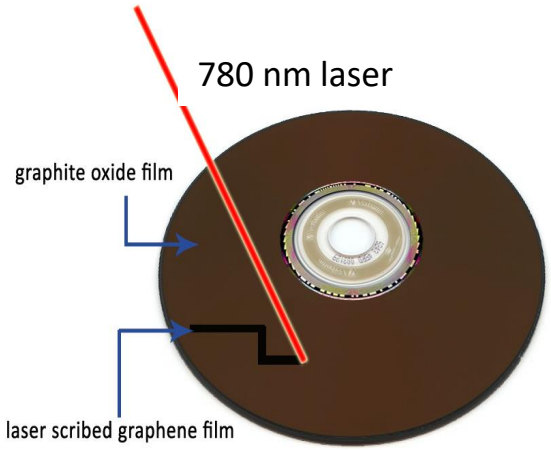
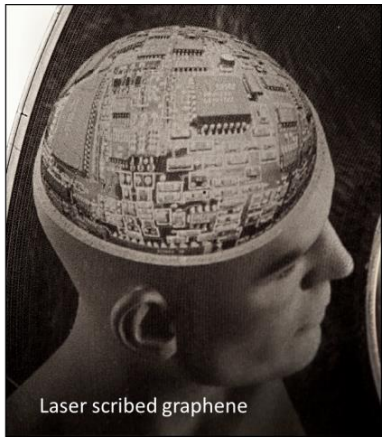
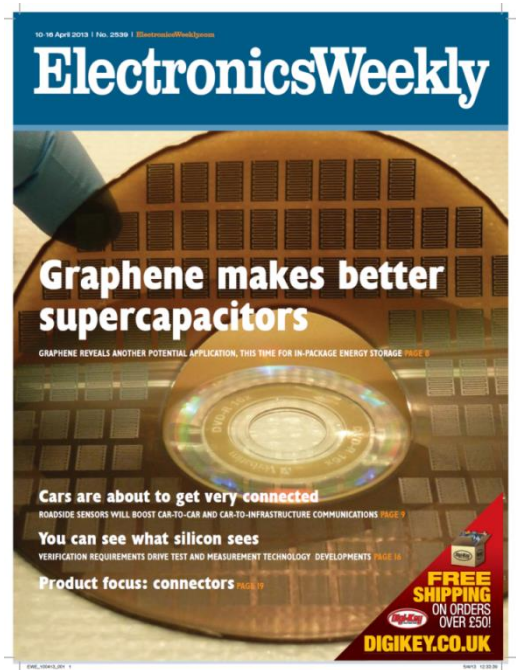
Graphene for Energy Storage and Other Applications

Richard B. Kaner

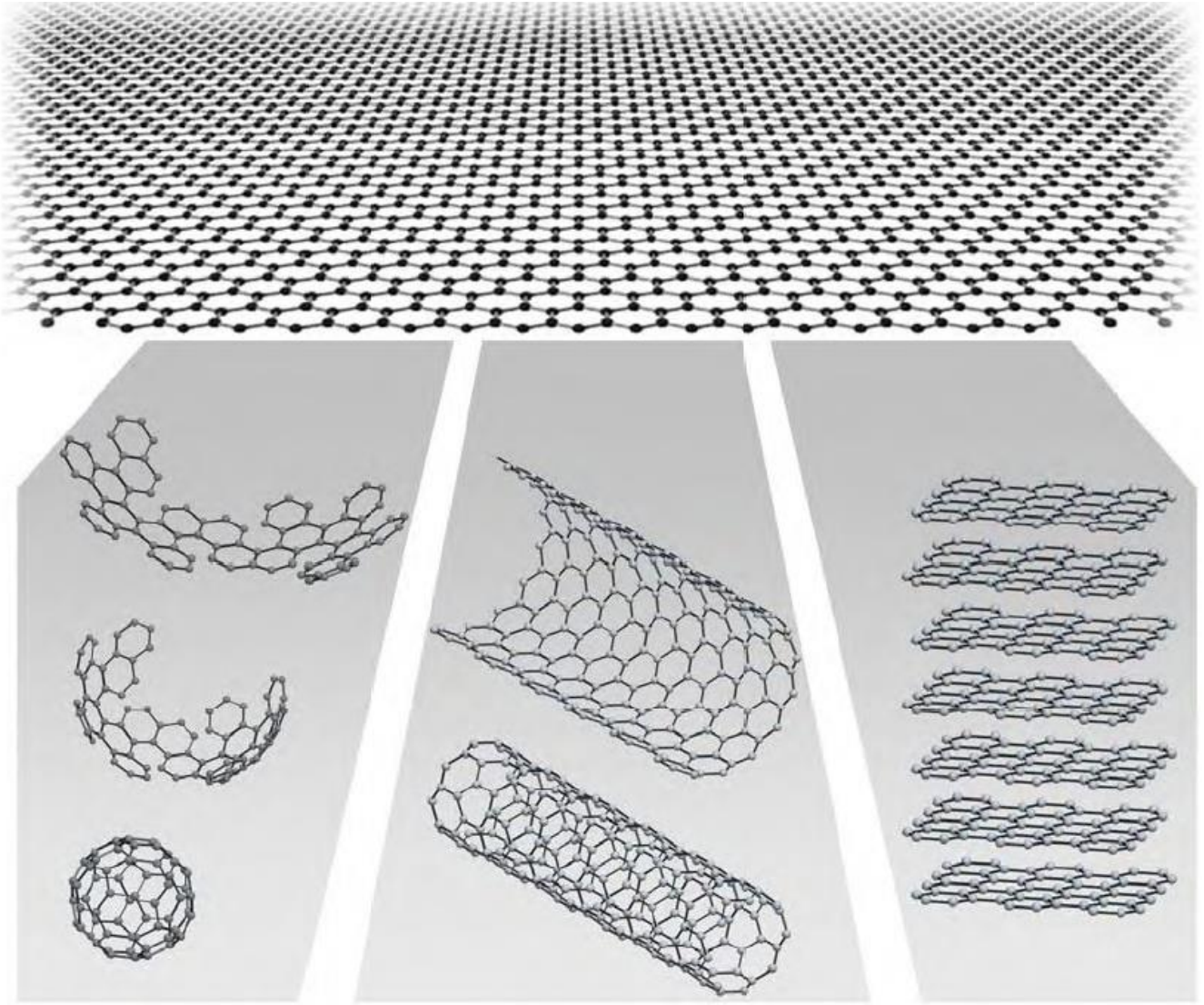
Distinguished Professor, Department of Chemistry & Biochemistry
Distinguished Professor, Department of Materials Science & Engineering
Dr. Myung Ki Hong Endowed Chair in Materials Innovation
University of California, Los Angeles (UCLA)







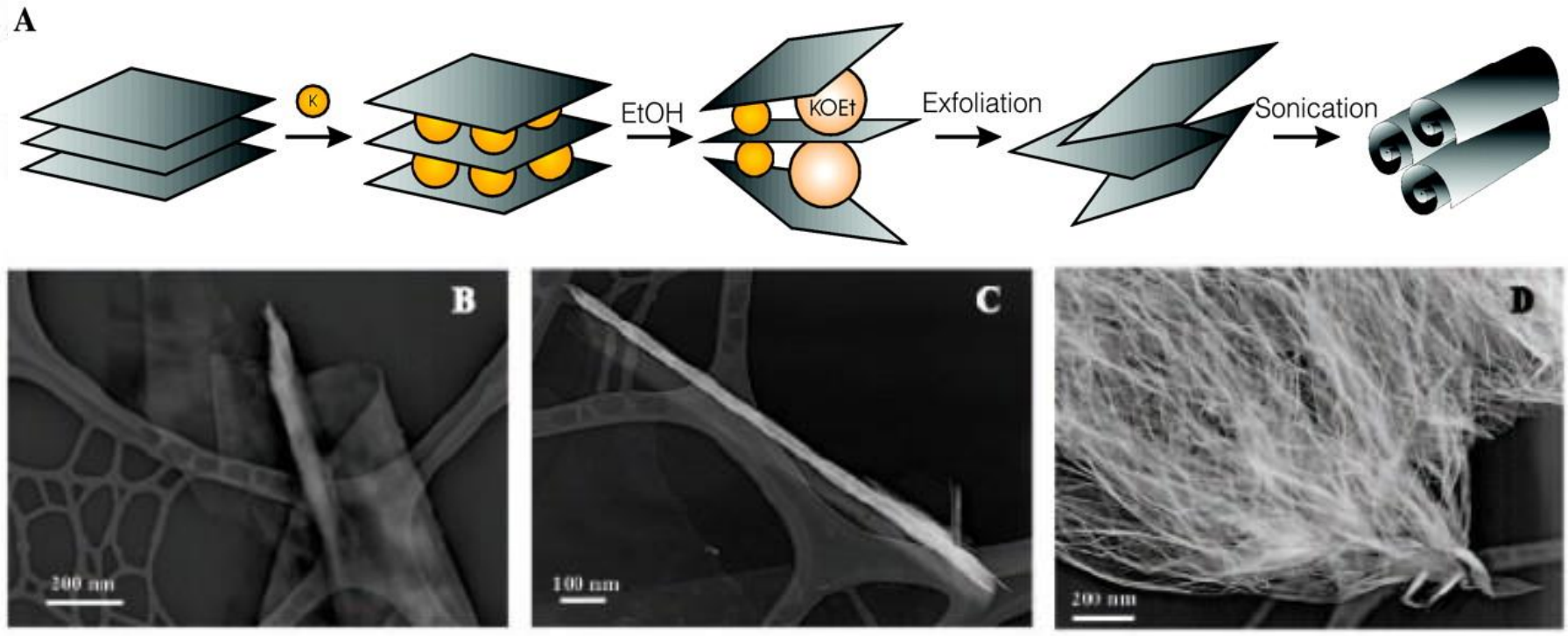
Graphene: The Building Block for All Forms of Carbon



Graphene ➔ 0D fullerenes, 1D carbon nanotubes and 2D graphite.

Geim and Novoselov, *Nature Materials* **6**, 183–191 (2007)

Intercalation and Exfoliation of HOPG



- Produces carbon nanoscrolls comprised of few layer graphene

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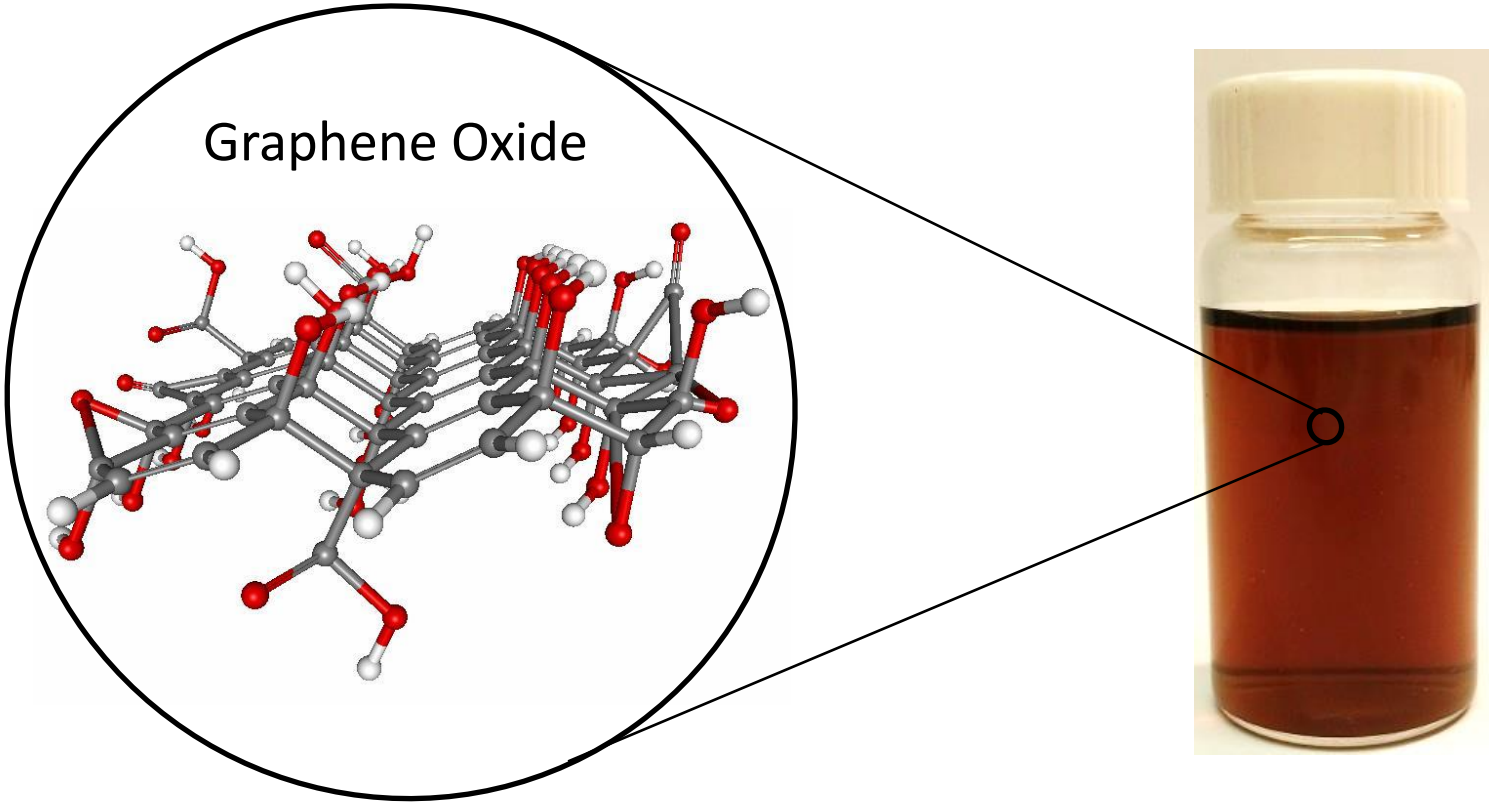
U.S. Patent #6,872,330 filed May, 2002

Viculis, Mack, Kaner, *Science*, **299**, 1361 (2003)

Solutions of Graphene Oxide

- Highly oxidized graphite can be prepared with -OH,  , C=O and -COOH functionalities*
- The sheets interact strongly with water and exfoliate

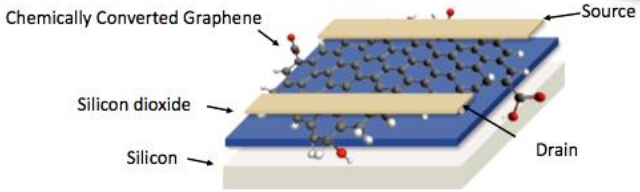


Brodie, *et al*. *Liebigs Ann. Chem.* **6,** 114 (1860)
*Kovtyukhova, Mallouk, *et al*. *Chem. Mater.* **11**, 3 (1999)

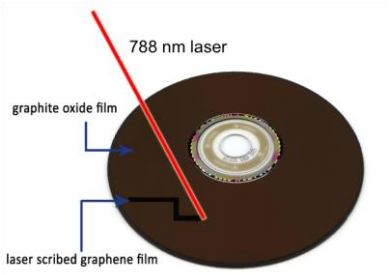
A Range of Applications Stemming from Graphene Oxide

GRAPHENE PAPER

SUPERCAPACITORS



ELECTRONICS



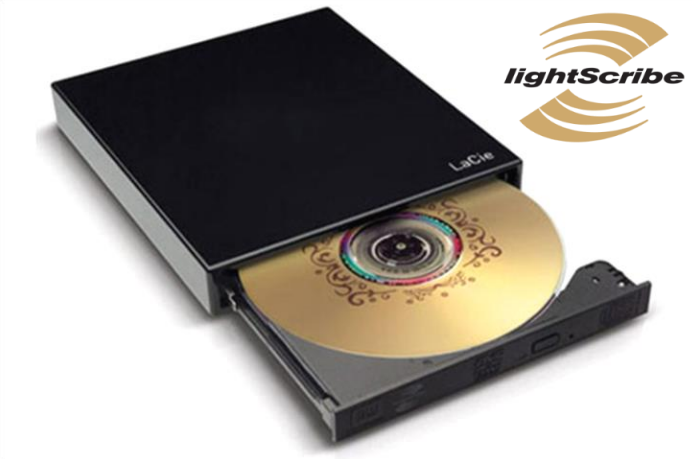
LIGHT SCRIBE LITHOGRAPHY

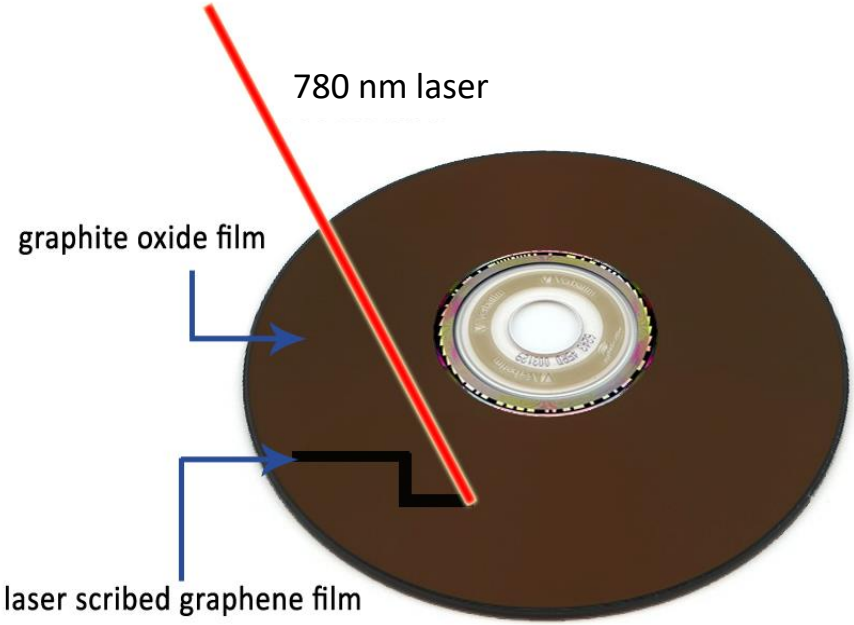
ROBUST CHEMICAL SENSORS

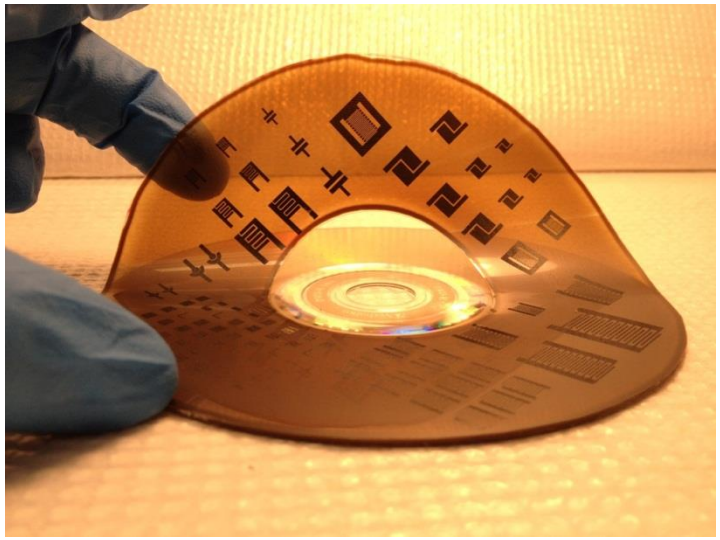
GRAPHENE OXIDE FOAM

Allen, Tung, Kaner, *Chem. Rev.* **110**, 132 (2010)
Wassei, Kaner, *Accounts of Chemical Research* **46**, 2244 (2013)

LightScribe: Graphene Electrodes in a DVD Burner

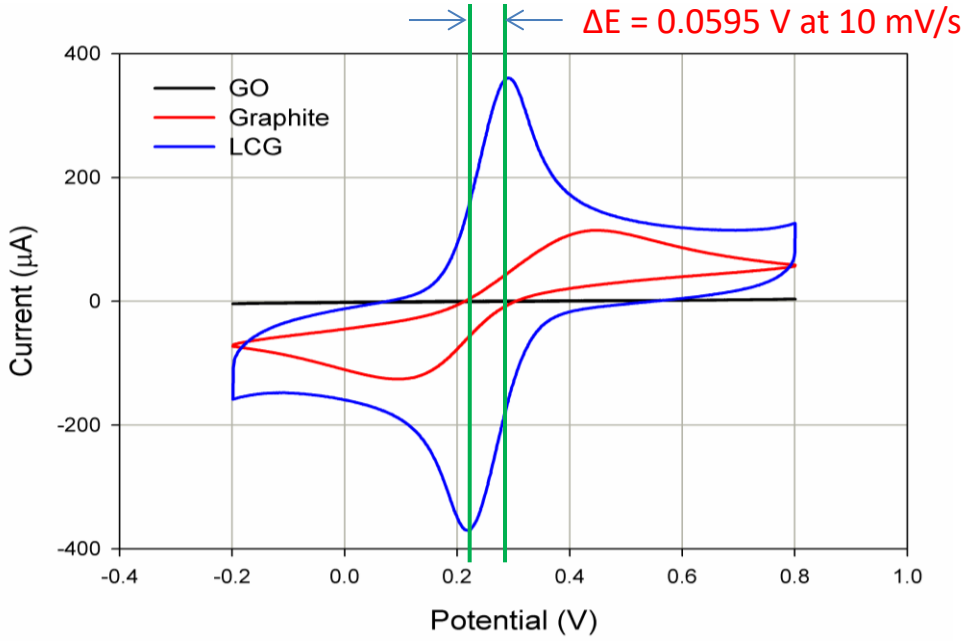


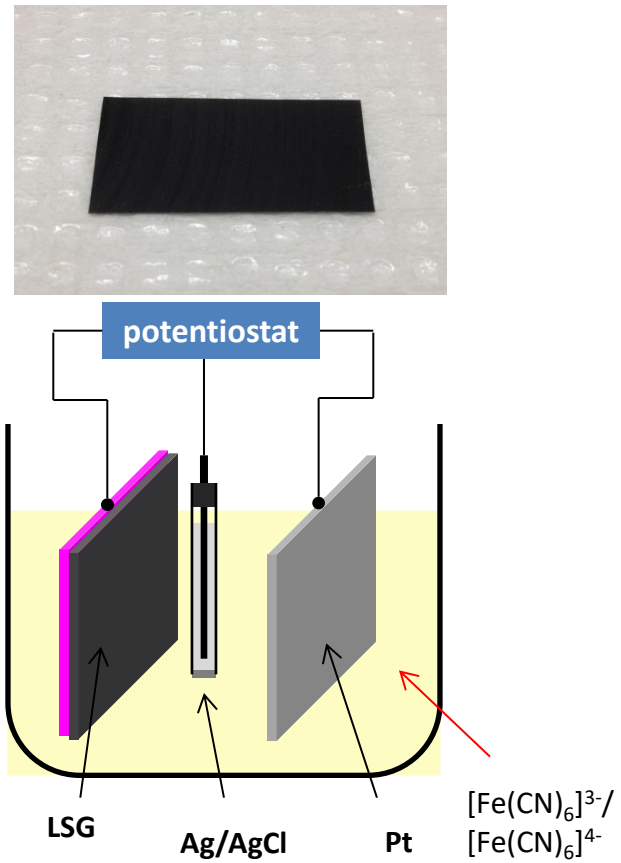




Strong, Dubin, El-Kady, Lech, Wang, Weiller, Kaner, *ACS Nano* **6**, 1395 (2012)

Electrochemical Applications of Laser Scribed Graphene





Ferro/ferri-cyanide couple as a redox probe

$Fe(CN)_6^{3-} + e^- \longrightarrow Fe(CN)_6^{4-}$

$$E = E^0 - \frac{0.05916\ \mathrm{V}}{z} \log_{10} \frac{a_{\mathrm{Red}}}{a_{\mathrm{Ox}}}.$$

	Graphite	CNT	LSG
k^o_{obs} (cm s^{-1})	$\mathbf{1.26 \times 10^{-4}}$	8.34×10^{-5} 3.67×10^{-3}*	$\mathbf{1.33 \times 10^{-2}}$
		* Chem. Asian J. 2008, 3, 2046–2055.	All-carbon electrode (no current collector)

Making Graphene Supercapacitors in a DVD Burner

Making graphene supercapacitors is as easy as burning a DVD

DVD disc

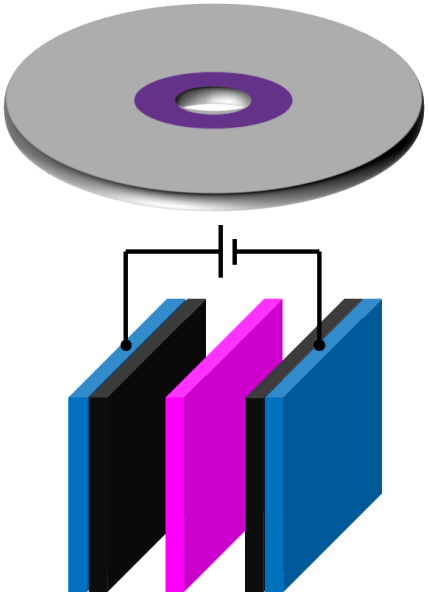
Apply GO film supported on flexible substrate

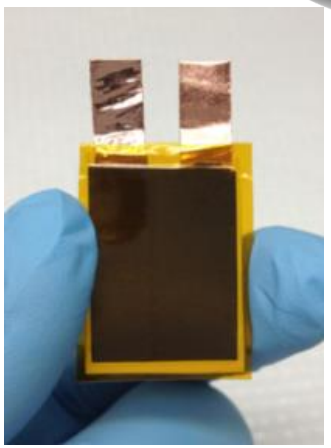
LightScribe in a computerized DVD drive

Laser

Peel off LSG film

Device fabrication





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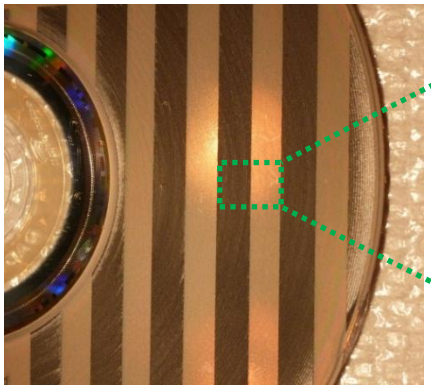
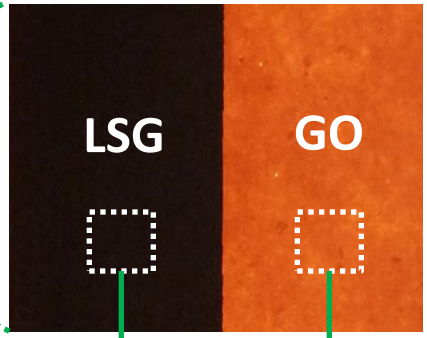
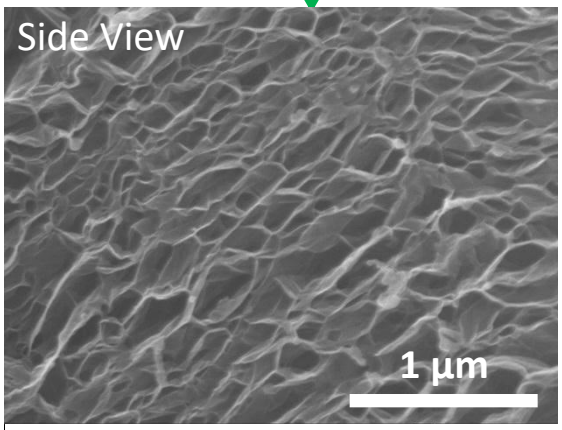
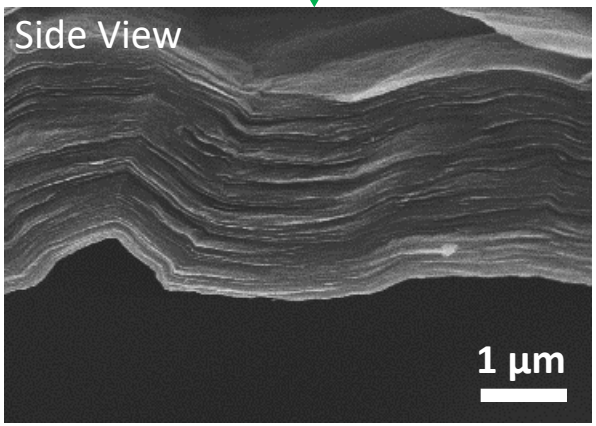
El-Kady, Strong, Dubin, Kaner, *Science* **335**, 1326 (2012)

High-Performance Laser Scribed Graphene Electrodes (LSG)









	Activated Carbon	LSG	Impact
Electrical conductivity (S/m)	10-100	1740	High power density
Surface area (m^2/g)	1000-2000 (micropores)	1520 (accessible)	High energy density
Mechanical properties	Powder	Flexible electrodes	Flexible devices
Binders and current collector	Yes	No	Simple fabrication

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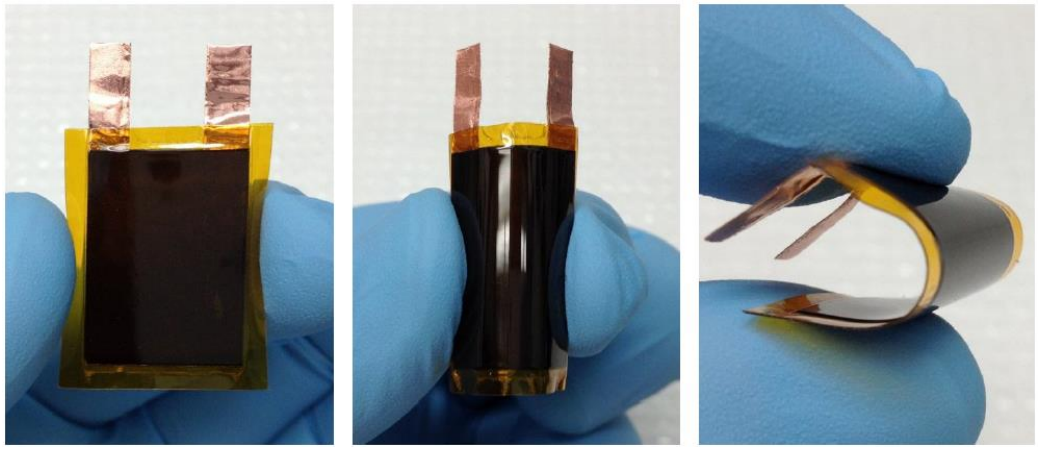
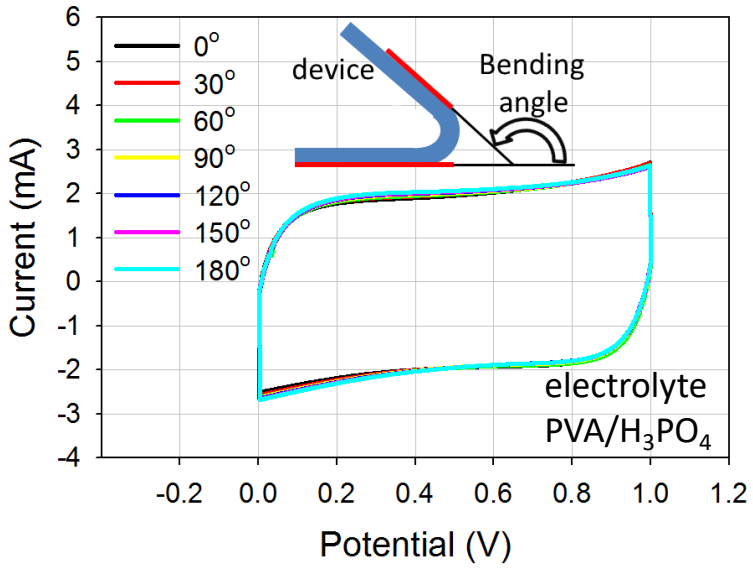
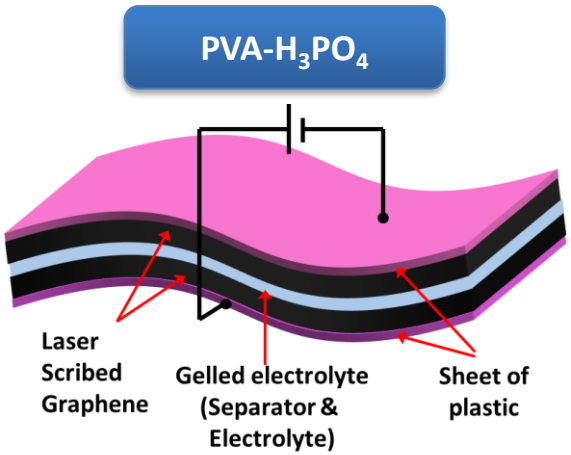
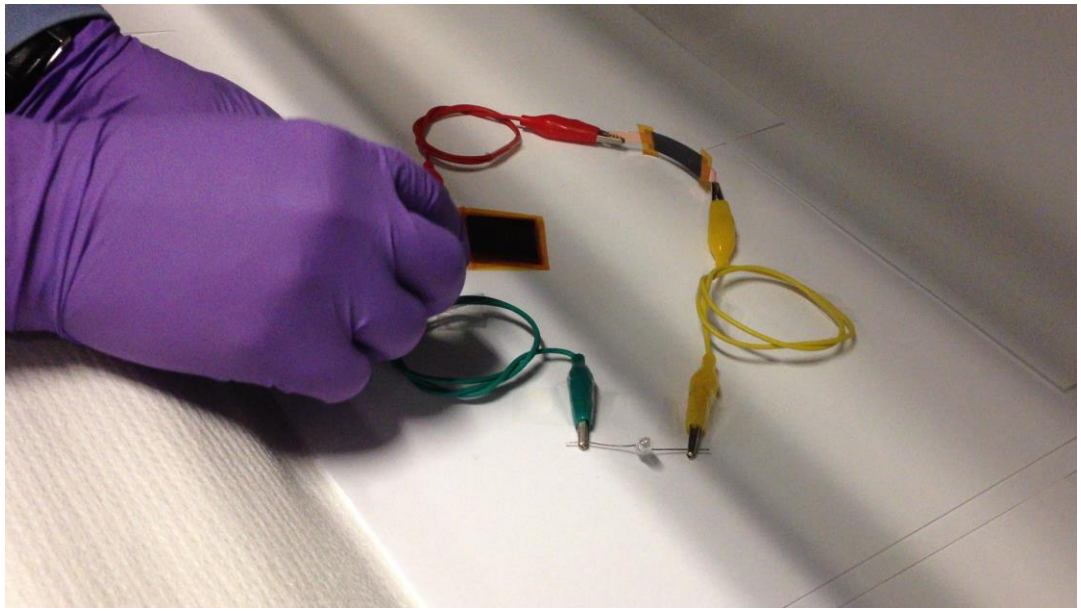
Science **335**, 1326 (2012)

Flexible, All-Solid-State Supercapacitors









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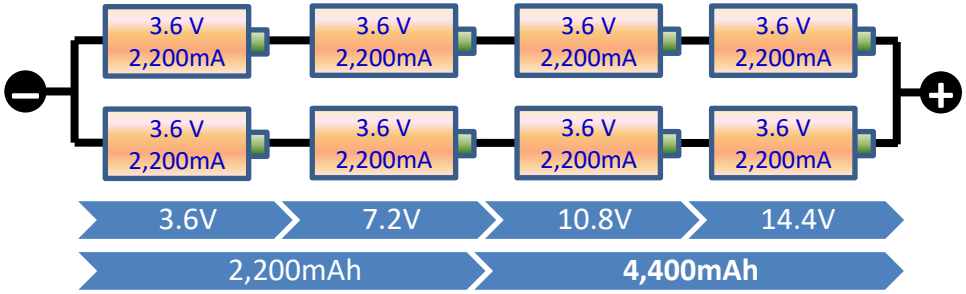
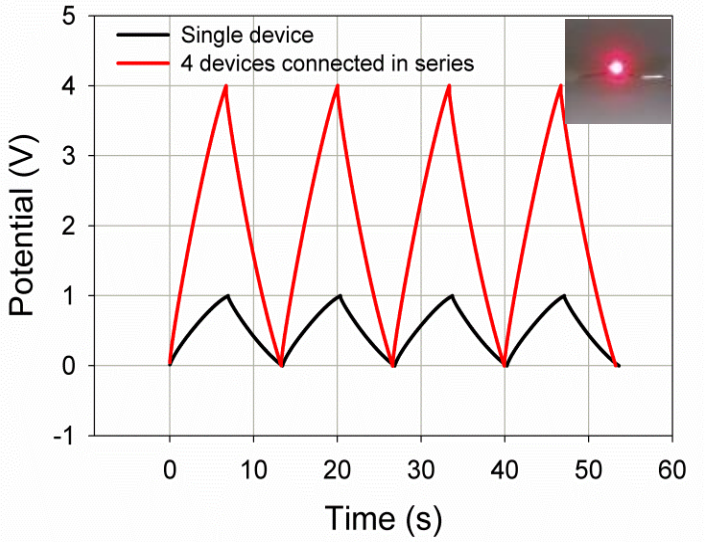
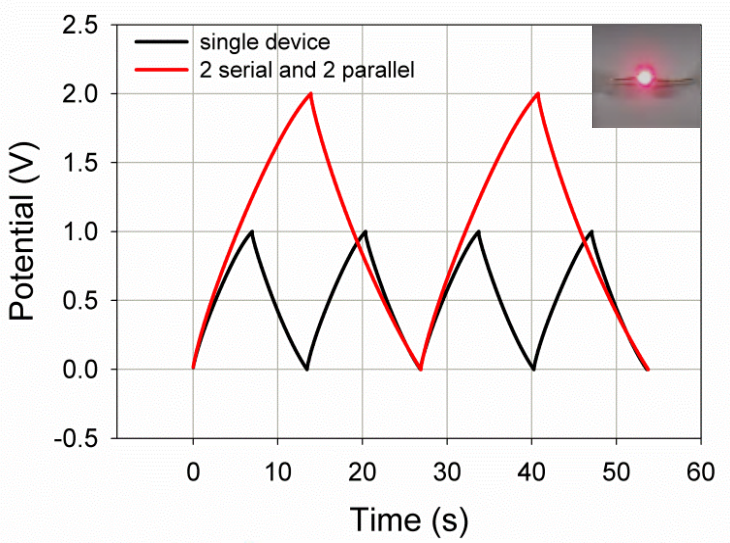
Science **335**, 1326 (2012)

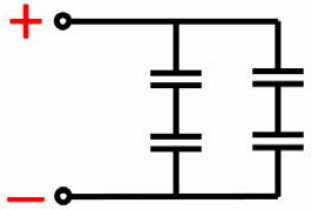
Tandem Supercapacitors



Tandem supercapacitors







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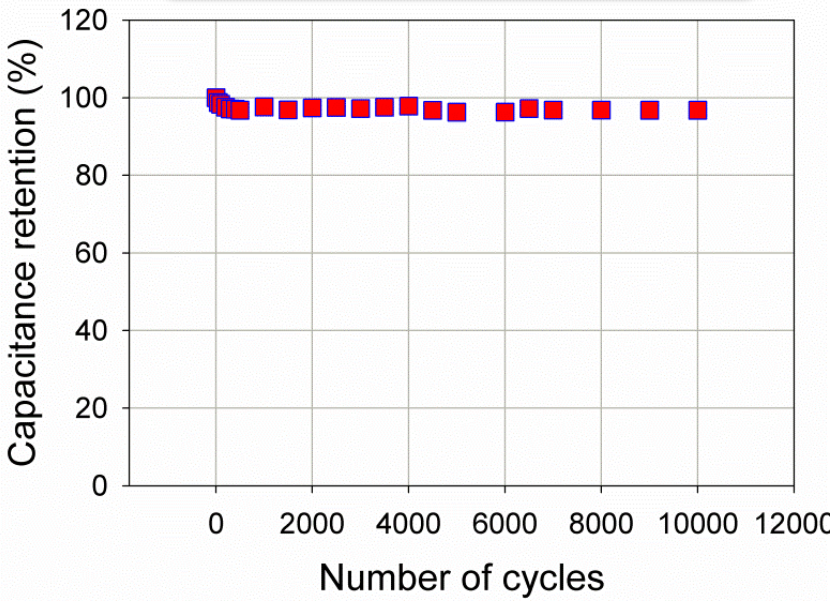
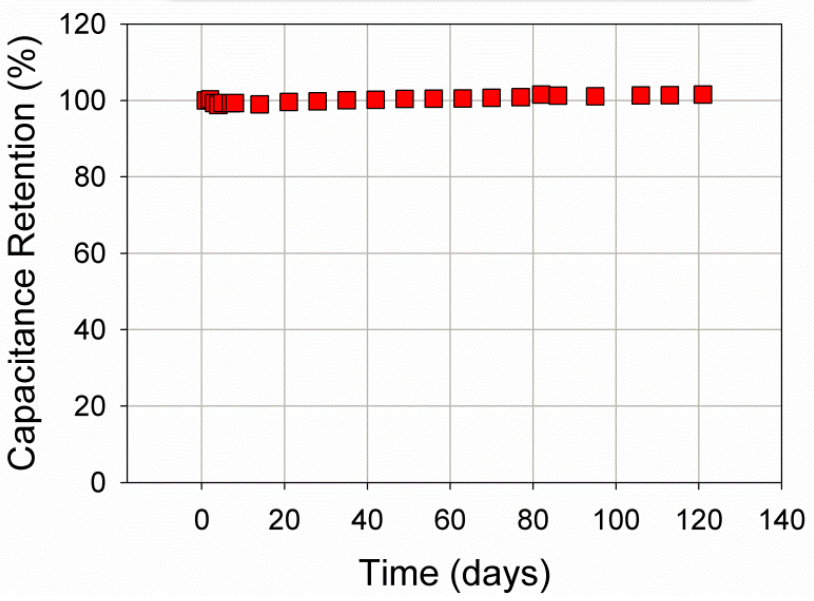
Cycling and Shelf-Life

Cycling life



Shelf life



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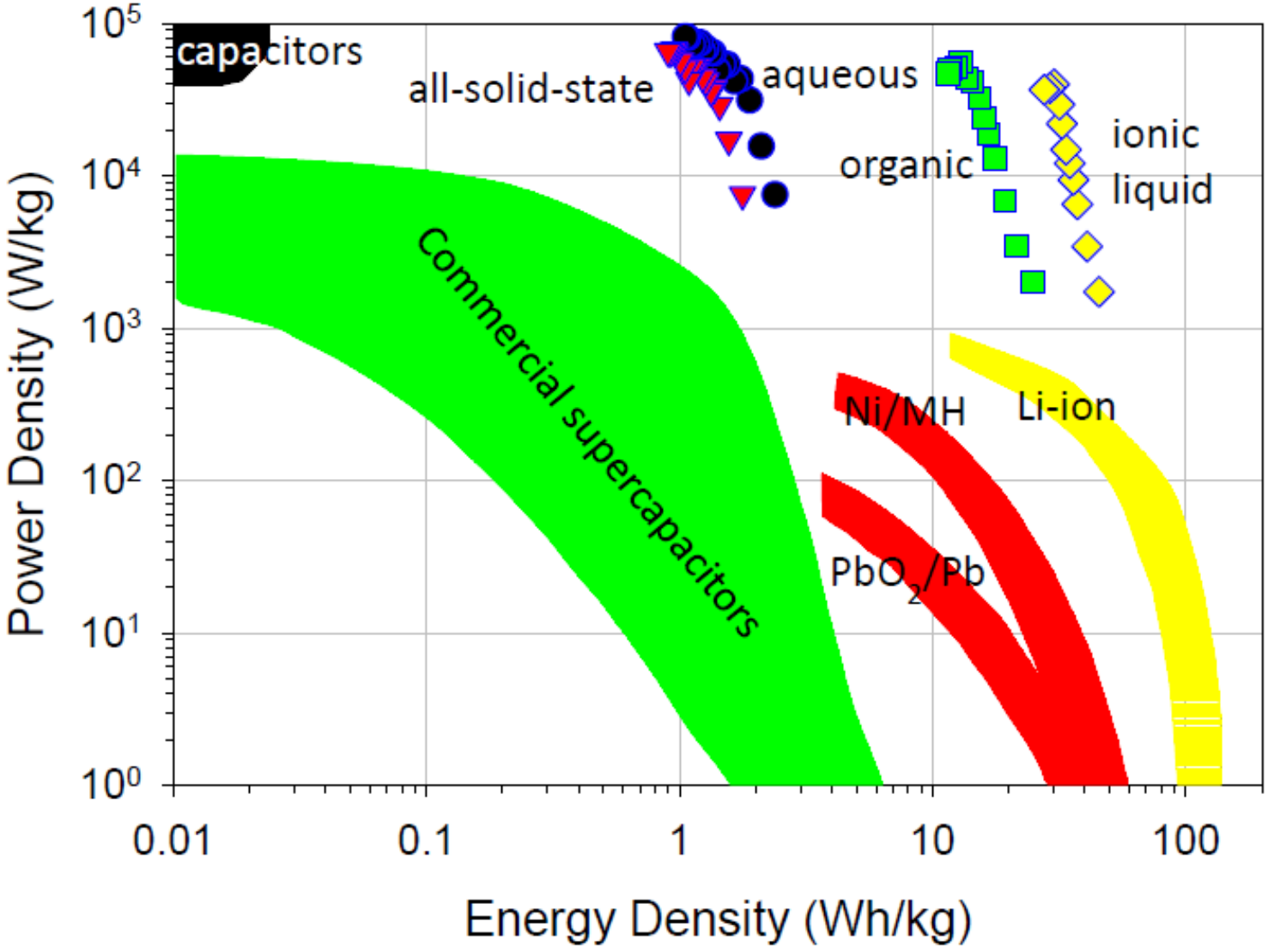
Science **335**, 1326 (2012)

LSG vs. Commercial Supercapacitors



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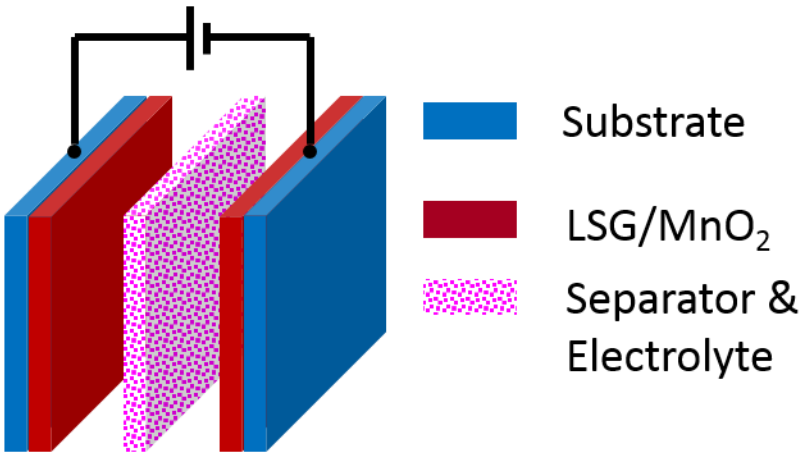
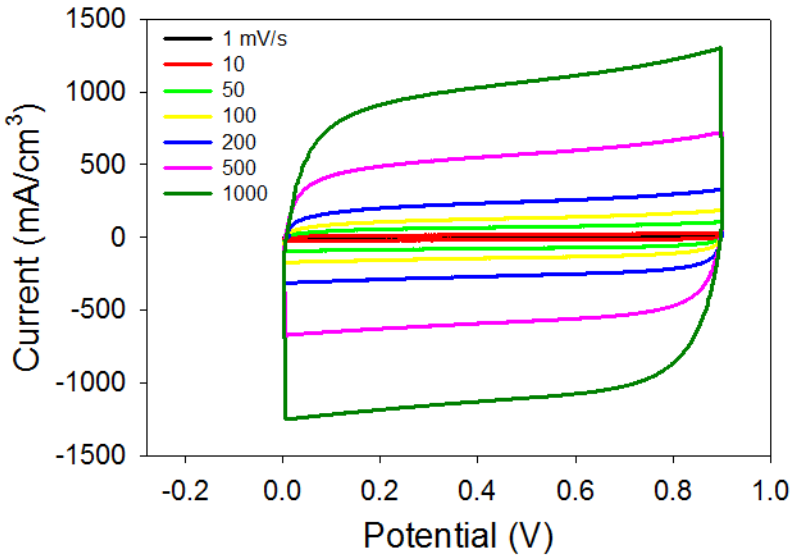
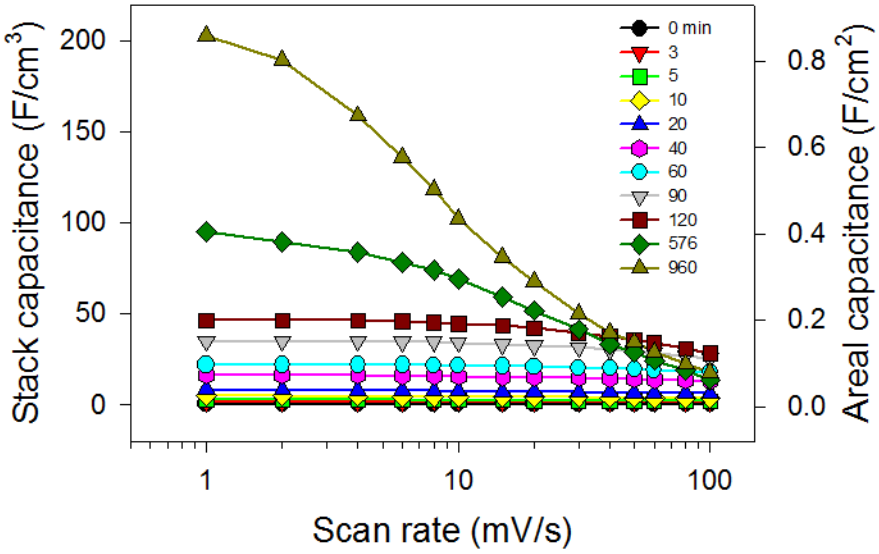
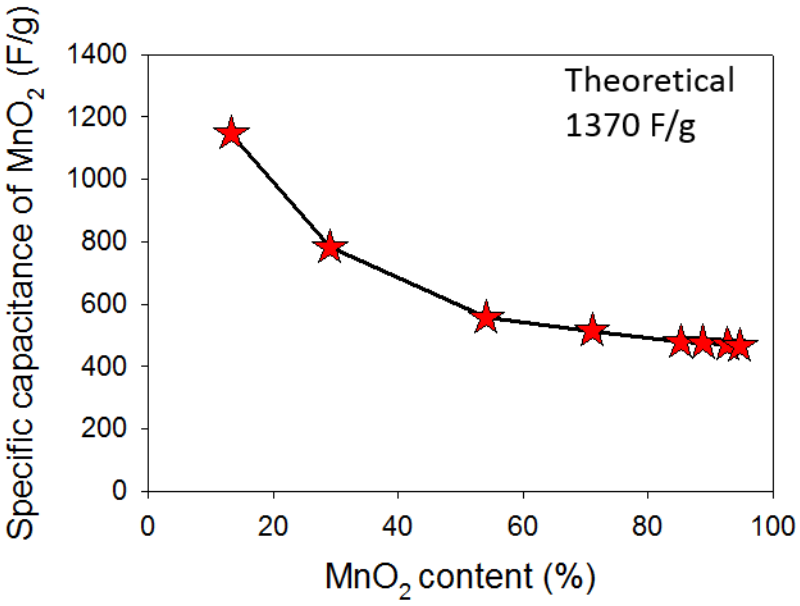
Symmetric Supercapacitors



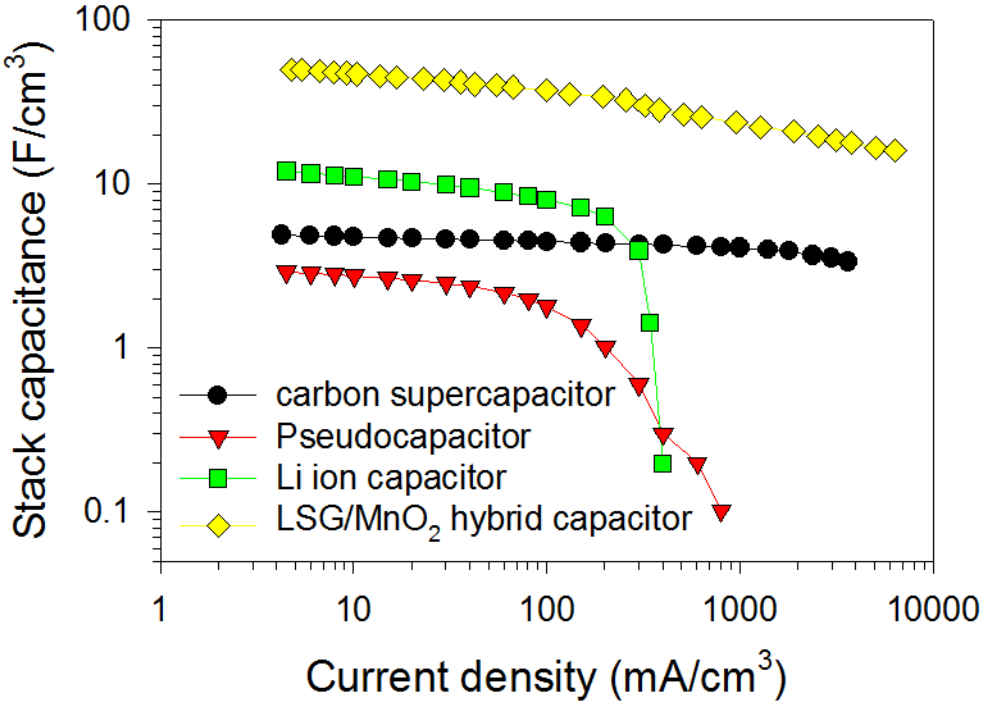




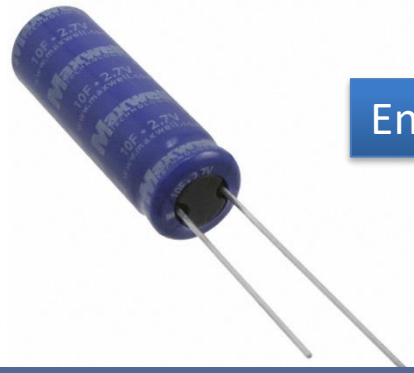


PNAS **112**, 4233 (2015)

Commercially Available Pseudo- and Hybrid-Capacitors



Li ion capacitor	Pseudocapacitor	EDLC
2.3V	3.3 V	2.7 V



Energy Density = ½ CV^2

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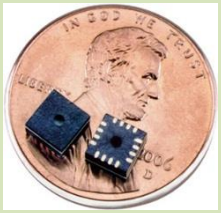
PNAS **112**, 4233 (2015)

Need for Miniaturized Energy Storage

Miniaturized electronics

Cardiac pacemaker

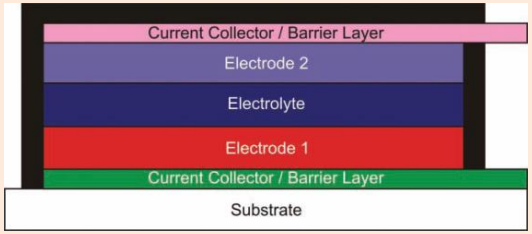
RFID

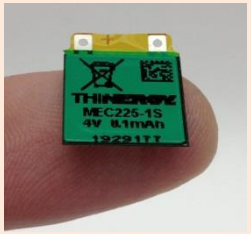


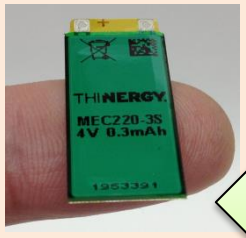
MEMS sensors

Hearing aids

Micro-batteries

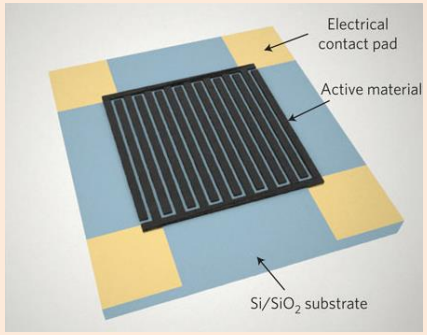


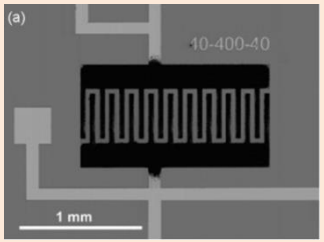


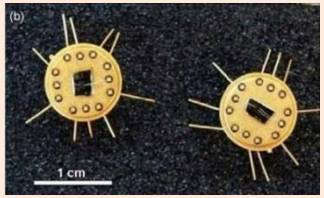


Adv. Energy Mater. 1, 10 (2011)

Micro-supercapacitors







Jos, Oudenhoven, Adv. Energy Mater. ***1***, 10 (2011)
Simon, Gogotsi *et al., Science* **328**, 480 (2010)
Simon, Gogotsi *et al., J. Power Sources* (2010)
Nature Nanotechnology **5**, 651 (2010)

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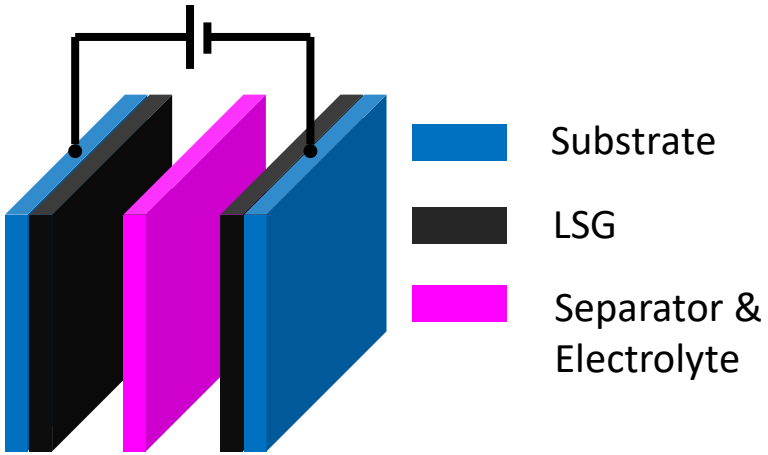
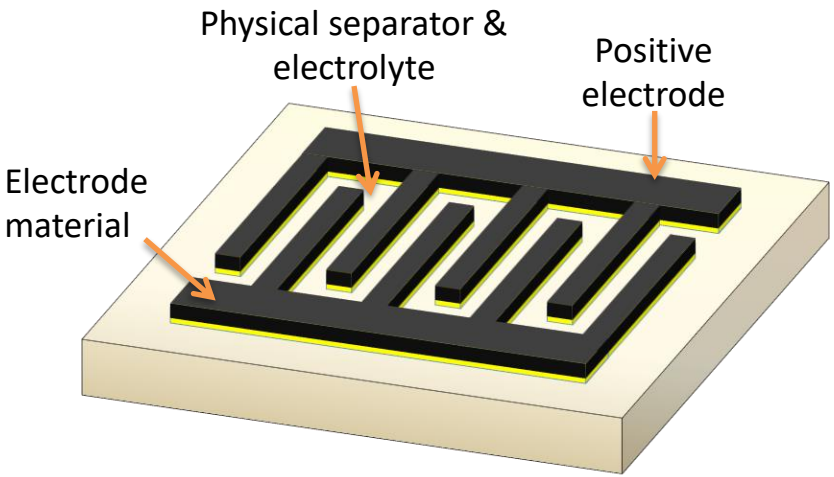
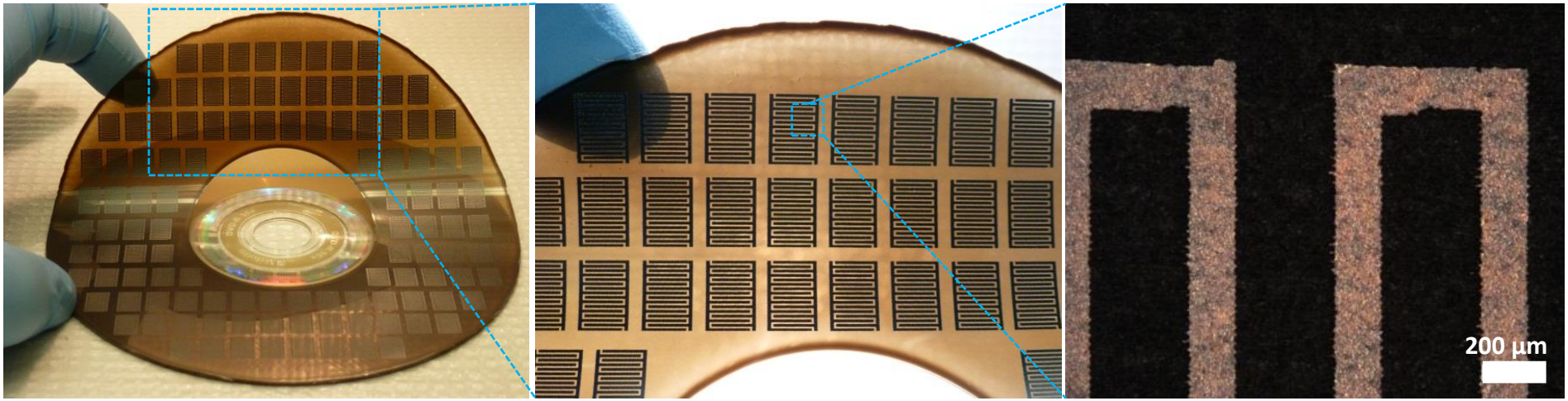
Scalable Fabrication of Graphene Micro-Supercapacitors



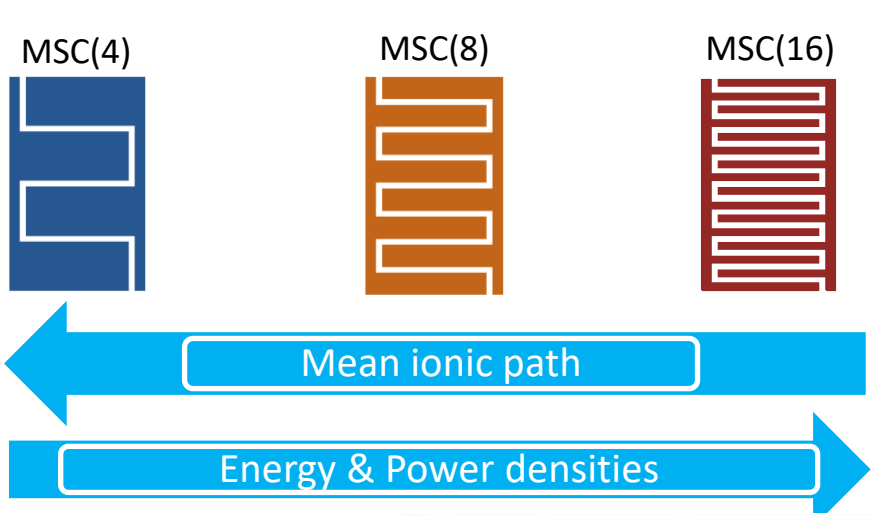


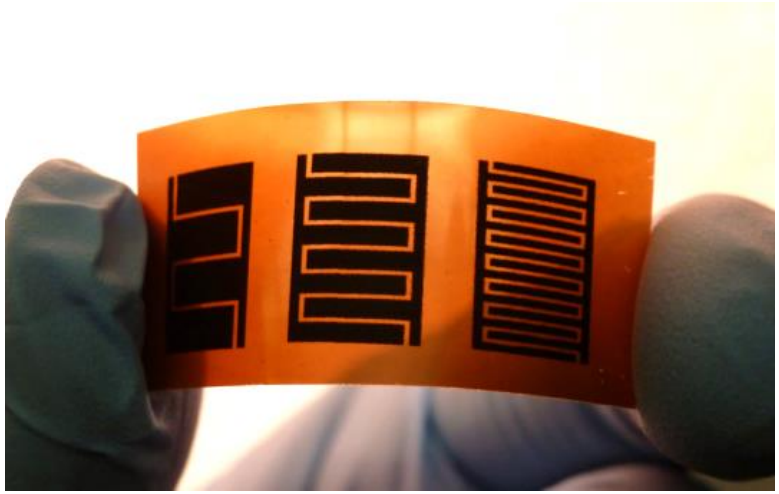
>100 micro-supercapacitors made in <30 minutes

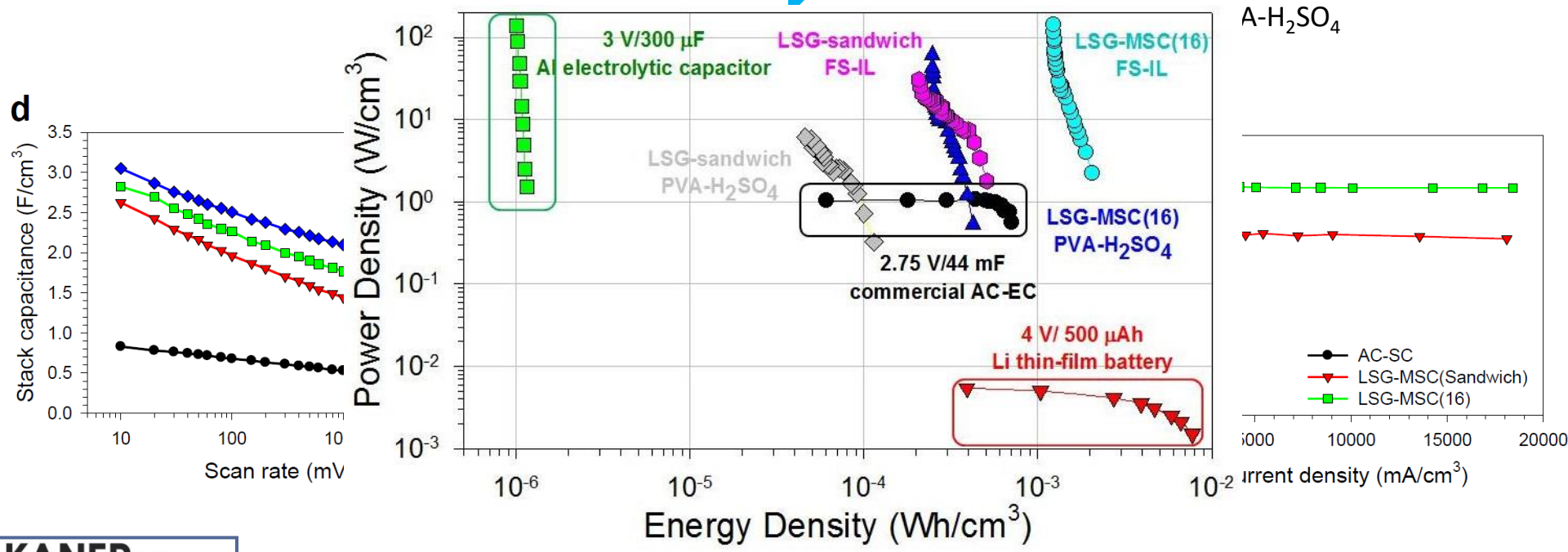


El-Kady & Kaner. *Nature Commun.* **4**, 1475 (2013)

Miniaturization Results in Increased Energy and Power







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Nature Commun. **4**, 1475 (2013)

NOVA: Search for the Super Battery

NANOTECH

Graphene Powered Batteries

→ MAKING MATERIALS MATTER

Product Offering and Commercial Readiness

100% American-Made

- Purchasers are looking to secure domestically manufactured battery alternatives over existing internationally sourced supply chains
- Nanotech's mid-scale production operates in Chico, California and qualifies for both Advanced Manufacturing PTC Credits ($35/kWh) and Electrode Active Materials PTC (10% of active materials costs)

Already Producing at Scale

- Nanotech has an operational mid-scale manufacturing facility, located in Chico California, capable of producing 150MWh or 1 million batteries per month of 18650 and 21700 cells
- The Company is ready to finance a full-scale manufacturing facility with a high-quality product offering and a growing customer base

Chemistry Agnostic & Safe Technology Platform

- Nanotech has designed, developed, and commercialized multiple battery formats across LCO, NMC, and LFP chemistries to produce the safest high-performing batteries available today
- Nanotech's IP and trade secrets are chemistry agnostic, allowing the Company to target multiple existing market segments and adapt with the evolution of battery chemistries moving forwards

Graphene-Powered Cells

- Nanotech is the only company to have industrialized the production of high purity, single-layer graphene
- Graphene improves conductivity, safety, energy density, and cycle life in batteries and has applications across multiple other high-value industries

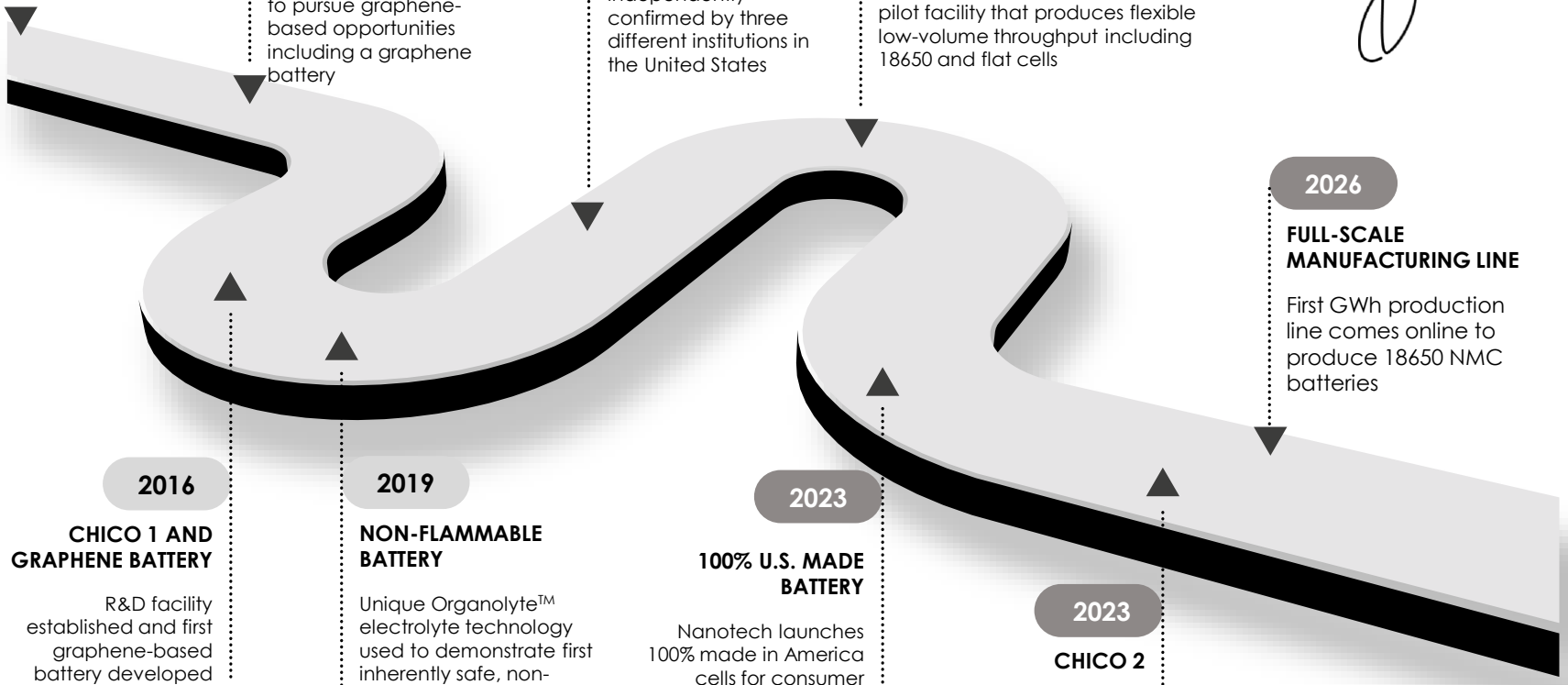
Strong Customer Base Following

- Nanotech is in discussion with a number of customers that can take the full production capacity of their full-scale manufacturing line
- $13GWh+ annual sales in active negotiation

BASF
We create chemistry

Nanotech's Technology and Production Roadmap

From Technology Incubation to Commercialization



2002

WORLD'S FIRST GRAPHENE IP

Spin out of UCLA with issuance of the first graphene patent

2014

NANOTECH ENERGY FOUNDED

Nanotech was founded to pursue graphene-based opportunities including a graphene battery

2016

CHICO 1 AND GRAPHENE BATTERY

R&D facility established and first graphene-based battery developed

2019

NON-FLAMMABLE BATTERY

Unique Organolyte™ electrolyte technology used to demonstrate first inherently safe, non-flammable li-ion battery

2021

PURE GRAPHENE

Achieved 95% monolayer graphene independently confirmed by three different institutions in the United States

2022

CHICO 1

Successfully commissions 3MWh pilot facility that produces flexible low-volume throughput including 18650 and flat cells

2023

100% U.S. MADE BATTERY

Nanotech launches 100% made in America cells for consumer product applications

2023

CHICO 2

Medium-scale production facility begins manufacturing cells in Q4

2026

FULL-SCALE MANUFACTURING LINE

First GWh production line comes online to produce 18650 NMC batteries

NANOTECH

Technology Incubation Period

Company Commercialization

How Graphene Enhances Nanotech's Batteries

The integration of graphene into electrodes improves the performance and safety of battery cells

Improved Energy Density

Increase the overall energy density of the battery by increasing the reversible capacity of the cathode. Our graphene can be utilized to increase the capacity of LFP by 5-20%

Longer Cycling Life

Graphene can increase the cycling life of the battery. Graphene can be uniformly coated on the cathode, which provides good protection for cathode particles against volume expansion or agglomeration

Increased Power Density

Increase the power density of the cells by manipulating the electronic and ionic conductivity of the electrodes and electrolytes

Next Generation Silicon Anodes

Integrating graphene into silicon anodes provides a conductive, flexible matrix that mitigates large volume changes and instability during use, enhancing conductivity, charge retention, and overall battery life

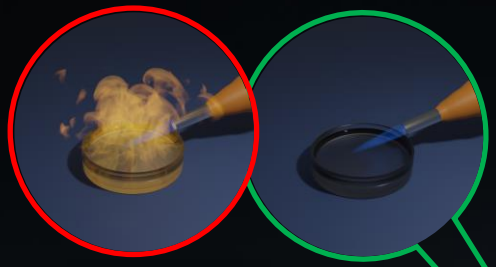
Reduced Resistance

The presence of graphene also reduces cell impedance

Nanotech's Unique Battery Technology

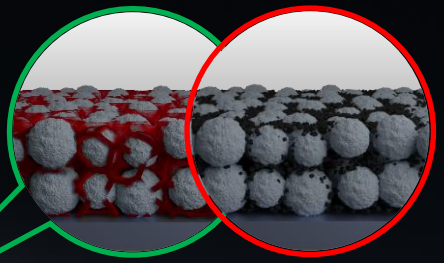
Nanotech's portfolio of protective patents, trade secrets, and industry experience offers a platform that: (i) introduces graphene into the electrodes, (ii) creates a non-flammable electrolyte, and (iii) produces a next generation lithium-ion battery across multiple cell formats

ELECTROLYTE



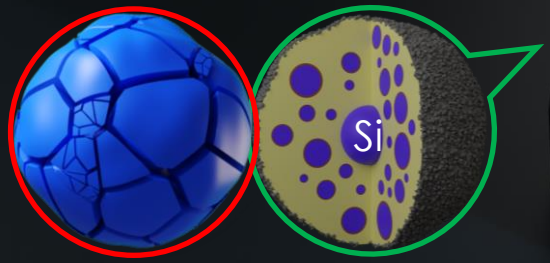
Organolyte™ is a non-flammable electrolyte that offers high energy density and functions across a wide range of operating temperatures without sacrificing safety measures, unlike competitors

CATHODE



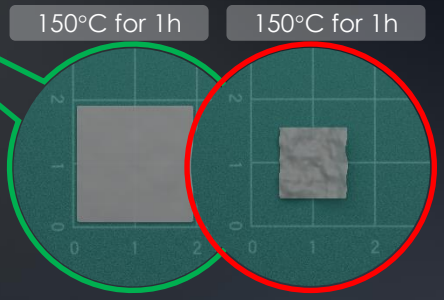
Graphene wraps the cathode particles to improve cycle life, energy density, safety, and conductivity

ADVANCED ANODES



Graphene is enabling the next-generation of anodes such as silicon by improving strength, durability, and life cycle

CURRENT COLLECTOR & SEPARATOR



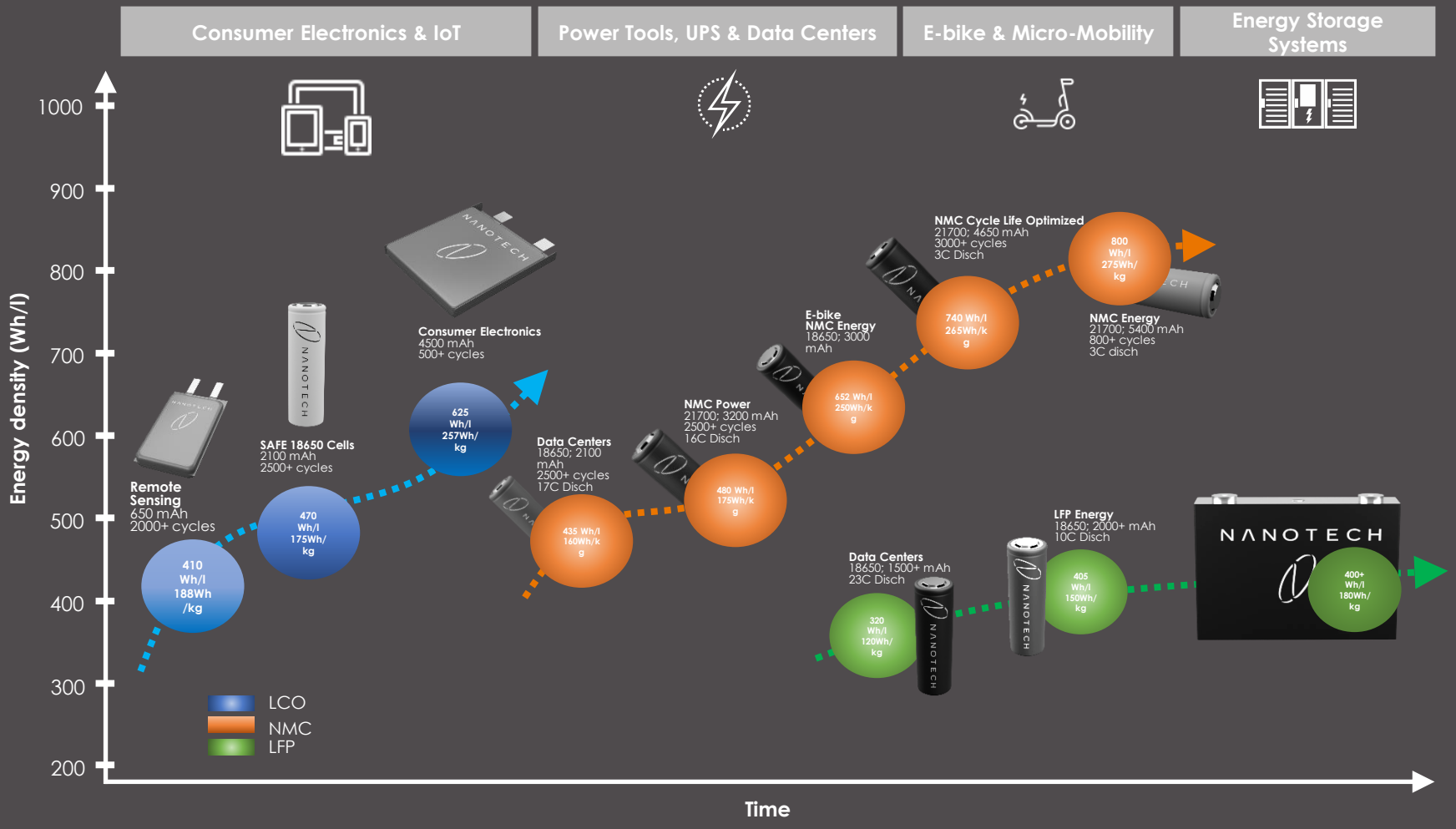
High thermal separators provide additional safety features by functioning at higher temperatures. Also utilizing lighter metalized plastic current collectors can improve the safety and energy density of batteries

Traditional Lithium ion

Nanotech Battery Tech

Multiple Battery Formats Using Nanotech Technology

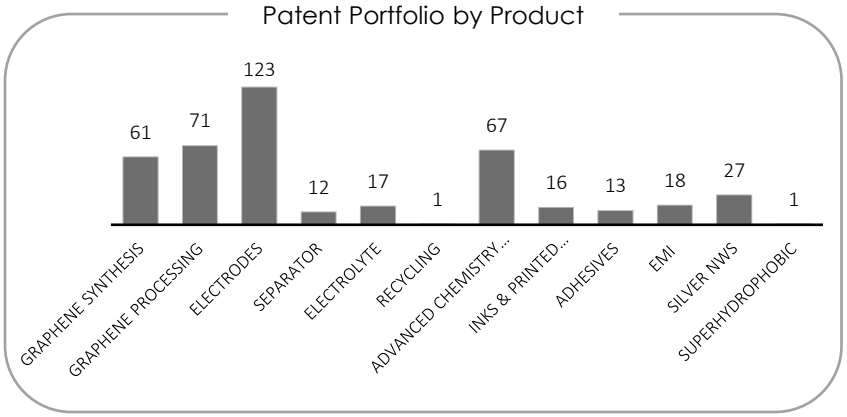
On the back of its proprietary graphene breakthrough, Nanotech has designed, developed, and commercialized multiple battery chemistries that are both safe and high-performing



Nanotech's Patent Portfolio

Nanotech has built a strong global portfolio of over 300 patents around its graphene and battery platforms

- Nanotech has the very first graphene patent ever submitted and issued
- The Company continues to be the only company producing non-restacking single layer graphene sheets on a commercial scale.
- The Company has over 300 patents filed covering all aspects from graphene synthesis, processing to applications in batteries, supercapacitors, inks, adhesives, EMI Shielding, printed electronics, its non-flammable Organolyte™ electrolyte technology, Li-S, Si anode, separators, and silver nanoparticles / nanowires



Flag	Country	Patents Issued	Patents Pending	Total
	U.S.	54	25	79
	Europe	12	17	29
	China	11	16	27
	Japan	17	10	27
	South Korea	14	11	25
	Canada	8	17	25
	Australia	16	6	21
	India	6	15	21

Flag	Country	Patents Issued	Patents Pending	Total
	Taiwan	14	4	18
	Israel	11	3	14
	Mexico	4	7	11
	Brazil	7	1	8
	Hong Kong	1	3	4
	Vietnam	2	1	3
	Eurasia	1	0	1
	Indonesia	1	0	1

Flag	Country	Patents Issued	Patents Pending	Total
	Germany	1	0	1
	France	1	0	1
	Italy	1	0	1
	Turkey	1	0	1
	UK	1	0	1
	PCT	1	0	1
	Total	**185**	**145**	**330**

Nanotech's Cell Offering

LFP: Performance Overview

Faster Charging

- Nanotech's LFP cells can withstand higher current when compared to market alternatives
- This is an important characteristic for electric vehicle applications as it can better cope with fast charging scenarios

Higher Energy Density

- Nanotech's LFP Cells have 30% Higher Energy Density
- Commercial 18650 LFP cells offering ~1200mAh, whereas Nanotech's LFP power cell delivers up to 1600 mAh

Improved Safety

- Nanotech's LFP Cells have a better safety rating than existing state of the art LFP cells

Larger Usable Capacity

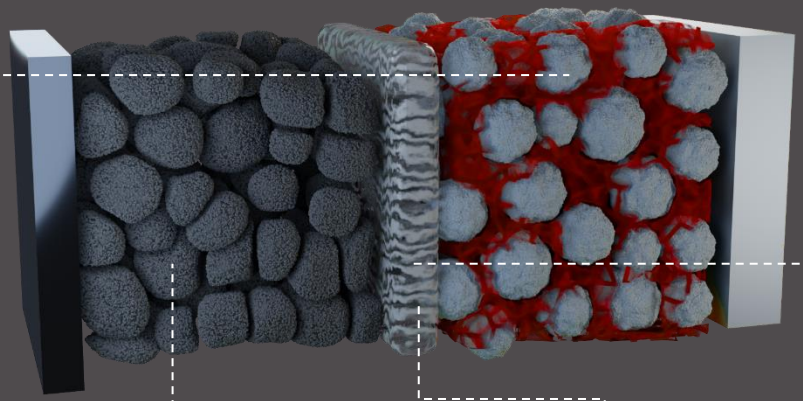
- Nanotech's LFP can fully discharge at extremely high currents (up to 30A), while maintaining a reasonable temperature of <70oC
- Unlike traditional NMC cells, where you often need to limit the depth of discharge to around 70-80%, Nanotech LFP power cells can be fully discharged without concerns of excessive overheating

Long Term Cycling

- The introduction of graphene into the cathode significantly improves cycling stability to over 6,000 cycles under ideal conditions

Nanotech's Unique Battery Technology

Nanotech's portfolio of protective patents, trade secrets, and industry experience offers a platform that: (i) introduces graphene into the electrodes, (ii) creates a non-flammable electrolyte, and (iii) produces a next generation lithium-ion battery across multiple cell formats



A Cathode

Graphene wraps the cathode particles to improve cycle life, energy density, safety, and conductivity

B Anode

Graphene is enabling the next-generation of anodes such as silicon by improving strength, durability, and life cycle

C Electrolyte

Organolyte™ is a non-flammable electrolyte that offers high energy density and functions across a wide range of operating temperatures without sacrificing safety measures, unlike competitors

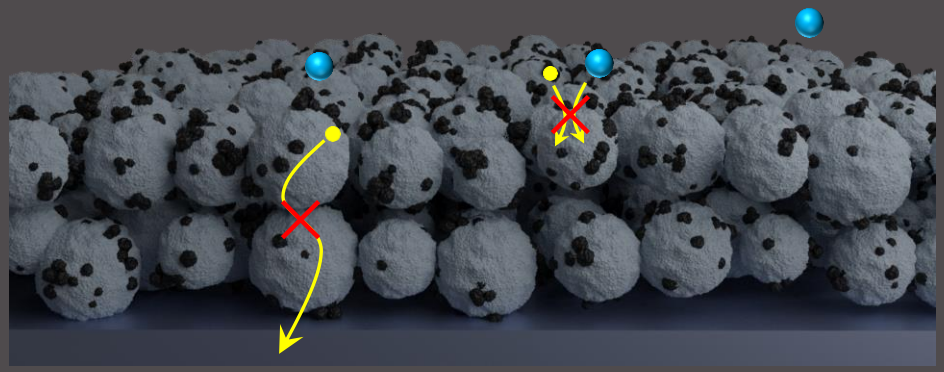
D Separator

High thermal separators provide additional safety features by functioning at higher temperatures

A How Does Graphene Optimize the Cathode?

Graphene enables an "expressway" to facilitate electron transfer

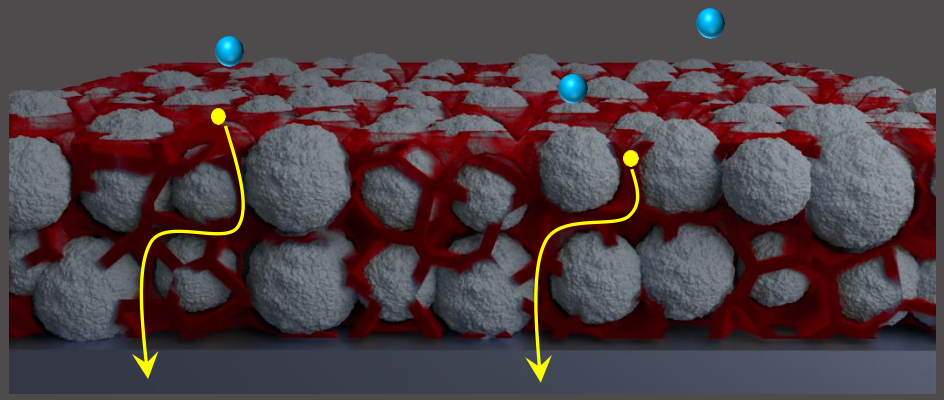
Traditional Approach



Point-to-Point Contact

In traditional electrodes, poor distribution of carbon black causes slow ion insertion and interparticle resistance, compromising the overall power density of the cell

Nanotech Approach



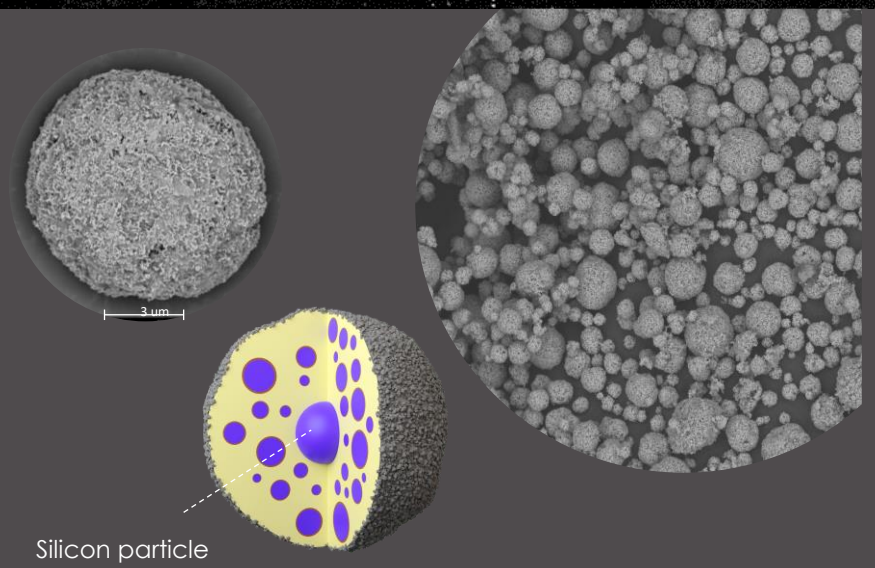
Plane-to-plane Contact

Graphene provides 3D network, acting as an ideal electronic and mechanical support to increase the reversible capacity, power and cycling stability of standard cathodes

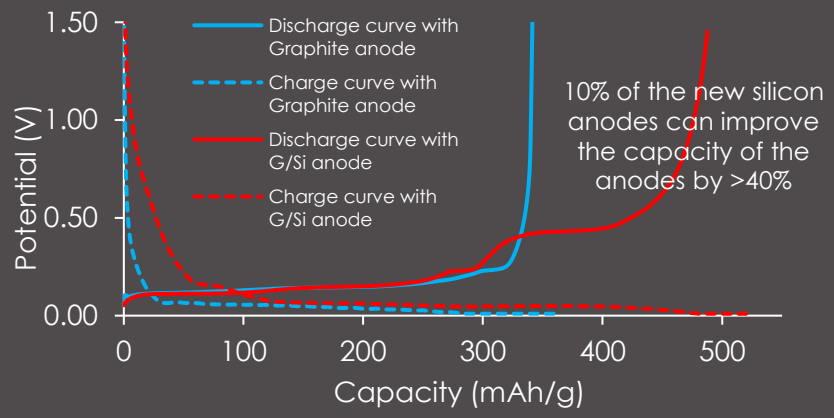
B Graphene Allows for High Capacity and Stability in Next-Gen Silicon Anodes

Nanotech's Silicon Anode Solution

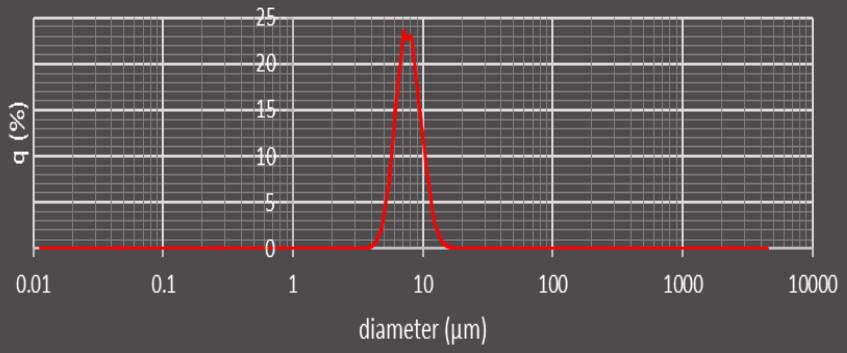
- Nanotech currently utilizes graphite for its anodes, but continues to develop and integrate its high-purity graphene into silicon anodes for next generation cells
- In a conventional graphite anode, it takes six carbon atoms to hold one lithium ion. In a silicon anode, each silicon atom can hold four!
- Silicon can store up to 10 times more lithium compared to graphite which enables batteries to have much greater energy
- Unfortunately, silicon anodes experience huge volume change (up to 300%) during charge and discharge and eventually leading the anode to disintegrate
- Graphene is a promising host for silicon nanoparticles for the design of high-capacity anodes
- The particle size distribution measurements show the powder with D50=8um, which is ideal for battery applications



Silicon Anodes Improve Capacity



Particle size distribution for silicon

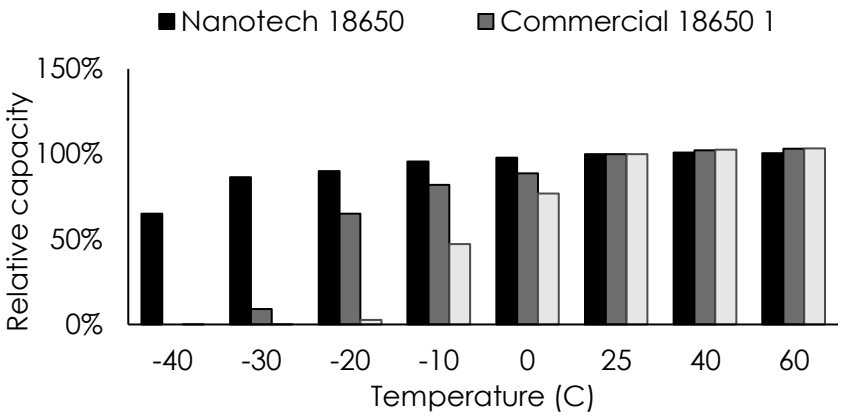


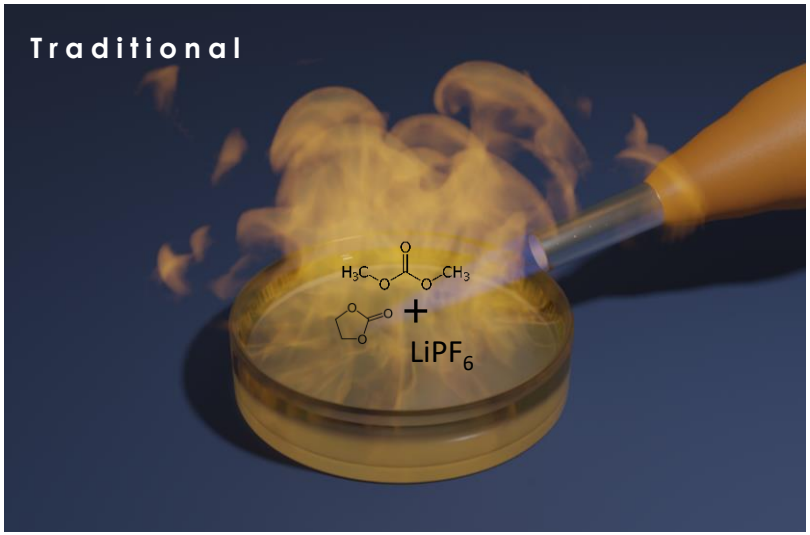
C Nanotech's Proprietary Electrolyte

Overview

- Nanotech's proprietary electrolyte technology, Organolyte™, enhances the safety rating of cells by utilizing patented high flashpoint / non-flammable electrolytes
- Organolyte™ reveals a wider operation temperature range
- The electrolyte not only expands a battery's operating temperature rage, but also improves its low temperature performance as displayed in the graph on the right
- Organolyte™ is a liquid-based electrolyte made from solvents readily available in the market, which are controlled and manufacturer in their Chico 1 facility
- Nanotech has developed over 100 Organolyte™ formulations tailored to various chemistries, cell designs, and applications

Temperature Dependence of Discharge Capacity





Manufacturing Roadmap to Fulfill Customer Orders

Nanotech is commissioning its Chico 2 facility, which will be running at full capacity by Q2 2025

Chico 1

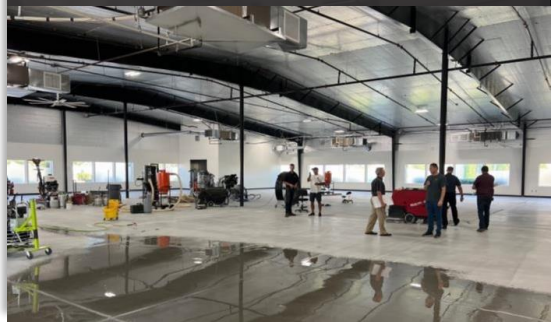
Best-in-Class R&D Center

- Pilot facility operating since 2016
- Flexible low-volume throughput for sample cells
- Key R&D center for developing next-gen battery cells
- Produces ~100 battery per day
- Graphene production capabilities of up to 3 tones per year

Chico 2

Mid-Scale Production Facility

- Started commissioning in Q4 2023 and continues to ramp up production through 2024
- Capacity of 150MWh or 1 million batteries per month (20 cells per min)
- Semi-automated production line manufacturing18650 and 21700 cells
- Capable of producing LCO, NMC, and LFP cells
- 22.3 million cells committed, representing ~$150 million in revenue



Gigafactory

Full-Scale Production Facility

- 500,000 square foot facility with multiple production lines for various battery chemistries
- Full design complete and set to be operational in Q1 2026
- Capability to scale up to 6GWh or 600 million batteries per year
- Facility includes a scale up of graphene production
- Over 13GWh under contract

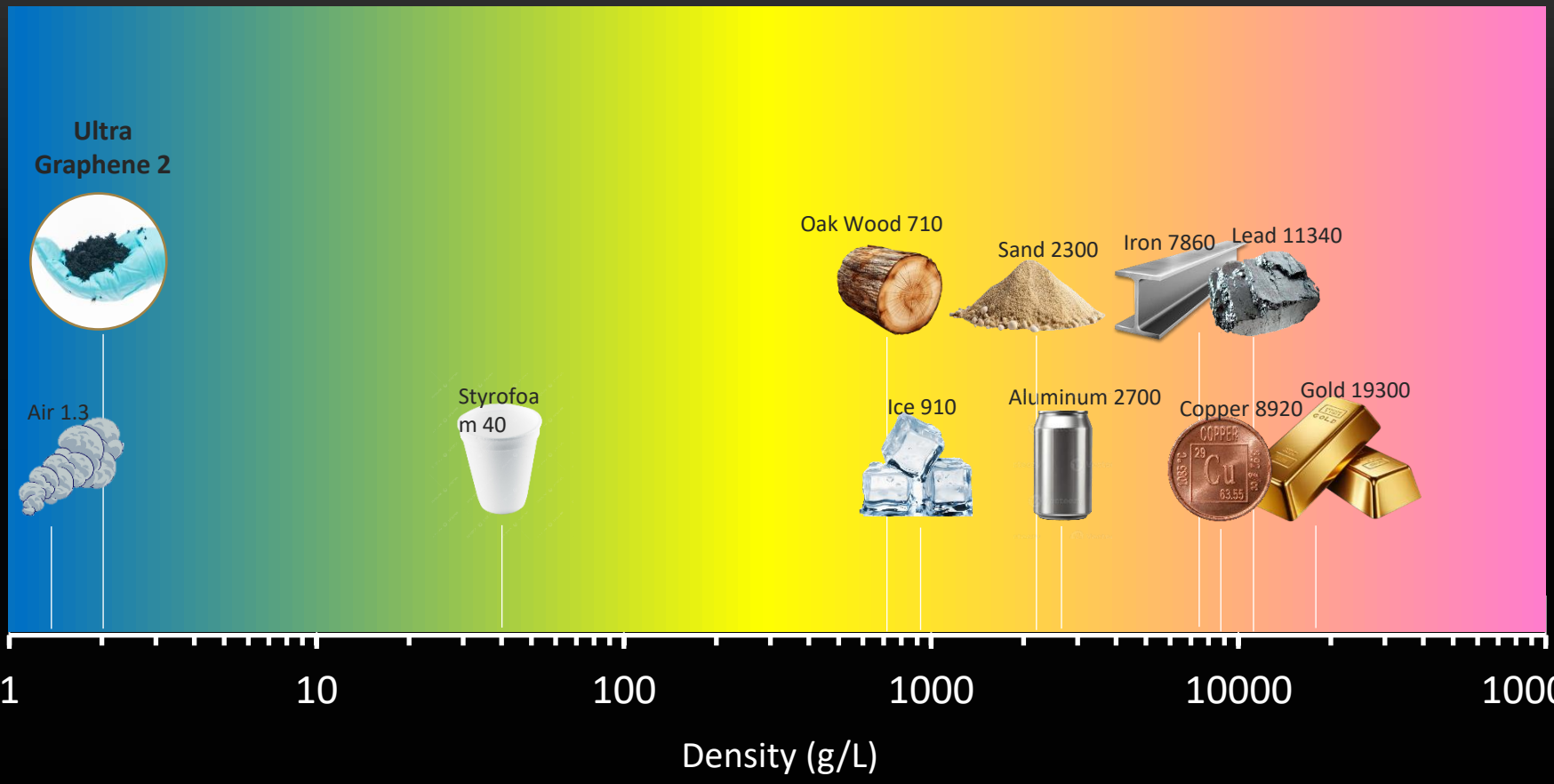
2016 — Today — 2026

LIGHTEST AND STRONGEST MATERIAL ON EARTH

Just 2 grams of graphene can fill a 1-liter bottle, showcasing its extreme lightness. In comparison, the same weight of graphite powder is shown, with graphene being 550 times lighter.

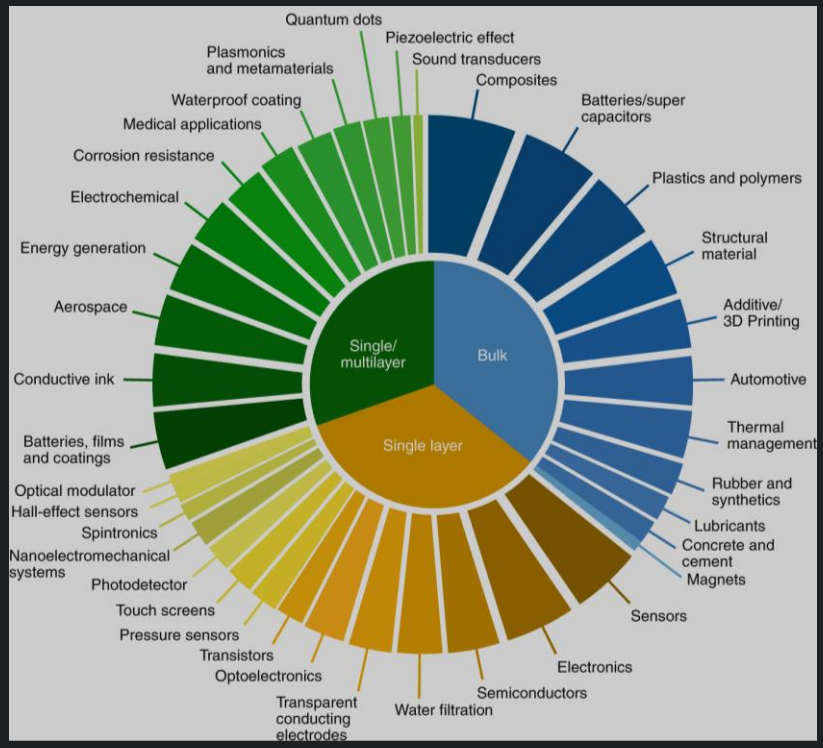
LIGHTEST AND STRONGEST MATERIAL ON EARTH

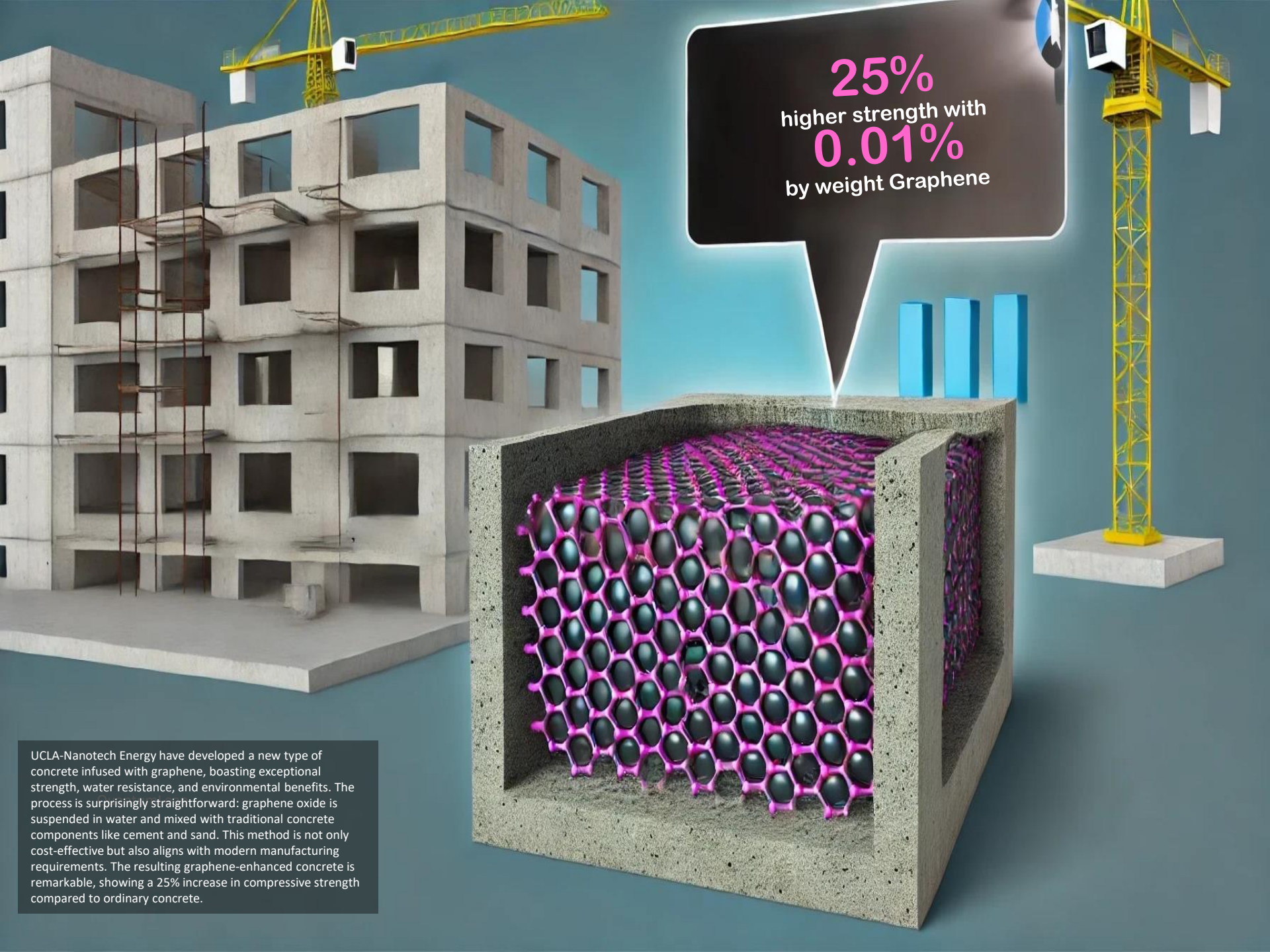
With a density of just 2 g/L, our graphene is one of the lightest materials known—comparable to air at 1.3 g/L. Despite its lightness, graphene is 4000 times lighter than steel yet 200 times stronger, having the potential to revolutionize the material industry.



GRAPHENE MANUFACTURE AND APPLICATIONS

- We can produce enough to meet the demands for Chico 2 battery production with 150+ MWh and planning for 2.5GWh
- Actively collaborating with the supply chain to explore opportunities for domestic supply and implement strategies to reduce manufacturing costs.
- Collaborating with customers to explore potential applications in the following areas:
  - **Construction:** Enhancing the electrical and/or mechanical properties of mortar and cement.
  - **Recycling:** Strengthening recycled polymers for improved mechanical performance.
  - **Energy Storage:** Enhancing the surface conductivity of silicon anodes for more efficient energy storage.
  - **Material Dispersions:** Improving the dispersibility of graphene in polar solvents and polymers for various applications.
  - **Advanced Coatings:** Developing superhydrophobic spray paints for ultradry surface applications.





UCLA-Nanotech Energy have developed a new type of concrete infused with graphene, boasting exceptional strength, water resistance, and environmental benefits. The process is surprisingly straightforward: graphene oxide is suspended in water and mixed with traditional concrete components like cement and sand. This method is not only cost-effective but also aligns with modern manufacturing requirements. The resulting graphene-enhanced concrete is remarkable, showing a 25% increase in compressive strength compared to ordinary concrete.

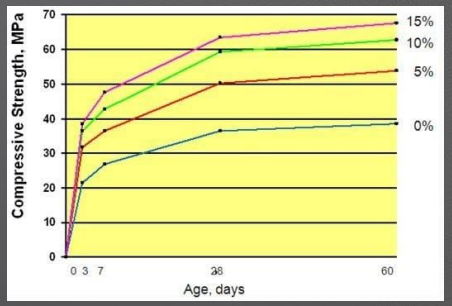
GRAPHENE OXIDE 1000 TIMES MORE EFFICIENT THAN SILICA FUME!!

High-performance concrete with Elkem MICROSILICA® has been used in landmark projects like the Burj Khalifa in Dubai. Remarkably, GO can achieve similar or better performance at just 0.01% loading compared to >10% silica used, making GO 1000 times more efficient!

WORLD'S TALLEST BUILDING

Source: Elkem [link]

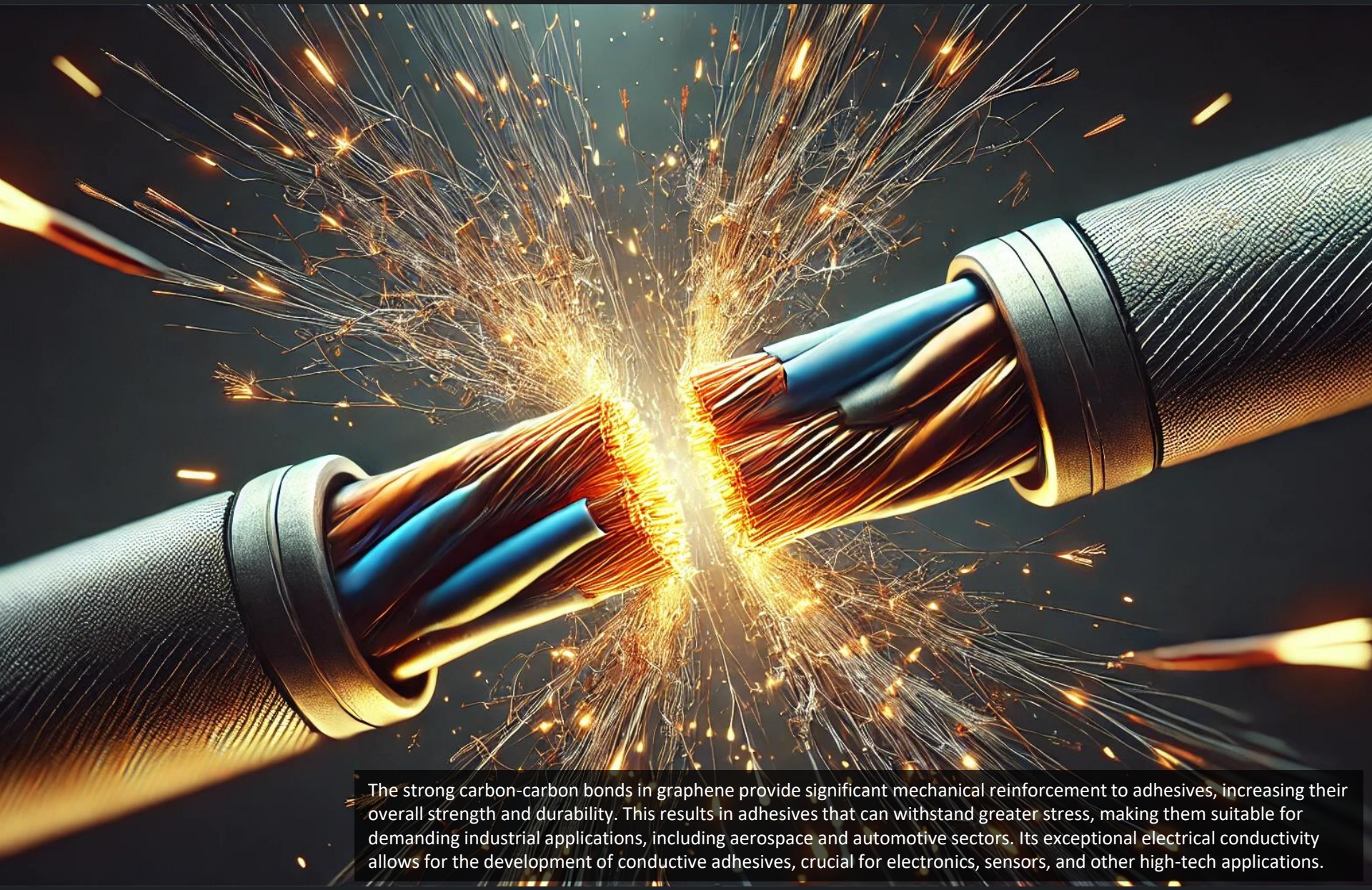
SILICA FUME CONCRETE



The plot shows influence of variable amounts of fume silica (from 5 to 15%) on the compressive strength of concrete

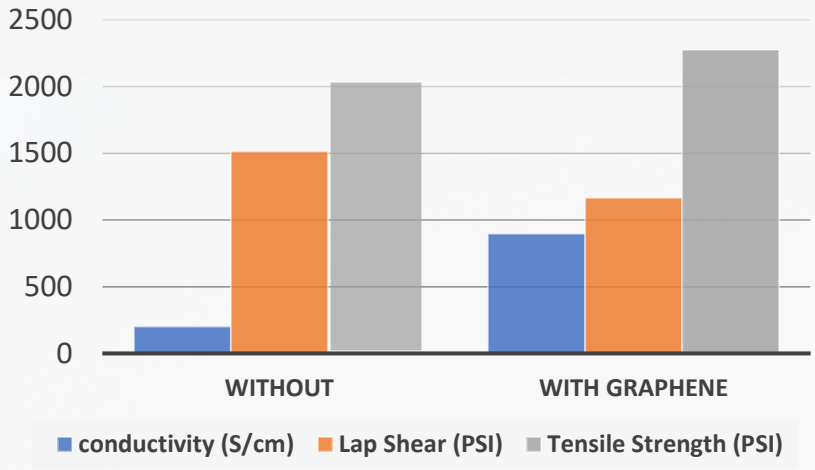
Source: The constructor.org [link]

GRAPHENE FOR STRONGER AND CONDUCTIVE ADHESIVES



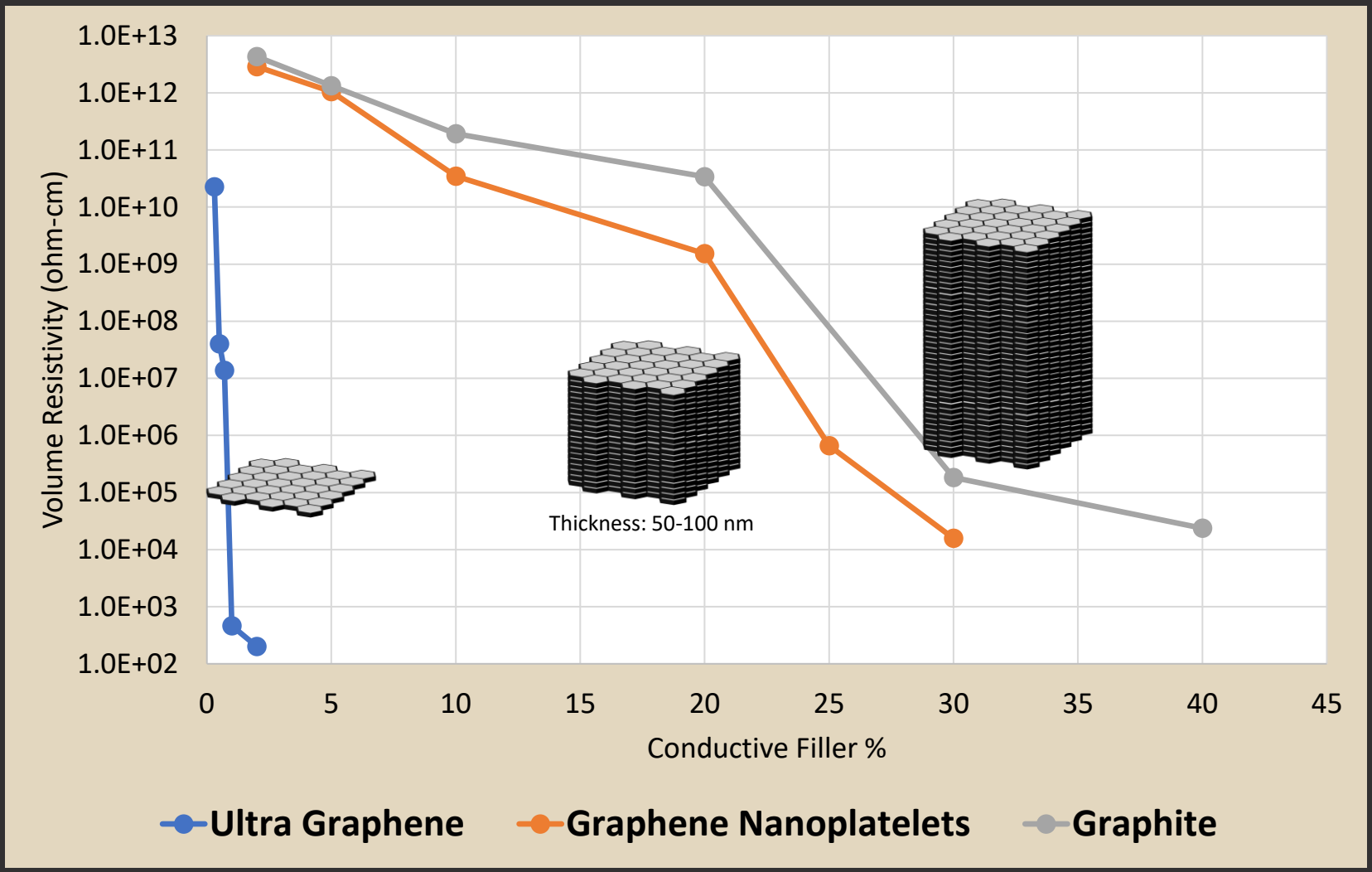
The strong carbon-carbon bonds in graphene provide significant mechanical reinforcement to adhesives, increasing their overall strength and durability. This results in adhesives that can withstand greater stress, making them suitable for demanding industrial applications, including aerospace and automotive sectors. Its exceptional electrical conductivity allows for the development of conductive adhesives, crucial for electronics, sensors, and other high-tech applications.

GRAPHENE FOR STRONGER AND CONDUCTIVE ADHESIVES



The incorporation of graphene into silver epoxy significantly enhances both electrical and thermal conductivity while maintaining or even improving mechanical strength. This makes it ideal for use in high-performance applications like aerospace, automotive, and advanced electronics, where reliable conductive adhesives are essential.

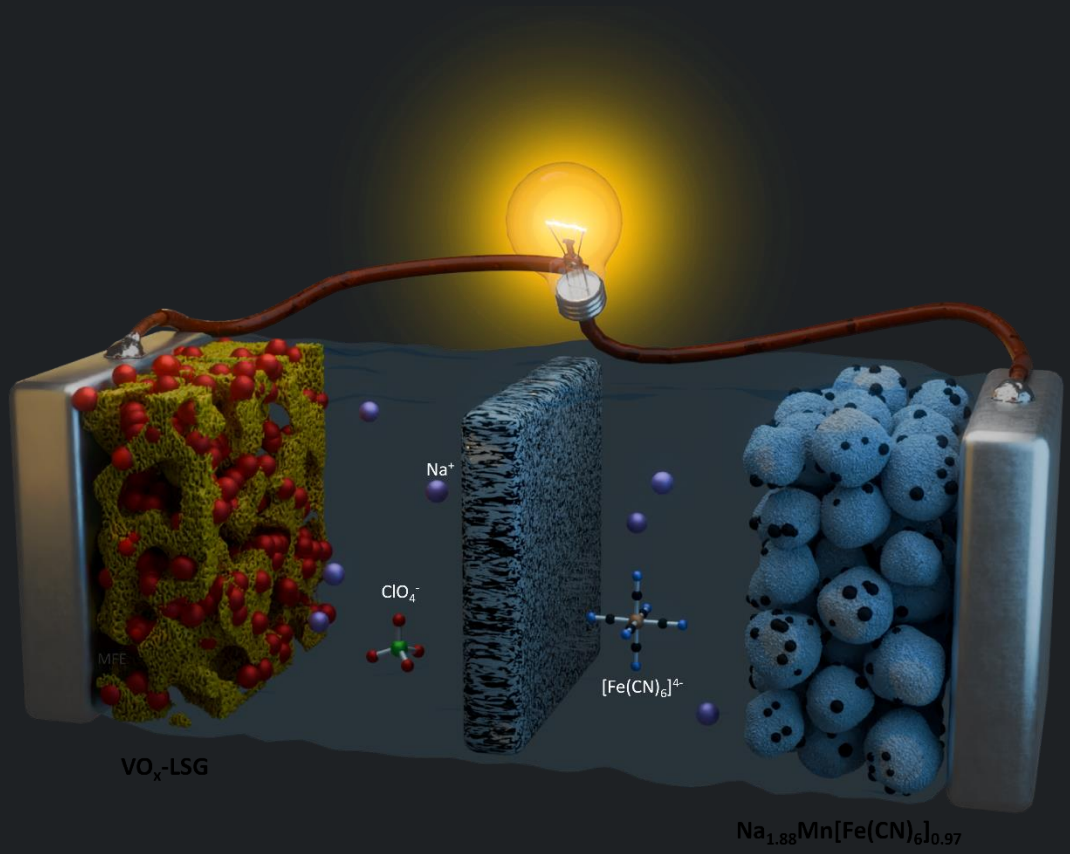
COMPARING NANOTECH GRAPHENE WITH MARKET: SUPPLIER #1



- Nanotech graphene reaches percolation at <1%, whereas other forms of competitor graphene reaches the same with 25%+ loading
- Lower filler loadings results in better mechanical properties

→MAKING MATERIALS MATTER

GRAPHENE FOR ULTRAFAST SODIUM ION BATTERIES



Advancing Sodium-Ion Battery Technology:

- **High-Capacity Anodes**: Our research at UCLA leverages graphene in designing high-capacity anodes. The combination of graphene with vanadium oxide results in faster performance compared to conventional hard carbon anodes. Graphene's high surface area and excellent conductivity facilitate rapid charge transfer, leading to improved battery efficiency and cycle life .
- **Superior Cathodes**: We are also developing graphene-based cathodes that significantly outperform the widely used Prussian Blue analogues. Graphene enhances the structural integrity and conductivity of cathode materials, resulting in better overall battery performance .

Why Graphene Matters:

- **Enhanced Conductivity**: Graphene's superior electrical conductivity accelerates charge/discharge cycles, making it ideal for ultrafast applications .
- **Structural Stability**: Its mechanical strength supports stable electrode structures, which is critical for the longevity of sodium-ion batteries .

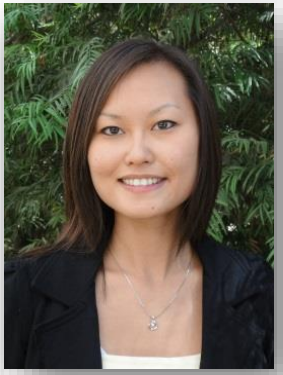
Lu, Yong, Yanying Lu, Zhiqiang Niu, and Jun Chen. "Graphene-Based Nanomaterials for Sodium-Ion Batteries." *Advanced Energy Materials* 8, no. 17 (2018): 1702469.

Zhang, Yan, Xinhui Xia, Bo Liu, Shengjue Deng, Dong Xie, Qi Liu, Yadong Wang, Jianbo Wu, Xiuli Wang, and Jiangping Tu. "Multiscale graphene-based materials for applications in sodium ion batteries." *Advanced Energy Materials* 9, no. 8 (2019): 1803342.

→MAKING MATERIALS MATTER

Dr. Maher El-Kady
Nanotech Energy

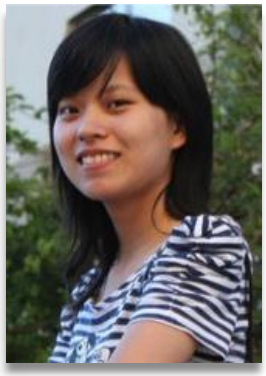
Dr. Volker Strauss
Max Plank Institute



Dr. Lisa Wang
Lam Research

Dr. Jee Youn Hwang
Hyundai

Dr. Sergey Dubin
Z-Power



Dr. Mengping Li
Lam Research

Dr. Veronica Strong
Intel

Dr. Jonathan Wassei
Rolith Inc.

Dr. Scott Gilje
Northrop-Grumman

Dr. Matthew Allen
McKenzie & Co.

Dr. Vincent Tung
KAUST

Dr. Yuanlong Shao
Soochow Univ.