Turbostratic Carbon Nano Onion for high-power density V redox flow battery

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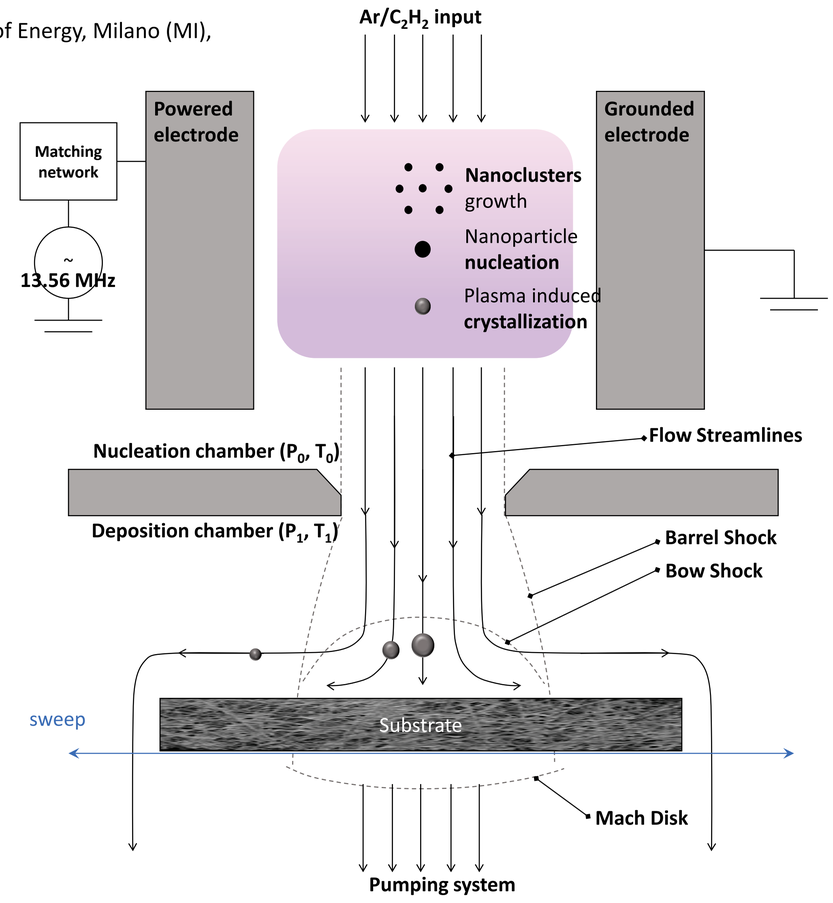
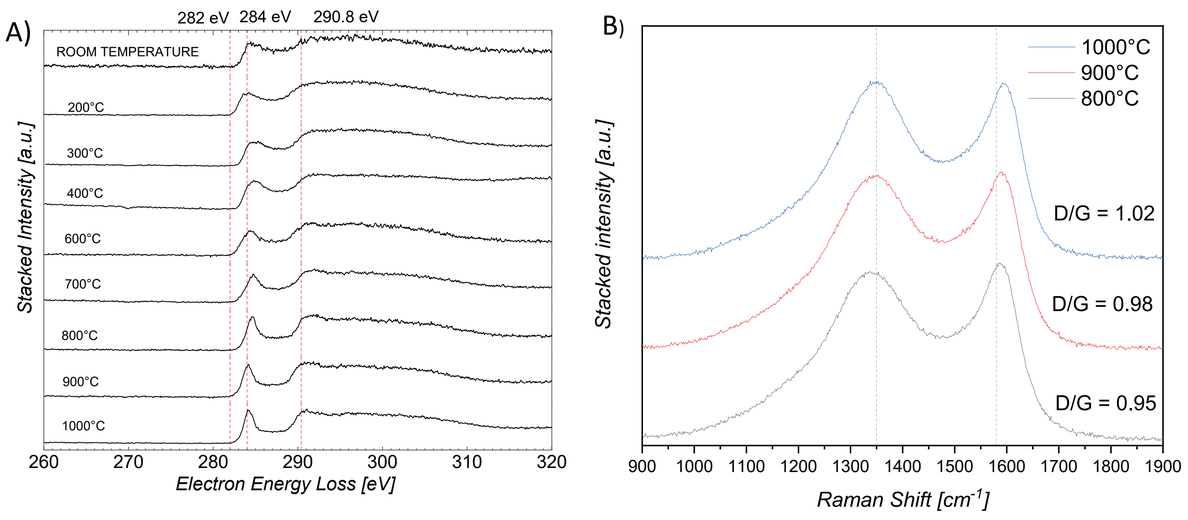
1. Material Fabrication by Plasma Enhanced Nanoparticle Jet Deposition

1. **Capacitively coupled plasma** induces acetylene cracking and **in-flight polymerization**
2. An aerosol of **spherical hydrogenetated Carbon nanoparticles**, **HCNPs,** forms and grows in the plasma volume
3. The aerosol is **quenched by a supersonic expansion** in a low pressure chamber
4. **Ballistic impact** control the deposition of HCNPs onto the substrate
5. **Thermal treatment** leads to the formation of **highly defective turbostratic carbon nano-onions (TCNOs)**

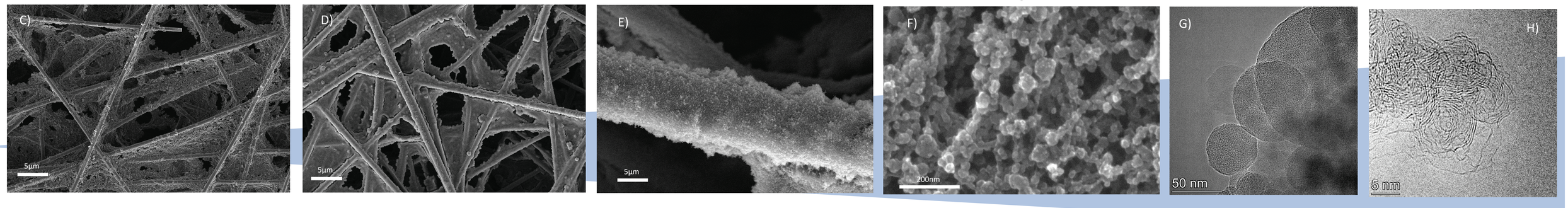


2. Annealing Treatment & Material characterization



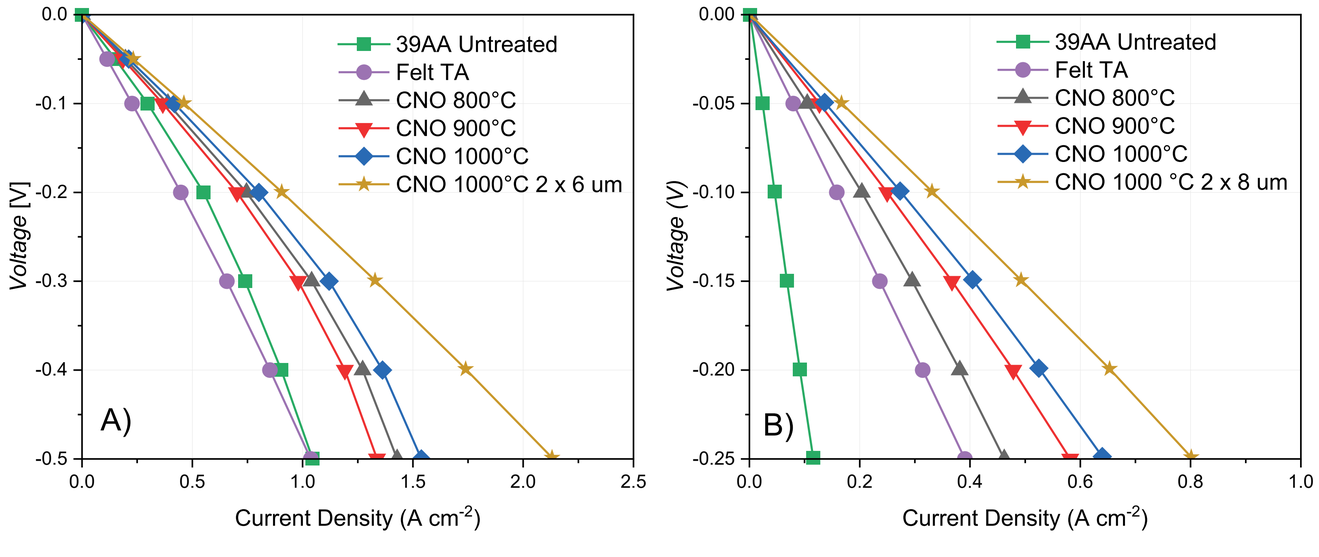
	Deposited	800°C	900°C	1000°C
SSA ($m^2\ g^{-1}$)	426	425	400	310

- **A) In-situ Electron Energy Loss Spectroscopy (EELS)**: graphitization starts at 600°C and TCNO forms above 1000 °C. Specific surface area from 426 to 310 m^2/g with T.
- **B) Raman:** from HCNP to disordered C nanostructures with annealing temperature
- **C-F) SEM** micrographs of pristine and **TCNO functionalized C paper electrode**
- **G-H) High-Resolution Transmission Electron Microscopy** pre and post annealing at 1000 °C showing the transition from HCNP to TCNO

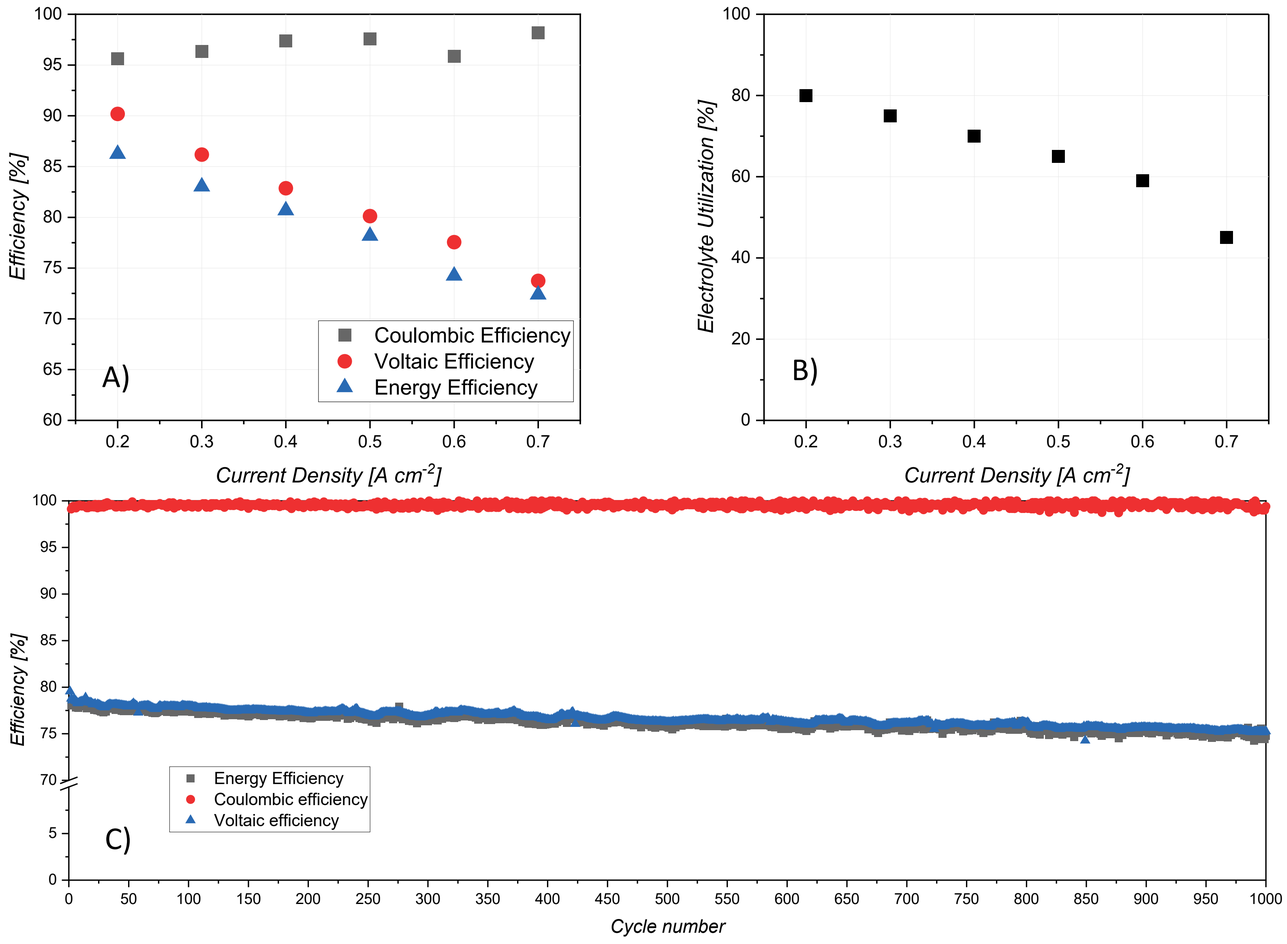


3. Electrochemical Properties

- **Test in symmetric cell** at State Of Charge **(SOC) 50%** for positive and negative
- Carbon paper with TCNO annealed at 1000 °C is the best performer
- A) maximum current density of **1.54 A cm^{-2}** @ **-0.5 V** for V^{4+}/V^{5+} (1000°C)
- B) maximum current density of **0.64 A cm^{-2}** @ **-0.25 V** for V^{2+}/V^{3+} (1000°C)
- **6 µm and 8 µm are the optimal thicknesses for V^{4+}/V^{5+} and V^{2+}/V^{3+}** respectively
- stacking **two CP-TCNO electrodes** improves kinetic limited reactions at both positive and negative electrode (especially for V^{2+}/V^{3+})



4. Full cell performance & stability



- **Energy Efficiency of 80.7 %** at **400 mA cm^{-2}** current density.
- **Electrolyte utilization of 70.0 %** at **400 mA cm^{-2}** current density.
- **Degradation of 0.004 % per cycle** in energy efficiency.

Performance cell set-up :
4 cm^2, Interdigitated flow field, Nafion 211®, 2 x electrodes / side, 1.1M V in 5M H_2SO_4, 40 mL min^{-1} flux velocity, 50 mL volume, CUT-OFF: 1.7V / 1.0 V

Stability cell set-up :
4 cm^2, Interdigitated flow field, Nafion 212®, 2 x electrodes / side, 1.1M V in 5M H_2SO_4, 40 mL min^{-1} flux velocity, 20 mL volume, CUT-OFF: 1.7V / 1.0 V

5. Conclusion and impact

Turbostratic Carbon Nano-Onions-CP electrodes disrupt the state of art in Vanadium Redox Flow Battery allowing high current density operations and improving electrolyte utilization