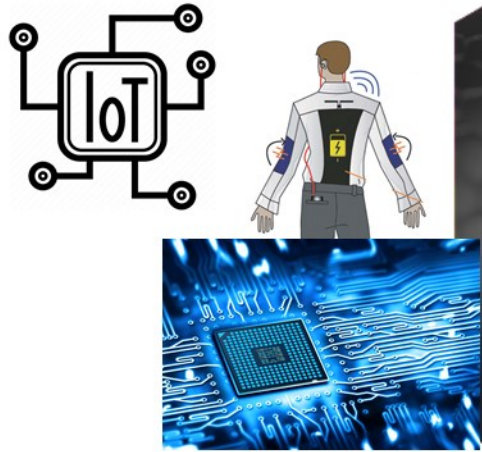


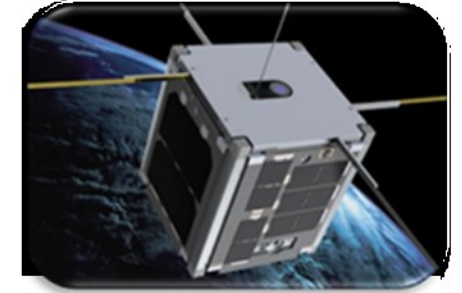
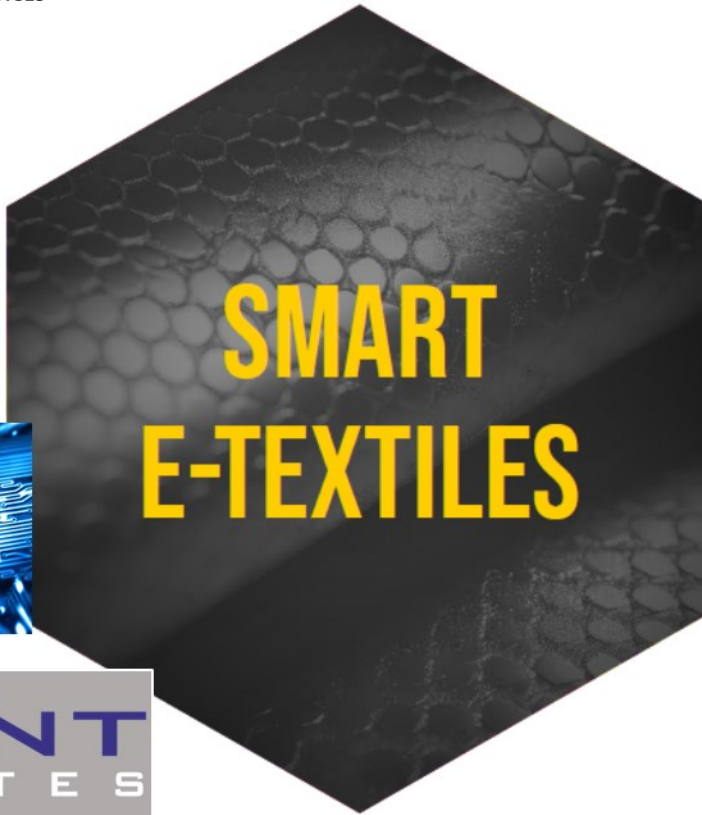
GRAPHERGIA

INNOVATIVE PILOT LINES FOR **SUSTAINABLE**  
**GRAPHENE-BASED** FLEXIBLE AND STRUCTURAL  
**ENERGY** HARVESTING AND **STORAGE** DEVICES

Started: October 2023, 42 Months, 11 EU partners



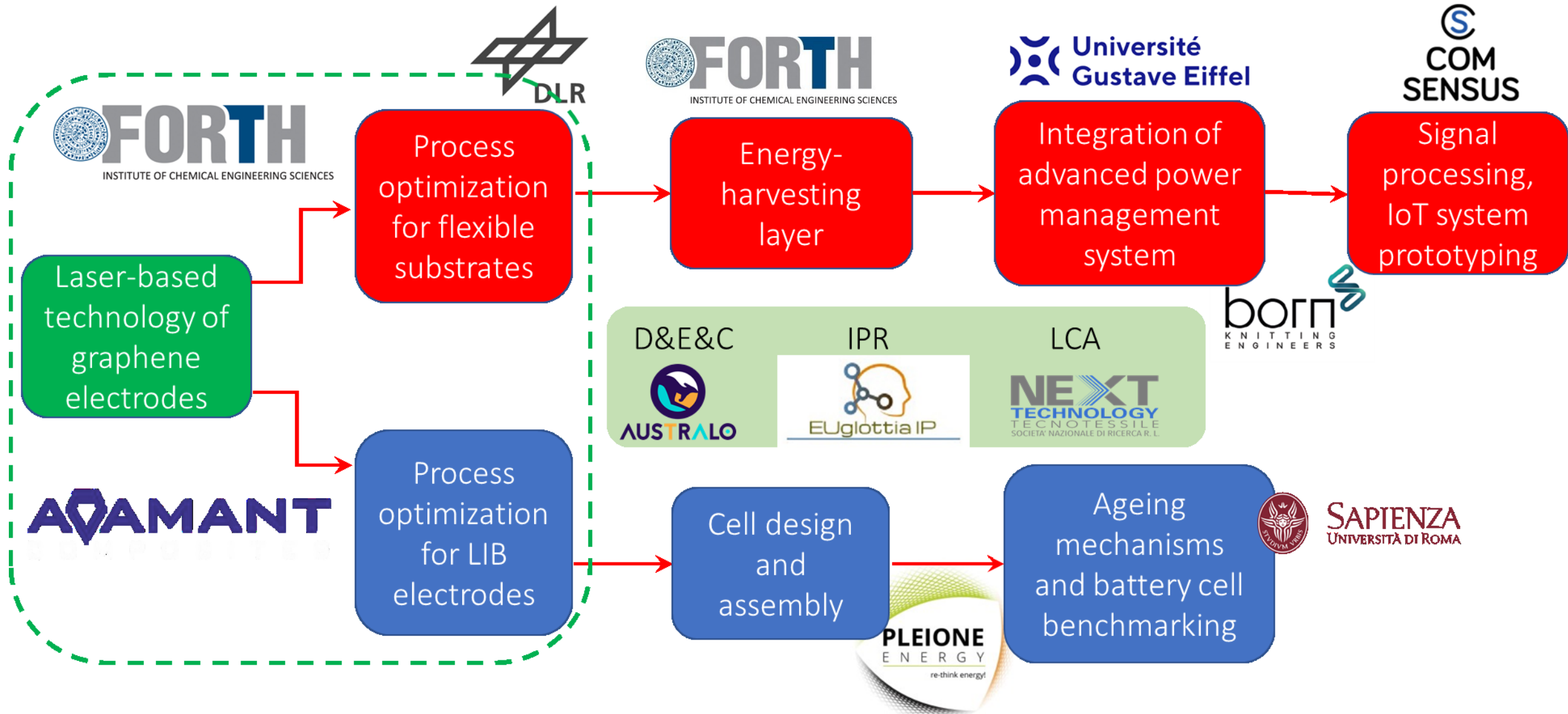
In addition to providing **batteryless** solutions for wearables, this technology offers a user-centric interface to the IoT through wireless sensor signal



The outcome is a **laser-based, "dry-electrode fabrication"** approach for graphene/Si-based LIB anodes

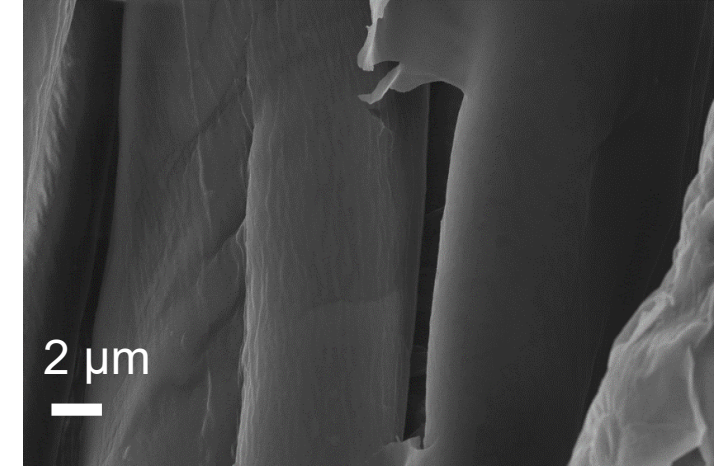
# Two main directions of GRAPHERGIA

[A] All-in-one self-charging power textiles. [B] Electrodes for Li-ion batteries.



# DIGITAL MANUFACTURING OF GRAPHENE-ENABLED DEVICES

## Graphene-wrapped fibers

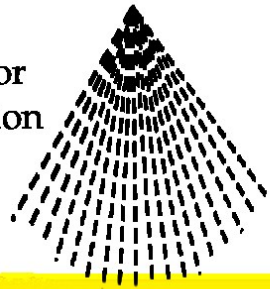


## Advantages

- Digital manufacturing
- Compatibility with Industry 4.0
- Reduction of CRMs
- Toxic/pollutant-free environment
- Novel decarbonized industrial processes

Roll-to-roll (R2R) pilot line (ADAMANT COMPOSITES Ltd.)

Precursor deposition



Dry / processing unit

Graphene synthesis  
*wide beam*

Graphene patterning for SCs  
*narrow beam*



# A VERY BRIEF HISTORY OF LASER-ASSISTED “GRAPHENE” SYNTHESIS



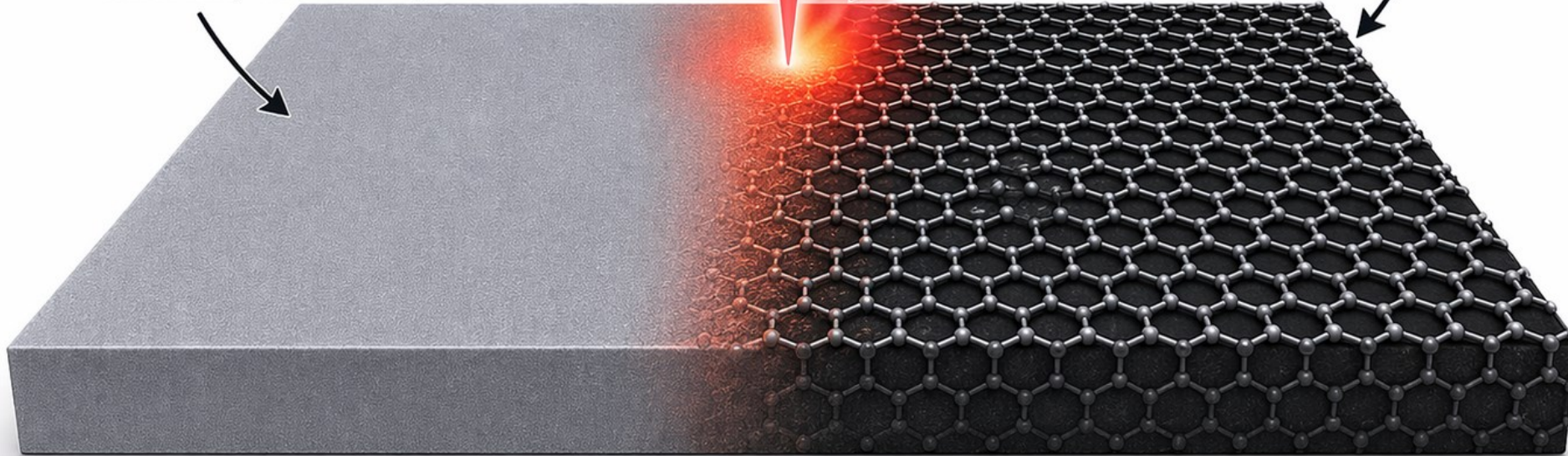
**Laser Irradiation**

**Incident Laser Beam**

**Precursor Material**  
(Polymer, Biomass, GO, Carbon, Carbides)

**Local Heating**  
Drives Transformation to Graphene

**Graphene**  
( $sp^2$  Carbon Honeycomb Lattice)



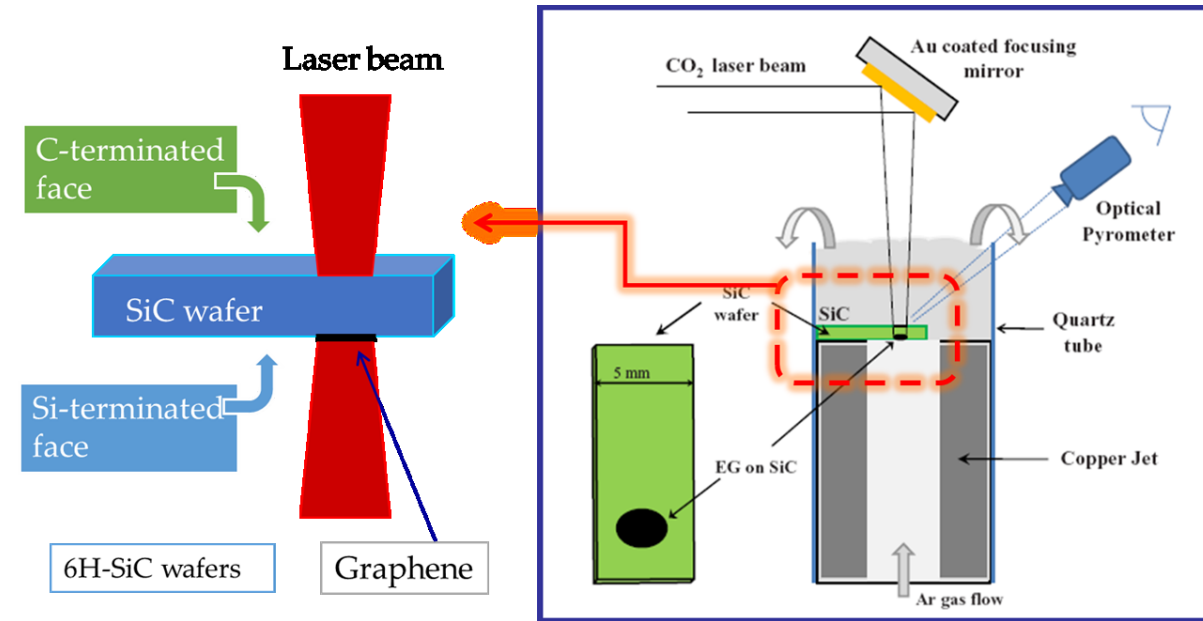
## Early fundamental works

- ✓ **1982:** UV-laser ablation of polymers (Kawamura *et al.*, and [Srinivasan \*et al.\*](#)) groundwork for laser photodecomposition/carbonization of Kapton (PI).
- ✓ **1993–1994:** Excimer-laser irradiation of Kapton yields a **dark, electrically conducting, porous, patternable, carbon layer**; resistivity drops by ~15–16 orders of magnitude.
- ✓ **1990s–2000s:** Laser micromachining on polymers matures; conductive residues recognized/used as **micro-patterned carbon**.

These works show that **lasers can convert polymers to conductive graphitic carbon** long before the “LIG” term was coined.


# LASER-ASSISTED “GRAPHENE” SYNTHESIS

- ✓ **2012: Laser-induced graphene on SiC wafers – Epitaxial Graphene (Our group)**
  - Rapid photothermal graphitization of SiC to turbostratic few-layer graphene
  - Additional work on SiC particles → graphene/nc-Si for battery anodes (GRAPHERGIA)



- ✓ **2012 (UCLA, R. Kaner group):** Laser scribing of high-performance and flexible graphene-based electrochemical capacitors
- ✓ **2014 (Rice Univ.):** CO<sub>2</sub>-laser scans on PI produce **3D porous graphene-like structures** [laser-induced graphene (LIG)].
- ✓ **2014–currently:** Expanded to other wavelengths/atmospheres/substrates; doped; applications in **supercapacitors, sensors, filtration, smart textiles.**

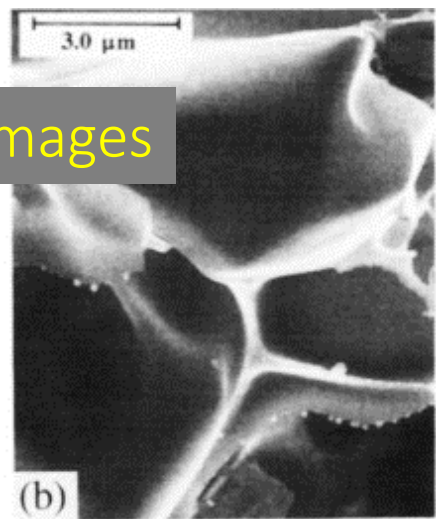
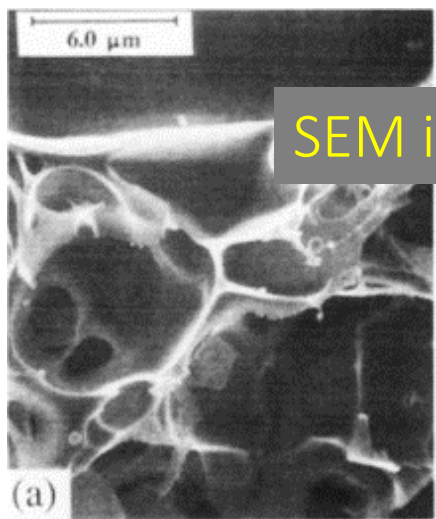
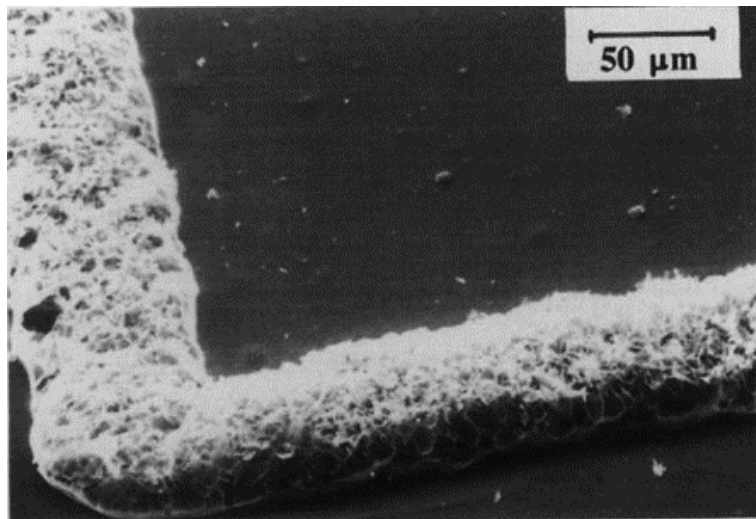
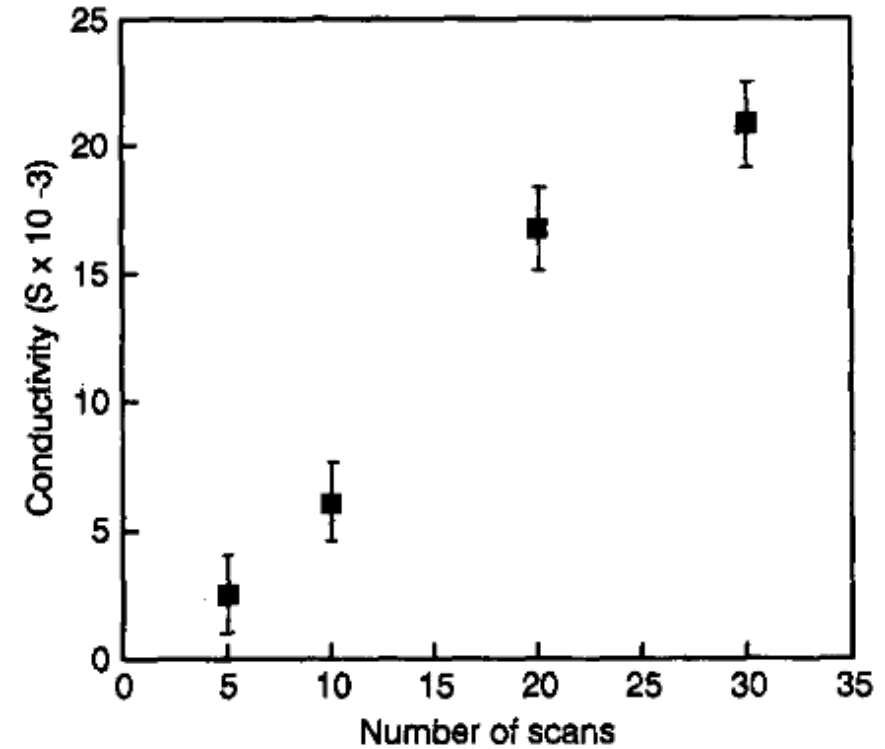
# LASER-ASSISTED "GRAPHENE" SYNTHESIS

 **Synthetic Metals**  
Volume 66, Issue 3, **October 1994**, Pages 301-307

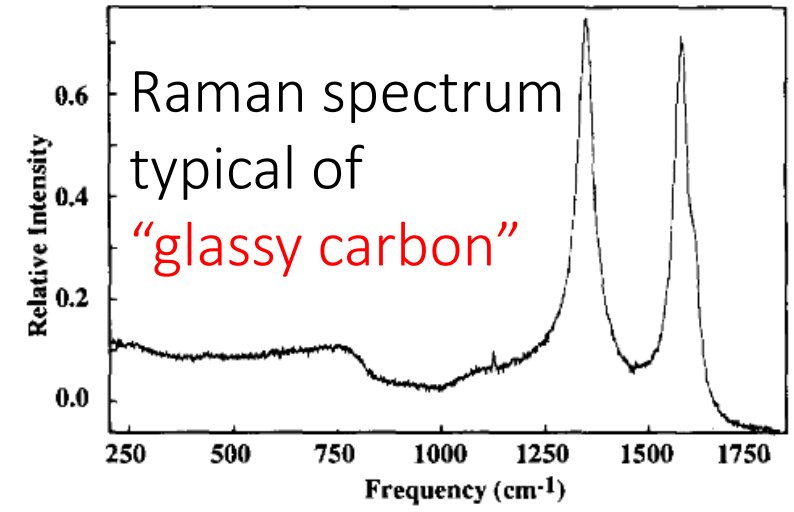
Short communication

**Ultraviolet laser irradiation of the polyimide, PMDA-ODA (Kapton<sup>TM</sup>), to yield a **patternable, porous, electrically conducting carbon network****

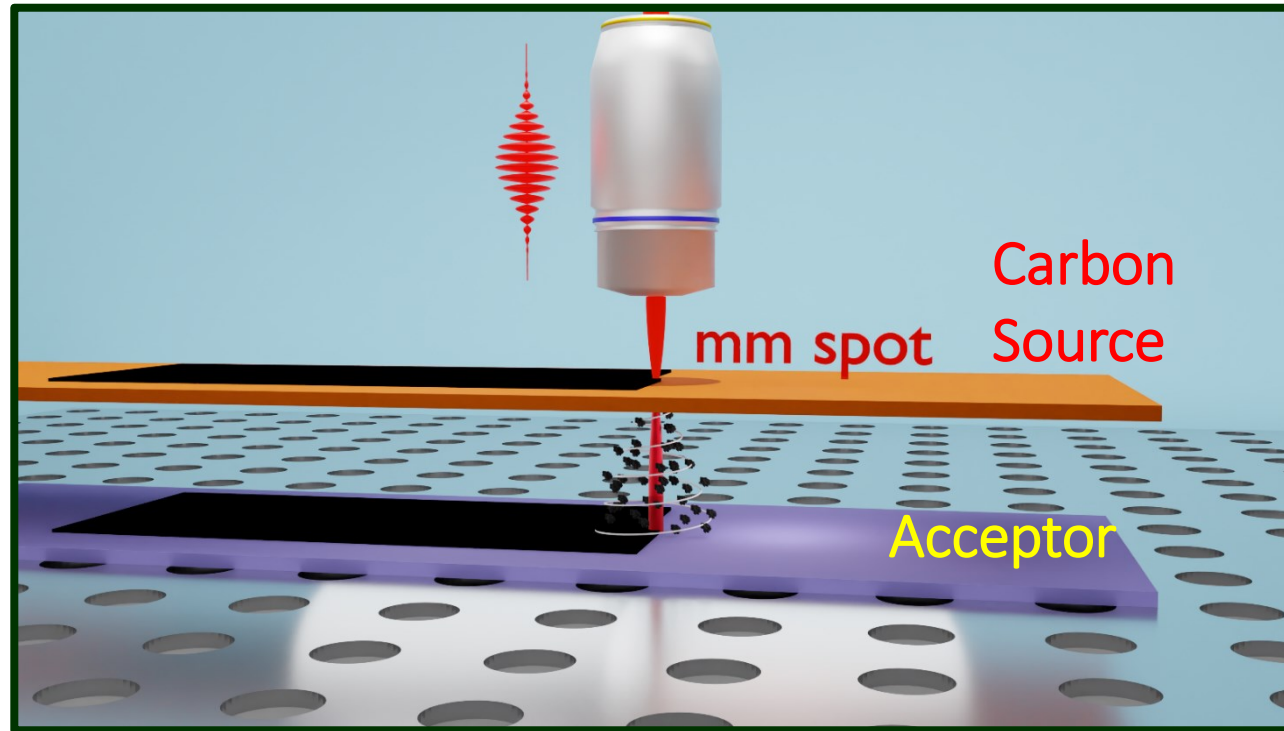
R. Srinivasan<sup>a</sup>, R.R. Hall<sup>b</sup>, W.D. Wilson<sup>b</sup>, W.D. Loehle<sup>b</sup>, D.C. Allbee<sup>b</sup>



SEM images



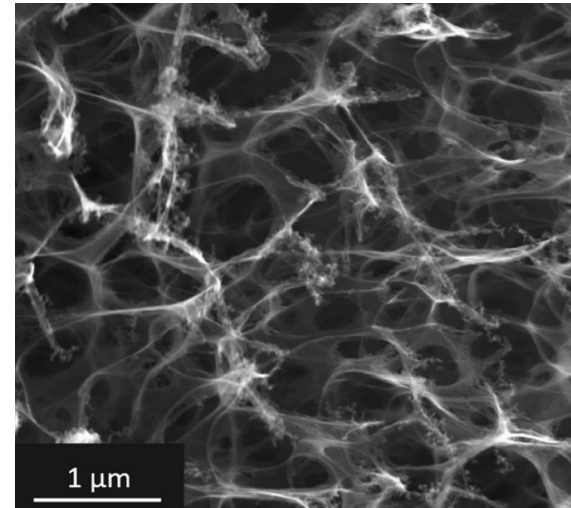
# THE LASER-ASSISTED EXPLOSIVE SYNTHESIS & TRANSFER (LEST) METHOD



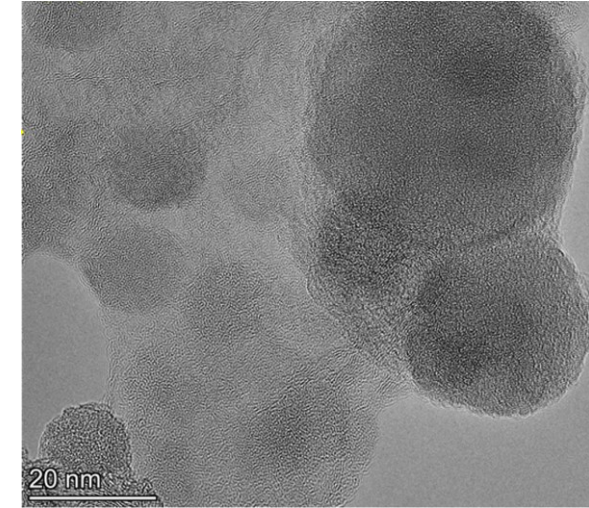
K. Bhorkar, S. N. Yannopoulos *et al.*, *npj 2D Mater Appl* **6**, 56 (2022)

- Single carbon source (i.e. biomass, polymer, ... )
- Complex carbon precursor (i.e. containing S, N, ...)
- Use of multiple carbon precursors (i.e. metal salts)

Graphene foam



Graphene nanohybrid



- Neat graphene-based electrode
- Doped graphene-based electrode
- NP-decorated graphene-based electrode