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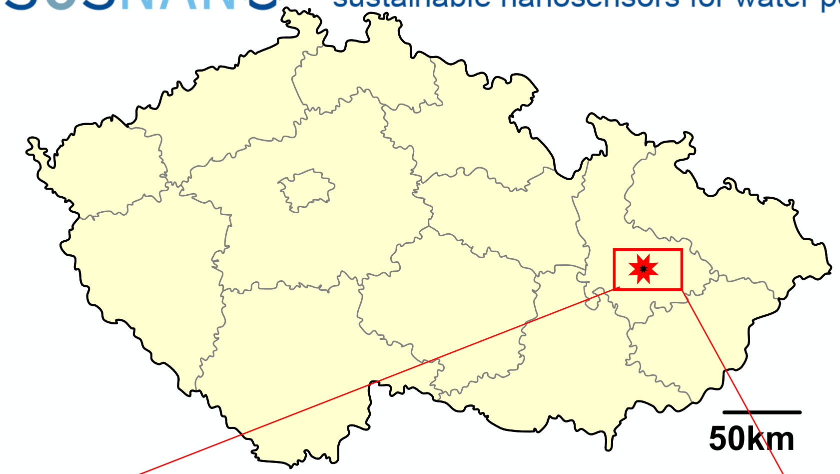
Practical applications of graphene-based derivatives in different fields of electrochemistry.

Petr Jakubec

Twinning to boost the scientific and innovation capacity of the Universiteti i Tiranës to develop sustainable nanosensors for water pollution detection

Practical applications of graphene-based derivatives in different fields of electrochemistry.



CATRIN
Czech Advanced Technology and Research Institute

Regional Centre of Advanced Technologies and Materials (RCPTM)

Institute of Molecular and Translational Medicine (IMTM)

Centre of the Region Haná for Biotechnological and Agricultural Research (CR Haná)

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Practical applications of graphene-based derivatives in different fields of electrochemistry.

Carbon Nanostructures, Biomacromolecules and Simulations

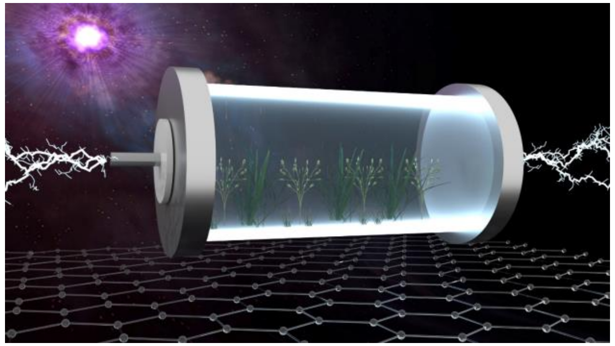
Group Leader

Prof. Dr. Michal Otyepka (ERC Consolidator – 2D-Chemistry (PI), ERC Proof of Concept – UP2DChem (PI))

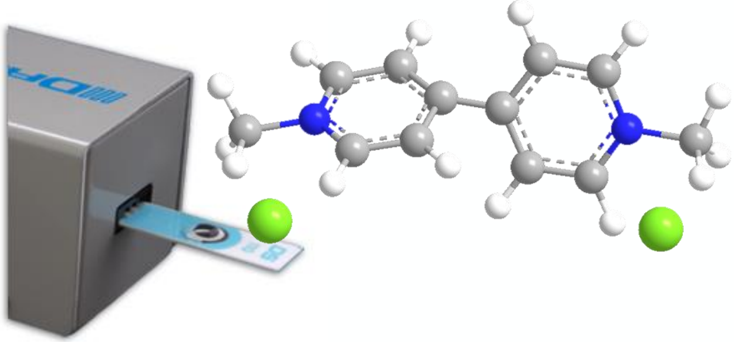
Research Areas

- Synthesis, characterization and applications of low-dimensional carbon-based materials.
- Functionalization and chemical modification of graphene and its derivatives.
- Utilization of low-dimensional carbon-based materials in catalysis, energy storage, sensing and imaging applications.

Energy storage applications



Electrochemical sensing applications



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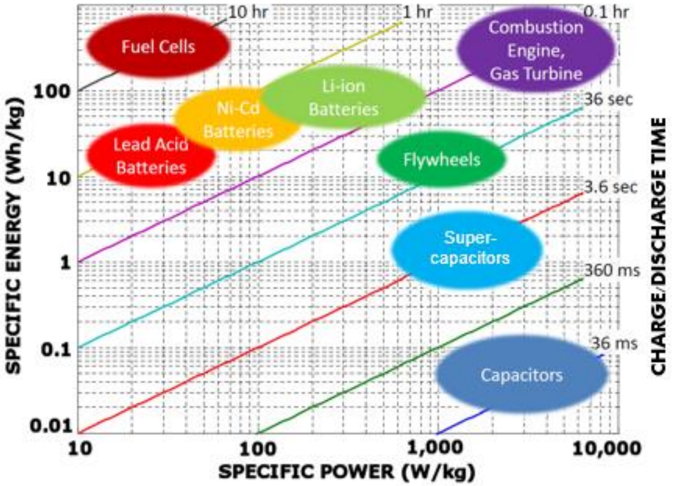
Energy storage applications — supercapacitors



BATTERY VS ULTRACAPACITOR

PARAMETER	BATTERY	ULTRACAPACITOR
Energy Density	100Wh/kg	10Wh/kg
Power Density	1kW/kg	10kW/kg
Efficiency	~80%	>90%
Cyclability	400 – 2500	1,000,000
Calendar life	Short (4..6 years)	Long (15+ years)
Low Temperature	-20°C	-40°C
High Temperature	+60°C	+85°C…+100°C
Death	Sudden	Predictable
Principle	Electrochemical	Electrostatic
Cost	0.07 - 0.2 $/kWh/cycle	$0.006 $/kWh/ cycle

https://www.nextbigfuture.com/2017/08/supercapacitors-game-changing-improvement-on-energy-density-compared-to-batteries.html

https://www.kemet.com/en/us/technical-resources/supercapacitors-vs-batteries.html

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Practical applications of graphene-based derivatives in different fields of electrochemistry.

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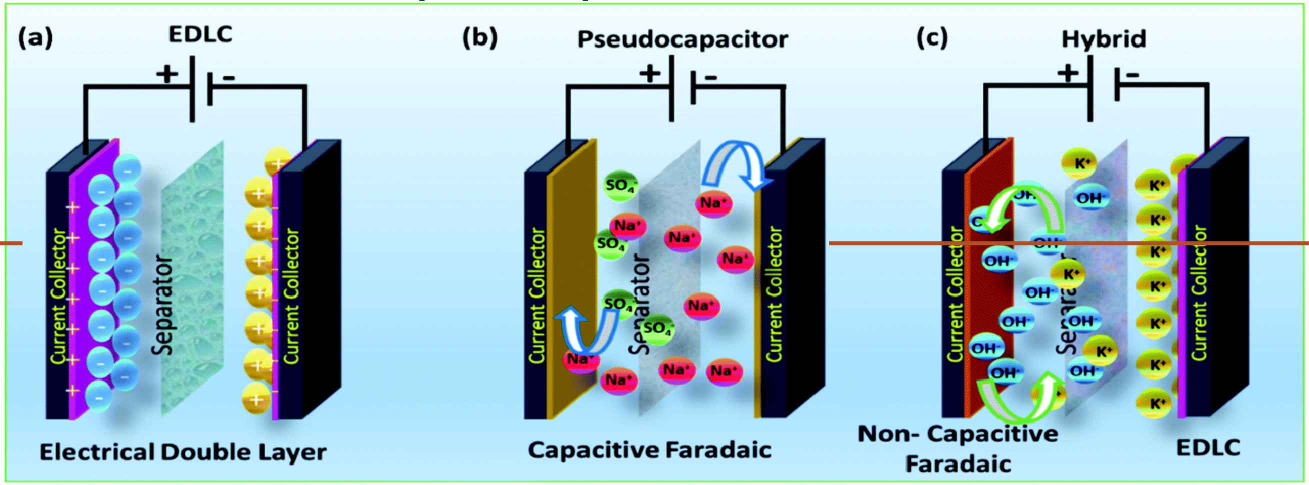
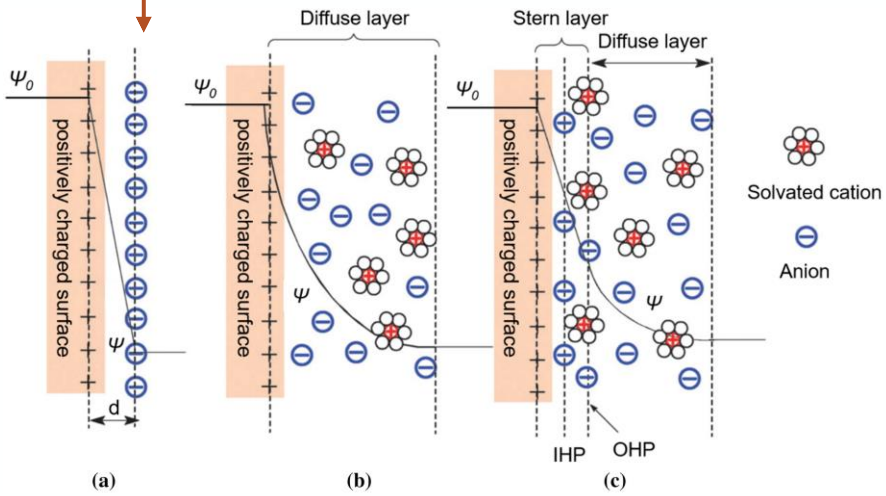
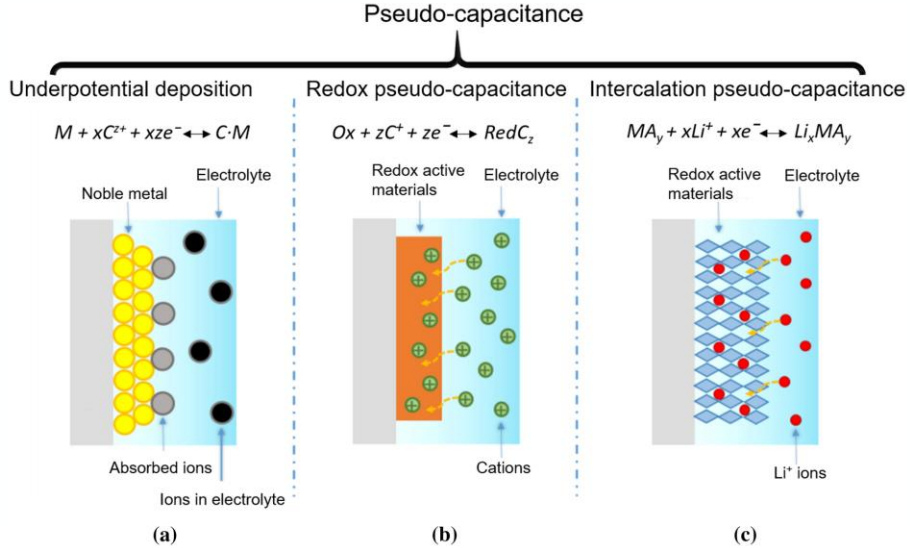
https://www.flickr.com/photos/lcf63/sets/72157691209919664

https://en.wikipedia.org/wiki/Supercapacitor

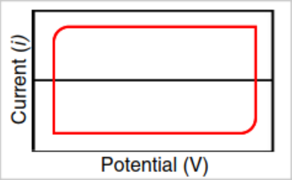
Energy storage applications — supercapacitors

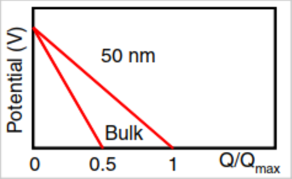






Electrical double layer capacitor



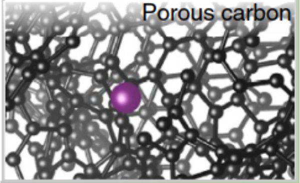


No phase change

Reversible ion adsorption

$i \sim v$

High specific surface area materials.
Example: Porous carbons (CDC, activated cabon), graphene, carbon onions



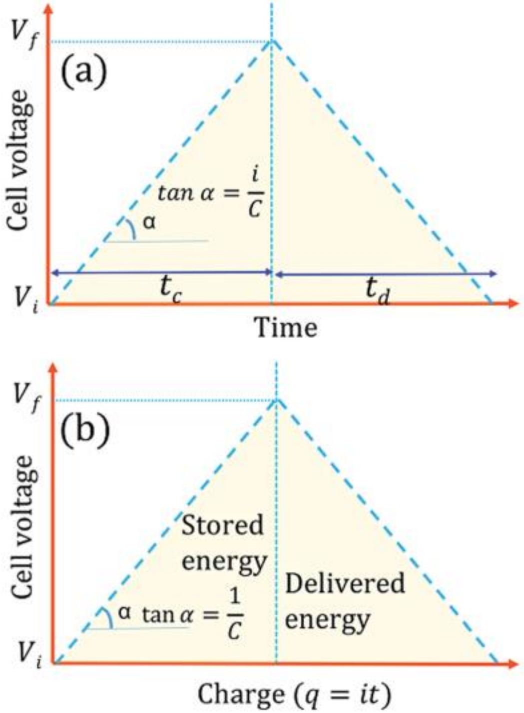


Fig. 6 V–t (a) and V–q (b) plots of the output signal of an ideal capa charged with a constant current, i, for a definite time, t, and discharged with the same current.

$$C_{wt} = \frac{4\int_{V1}^{Vn} i\,dV}{ms\,\Delta V} \text{ or } C_{vol} = \frac{4\int_{V1}^{Vn} i\,dV}{vs\,\Delta V} \text{ or}$$

$$C_A = \frac{2\int_{V1}^{Vn} i\,dV}{As\,\Delta V}$$

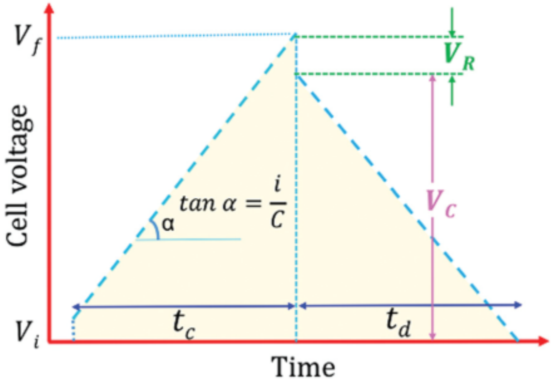
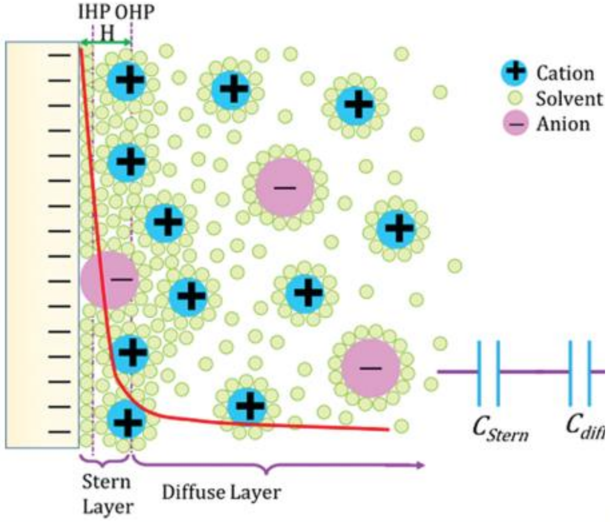


Fig. 11 Constant current charge–discharge profile of an R–C circuit. Contributions from V_R and V_C in the total voltage of the circuit are presented for the discharge step.



$$\frac{1}{C_{dl}} = \frac{1}{C_{Stern}} + \frac{1}{C_{Diff}}$$

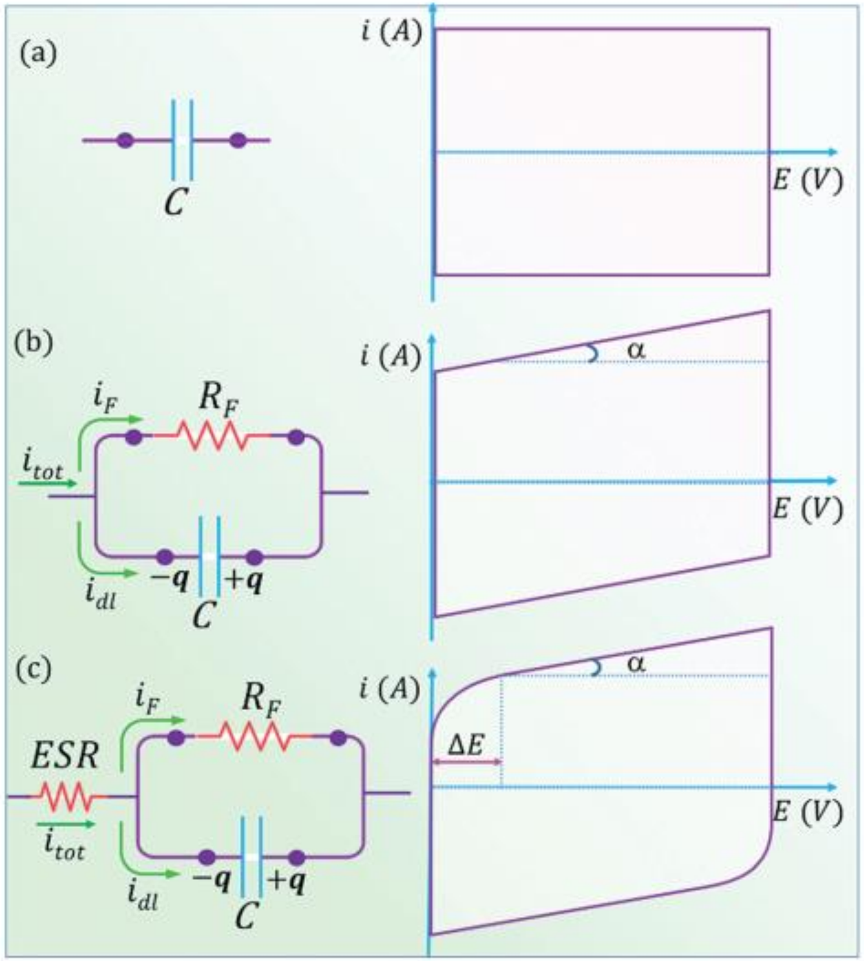


Fig. 38 Schematic representation of the equivalent circuit models and the corresponding CV curves of (a) an ideal electrical double layer capacitor, (b) a capacitor in parallel with a Faradaic charge transfer process, and (c) a simplified supercapacitor model comprising an ESR, Faradaic resistance, and double layer capacitor.

Noori A. et al. *Chem. Soc. Rev.*, **2019**, *48*, 1272
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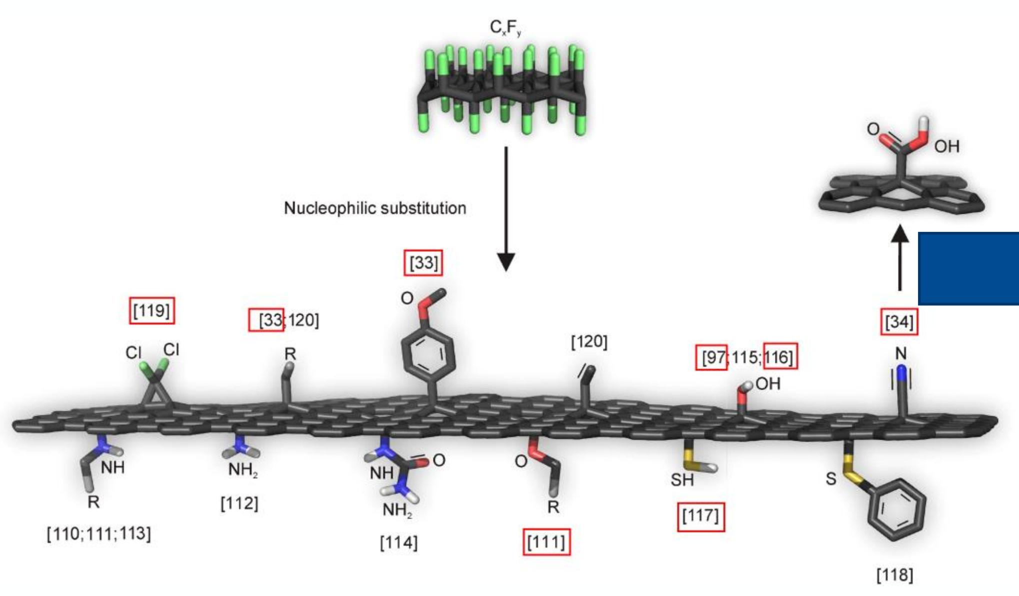
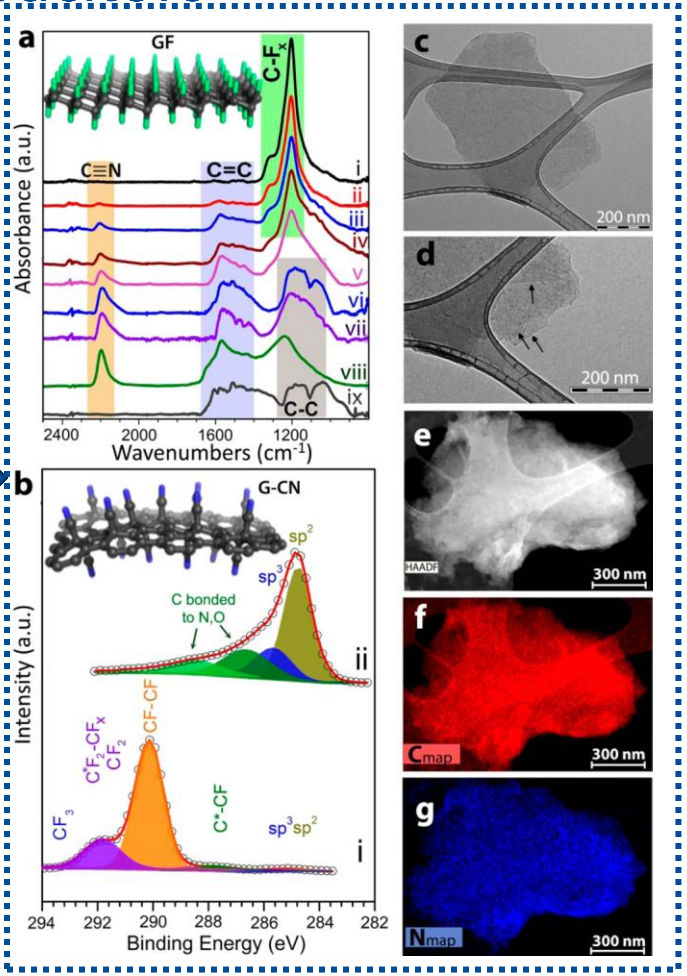
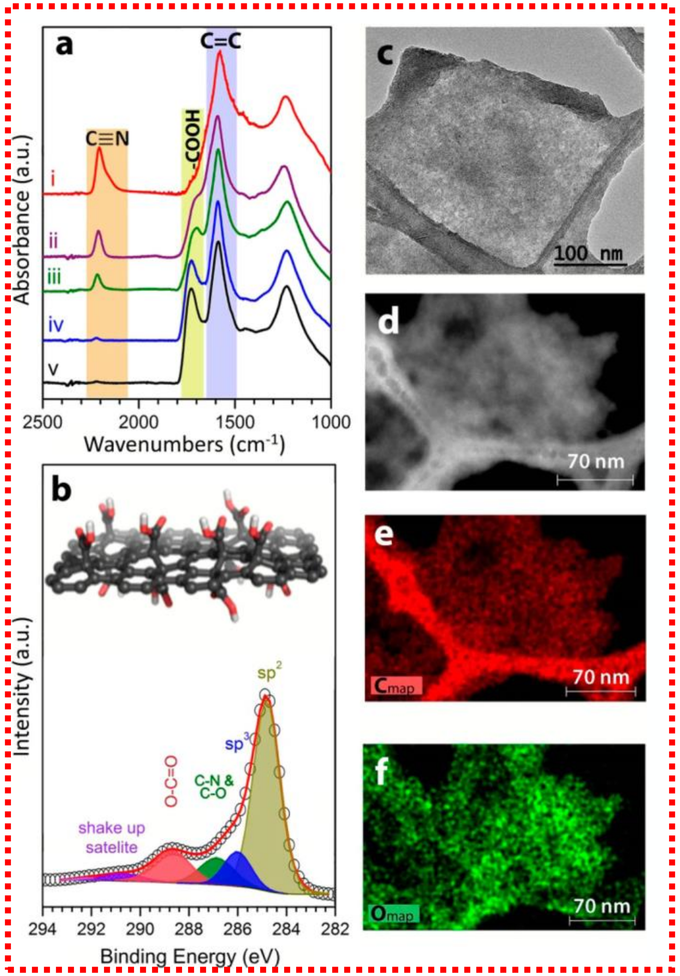
Energy storage applications — supercapacitors

Preperation of various graphene derivatives using the fluorographene chemistry

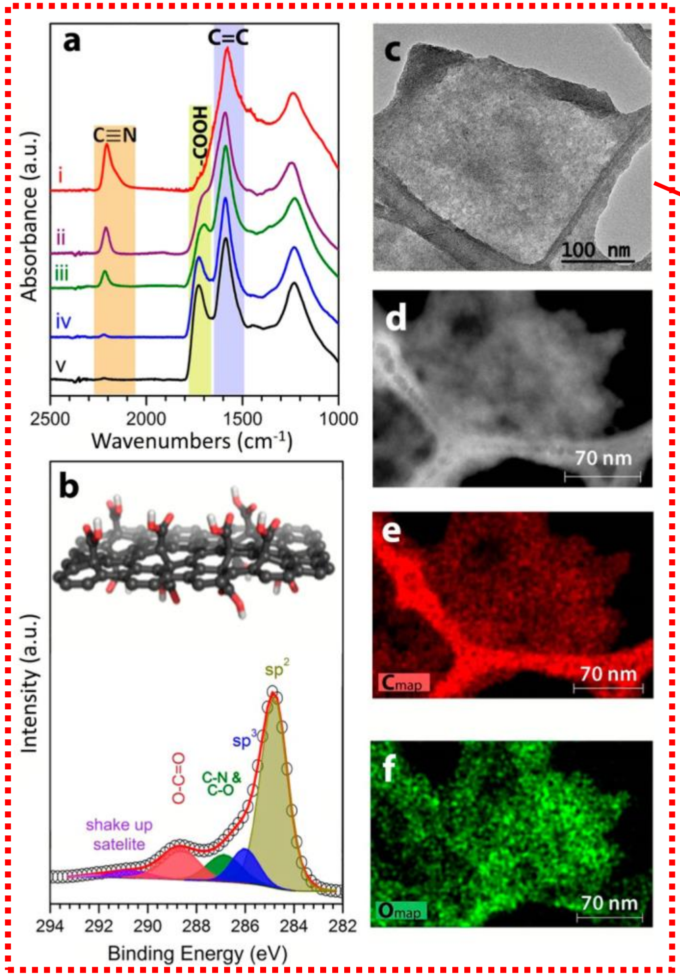


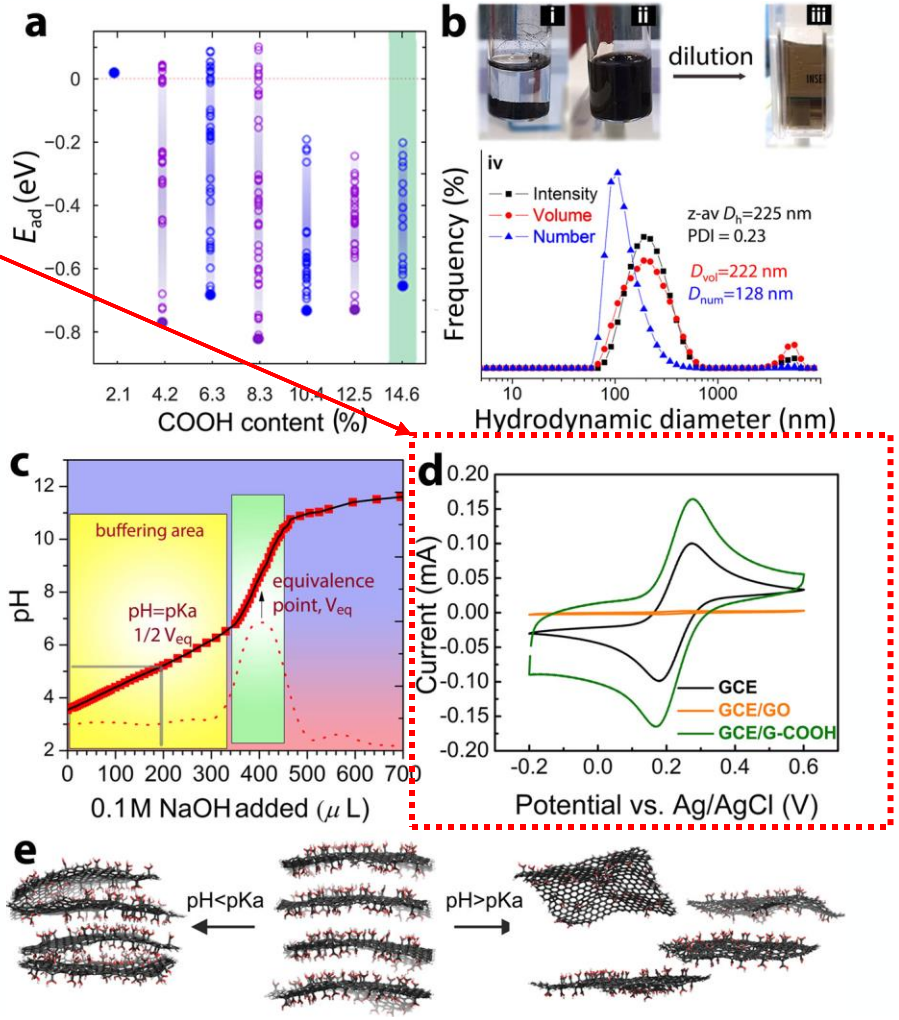




Bakandritsos A. et al. *ACS Nano*, **2017**, *11*, 3, 2982–2991

Energy storage applications — supercapacitors





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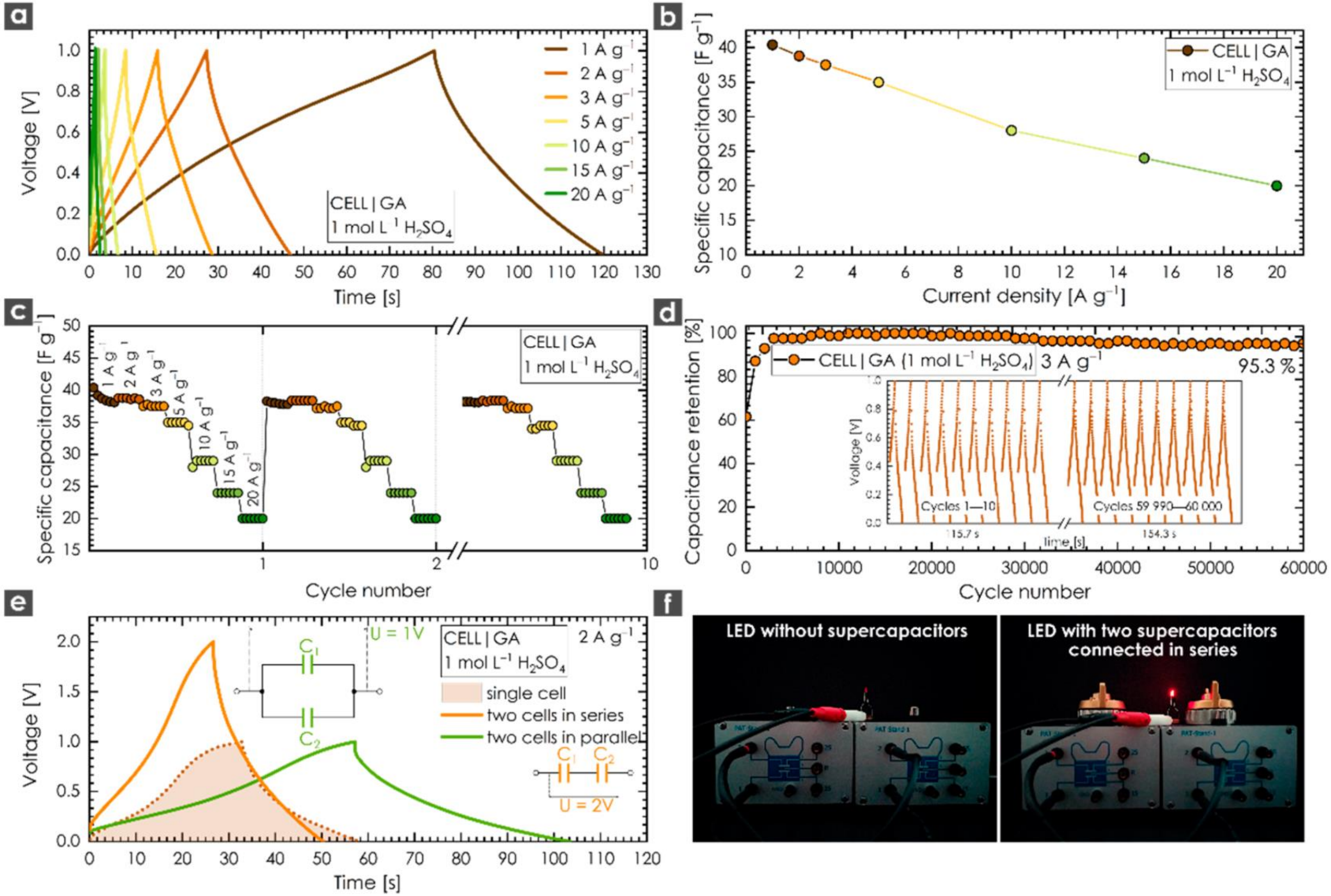
Energy storage applications — supercapacitors



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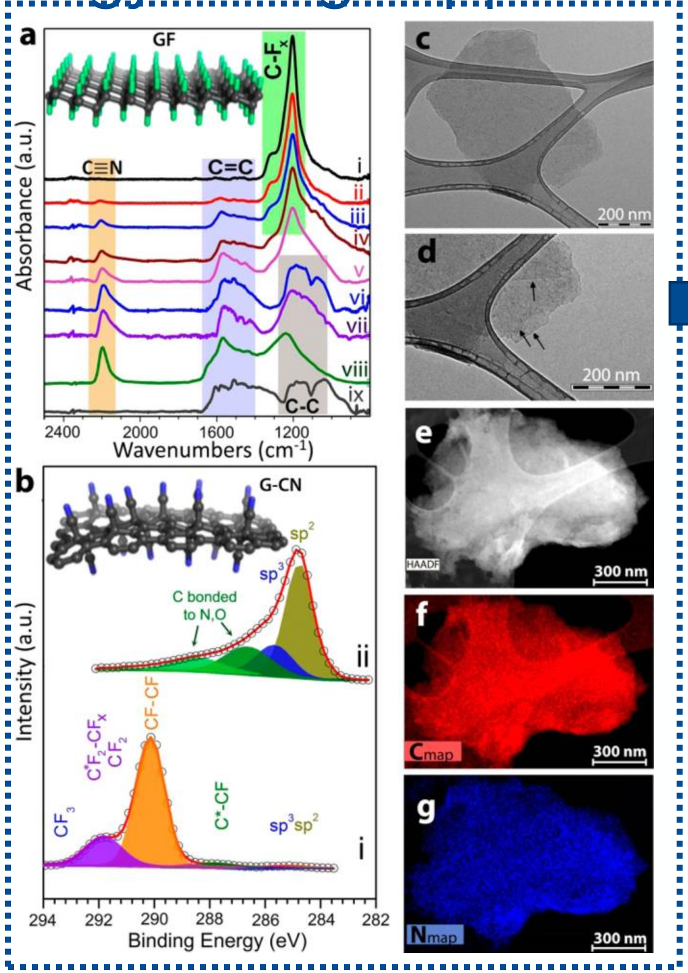
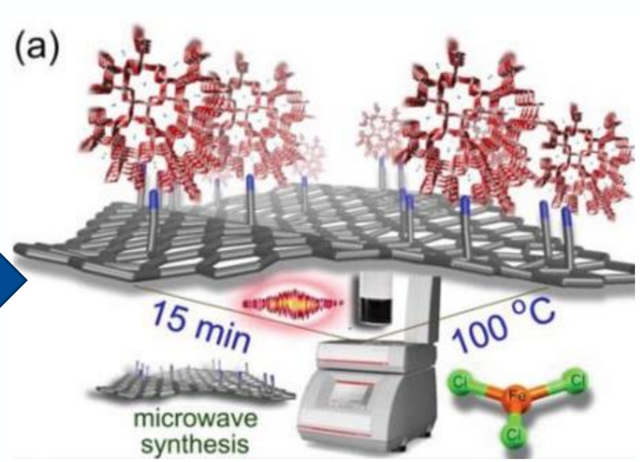
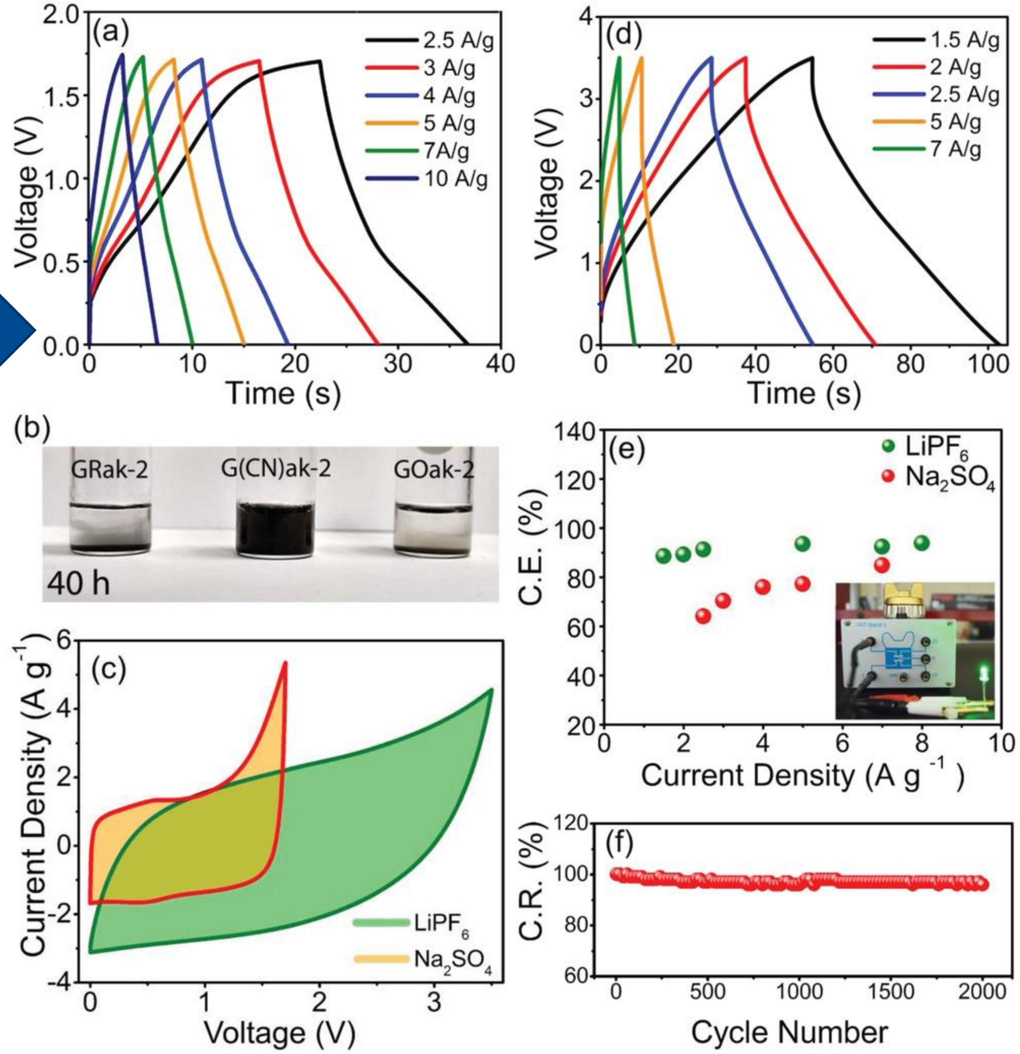
Energy storage applications — supercapacitors



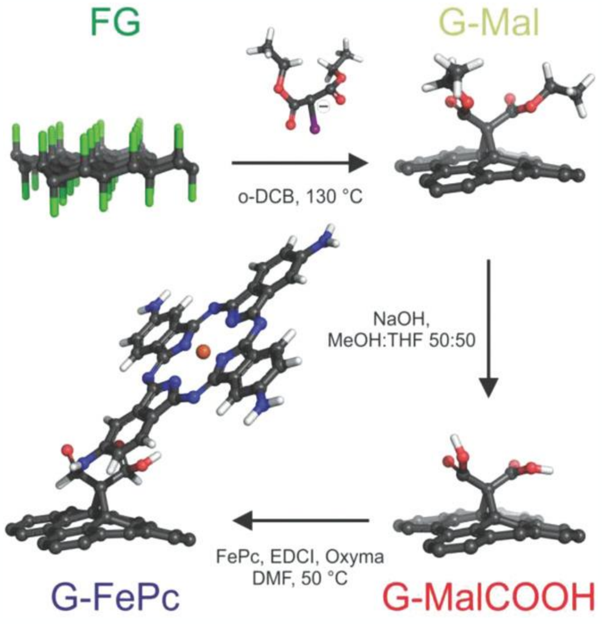
Bakandritsos A. et al. *ACS Nano*, **2017**, *11*, 3, 2982–2991



S. V. Talande et al. *Adv. Funct. Mater.* **2019**, *29 (51)*, 1906998



Energy storage applications — supercapacitors



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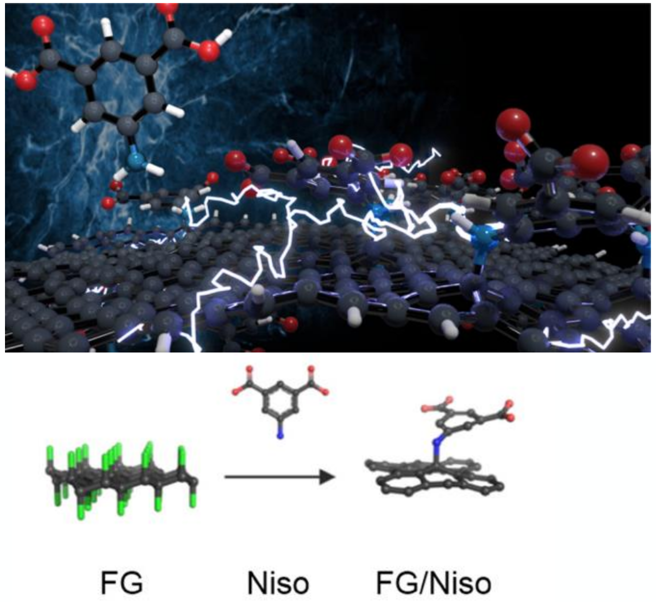
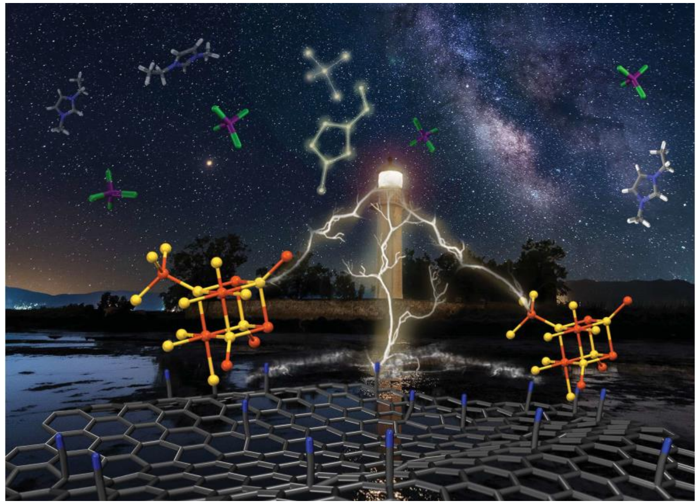


E. C. Vermisoglou et al. *Chem. Mater.* **2019,** *31 (13),* 4698-4709



S. V. Talande et al. *J. Mater. Chem. A* **2020,** *8 (48),* 25716-25726

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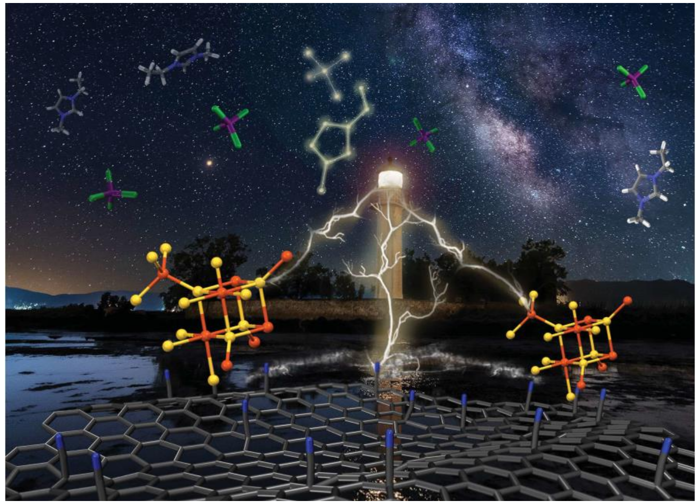
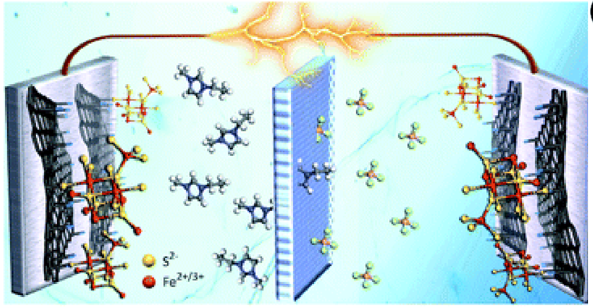
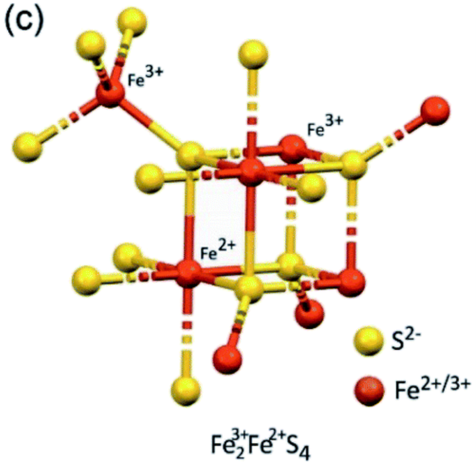
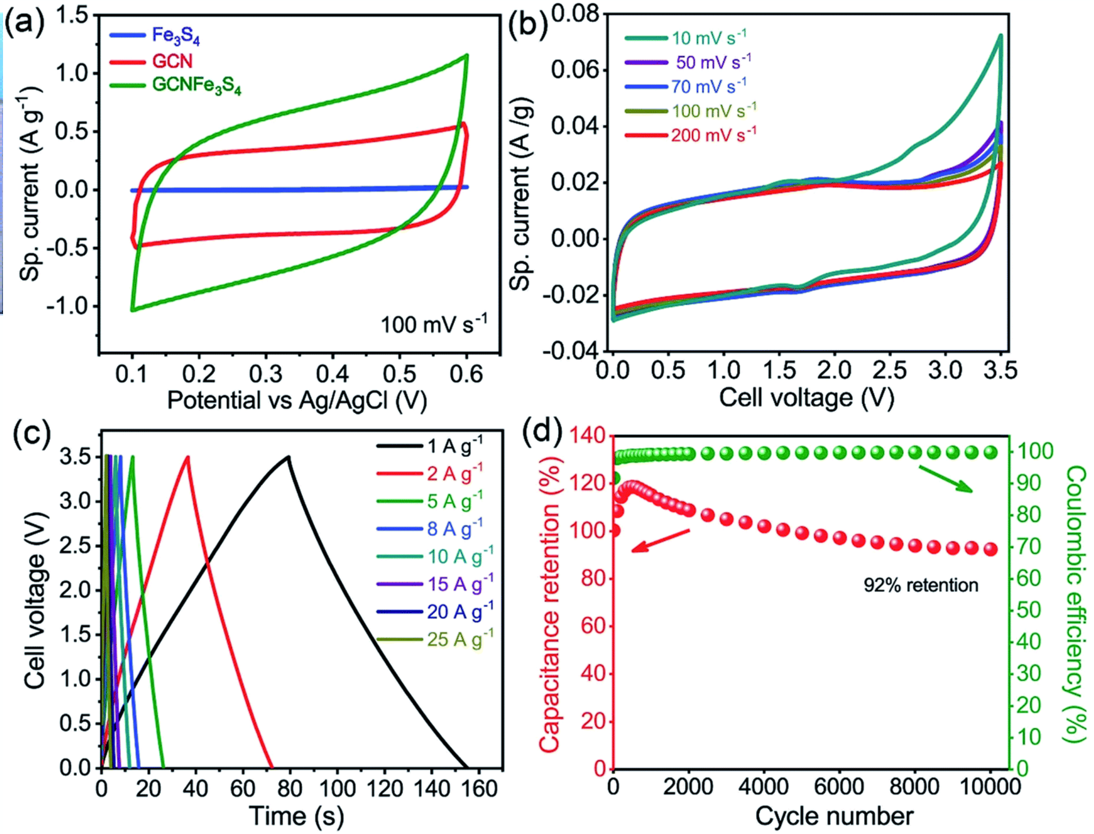
Energy storage applications — supercapacitors



S. V. Talande et al. *J. Mater. Chem. A* **2020**, *8 (48)*, 25716-25726







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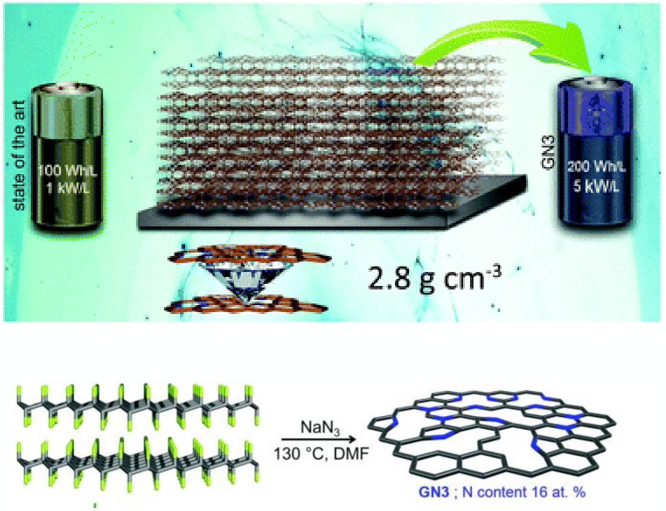
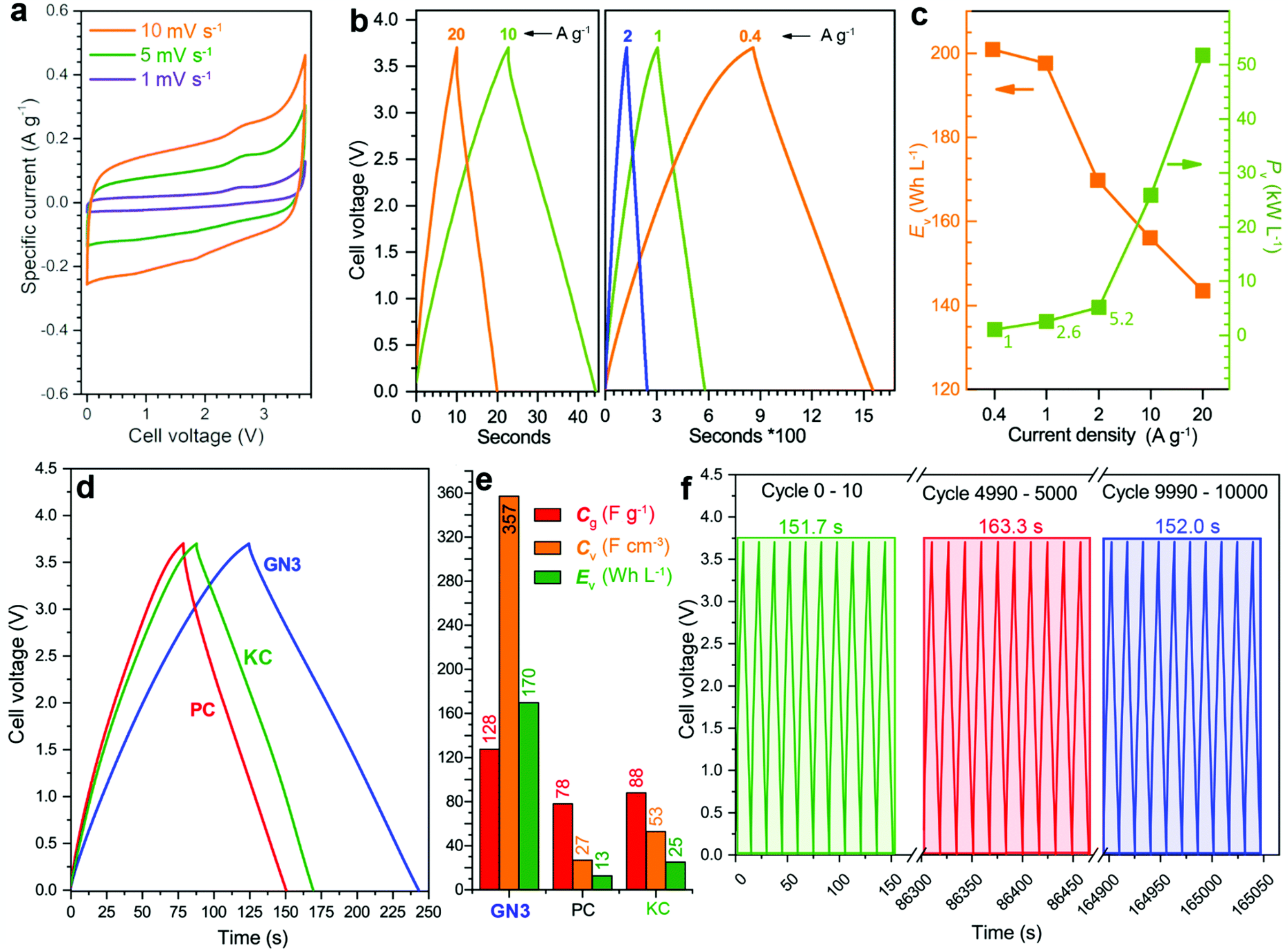
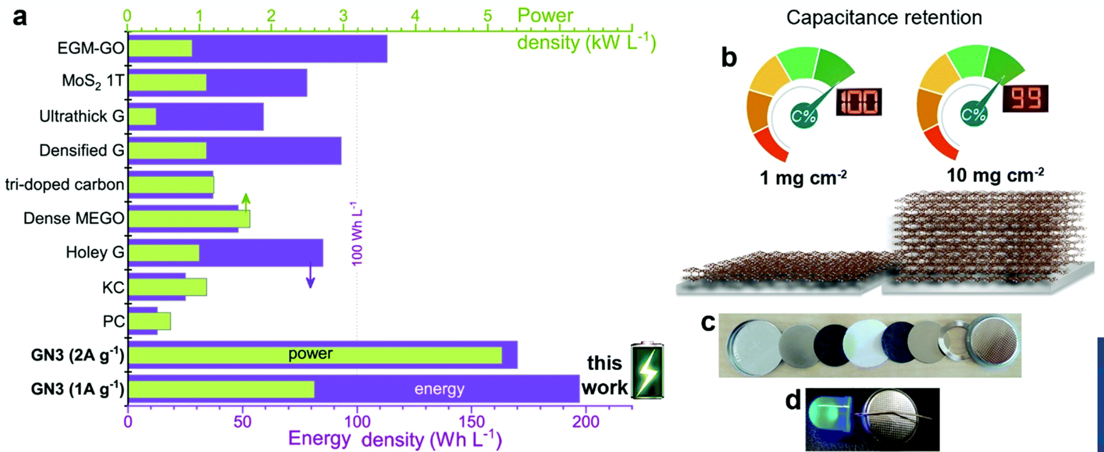
Practical applications of graphene-based derivatives in different fields of electrochemistry.

Energy storage applications — supercapacitors



V. Šedajová et al. *Energy Environ. Sci.* 2022, *15 (2)*, 740-748



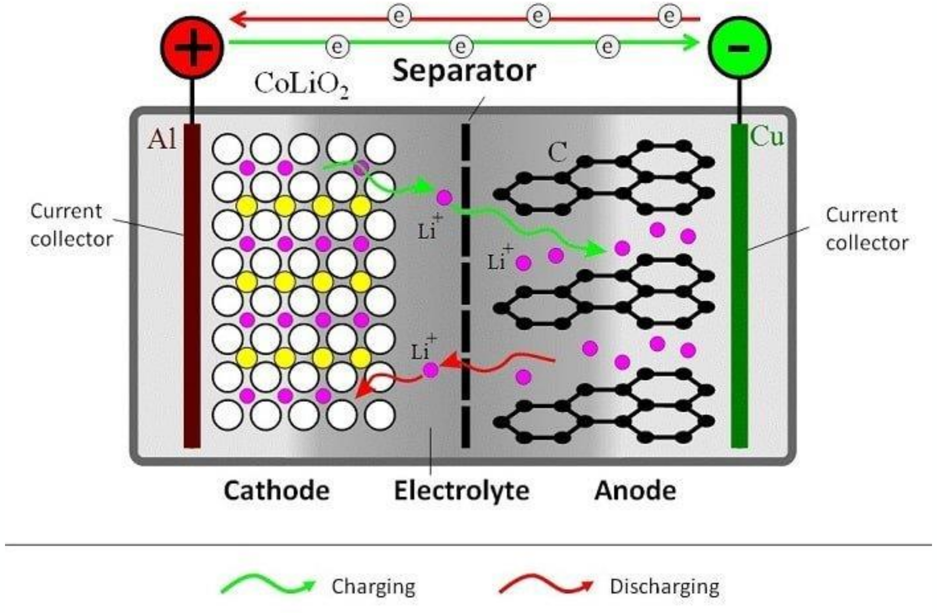


Energy storage applications — Li-ion batteries

- **Technology:** Anode (carbon), cathode (metal oxide), electrolyte (Li salt in organic solvent).

Lithium-ion Batteries Working Principle and its importance

A battery consists of such components as an anode, cathode, separator, electrolyte, and two (positive and negative) current collectors. The lithium is contained in the anode and cathode. The electrolyte acts as a medium to bring positively charged lithium ions through the separator from the anode to the cathode and vice versa. The movement of lithium ions creates free electrons in the anode, creating a charge on the positive current collector. The electrical current then passes through a system that is driven to the negative current collector from the current collector. The separator blocks the flow of electrons in the battery. The anode delivers lithium ions to the cathode while the battery discharges and generates an electrical current, producing a flow of electrons from one side to the other. When the device is plugged in, the opposite happens: the cathode releases lithium ions and the anode receive them.



- **Advantages:**
  - Different shapes.
  - High energy density – 200 Wh/kg, 530 Wh/l.
  - High capacity.
  - Low self-discharge (< 5 %).
  - No memory effect.
  - High nominal voltage: 3,7 V.
  - Lifetime 400–2500 cycles.

$$LiCo^{III}O_2 \rightleftarrows Li_{1-x}Co^{IV}O_2 + xLi^{+1} + x\,e^{-1} \qquad 0<x<0.5 \qquad E^\circ = 3.9V$$

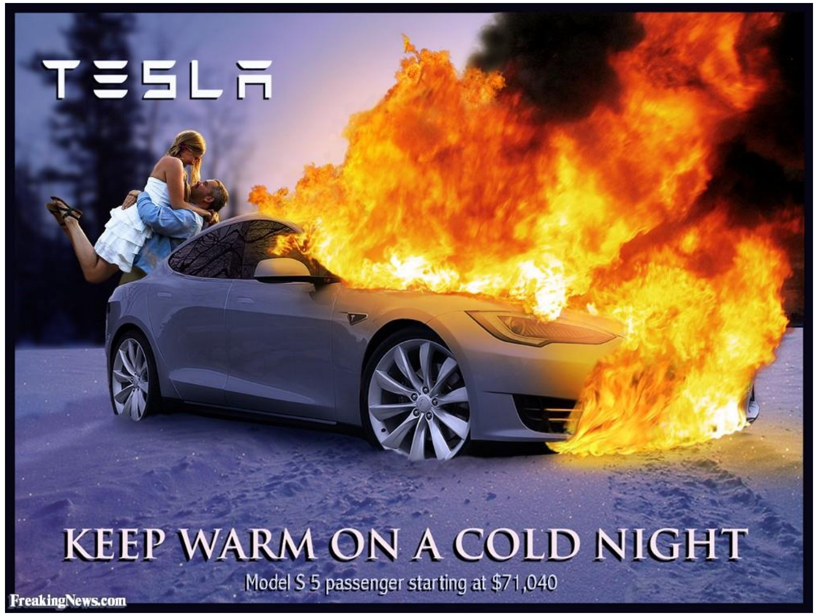
$$6C + xLi^{+1} + x\,e^{-1} \rightleftarrows Li_xC_6 \qquad x = 1 \qquad E^\circ = 0.2V$$

$$6C + LiCo^{III}O_2 \rightleftarrows Li_xC_6 + Li_{1-x}Co^{IV}O_2 \qquad E^\circ = 3.7V$$

https://www.meee-services.com/how-lithium-ion-batteries-work-and-why-they-are-so-important/
https://cs.wikipedia.org/wiki/Lithium-iontov%C3%BD_akumul%C3%A1tor
Abu-Lebdeh Y et al. *Nanotechnology for Lithium-Ion Batteries*, 2013, pp. 287.

Energy storage applications – Li-ion batteries

- Disadvantages:
  - Ageing – losing capacity does not matter if they are new or used.
  - When used inappropriate way a high risk of explosion or self ignition
  - Really bad when completely discharged for the long time.
  - Hard to recycle.
  - Hazardeous for the environment.



http://the-big-turn-on.co.uk/electric-cars-benefits-disadvantages/
https://cs.wikipedia.org/wiki/Lithium-iontov%C3%BD_akumul%C3%A1tor
https://www.elektrina.cz/problemy-elektromobilu
http://www.freakingnews.com/Tesla-Electric-Car-on-Fire-Pics-125260.asp

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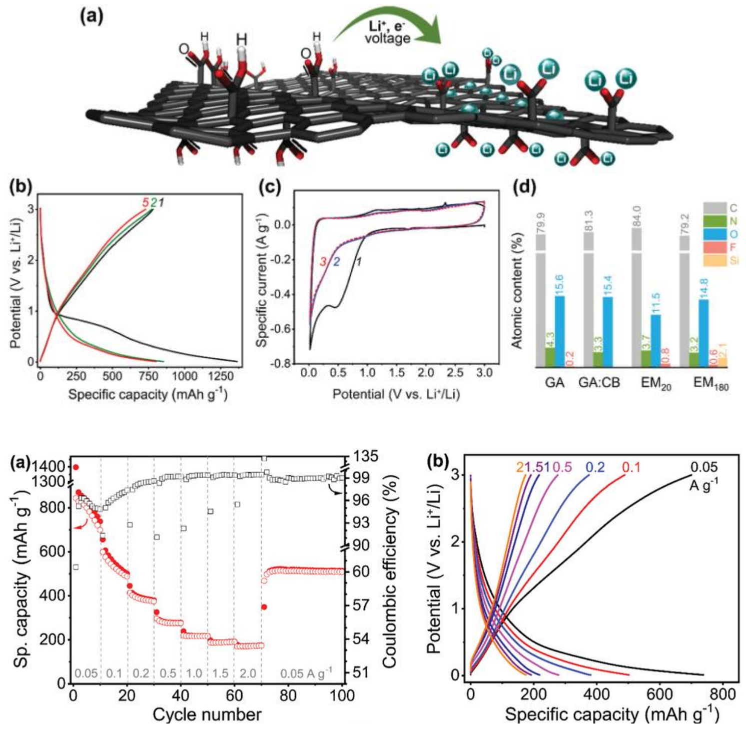
Energy storage applications — Li-ion batteries



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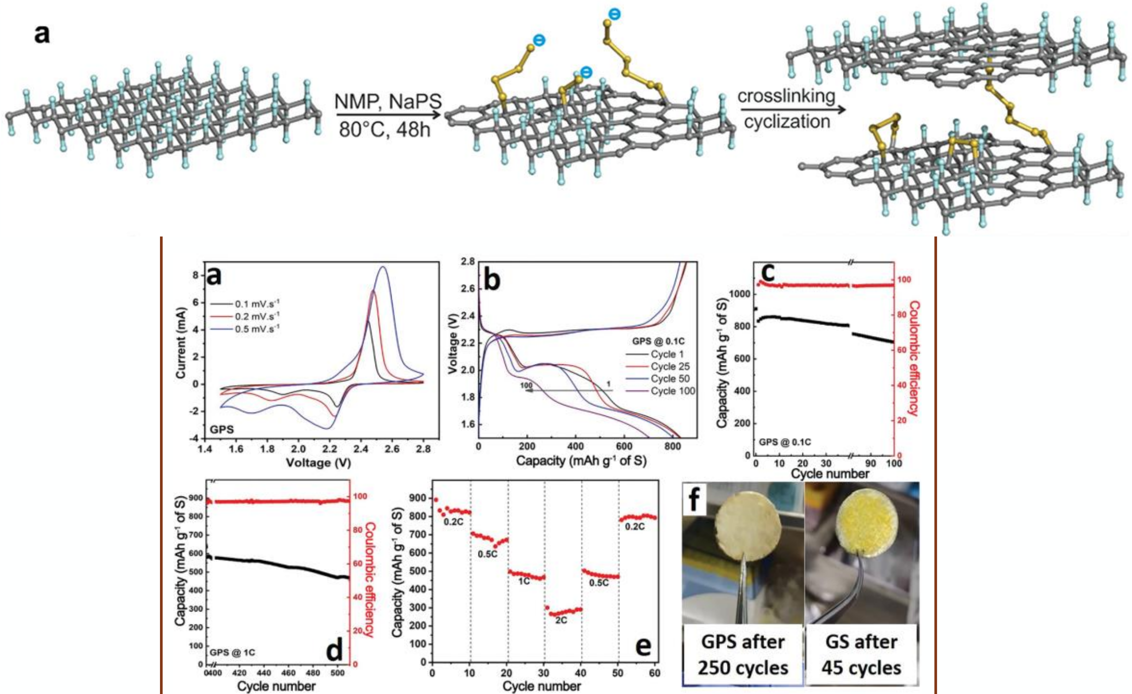

I. Tantis et al. Adv. Funct. Mater. **2021**, *31 (30)*, 2101326

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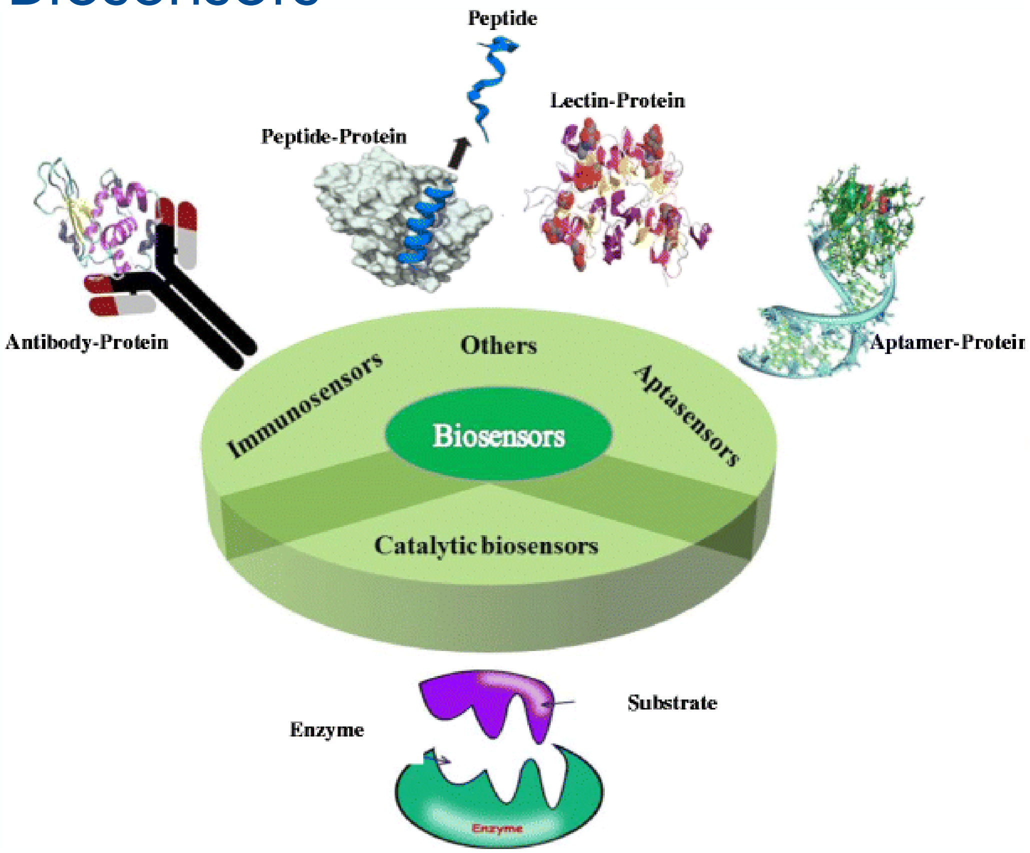
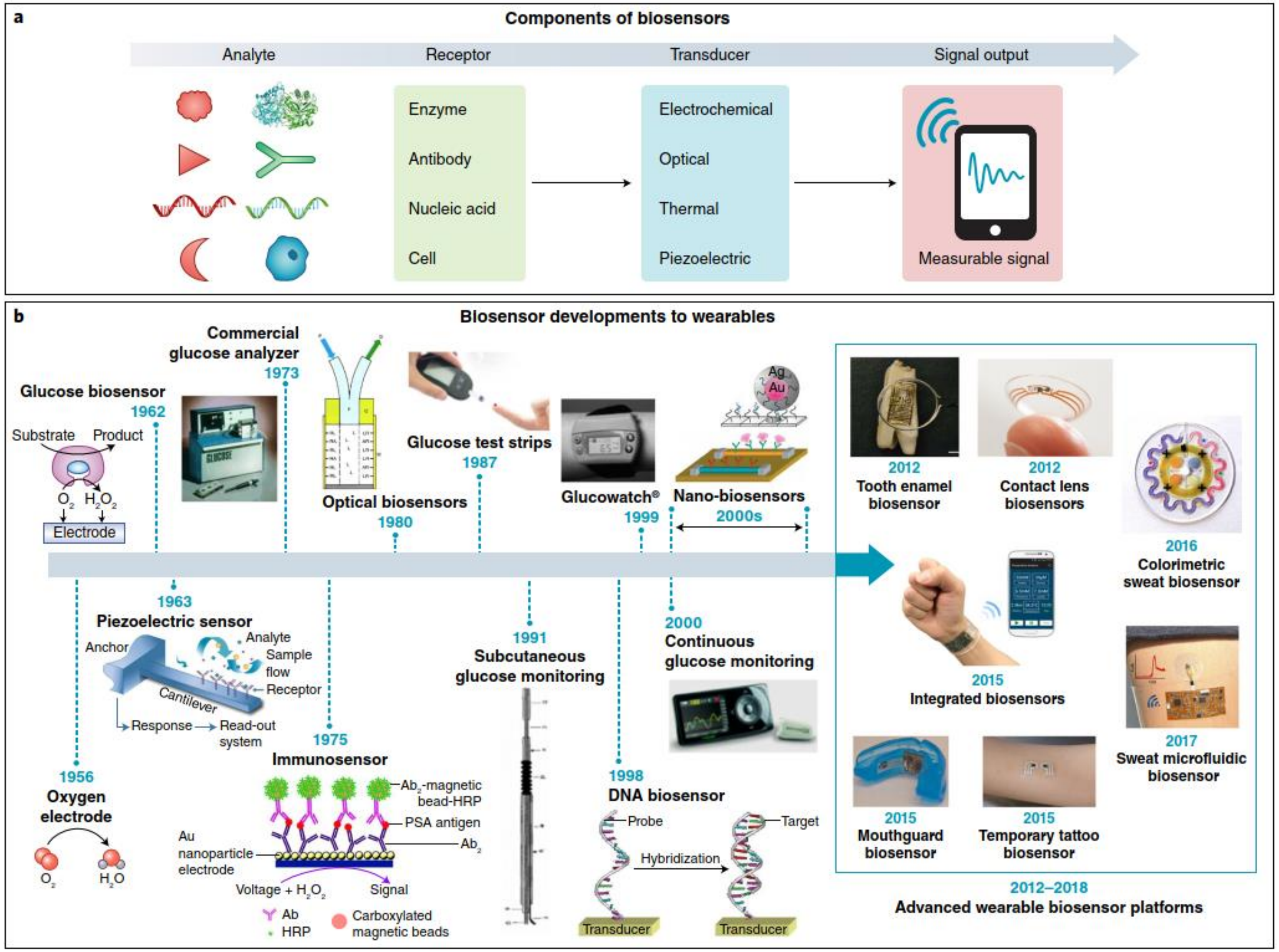
Biosensors





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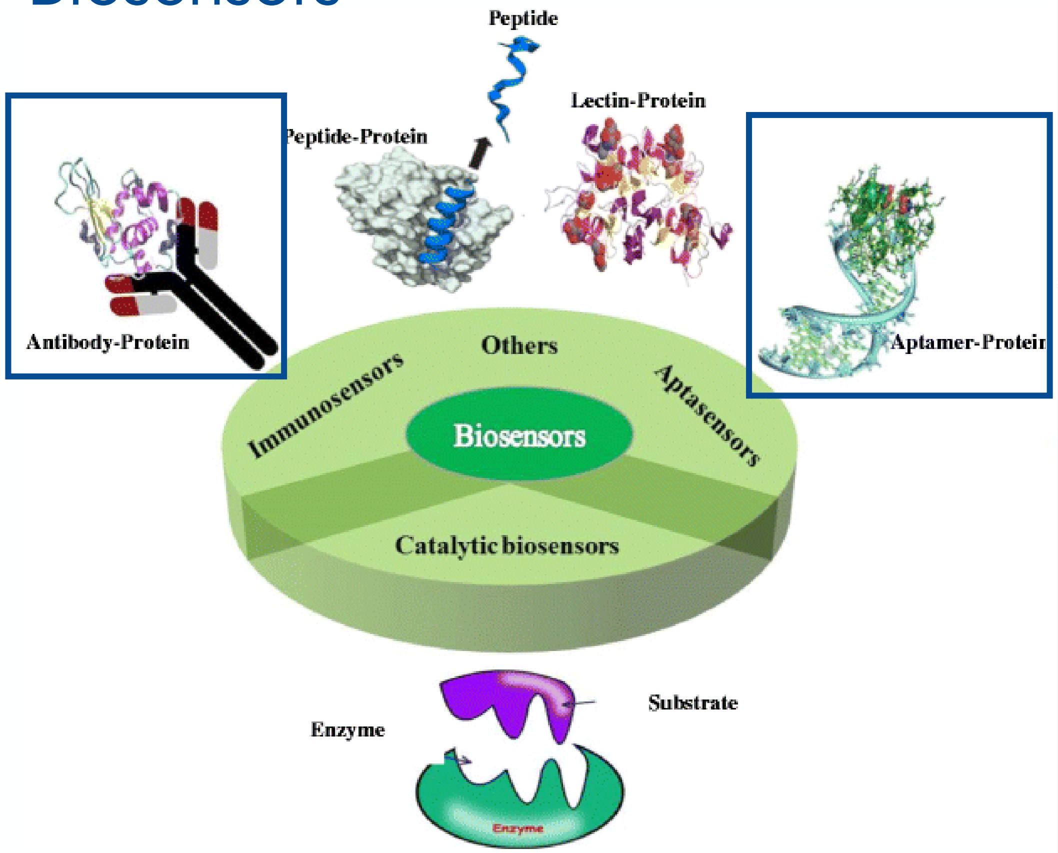
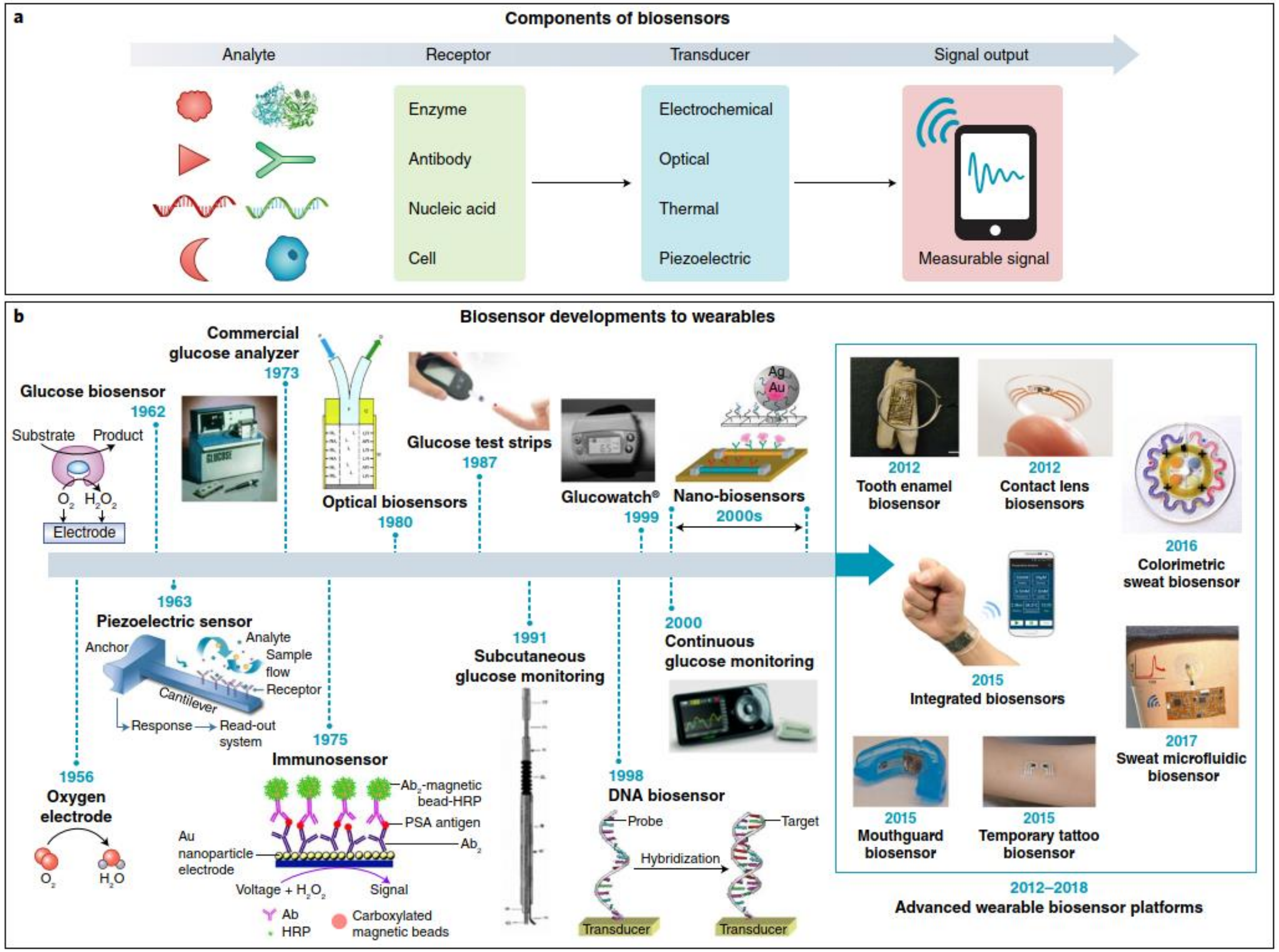
Biosensors





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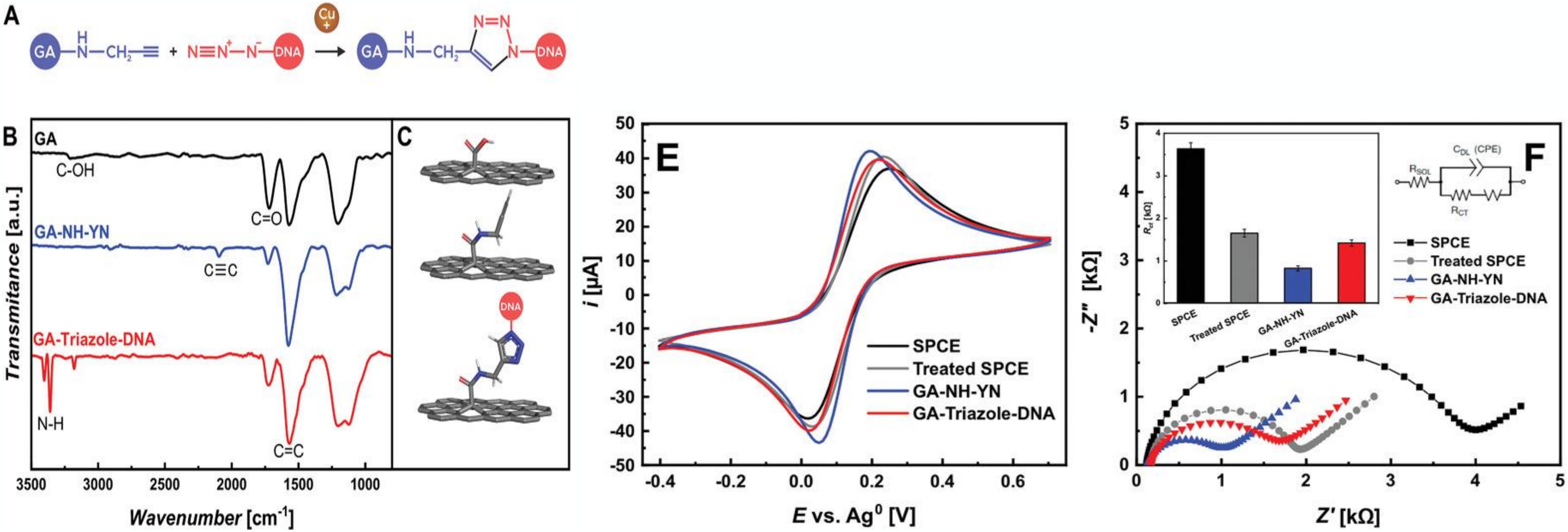
Biosensors

Click and Detect: Versatile Ampicillin Aptasensor Enabled by Click Chemistry on a Graphene–Alkyne Derivative



J. M. R. Flauzino et al. *Small* 2023, 10.1002/smll.202207216

Biosensors

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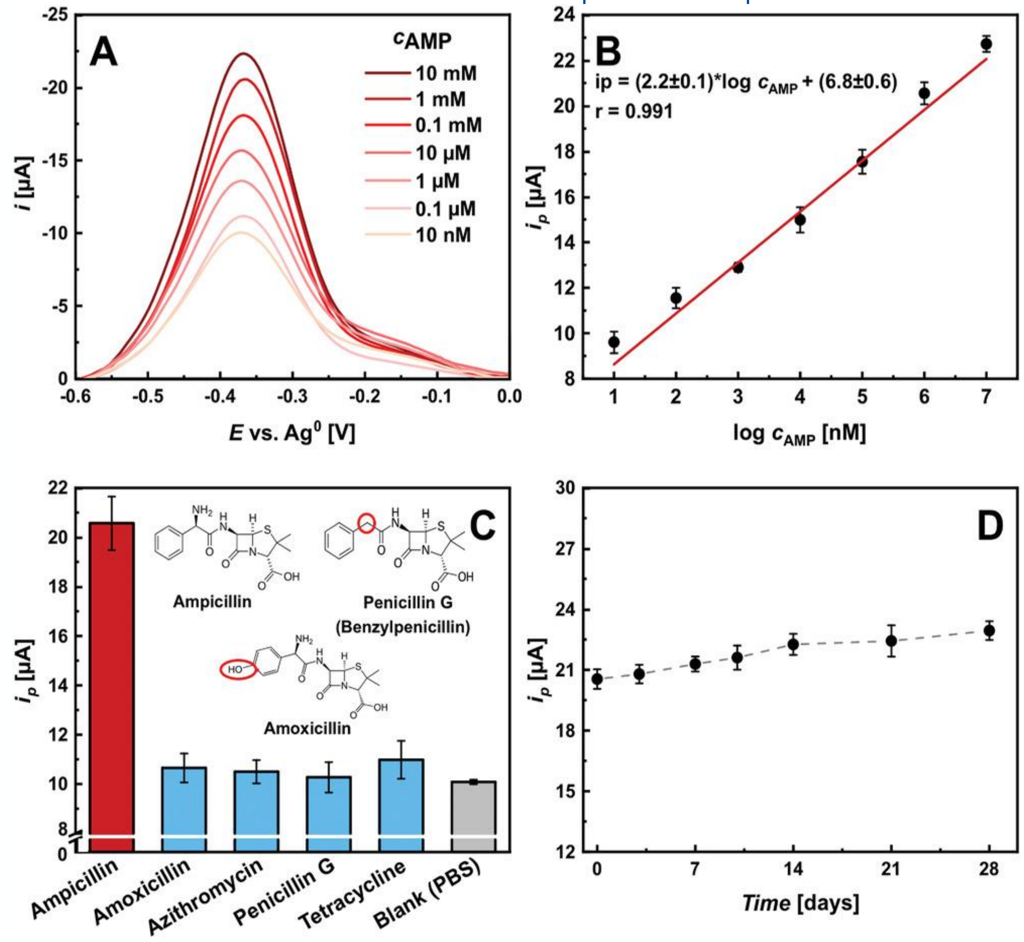
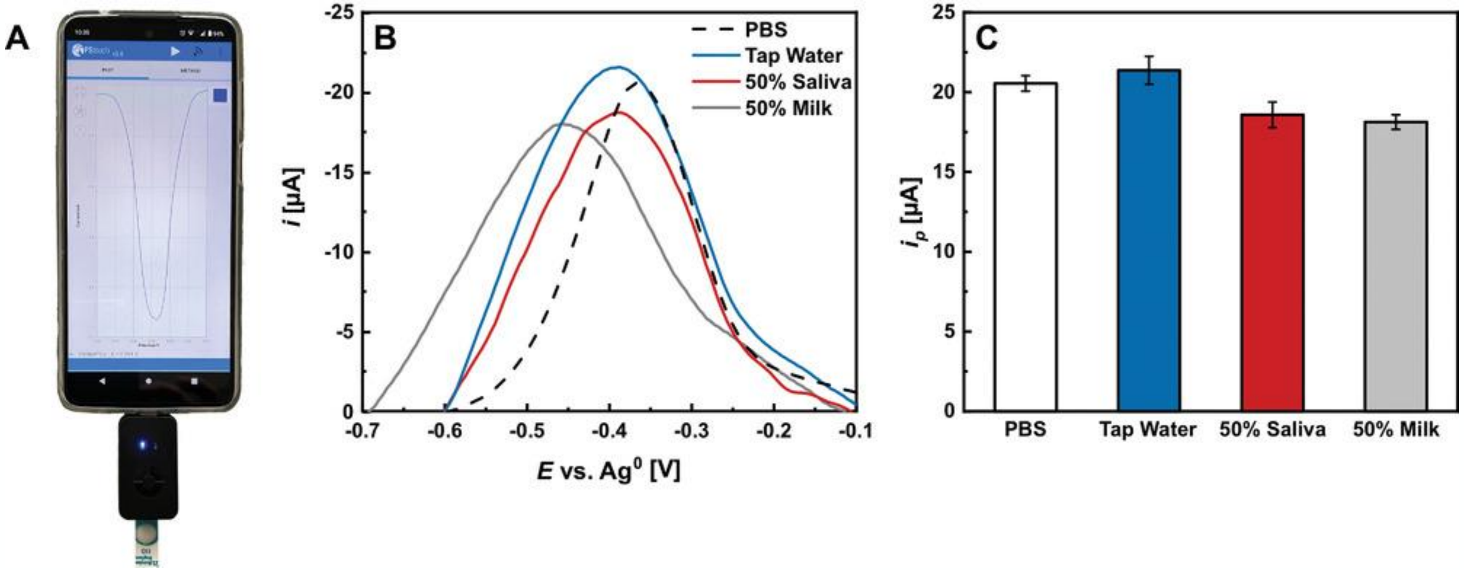
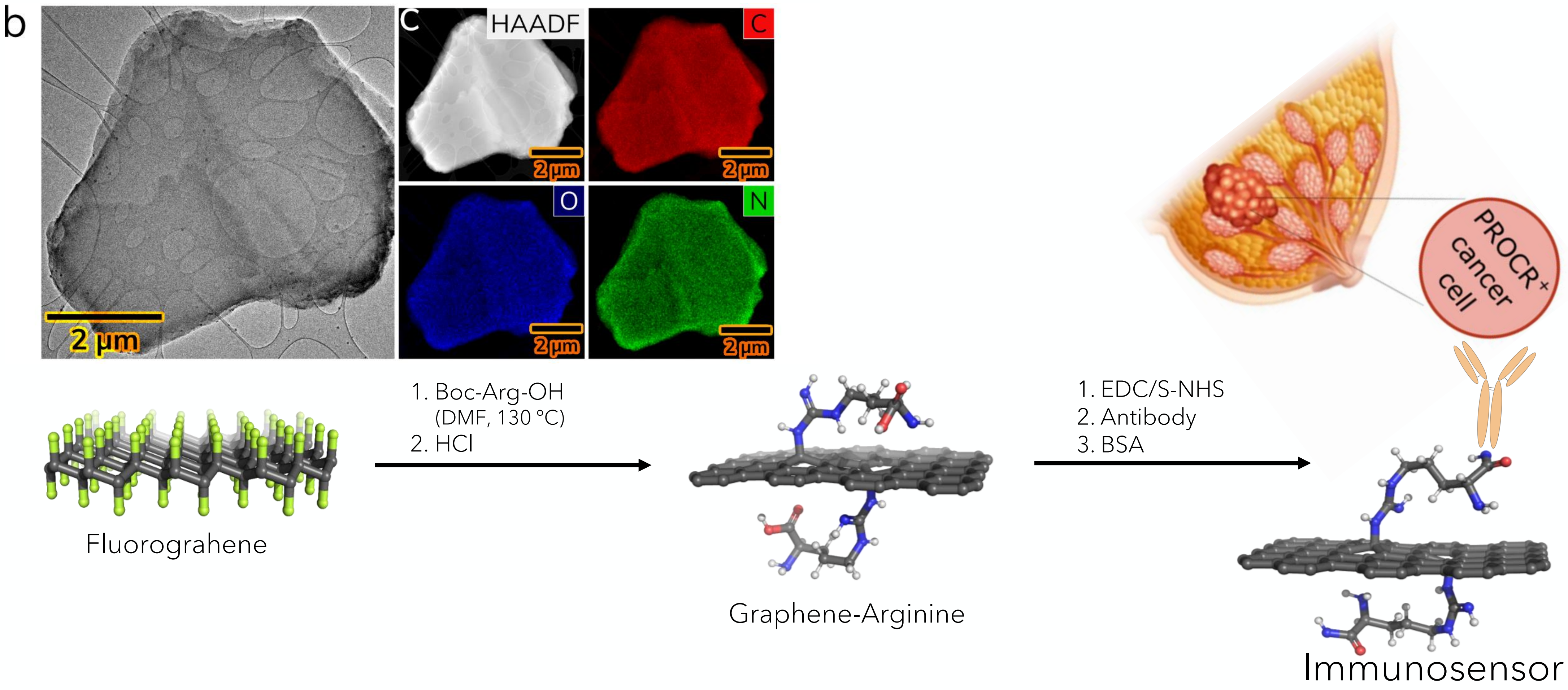




Graphene-based biosensors

Graphene-arginine sensing platform for the detection of endothelial protein C receptor



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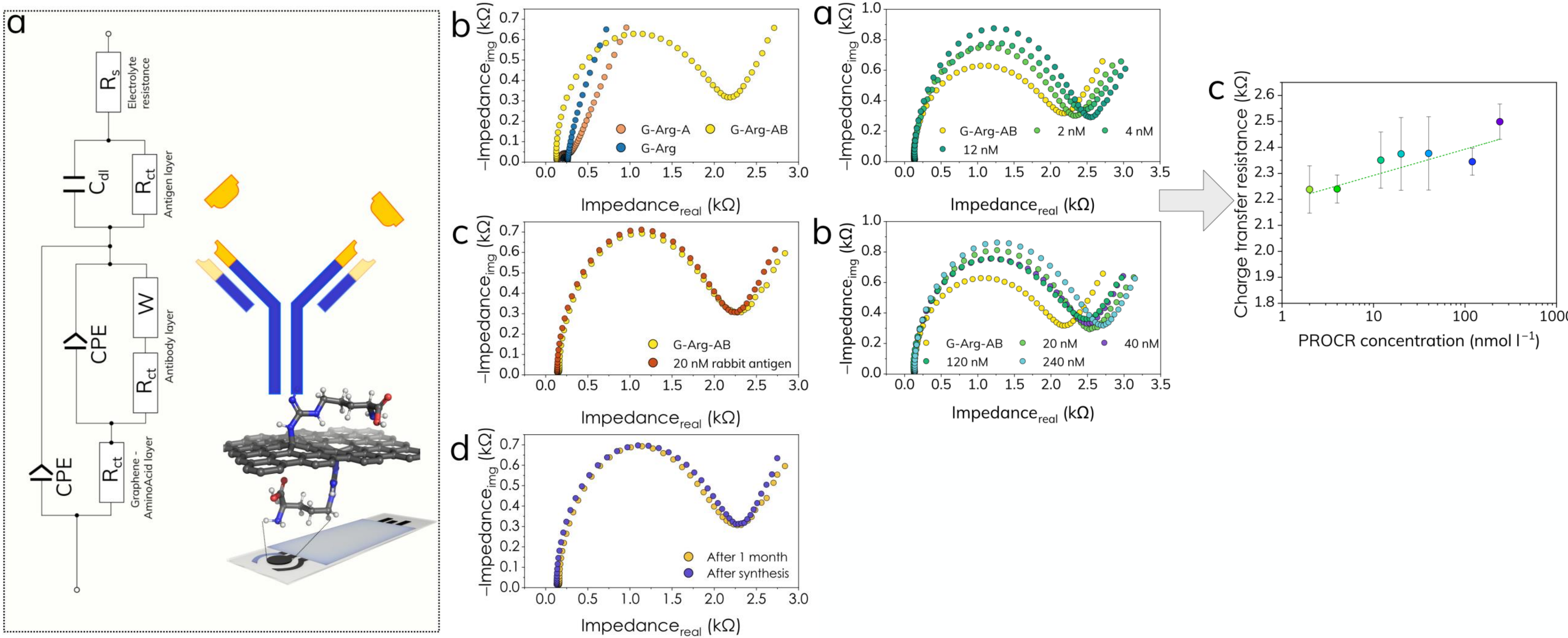

Thank you for attention

Q & A

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