Hybrid materials as cathode and carbon based materials as anode for asymmetric supercapacitor applications

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Outline

- ✓ **Overview**
- ✓ **Synthesis of hybrid materials**
- ✓ **Synthesis of carbon-based materials**
- ✓ **Results and discussion**
- ✓ **Conclusion**

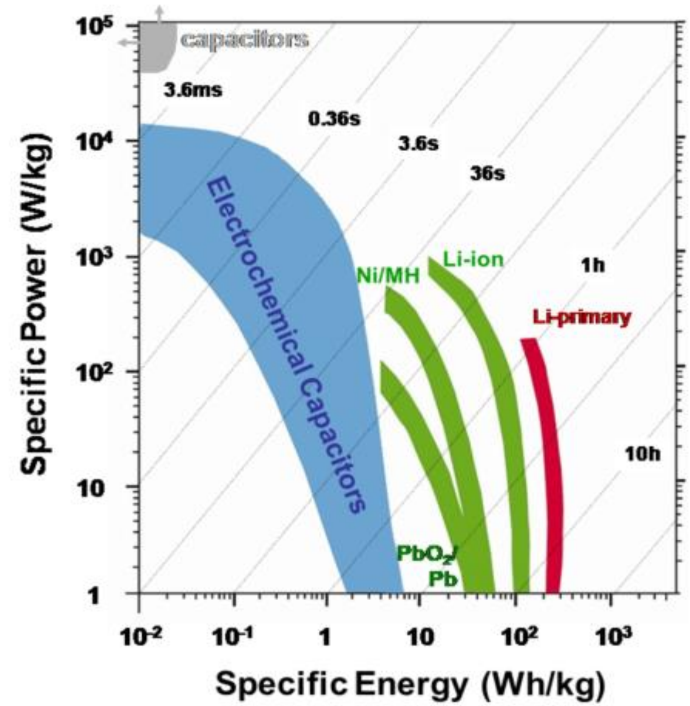
Why electrochemical capacitors (Supercapacitors)

✓ Due to the increasing demand for high-performance energy-storage systems alternative storage systems are considered.

✓ Supercapacitors are power devices with high power capability, long cyclic life, fast charge propagation dynamics with low maintenance cost.

✓ They are suitable for application in backup power sources, portable electronic devices, electric vehicles and hybrid electric vehicles (HEVs).

✓ Most of the available supercapacitor have energy density < 10 Wh/kg, when compared with batteries > 100 Wh/kg.



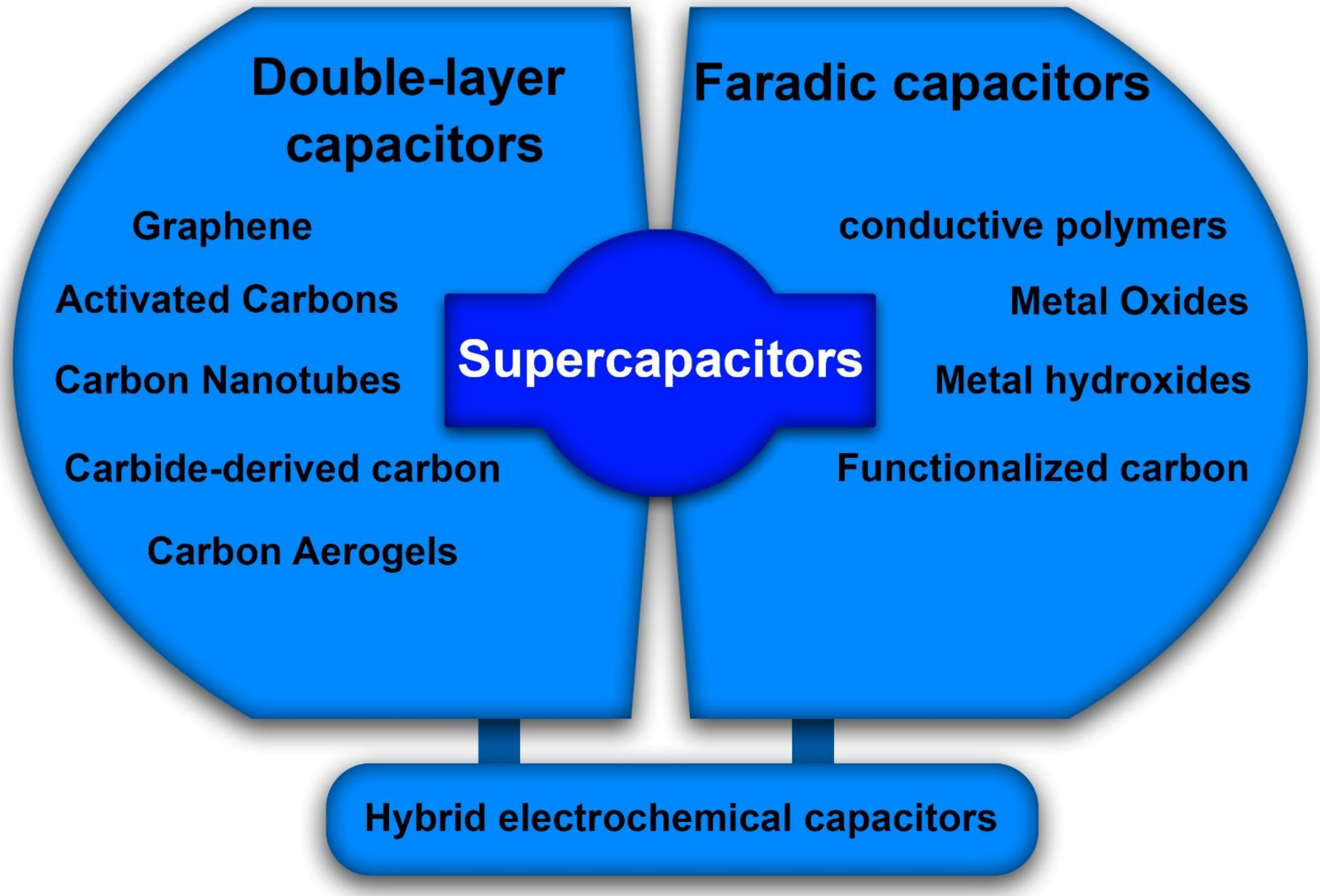
✓ Hence, there is the need to increase the energy performance of supercapacitors to be close to or even beyond that of batteries.

Batteries have low power density and high energy density

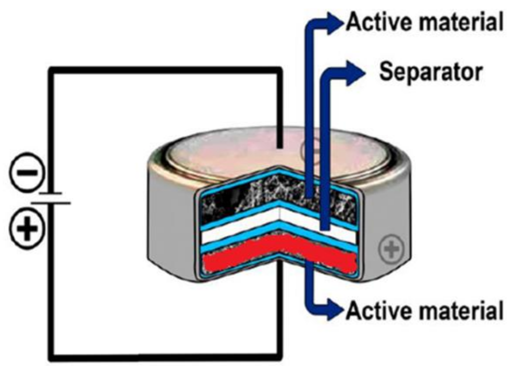
Supercapacitors have low energy density but high power density

Applications

Materials used for supercapacitor devices



Two types of Supercapacitor devices



Symmetric SCs

- Symmetric SCs without hybrid behaviour
  - EDLCs
  - Symmetric systems with Faradic materials
- Symmetric-hybrid materials

Asymmetric SCs

- Asymmetric-hybrid materials
  - One battery-type electrode
  - Electrodes of capacitive nature
- Asymmetric SCs without hybrid behaviour

Important parameters of Electrochemical Cell

- **Specific capacitance** (C_{sp}) of single electrode can be obtained using

(CV curve) (CD curve) (CD curve)

$$C_{sp} = \frac{\int I(v)dv}{mv\Delta V}(\mathrm{Fg}^{-1}),\quad C_{sp} = \frac{2I\int V(t)dt}{mV^2}(\mathrm{Fg}^{-1}),\ \xrightarrow{\text{EDLC}}\ C_{sp} = \frac{I\Delta t}{m\Delta V}(\mathrm{Fg}^{-1})$$

- A charge balance $Q_+ = Q_-$ between the two electrodes should be done; where Q_+ and Q_- are the charges stored in the positive and negative electrodes, respectively.
- The charge stored by each electrode can be expressed as $Q = C_{sp} m \Delta V$

$$\frac{m_+}{m_-} = \frac{C_{sp-}\Delta U_-}{C_{sp+}\Delta U_+}$$

- **The energy density** (E, in Wh kg^{-1}) of supercapacitor can be calculated from specific capacitance

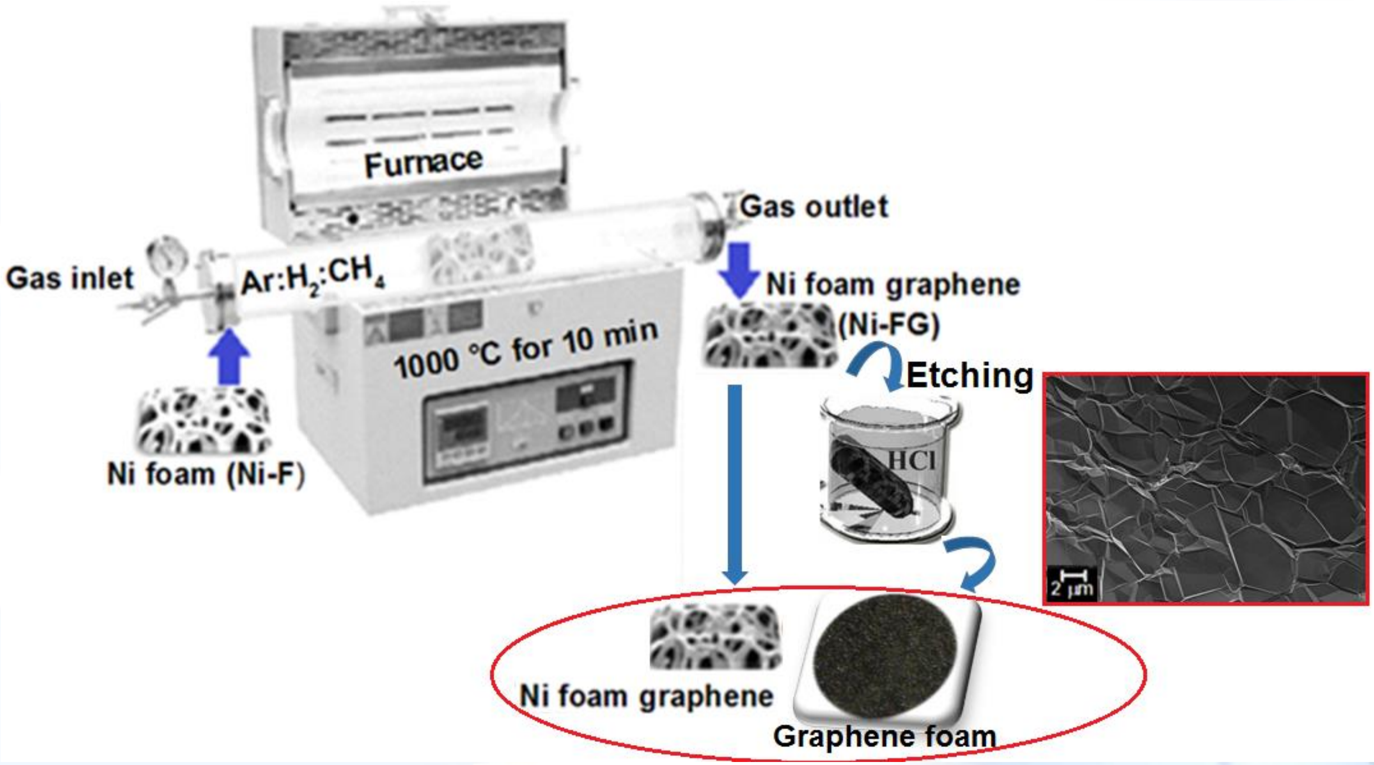
$$E_{\max} = \frac{C_{sp} \times \Delta U^2}{7.2}(\mathrm{Wh\ kg}^{-1})$$

- **Power density** (P, in W kg^{-1}) of a supercapacitor

$$P_{\max} = \frac{3.6 \times E_{\max}}{\Delta t}(\mathrm{W\ kg}^{-1})$$

Experimental studies

Synthesis of Graphene foam (GF)



- Methane (CH_4) decomposition at 1000^{o}C
- Graphene nucleation/growth on NF
- High surface NF used as substrate for growth

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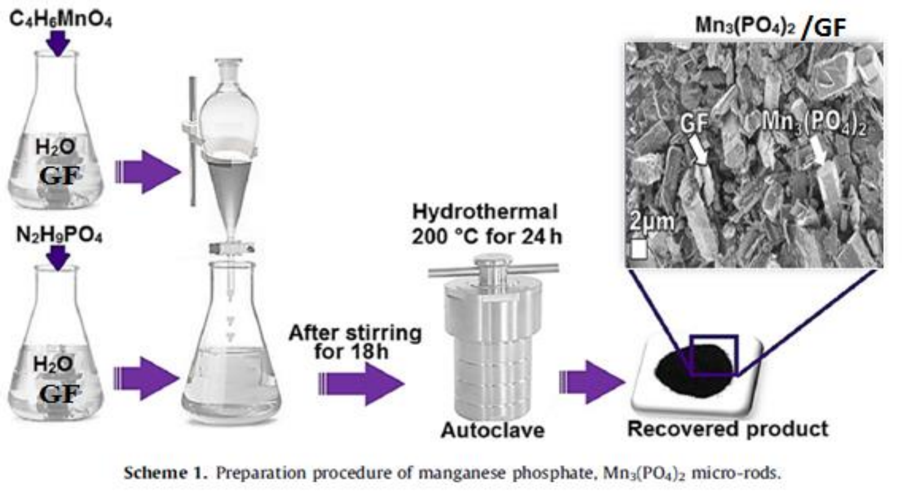
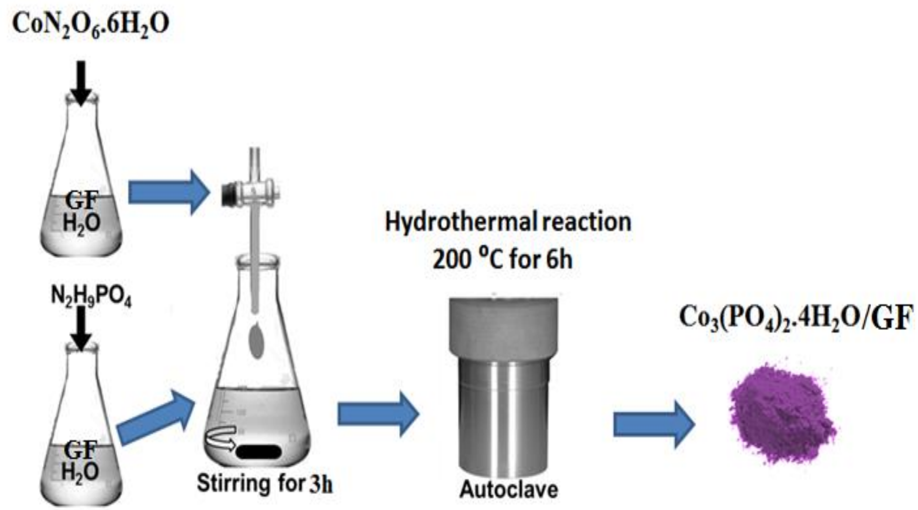
Synthesis of hybrid metal oxides

1. $Mn_3(PO_4)_2$/GF



Scheme 1. Preparation procedure of manganese phosphate, $Mn_3(PO_4)_2$ micro-rods.

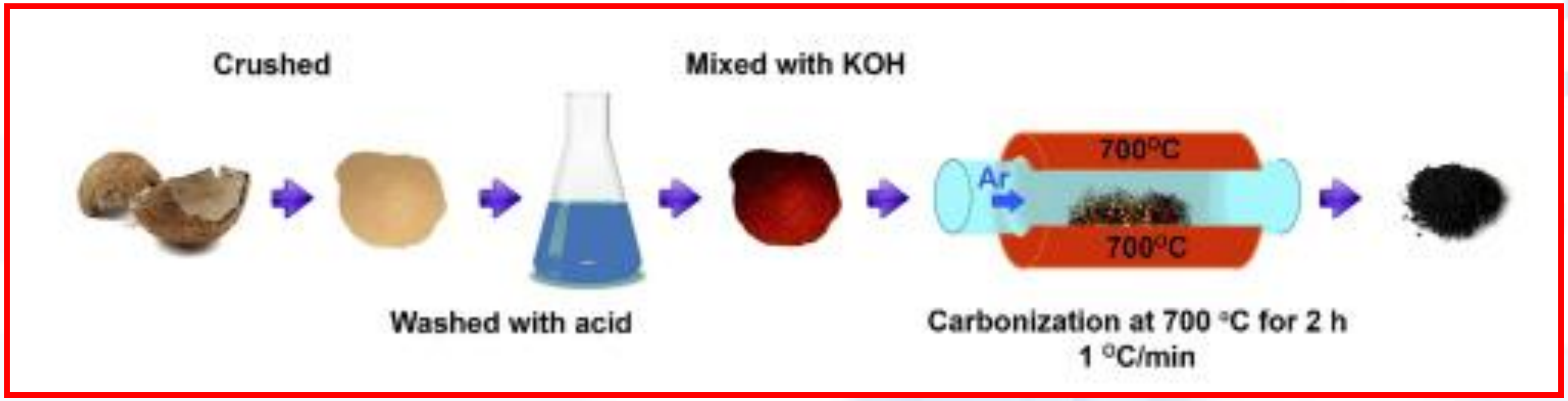
2. $Co_3(PO_4)_2.4H_2O$/GF



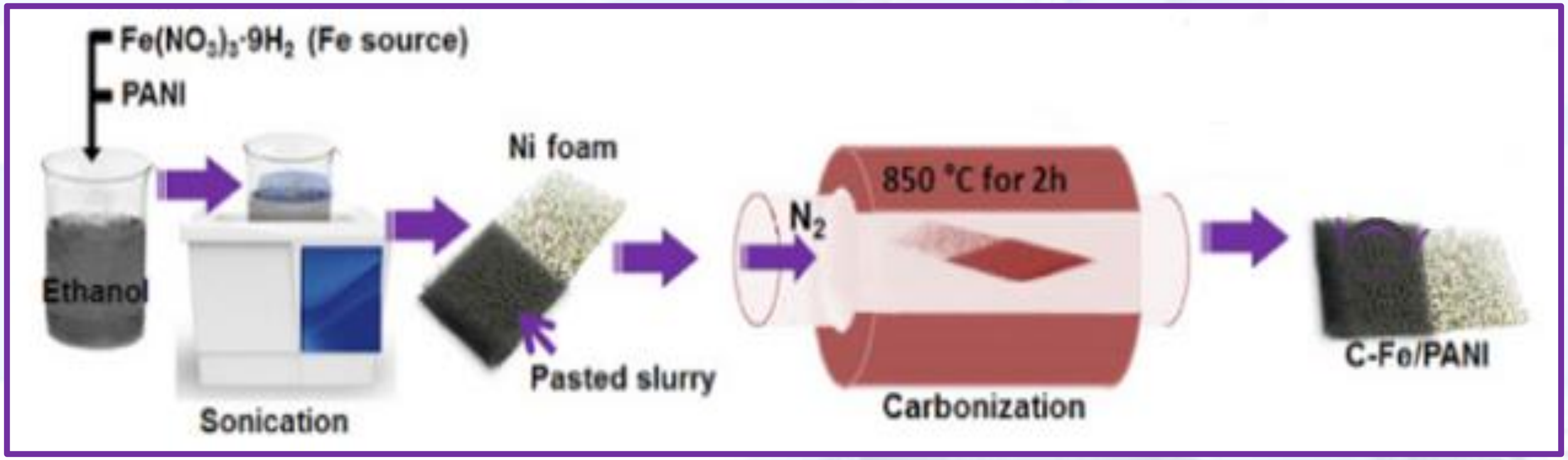
3. V_2O_5/GF

Synthesis of carbon-based materials

1. Activated carbon (AC) from coconut shell



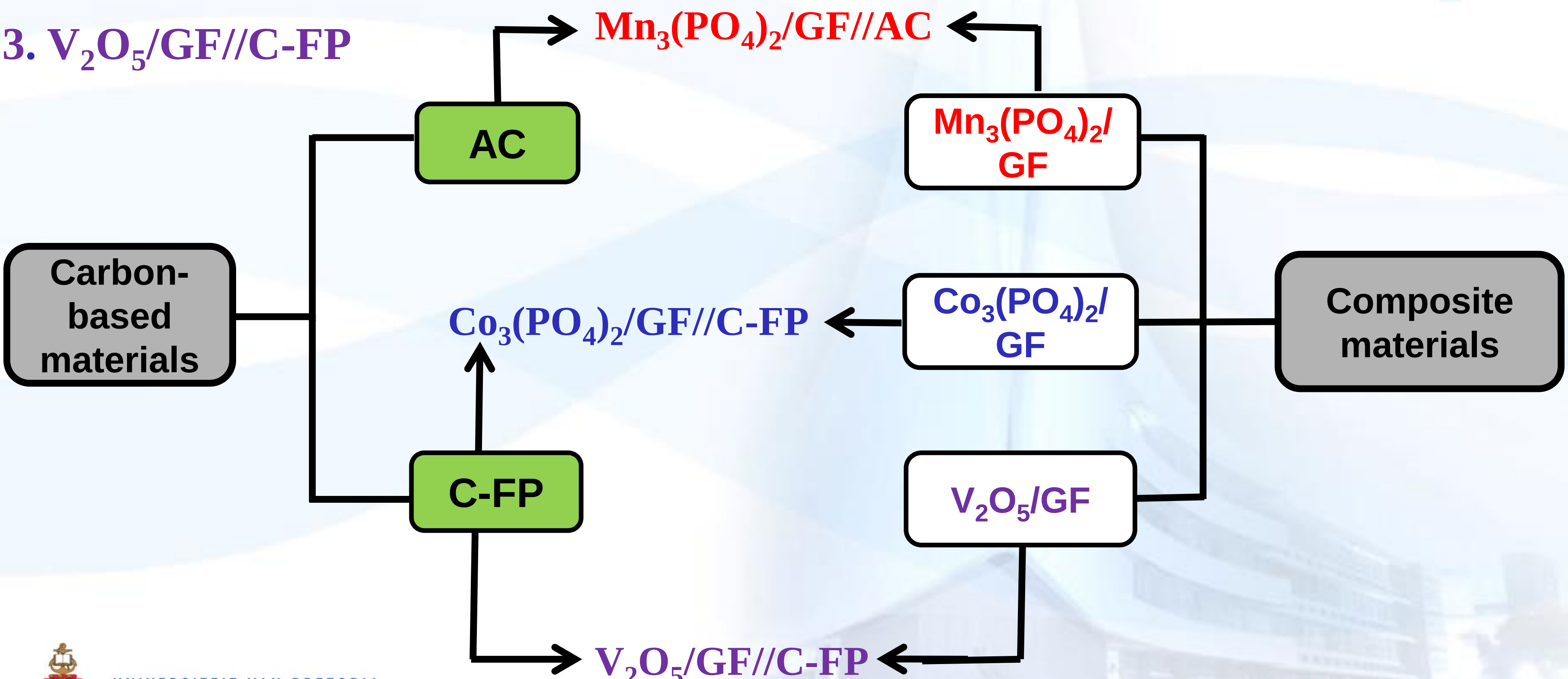
2. Carbonization of Fe cations adsorbed onto polyaniline (C-FP)



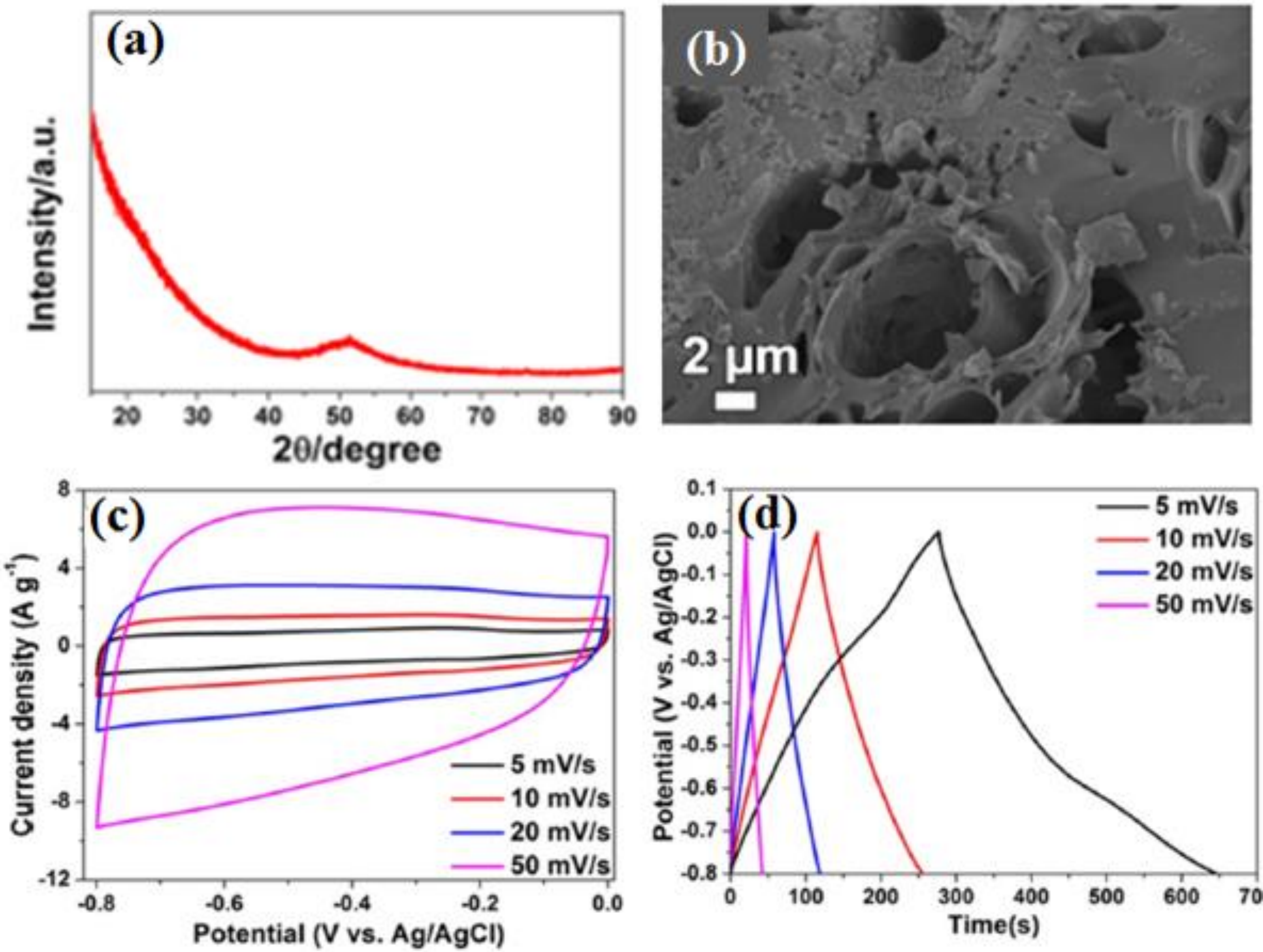
Hybrid asymmetric supercapacitors

Three composite materials have been used as positive electrodes and two carbon-based materials as negative electrodes in asymmetric supercapacitors:

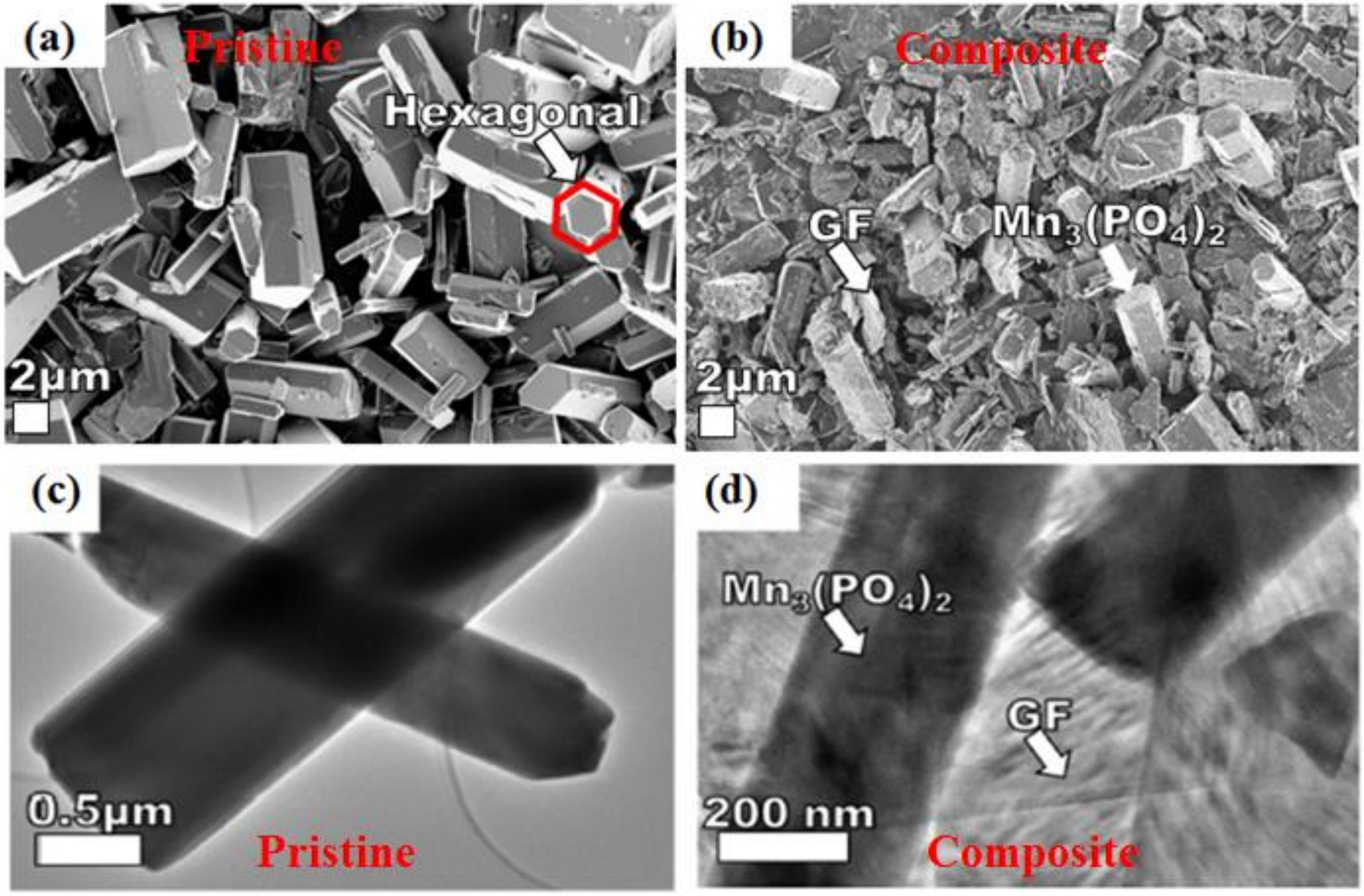
1. **$Mn_3(PO_4)_2$/GF//AC**
2. **$Co_3(PO_4)_2$/GF//C-FP**
3. **V_2O_5/GF//C-FP**



XRD, SEM, CV & CD (in 6 M KOH electrolyte) of AC



SEM & TEM: $Mn_3(PO_4)_2$ and $Mn_3(PO_4)_2$/GF



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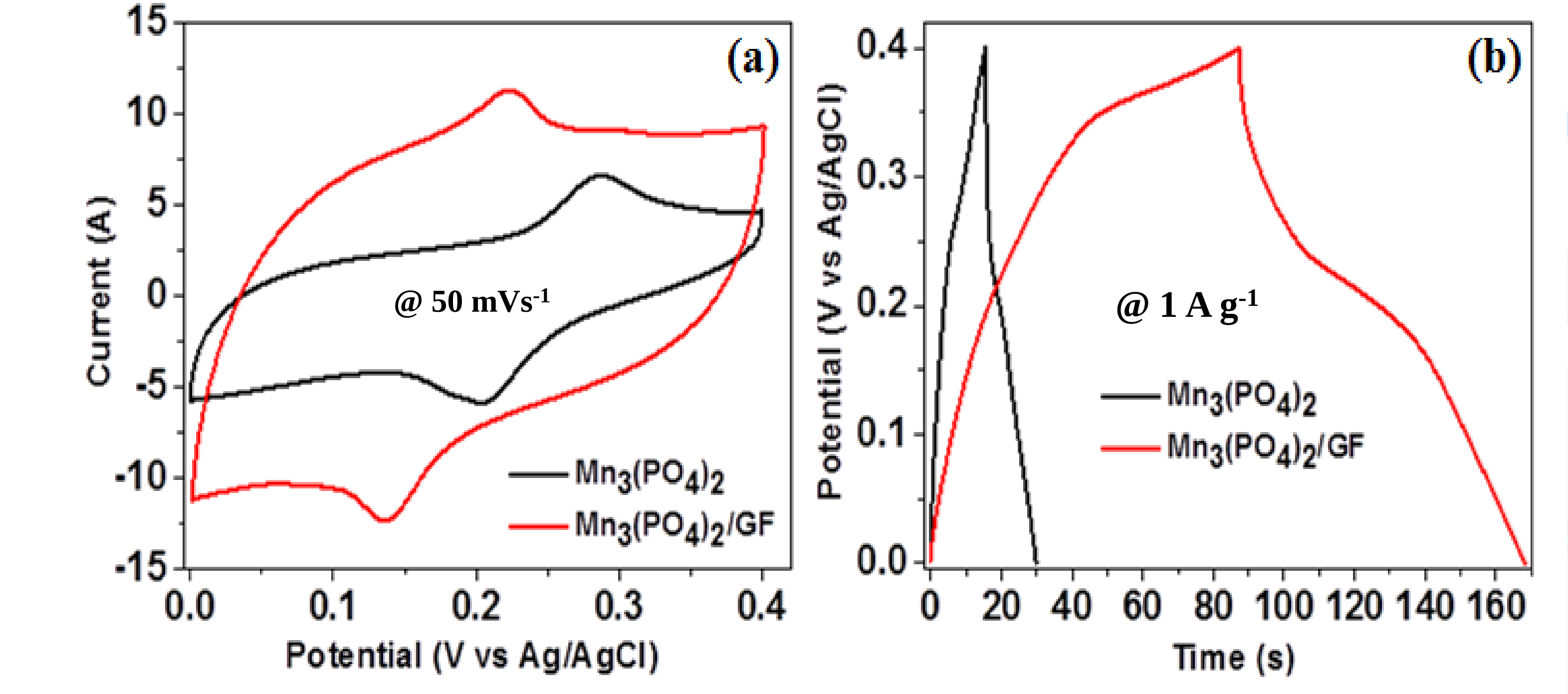
CV & CD (in 6 M KOH electrolyte) for $Mn_3(PO_4)_2$ and $Mn_3(PO_4)_2$/GF



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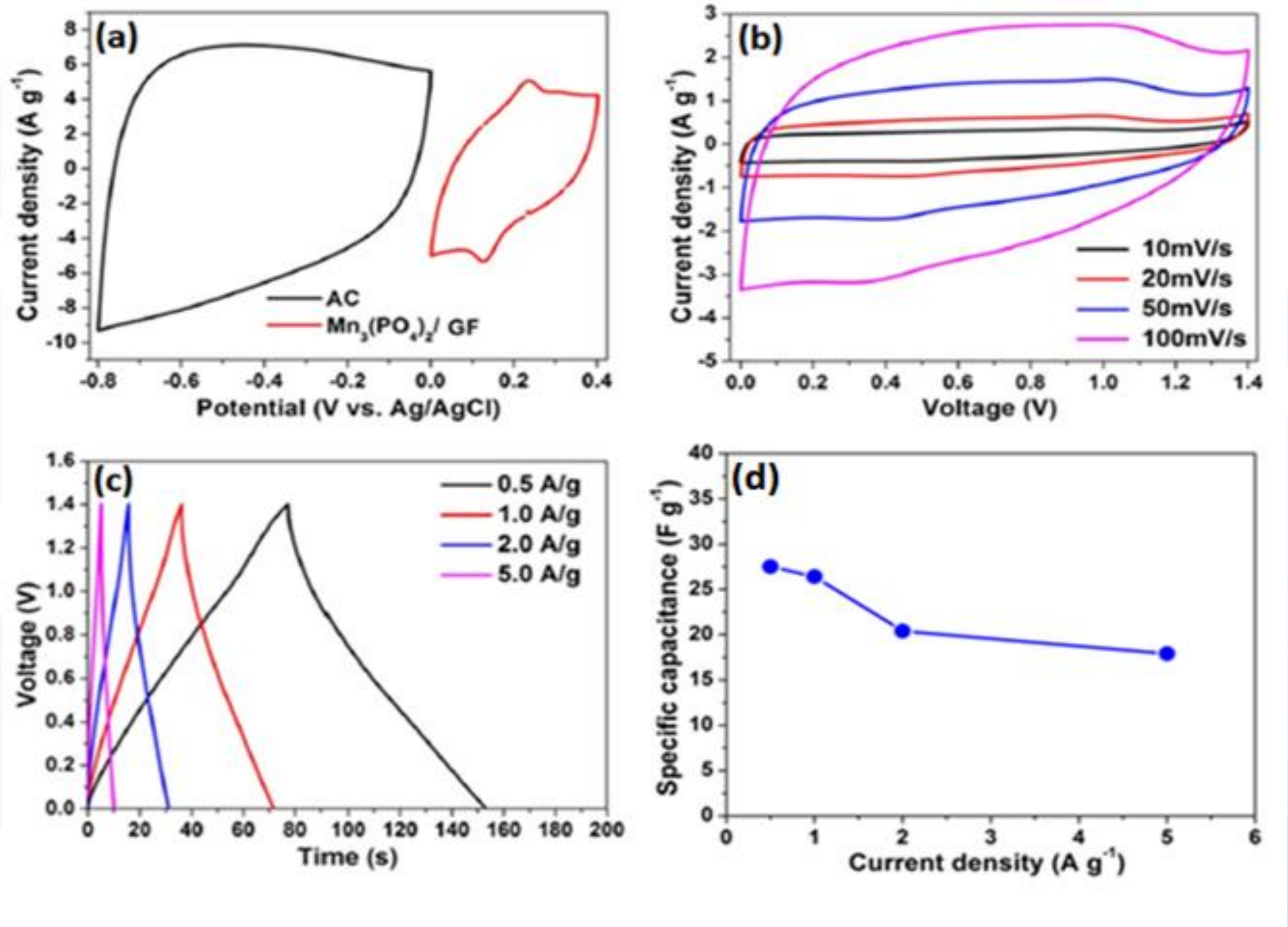
$Mn_3(PO_4)_2$/GF//AC asymmetric device



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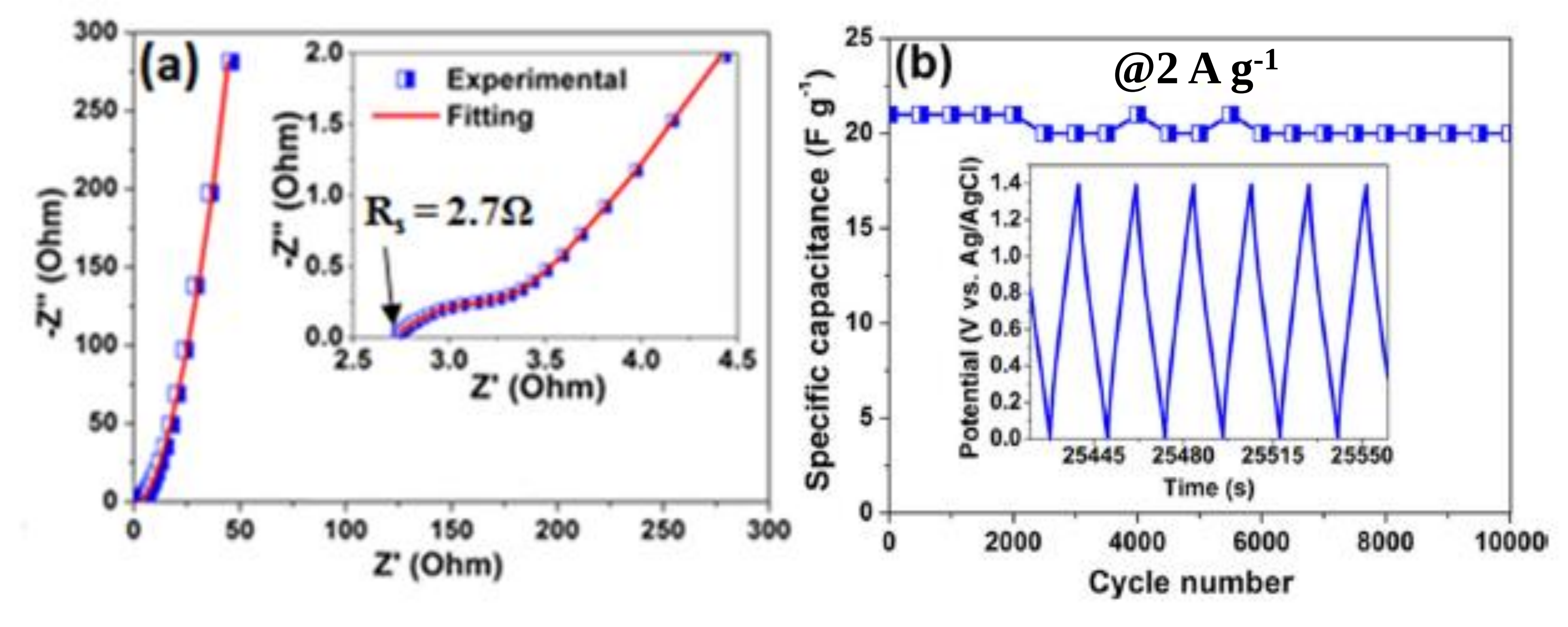
EIS & Stability: $Mn_3(PO_4)_2$/GF//AC device



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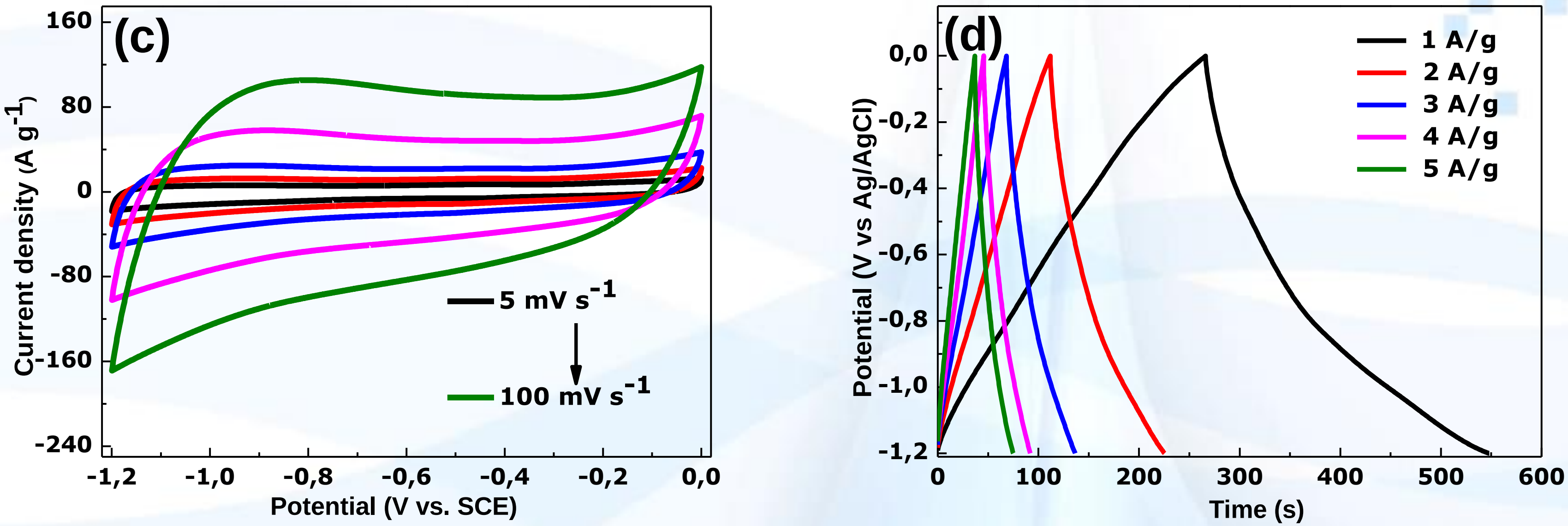
CV & CD (in 6 M KOH electrolyte) for Carbonization of Fe cations adsorbed onto polyaniline (C-FP)



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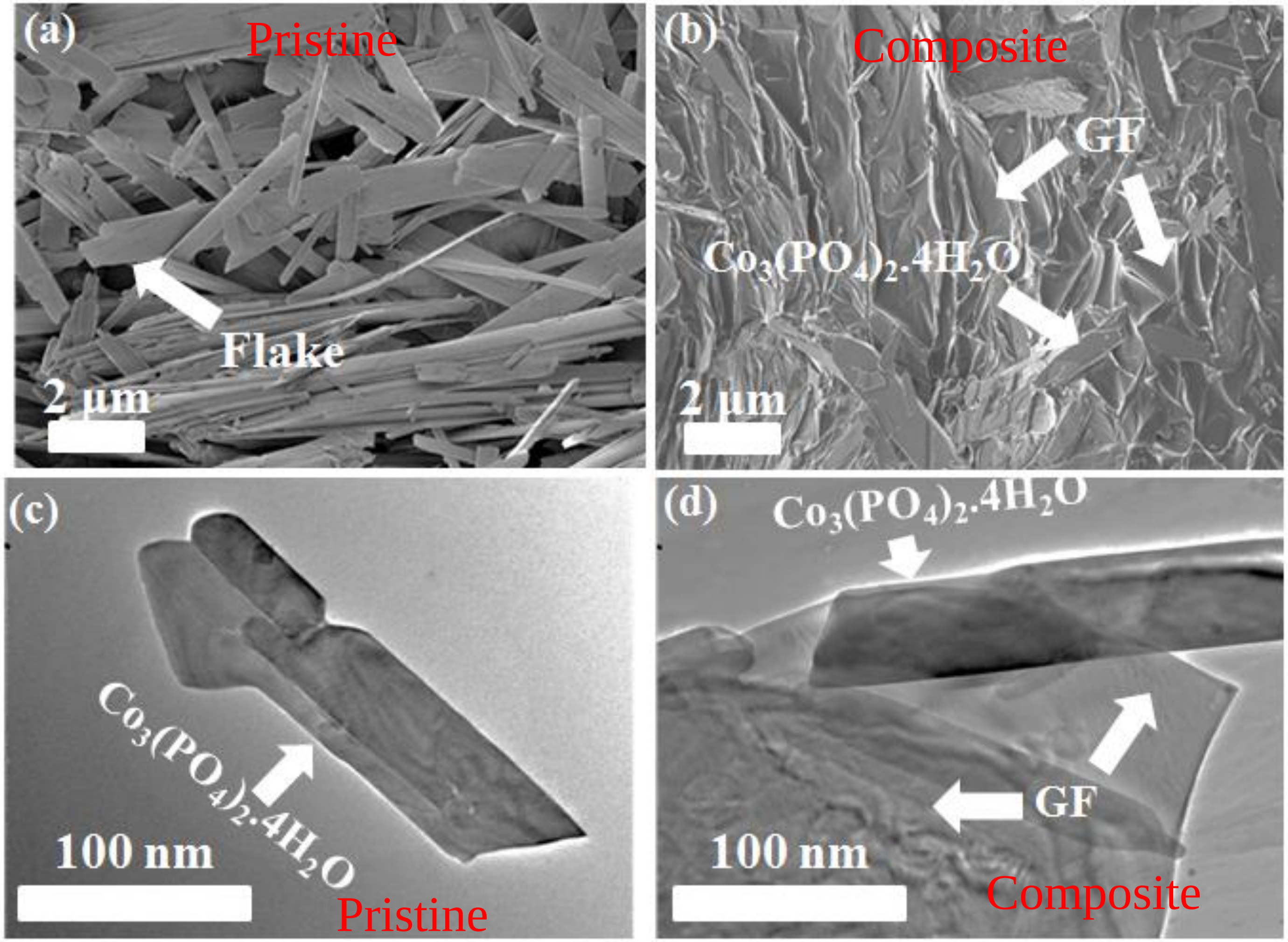
SEM & TEM: $Co_3(PO_4)_2.4H_2O$ and $Co_3(PO_4)_2.4H_2O/GF$



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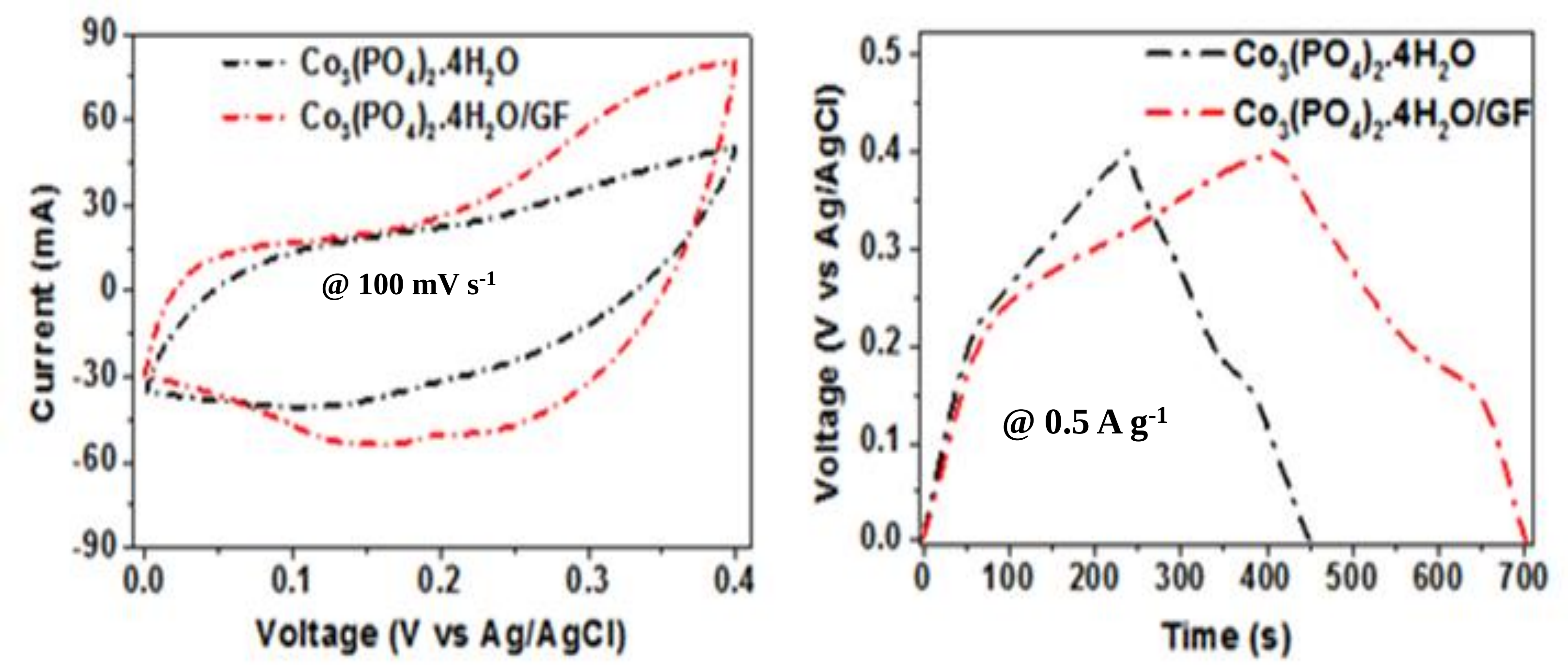
CV & CD (in 6 M KOH as electrolyte) for $Co_3(PO_4)_2.4H_2O$ and $Co_3(PO_4)_2.4H_2O/GF$



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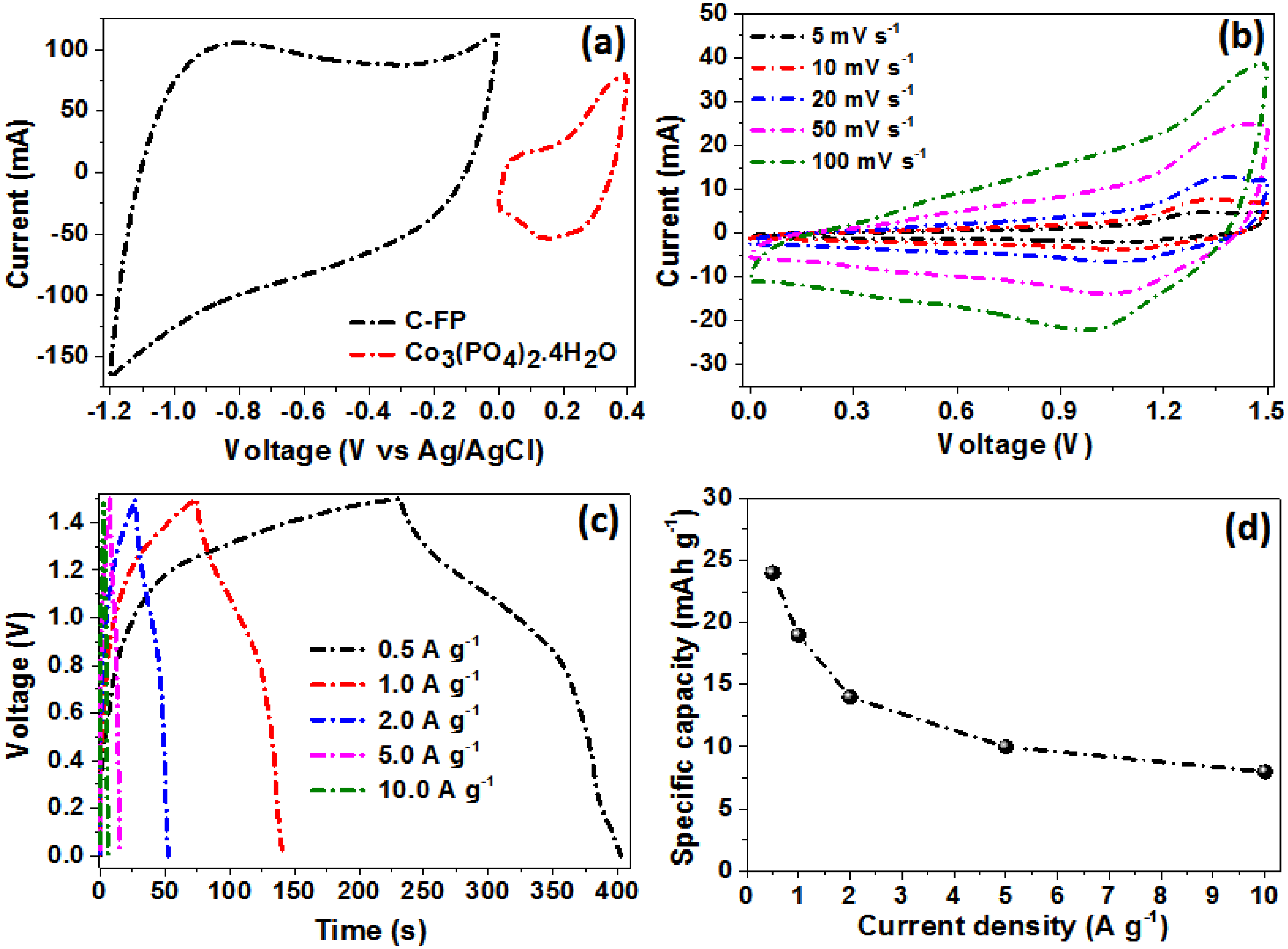
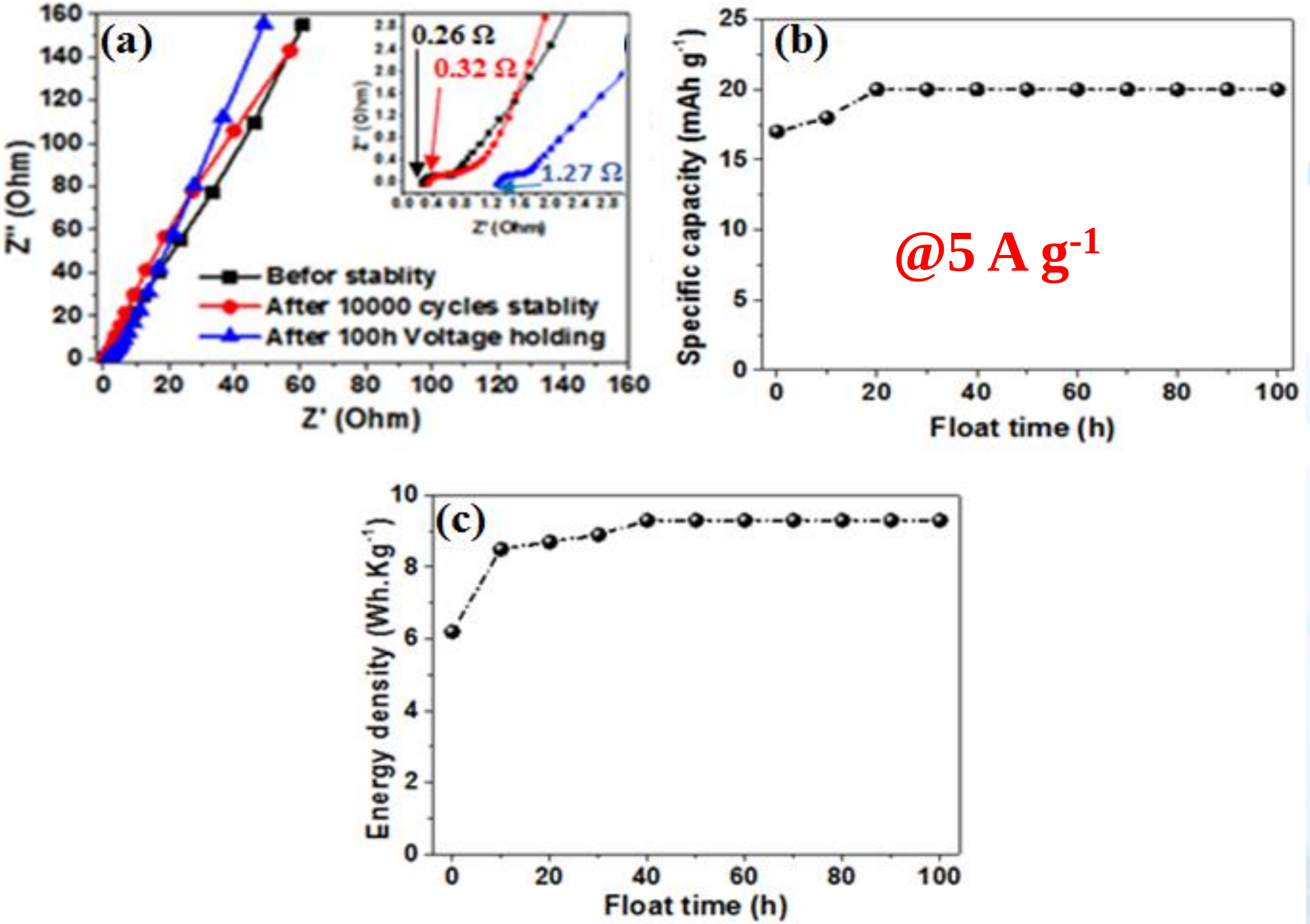
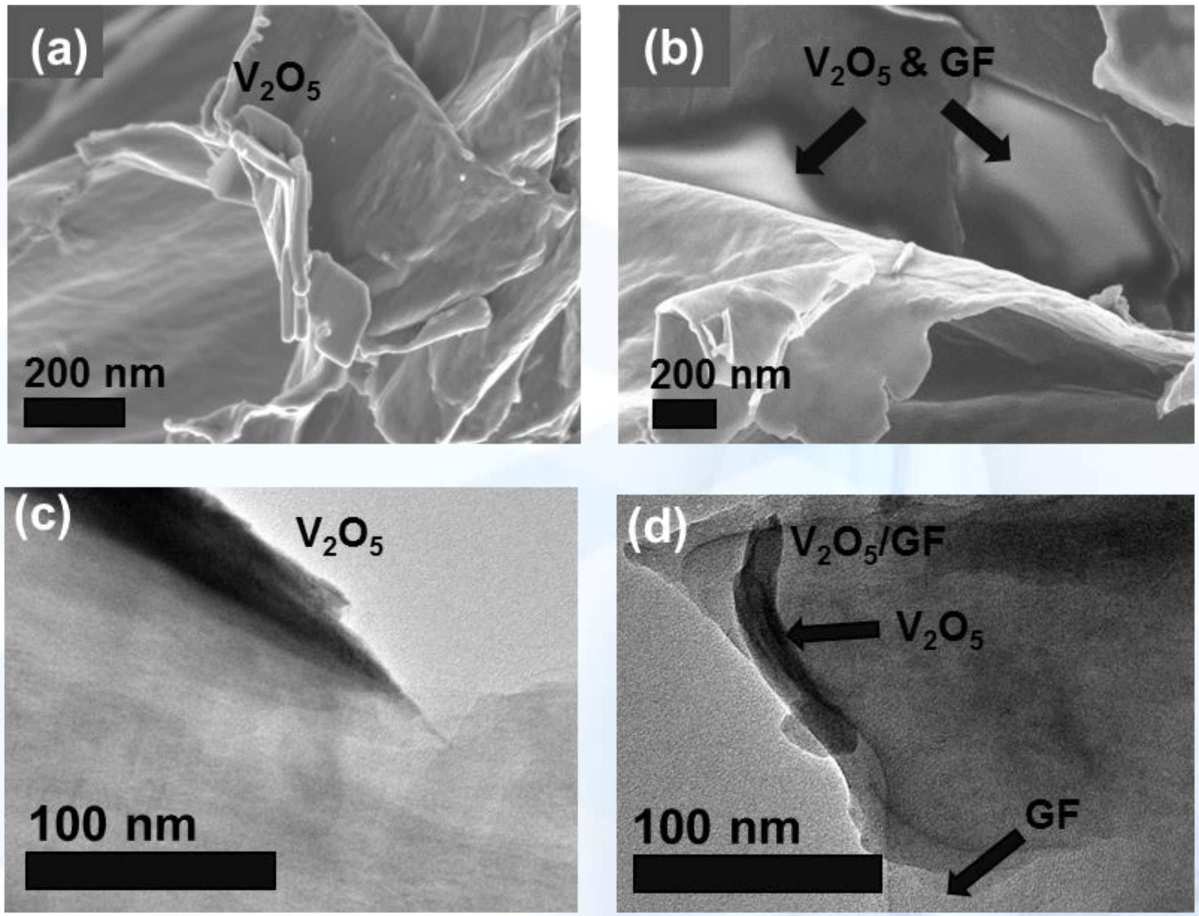
$Co_3(PO_4)_2.4H_2O$/GF//C-FP asymmetric device



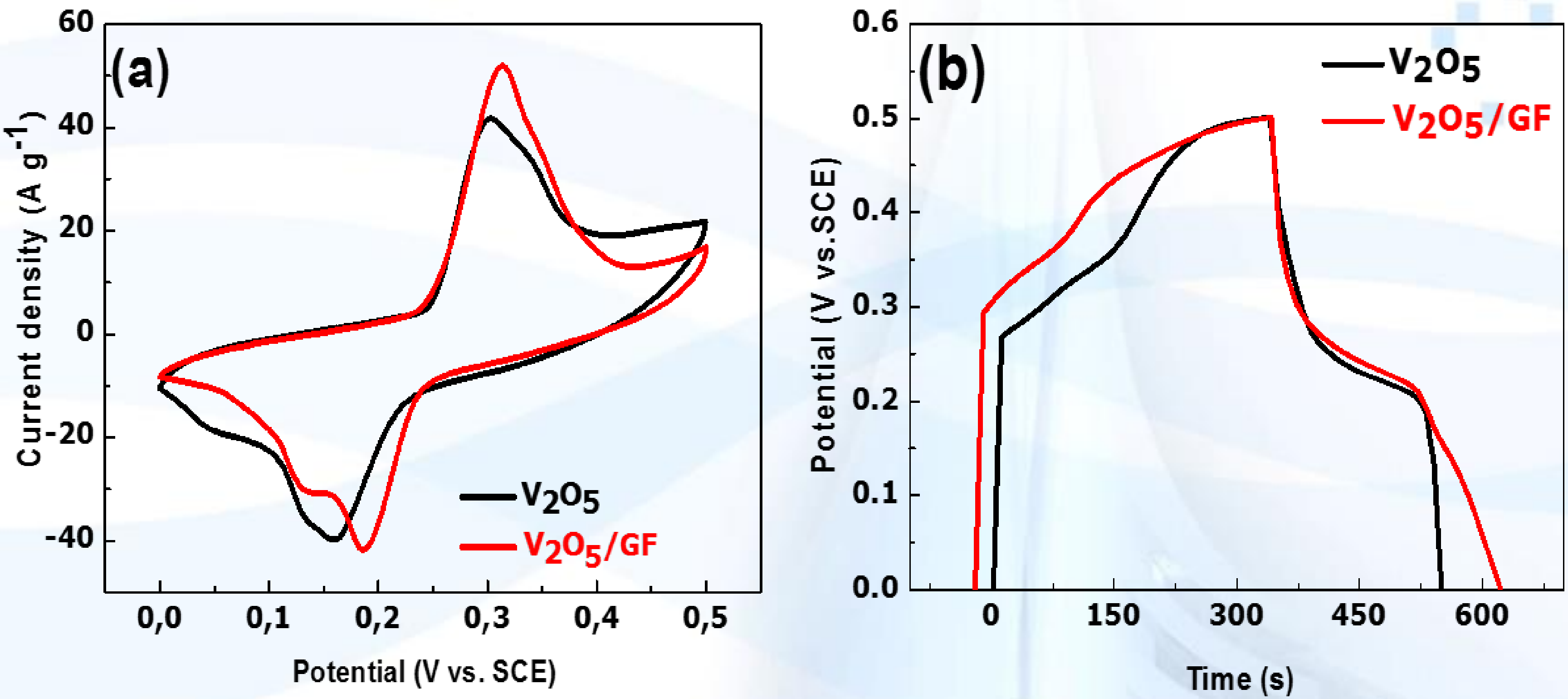
EIS & Stability: $Co_3(PO_4)_2.4H_2O$/GF//C-FP asymmetric device_



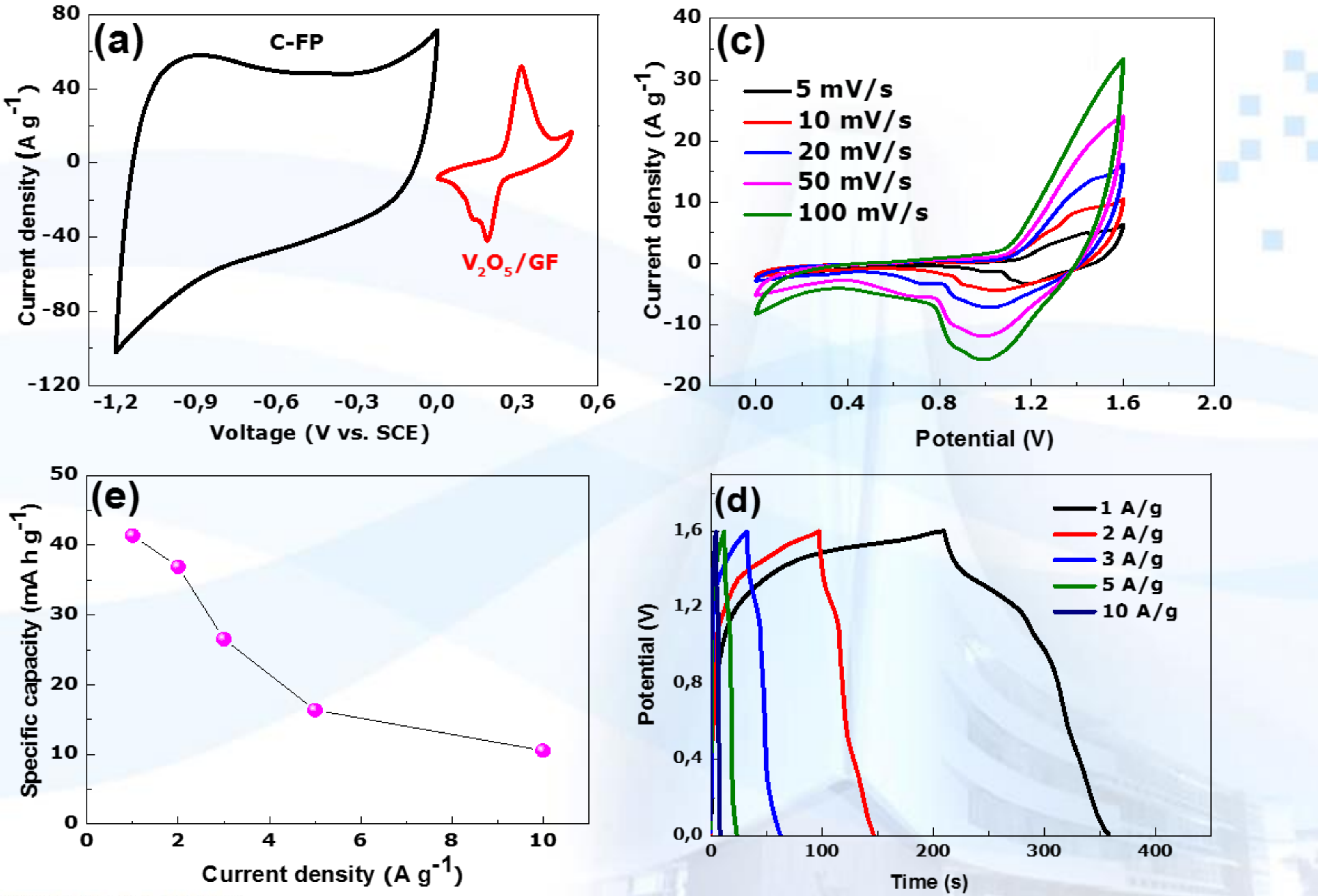
SEM & TEM: V_2O_5 and V_2O_5/GF



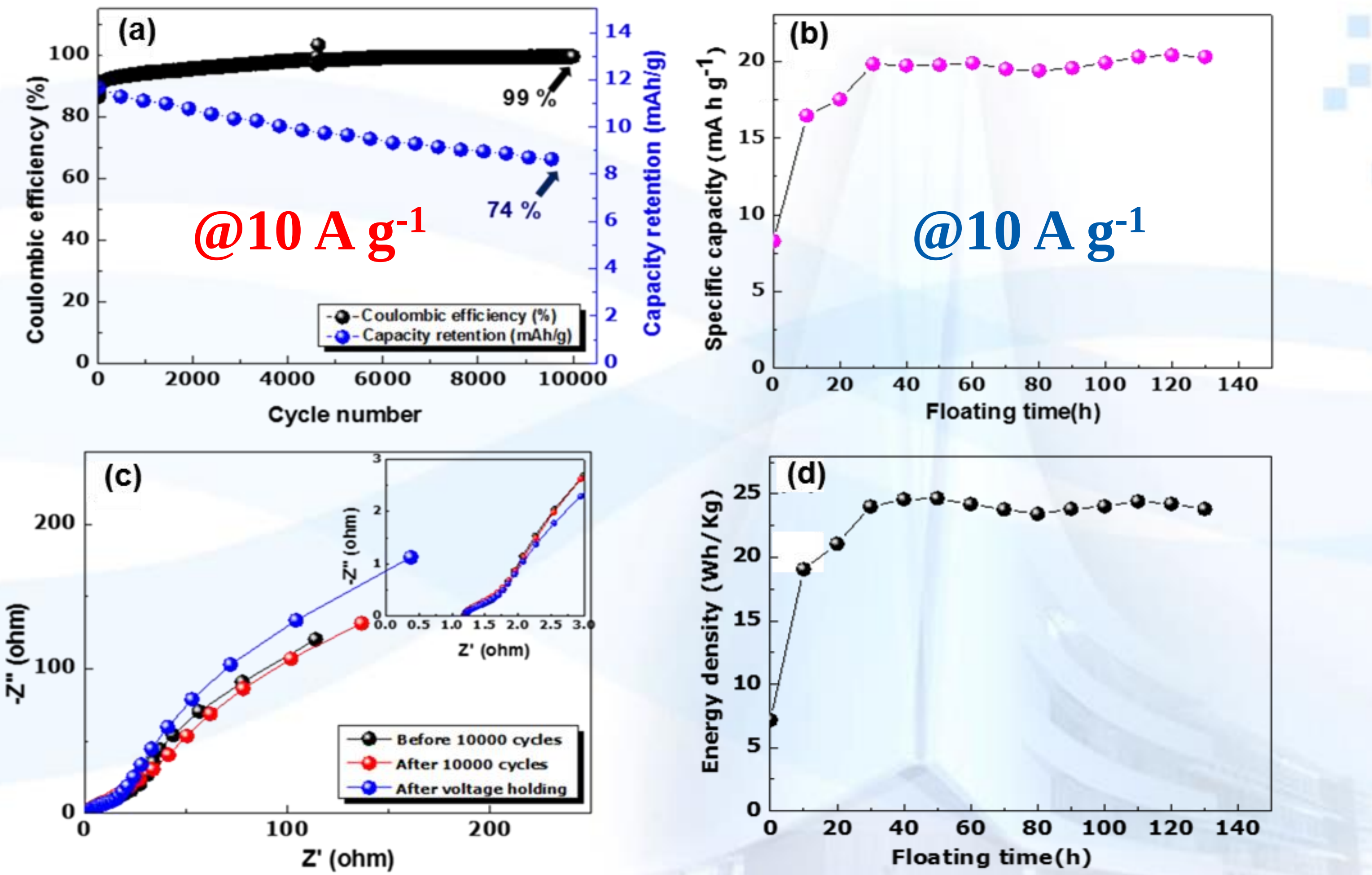
CV & CD (in 6 M KOH electrolyte) for V_2O_5 and V_2O_5/GF



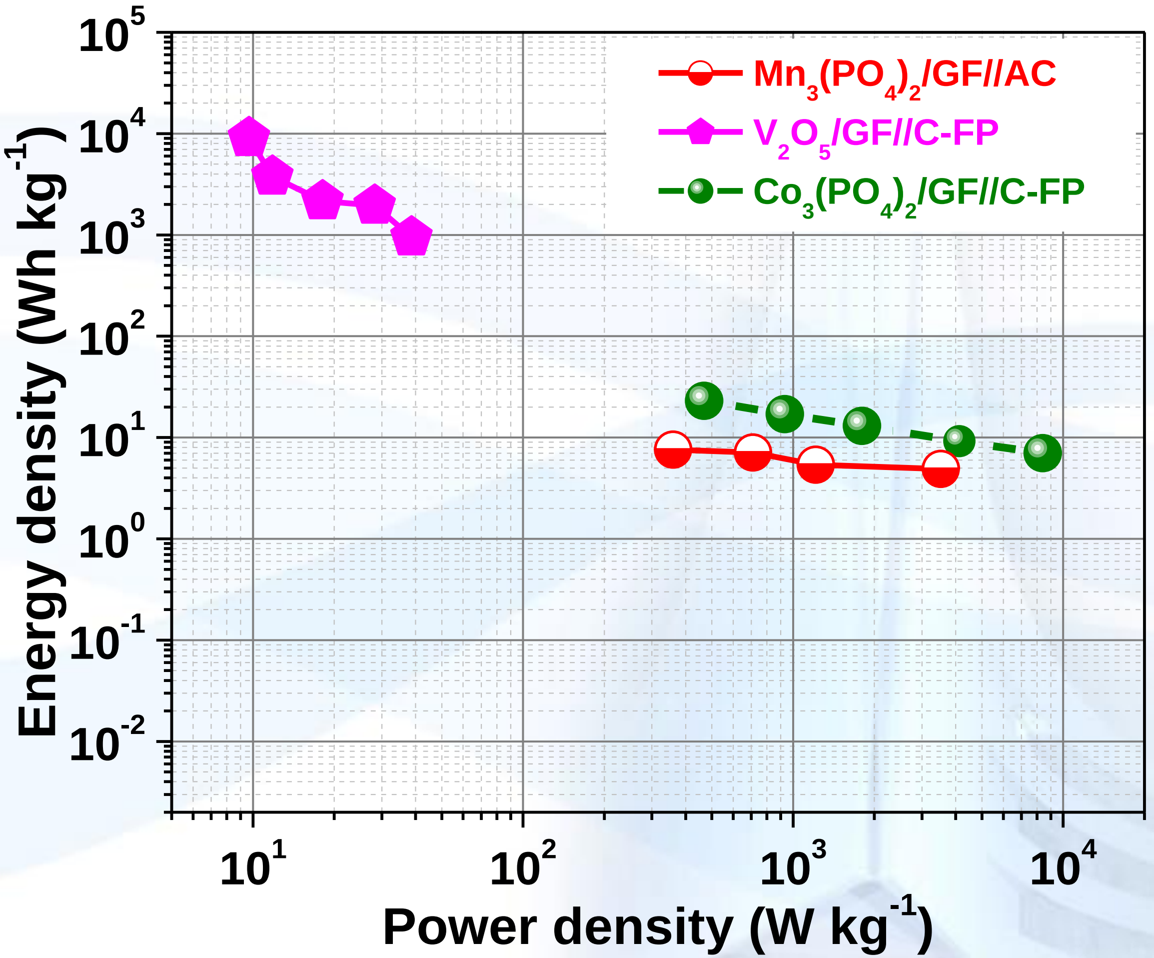
V_2O_5GF//C-FP asymmetric device



Stability and EIS: V_2O_5/GF//C-FP asymmetric device



Ragone Plot: Asymmetric devices



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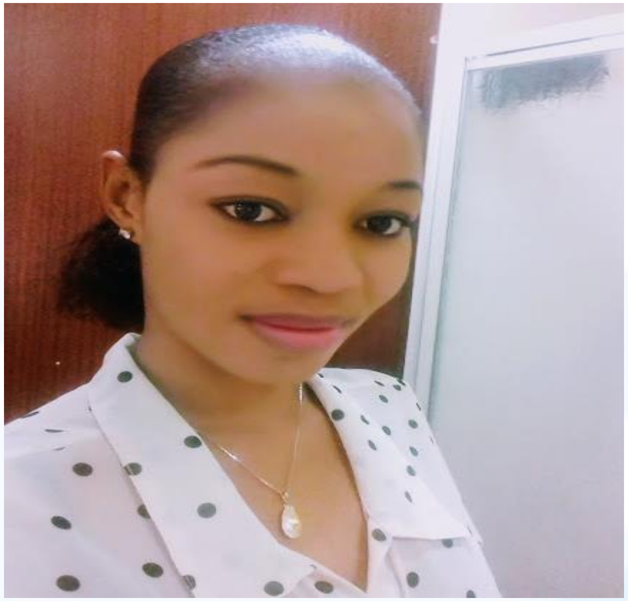
Conclusion

- We have successfully synthesized hybrid ($Mn_3(PO_4)_2$/GF, $Co_3(PO_4)_2$/GF and V_2O_5/GF) materials using hydrothermal approach.
- Activated carbon from coconut shell and carbonization of Fe onto polyaniline (C-FP) were also synthesized
- The electrochemical performance of the metal oxides was improved in three electrode by incorporation of the graphene foam into the metal oxide matrix.
- The hybrid materials have been used as positive electrodes and the carbon-based materials as negative electrodes in asymmetric supercapacitors.
- The results showed that asymmetric supercapacitors based on hybrid materials and carbon-based materials have great potential for energy storage applications.

Acknowledgements



Ndeye Maty Ndiaye, Ph.D Student

Abdulmajid Mirghni, Ph.D student

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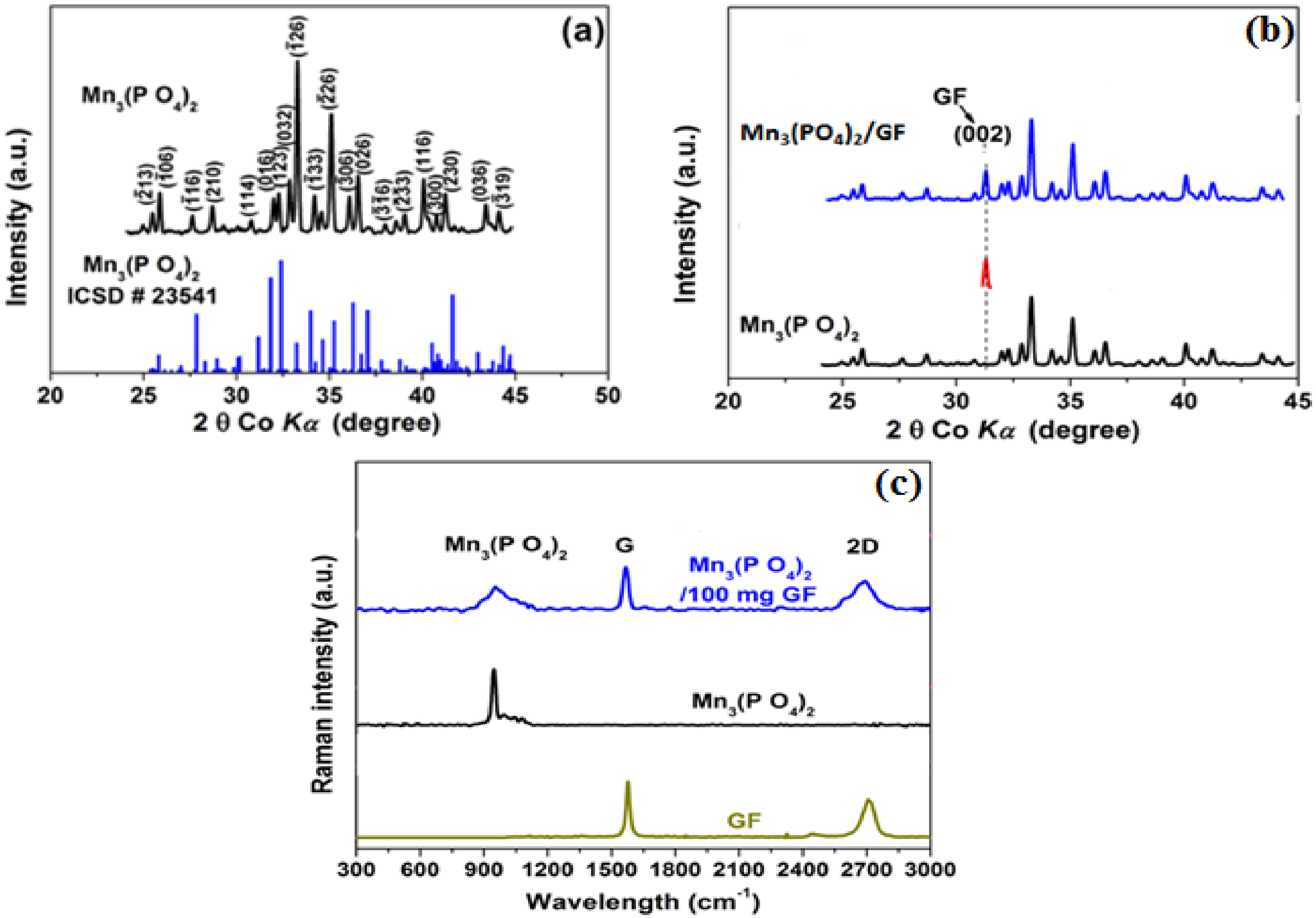
NRF | RISA
National Research Foundation | Research and Innovation Support and Advancement

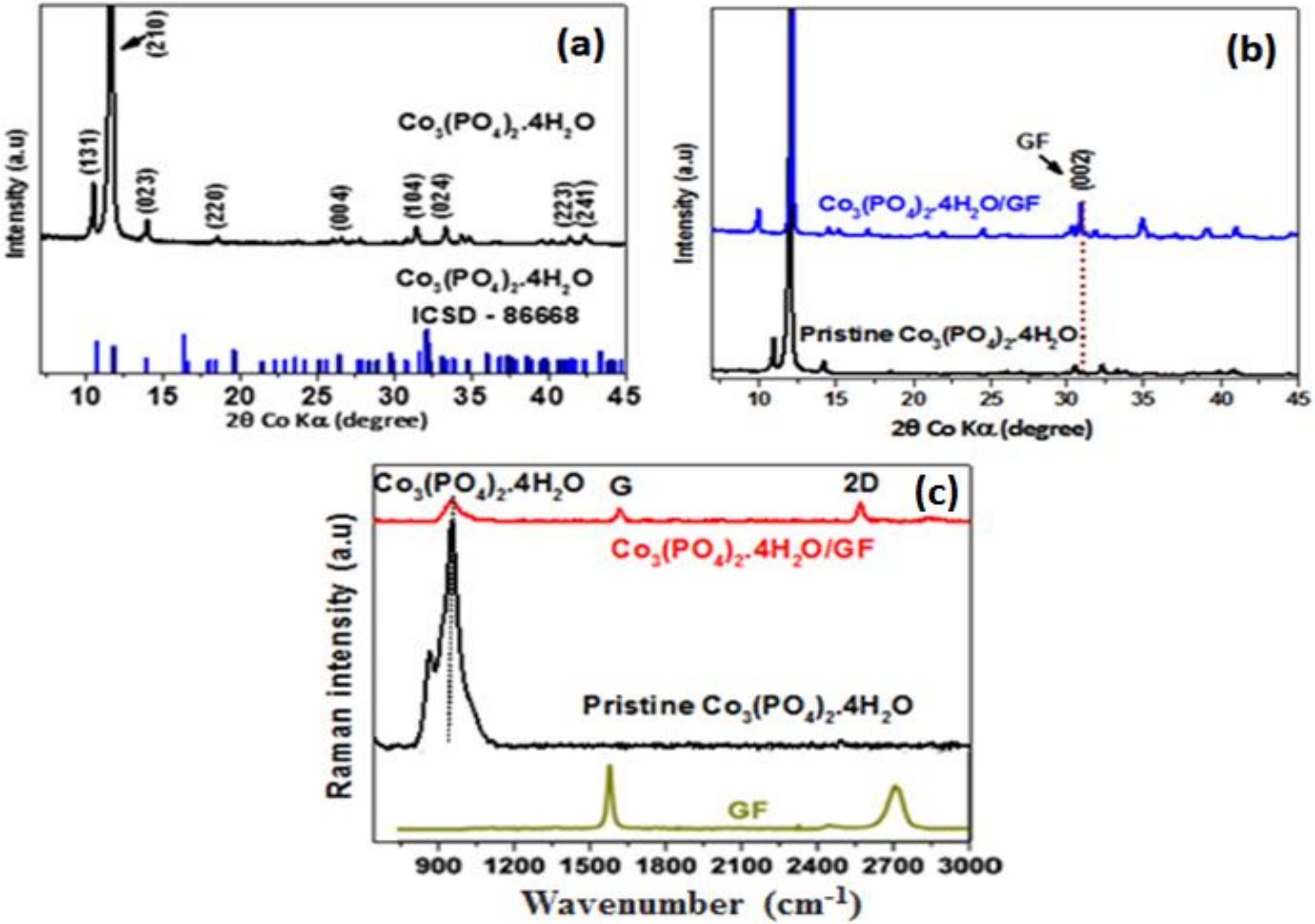
Nano-Carbon group

Thank you

XRD & Raman: $Mn_3(PO_4)_2$ and $Mn_3(PO_4)_2$/GF



XRD & Raman: $Co_3(PO_4)_2.4H_2O$ and $Co_3(PO_4)_2.4H_2O$/GF



XRD, Raman & XPS: V_2O_5 and V_2O_5/GF