Silicon doped Microporous Carbon Derived from Natural Fibers for Efficient Supercapacitor Device

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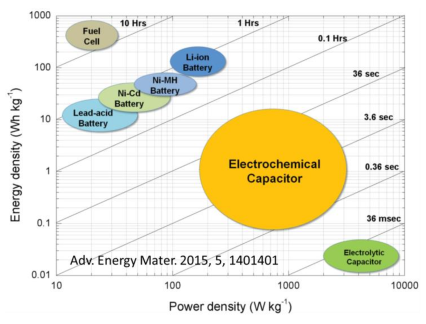
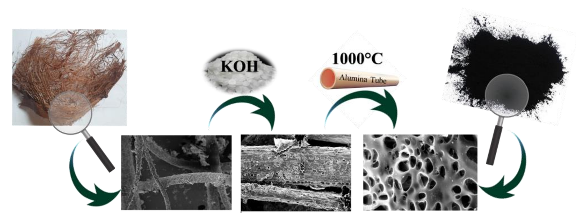
Introduction :

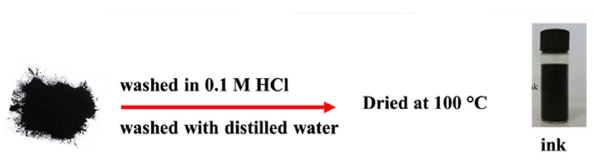
- The long term emission consequences of fossil fuel combustion posed a clear motivation towards the development of sustainable energy systems.
- Effective energy storage technologies are indeed essential for sustainable, steady, and reliable supply of energy.
- Supercapacitors (SCs) and batteries are energy storage devices with complimentary characteristics.
- While SCs can provide on-demand high power density, batteries can provide high energy density.
- Therefore, the challenging task is to improve the energy density of SCs without sacrificing their power density, which would make SCs the energy storage devices of choice.
- This could only be possible via the proper engineering of the electrode materials.

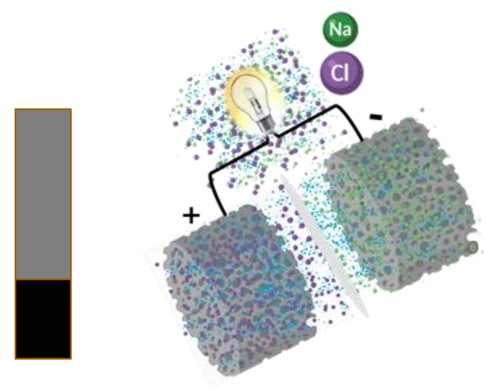


Methods:

- The amorphous carbon derived from palm fiber was synthesized in two steps. Frist, the fibers were mixed with KOH in 150 ml distilled water and stirred for 2 hrs i.e., **chemical activation**.
- The fibers were then collected and dried overnight at 100 °C. Second, carbonization was performed at 1000 °C in Ar atmosphere for 2 hrs i.e., **thermal activation**.
- The Activated amorphous carbon powder labelled Am-C was then washed in 0.1 M HCl.
- The diluted ink was then coated onto graphite sheet (current collector) by drop casting with a micropipette and then left to dry overnight at 100 °C.
- All measurements were performed in nitrogen-saturated 1.0 M NaCl at room temperature.



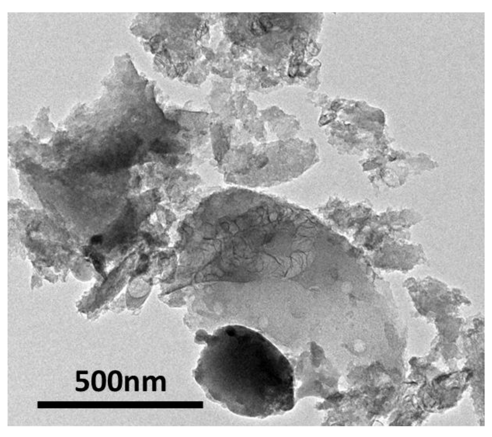


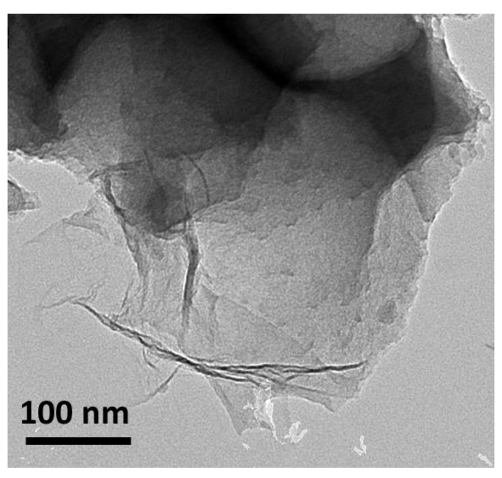


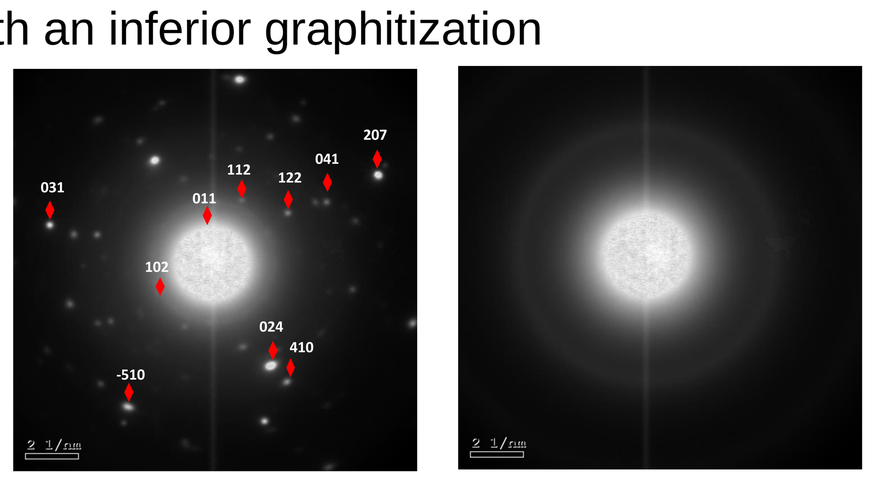
Material Characterizations

TEM

- The HR-TEM image of the carbonized Am-C powder shows graphene-like structure, confirming the effective thermal carbonization process.
- Interestingly, the selected area electron diffraction (SAED) pattern of Am-C, shows some crystalline planes of Cellulose Iβ along with amorphous carbon planes, suggesting the amorphous nature of the fabricated Am-C with an inferior graphitization

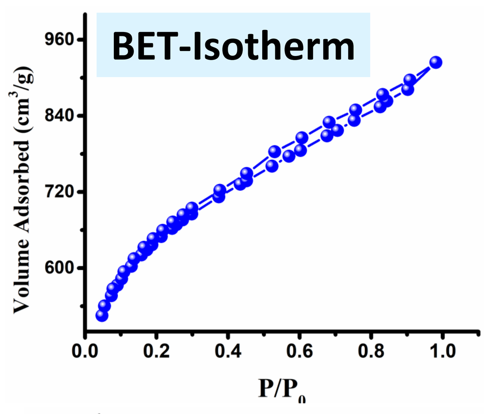


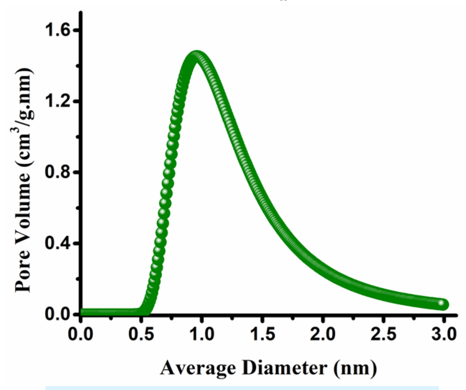




BET

- The isotherm reveals mixed features of types I&IV isotherms with noticeable H3 hysteresis loop starting at P/Po of 0.45.
- The calculated surface area based on the BET model is 2000 m^2/g with a total pore volume of 1.35 cm^3/g.
- Note that the obtained surface area is much higher than that reported for any carbon driven cellulosic fiber reported so far.
- The pore radius of range from 0.5 to 3 nm (mainly at 1.2 nm), indicating the presence of both micropores and small mesopores.
- The micropores are very essential to ensure maximum power density.

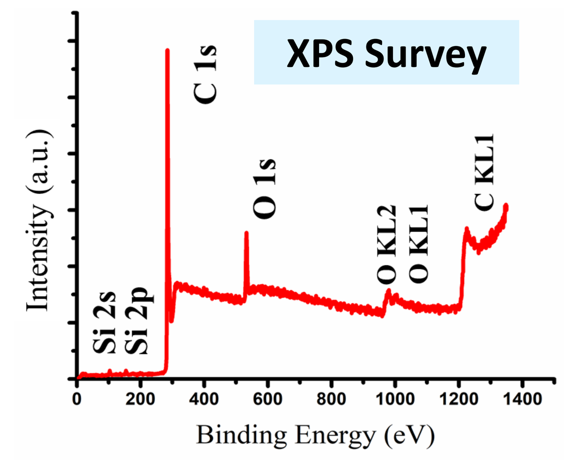


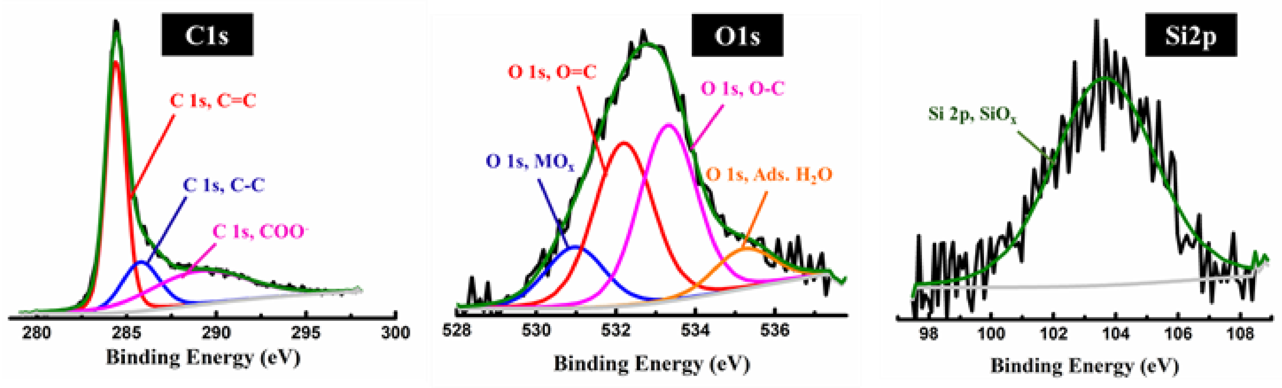


Pore Distribution

XPS

- The XPS survey profile displays four peaks ascribed for carbon 1s, oxygen 1s, and silicon 2s and 2p.
- The C 1s peak deconvolution shows three distinct peaks ofsp2 (C = C), sp3 (C-C), and carboxylate ion.
- Four O 1s deconvoluted peaks are obtained, assigned to oxygen present on metal oxide, C = O, C-O, and the chemisorbed/intercalated adsorbed water molecules.
- The CNPT- silicon is present as silicon oxide, highlighted from the high-resolution deconvolution of the Si 2p peak.

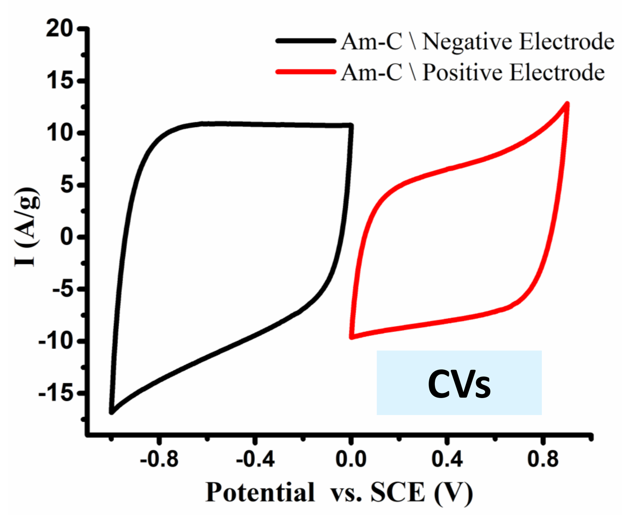




Results:

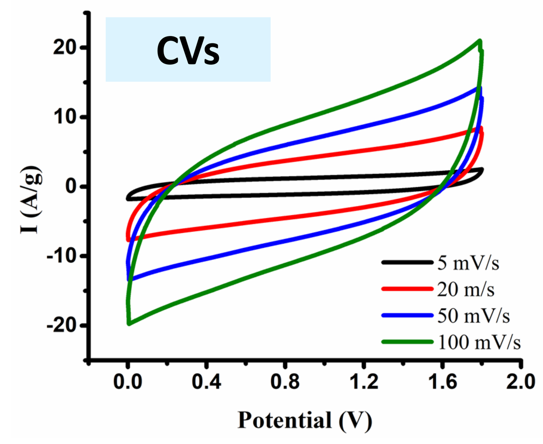
Half Cell Measurements

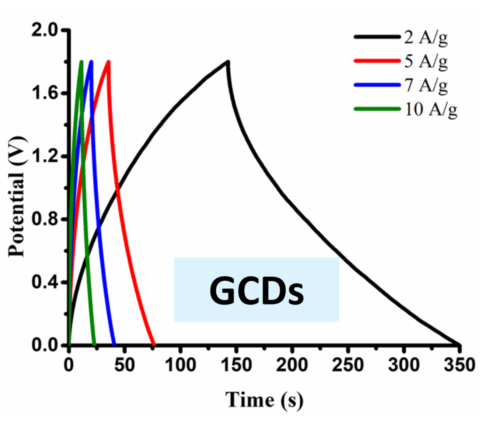
- Am-C material has been tested as a positive and negative electrode in a three-electrode electrochemical cell.
- The electrode possesses a large potential window of 1.9 V as 0.9 V and -1 V for the positive and negative electrodes, respectively.

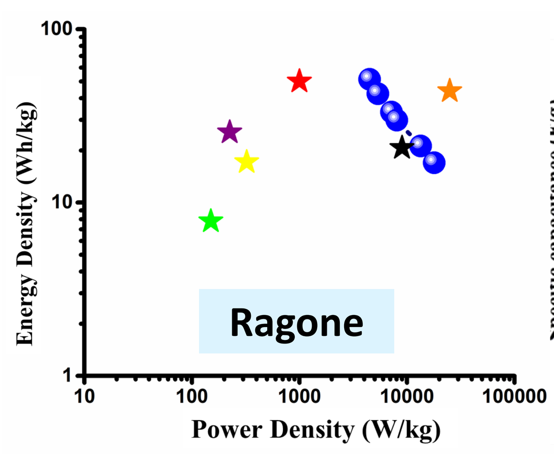


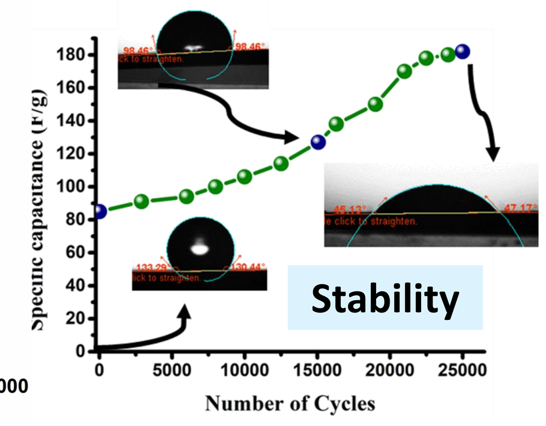
Full Device Measurements

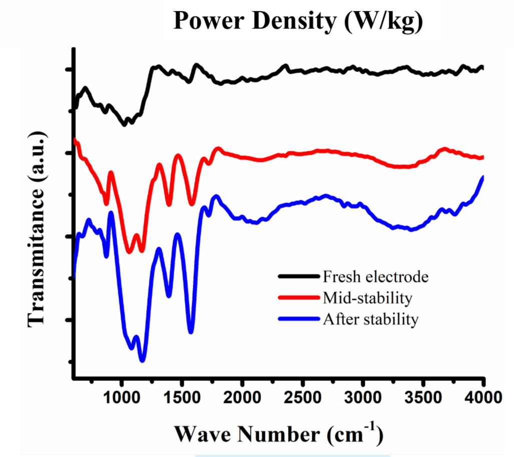
- The symmetric Am-C//Am-C supercapacitor device tested in 1.0 M NaCl aqueous electrolyte showed fairly high specific capacitances of 201 F/g at 5 mV/s and 337 F/g at 1 A/g.
- The device exhibits a stable performance across a potential window of 1.8 V with ultra- high energy and power densities of 51.4 Wh/kg at 4.5 kW/kg and 16.95 Wh/kg at 18 kW/kg.
- The device showed extraordinary increasing capacitive behavior upon cycling at 10 A/g for over 25,0000 cycles.
- The exceptional device performance could be ascribed to the electrochemical graphitization during long-term cycling together with the enhanced wettability as confirmed via Raman, FTIR, and contact angle measurements.



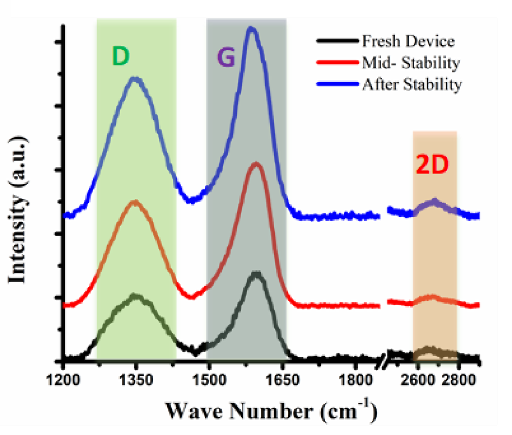








FTIR



Raman

Conclusion

- Indeed, natural precursors of carbon show exceptional and attractive behavior in terms of capacitance, long term cycle life, and energy and power density.
- Thus, optimizing such material systems would achieve a record in market commercialization of high rate performance supercapacitors..

References

- Dresselhaus, M. S.; Thomas, I. L. Nature 2001, 414 (6861), 332–337
- Zhao, X.; Johnston, C.; Grant, P. S. Journal of Materials Chemistry 2009, 19 (46), 8755.
- Sayed, D. M.; El-Deab, M. S.; Elshakre, M. E.; Allam, N. K. J. Phys. Chem. C 2020, 124 (13), 7007–7015.

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