Graphene Based Nanocomposite Electrodes for Energy Storage in Supercapacitors

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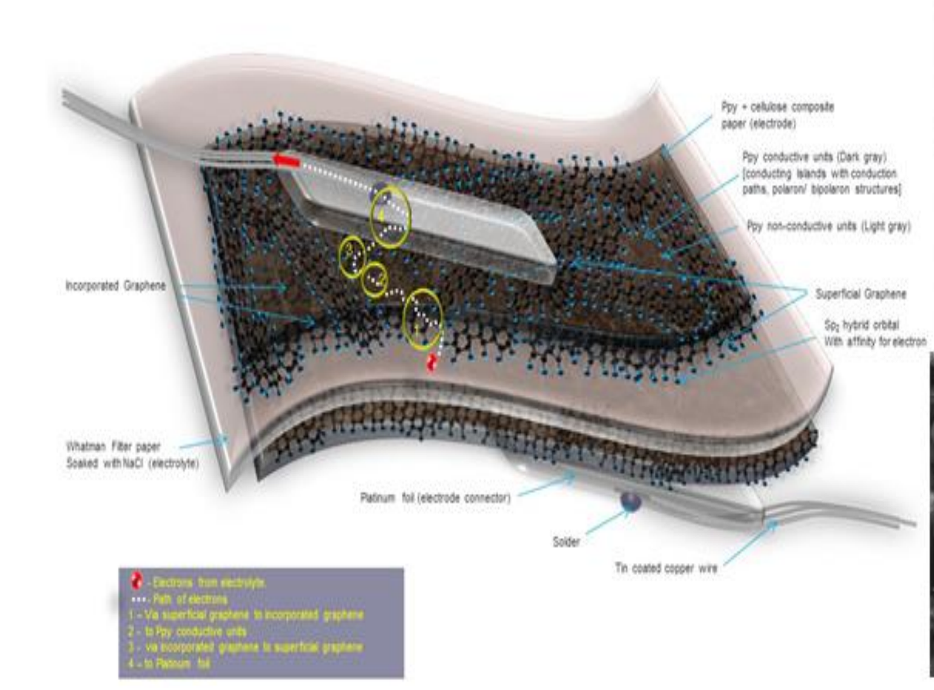
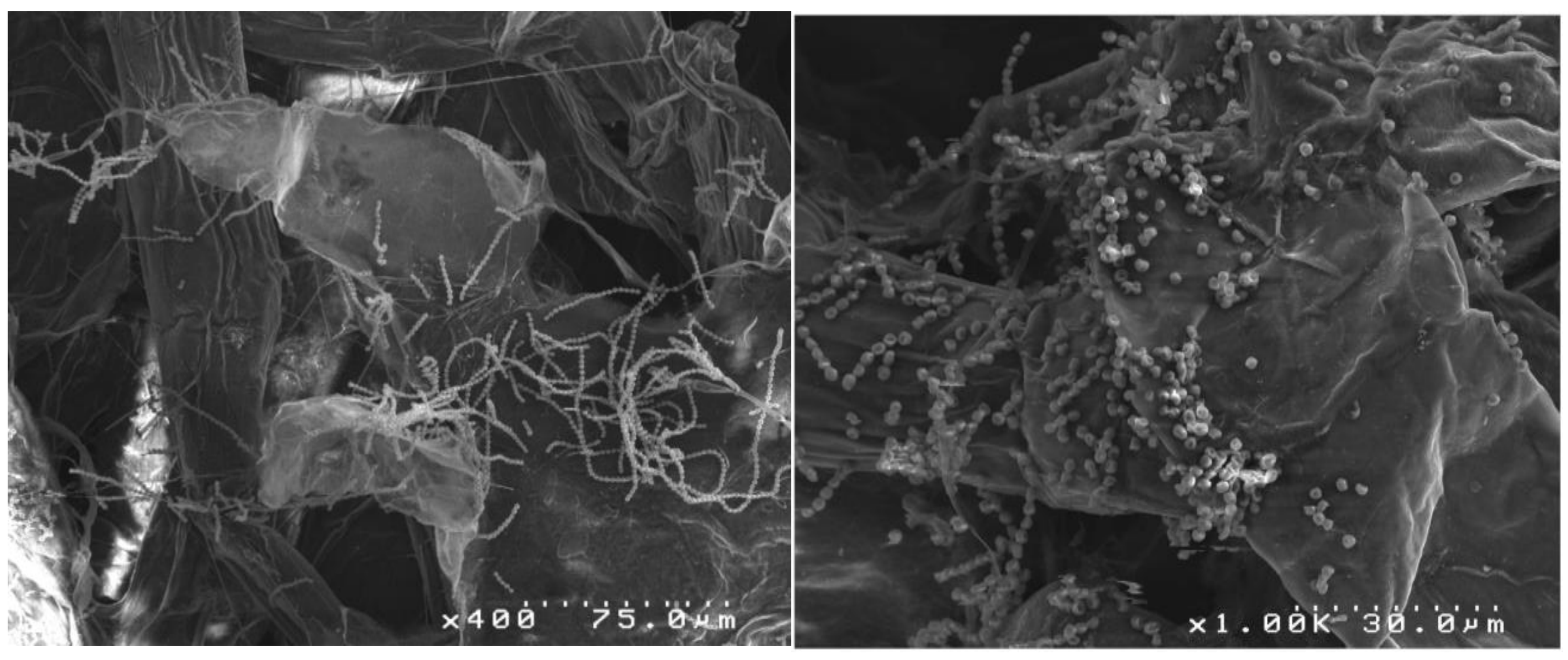
Abstract

There is an unmet need to develop high performance energy storage systems (ESS), capable of storing energy from both renewable and non-renewable sources to meet the current energy crisis and depletion of non-renewable sources. Amongst many available ESS, supercapacitors (ECs) are the most promising because they exhibit a high charge/discharge rate and power density, along with a long cycle life. A novel use of atomically thin carbon allotropes like graphene, carbon nanotubes (CNTs) and electrically conducting polymers (ECPs) such as polypyrrole (PPy) have been studied as high performance conducting electrodes in supercapacitor application. A novel templated sustainable nanocomposite electrode has been fabricated using cellulose extracted from *Cladophora c. aegagropila* algae as a component of the assembled supercapacitor device which later has been transitioned to a unique template-less freestanding nanocomposite supercapacitor electrode[1]. The specific capacitance of polypyrrole-graphene-cellulose nanocomposite as calculated from the cyclic voltammetry curve is 91.5 F g^{-1} at the scan rate 50 m Vs^{-1} in the presence of 1M NaCl electrolyte. The open circuit voltage of the device with polypyrrole -graphene-cellulose electrode was found to be around 225 m V and that of the polypyrrole -cellulose device is only 53 m V without the presence of graphene in the nanocomposite electrode. Understanding the fundamentals by fabricating template nanocomposite electrode led to developing a unique nanocomposite template-less freestanding film which comprises of polypyrrole-graphene-CNT hybrid[2]. Various experiments have been performed using different electrolytes such ascorbic acid, sodium sulfate and sulfuric acid in different scan rates. The specific capacitance of polypyrrole-graphene-CNT nanocomposite with 0.1 wt% of graphene-CNT, as calculated from cyclic voltammetry curve is 450 F g^{-1} at the scan rate 5 m V s^{-1}. For the first time a nanofibrous membrane has been developed as a separator which acts as an electrolyte reservoir and ionic diffusion membrane. The performance of the fabricated supercapacitor device has been analyzed using a multimeter and compared with a conventional alkaline (1.5 V) battery. Lighting up of 2.2 V light emitting diode has been demonstrated using the fabricated supercapacitor.

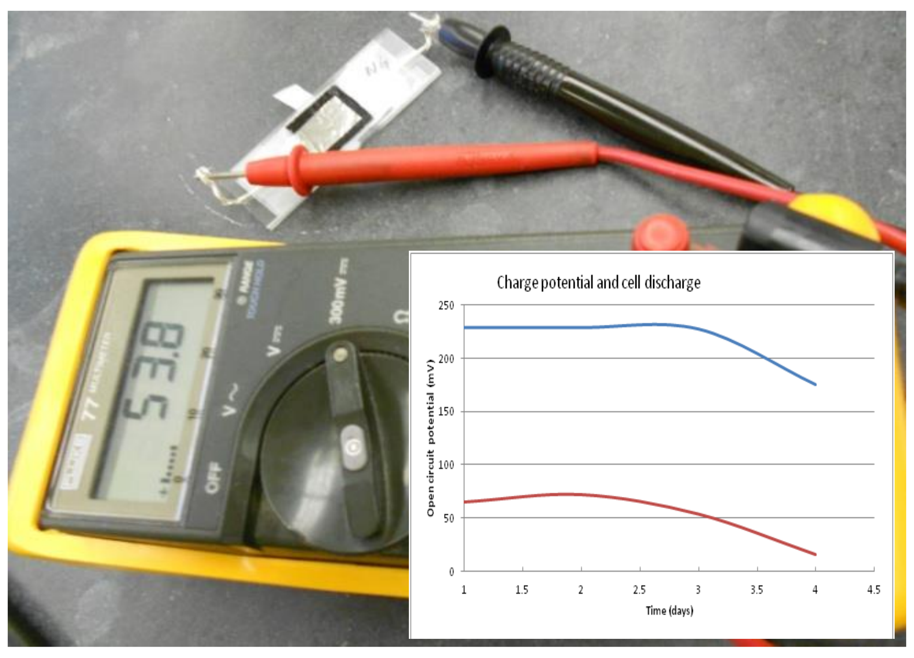
Template Electrode

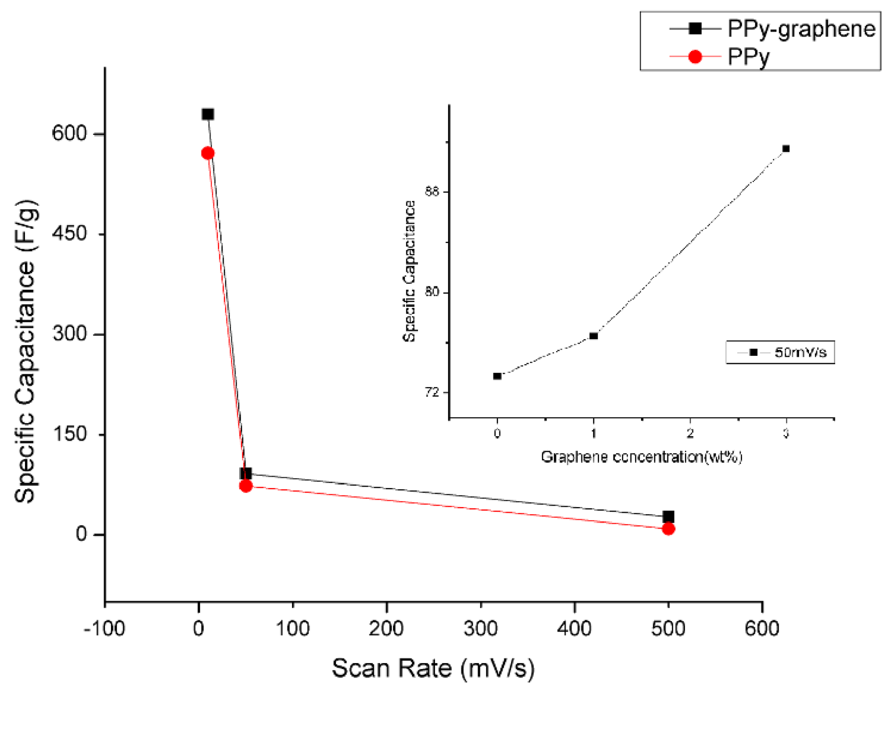




Scanning electron microscope images C) PPy-cellulose showing "necklace" like beaded morphology, D) PPy-graphene-cellulose nanocomposite where long chains of beads starts to break. (Inset (A,B)Optical images of nanocomposite made of cellulose extracted from marine algae, A) PPy-cellulose, B)PPy-graphene-cellulose

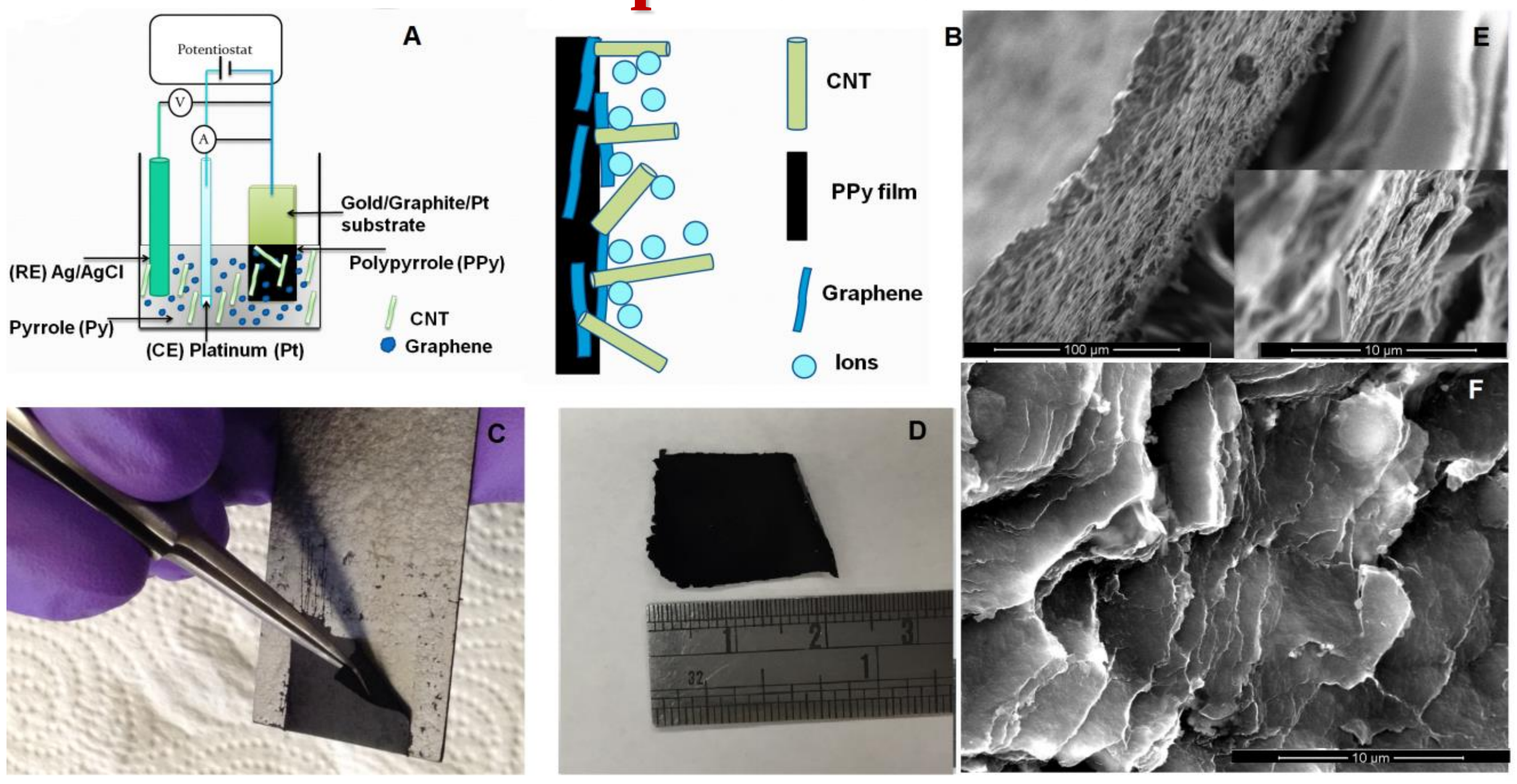
Multimeter connection with the supercapacitor device and voltage readings over 4 days



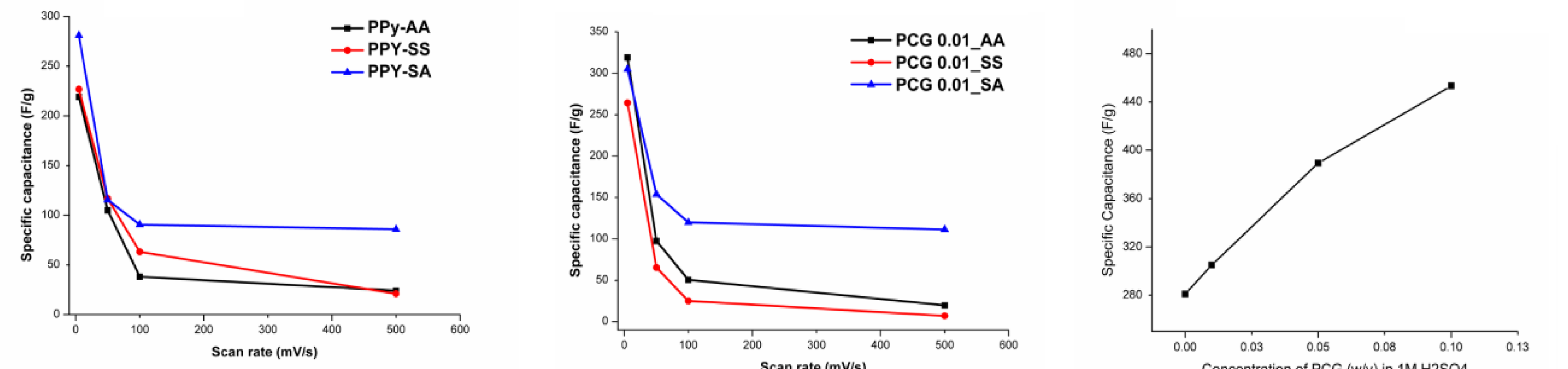


Variation of specific capacitance of PPy-cellulose and PPy-graphene-cellulose nanocomposite as a function of scan rate. (Inset: Specific capacitance change as function of graphene concentration at scan rate of 50 mVs^{-1})

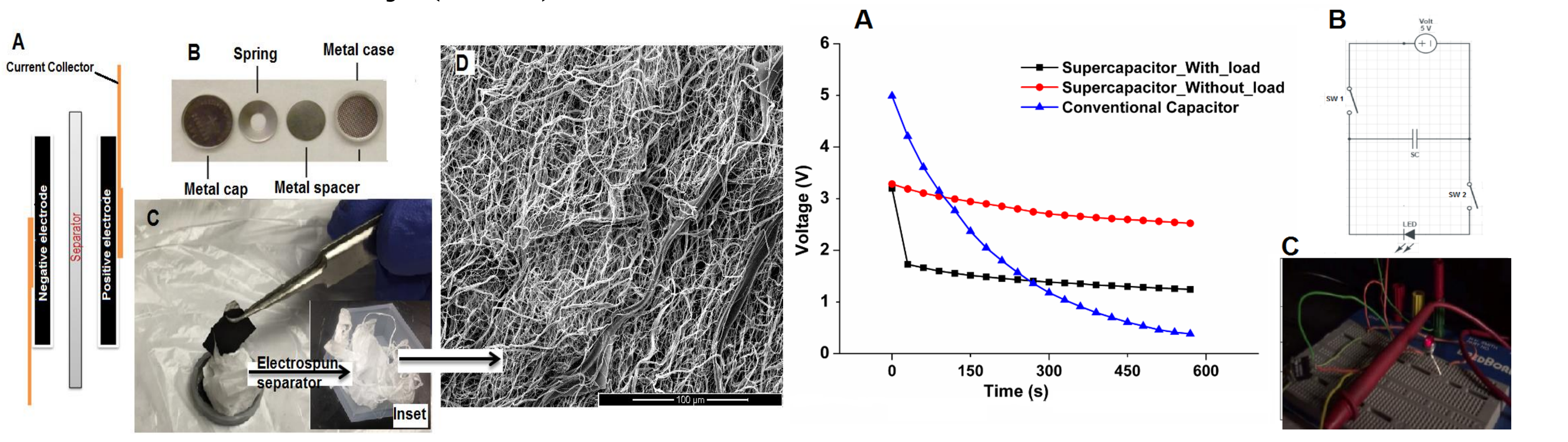
Template-less Electrode



A) schematic representing the fabrication process of the nanocomposite electrodes, B) schematic illustrating unique hybrid formation of the nanocomposite with graphene and CNT embedded within PPy matrix, C, D) Optical image of the actual freestanding on the graphite substrate with approx. dimension of 2cm X 2cm in area, E) possibility of selectively depositing these conductive electrodes on existing circuit making microelectrode based supercapacitor.



Specific capacitance w.r.t scan rate (mV/s) in three different electrolytes for A) control PPy, B) PCG nanocomposite with 0.01 wt % concentrations, C) specific capacitance values with increase in the concentration of graphene and CNT in the PPy (PCG)



A) schematic illustration of the entire device fabrication layout, B &C) actual device assembly, C (inset) a novel separator fabricated using electrospinning of polycaprolactone (PCL) nanofibers, D) SEM micrograph of randomly oriented PCL nanofibers used as a separator. Performance of actual supercapacitor device in comparison with supercapacitor

References

1) A. Aphale, A. Chattopadhyay, K. Mahakalkar, and P. K. Patra, "Synthesis and Electrochemical Analysis of Algae Cellulose-Polypyrrole-Graphene Nanocomposite for Supercapacitor Electrode," J. Nanosci. Nanotechnol., vol. 15, pp. 6225–6229, 2015
2) Ashish Aphale, Kapil Mahakalkar, Isaac Macwan, Ishita Mukerji, Paris Cox, Manoj Mahapatra, Prabhakar Singh, Pulickel Ajayan and Prabir Patra, "Fabrication and Experimental Analysis of Axially Oriented Nanofibers", Journal of Nanoscience and Nanotechnology, 2015 (Accepted)