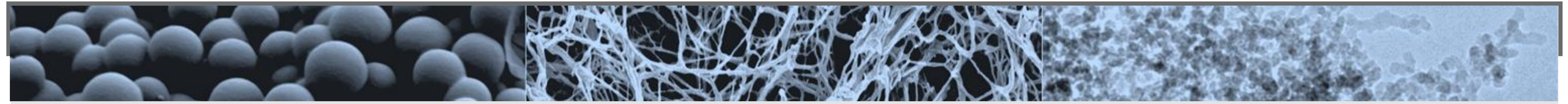
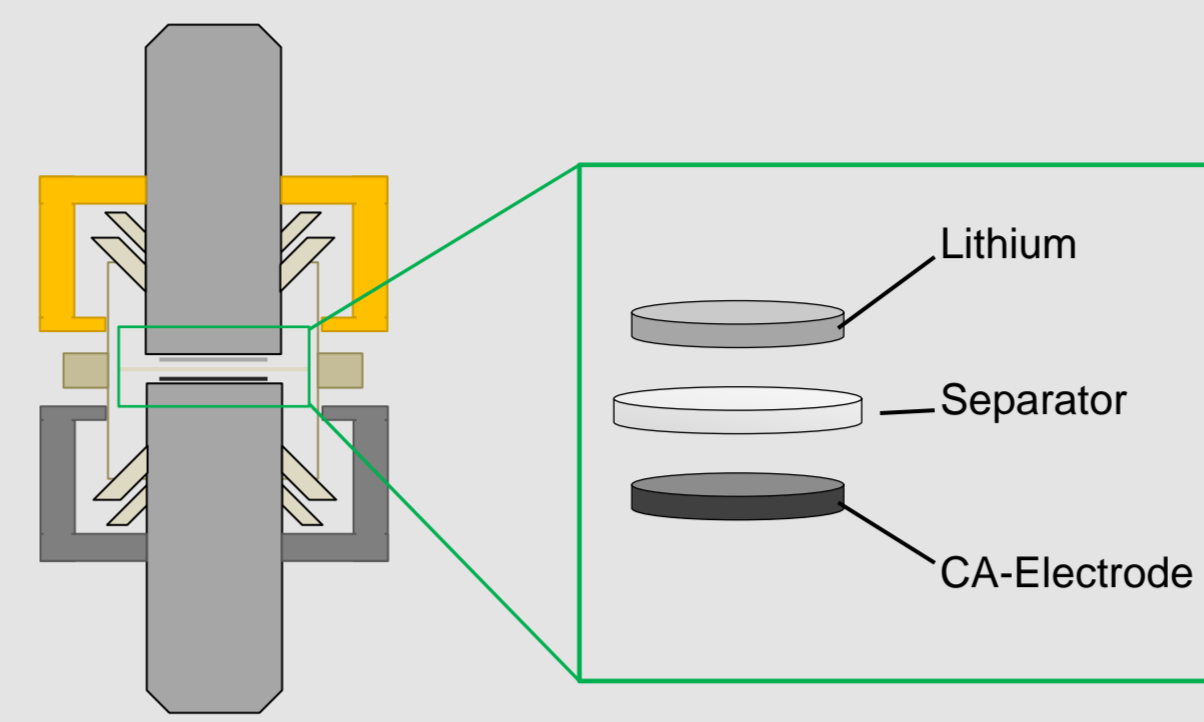


Highly microporous carbon aerogels encapsulating sulfur as cathodes for lithium-sulfur batteries

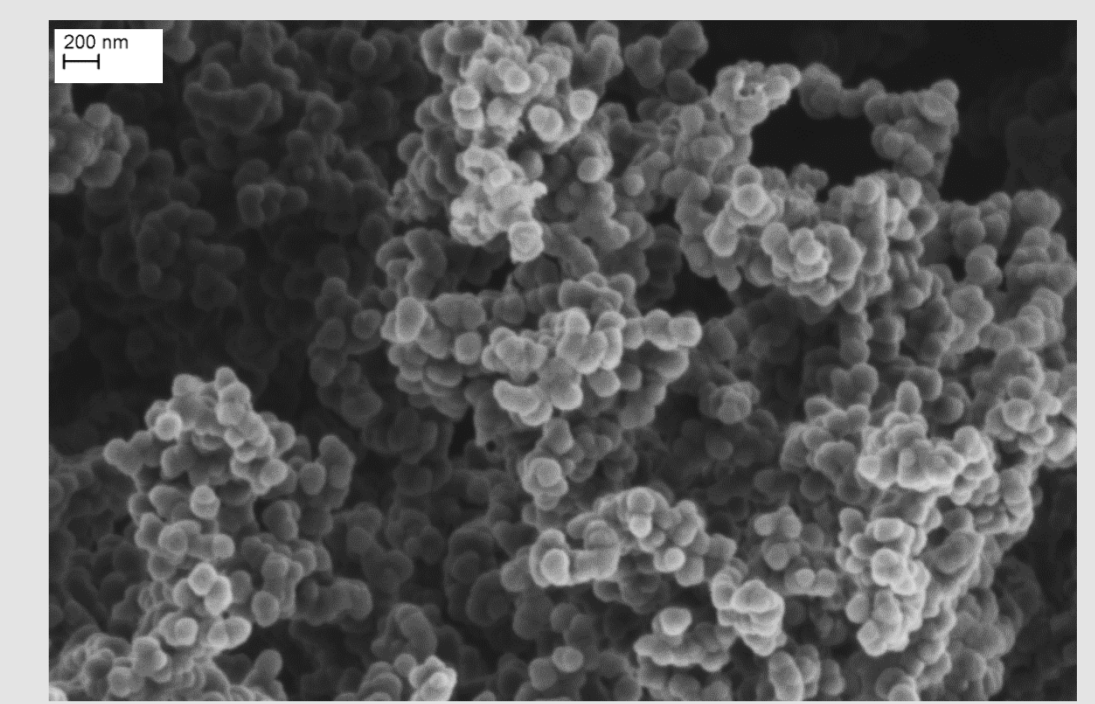


INTRODUCTION

Carbon aerogels (CAs) are highly promising materials as matrices for sulfur to act as cathodes in metal-sulfur batteries. Resulting from organic resorcinol-formaldehyde aerogels, CAs exhibit highly porous structures with porosities up to 97%, high surface areas of about 500-3500 m²/g, large pore volumes of about 0.1-2.5 cm³/g, and significant electrical conductivities of about 80-150 S/m. Additional important advantages of CAs are their tunable porous structures and pore size distributions. Their microstructures are adjustable during the synthesis of organic aerogels and their subsequent carbonization. Moreover, the elastic compressibility of CAs prevents the formation of cracks as a result of changes to the sulfur volume.

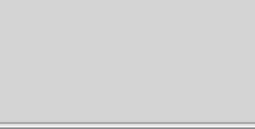
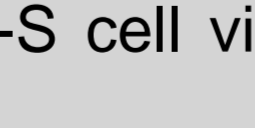
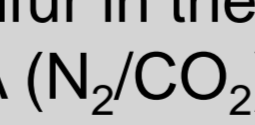
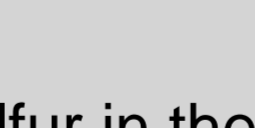
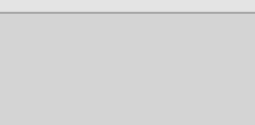
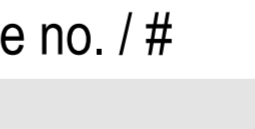
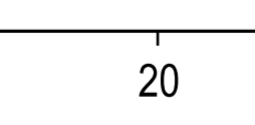
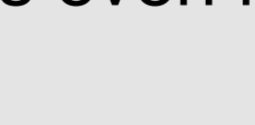
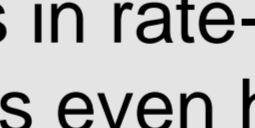
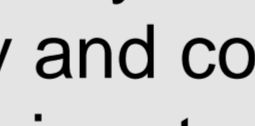
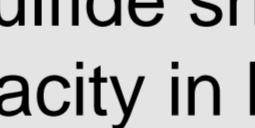
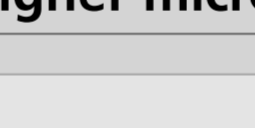
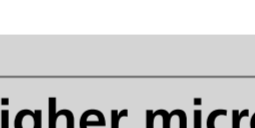
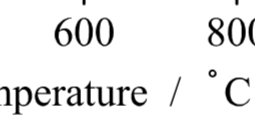
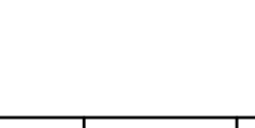
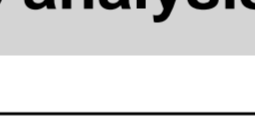
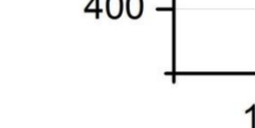
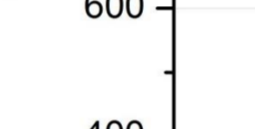
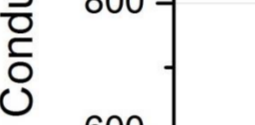
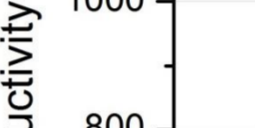
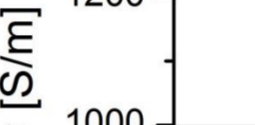
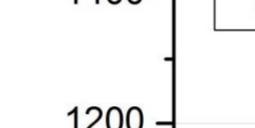
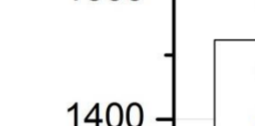
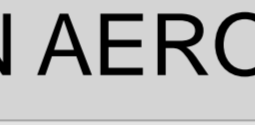
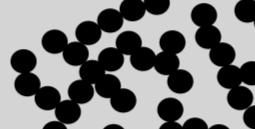
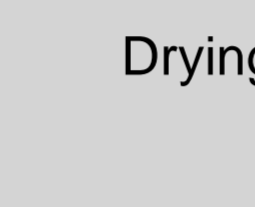
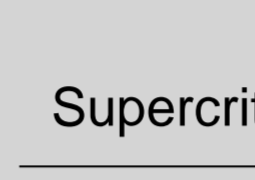
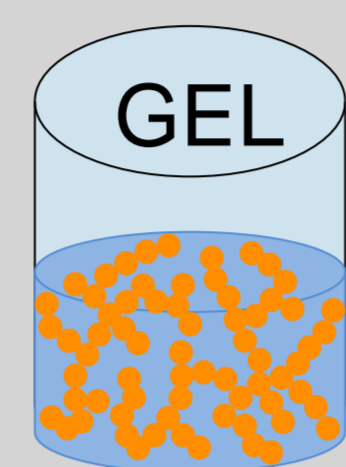
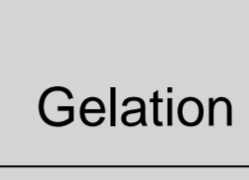
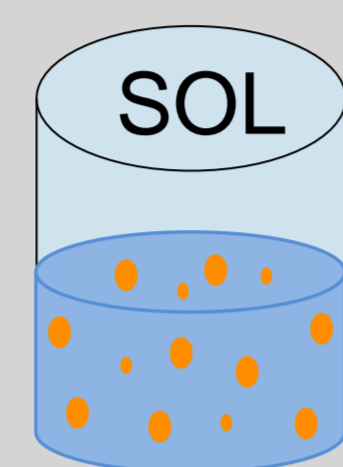
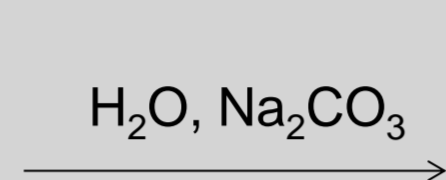
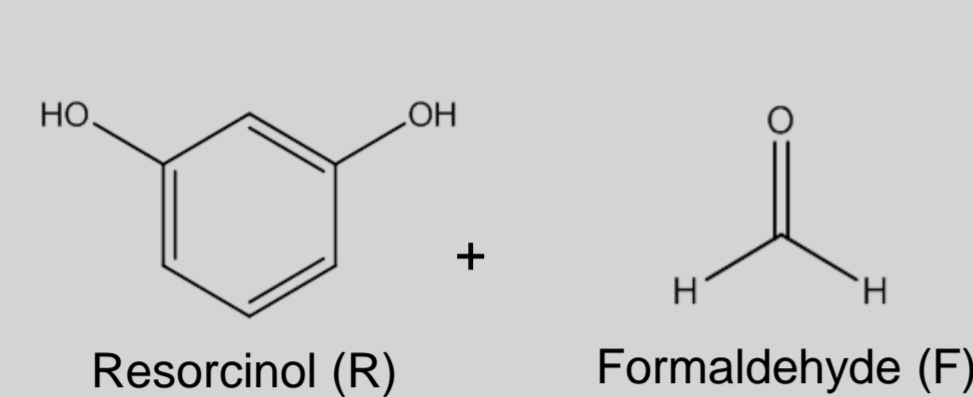


Testing battery cell



Microstructure of carbon aerogel

SYNTHESIS



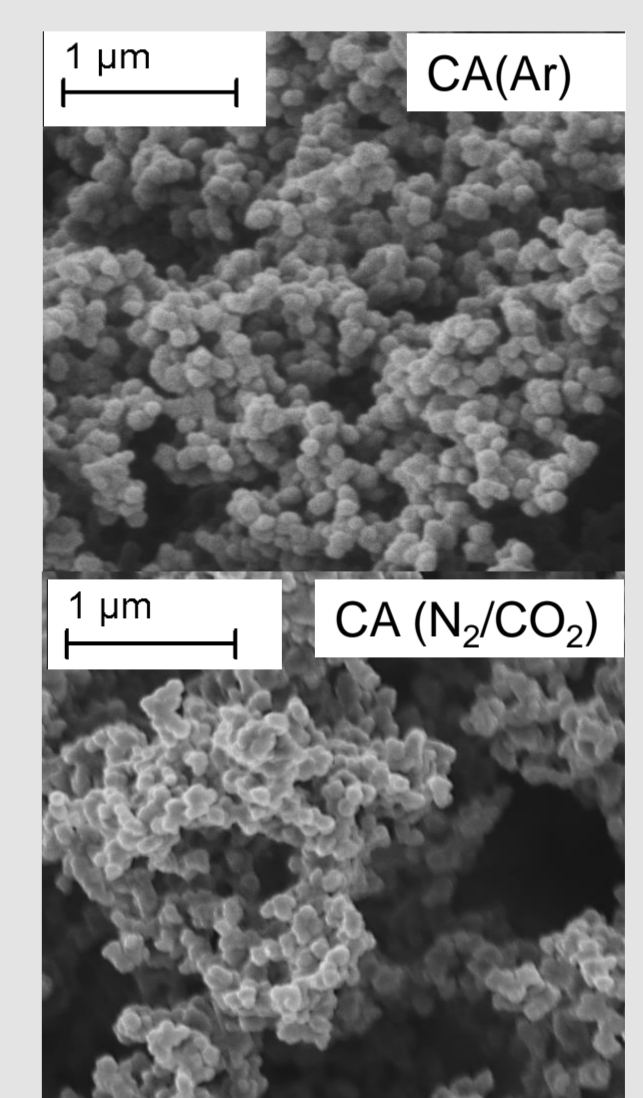
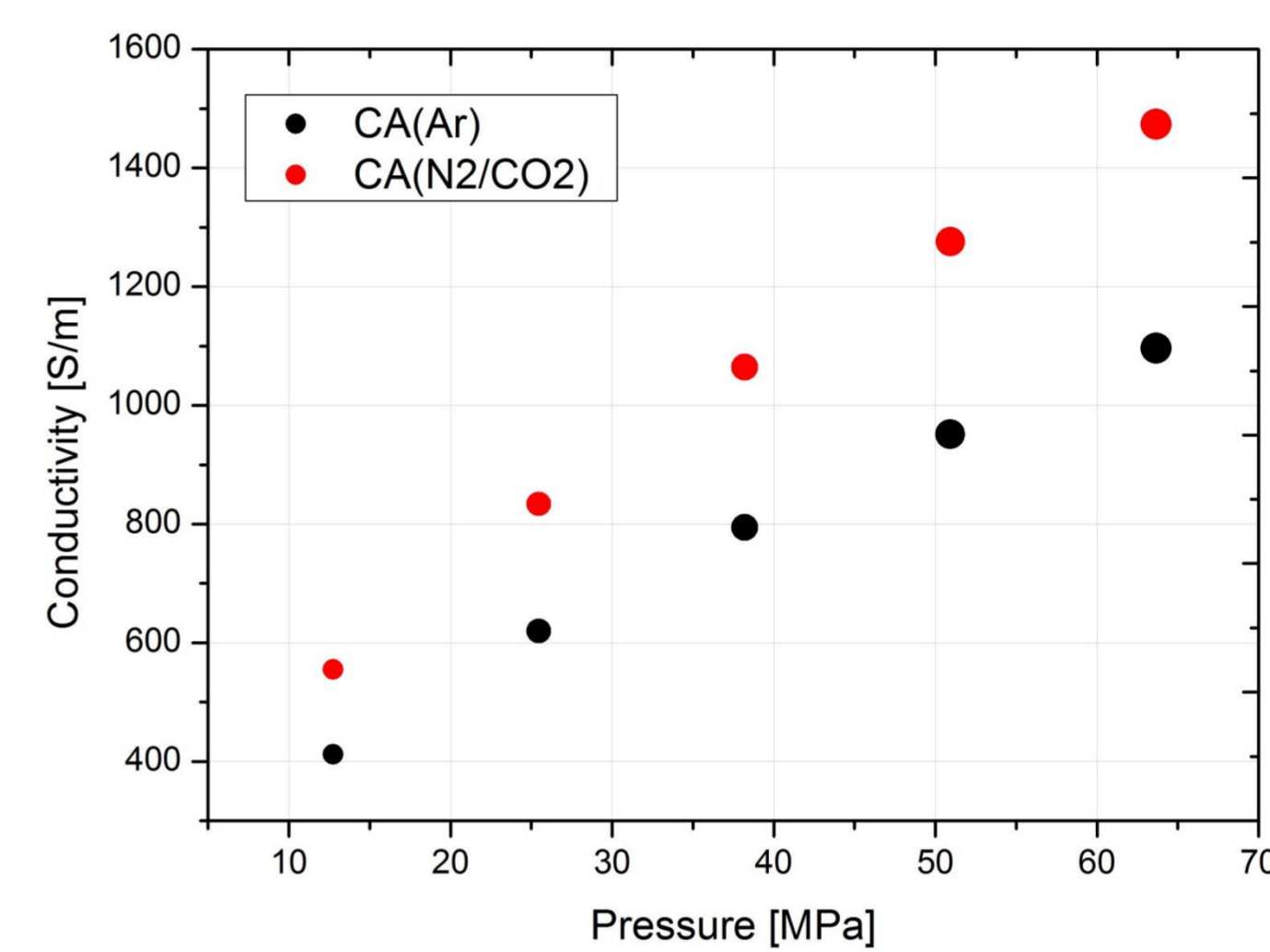
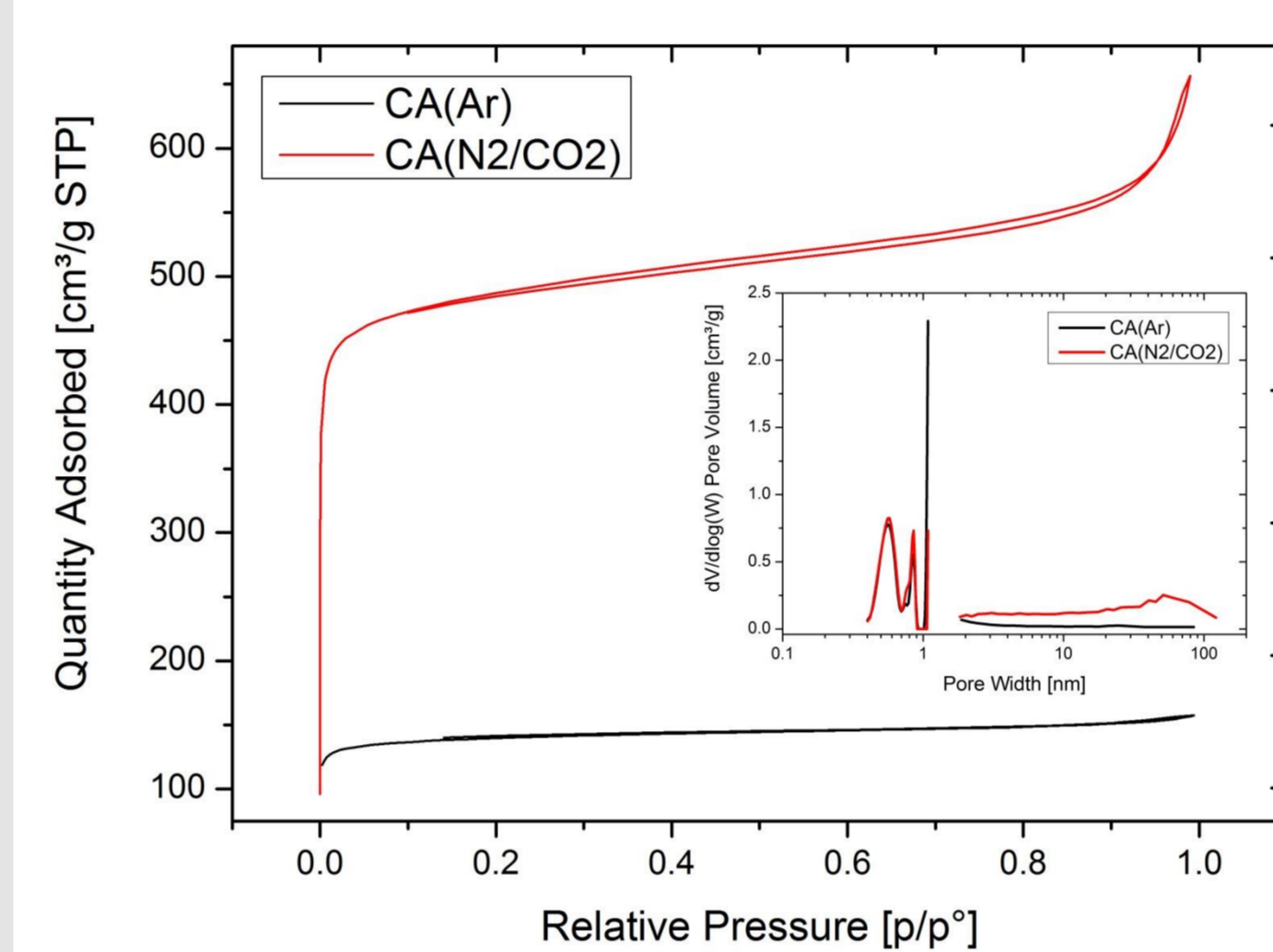
Carbonization conditions:	Molar ratios:	Reaction conditions:
Ar: 1 h, 1000°C, Argon atmosphere	Resorcinol/Formaldehyde = 0.5	stirring time 60 min at room temperature
N ₂ /CO ₂ : 5 h, 800°C, N ₂ atmosphere	Resorcinol/Water = 0.008	
3h, 1000°C, CO ₂ atmosphere	Resorcinol/Catalyst = 50	

CARBON AEROGEL (Ar)

CARBON AEROGEL (N₂/CO₂)

MICROSTRUCTURE

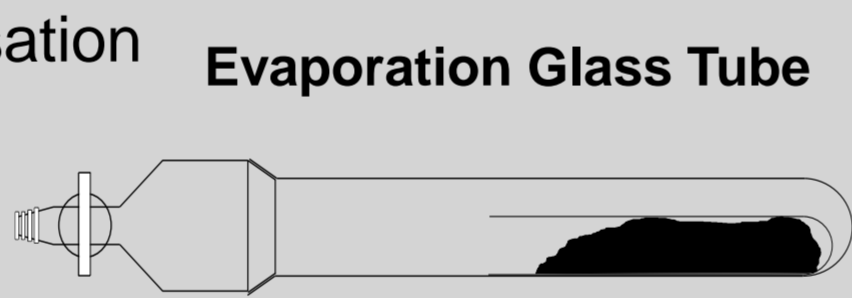
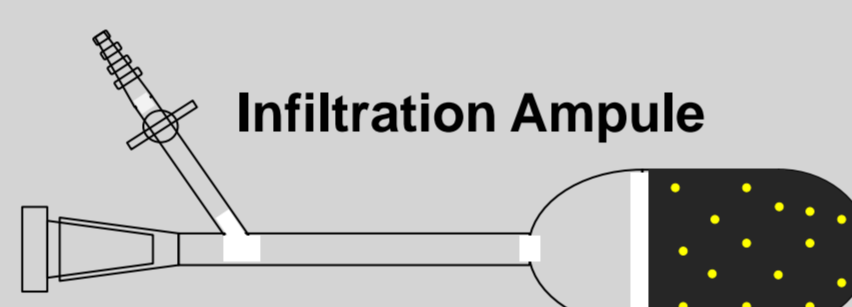
Properties	CA(Ar)	CA(N ₂ /CO ₂)
Skel. density [g/cm ³]	2.72	2.71
Bulk density [g/cm ³]	0.04	0.07
Porosity [%]	98.6	97.3
Specific surface area [m ² /g]	561	1912
Micropore volume [cm ³ /g]	0.18	0.60
Mesopore volume [cm ³ /g]	0.04	0.28



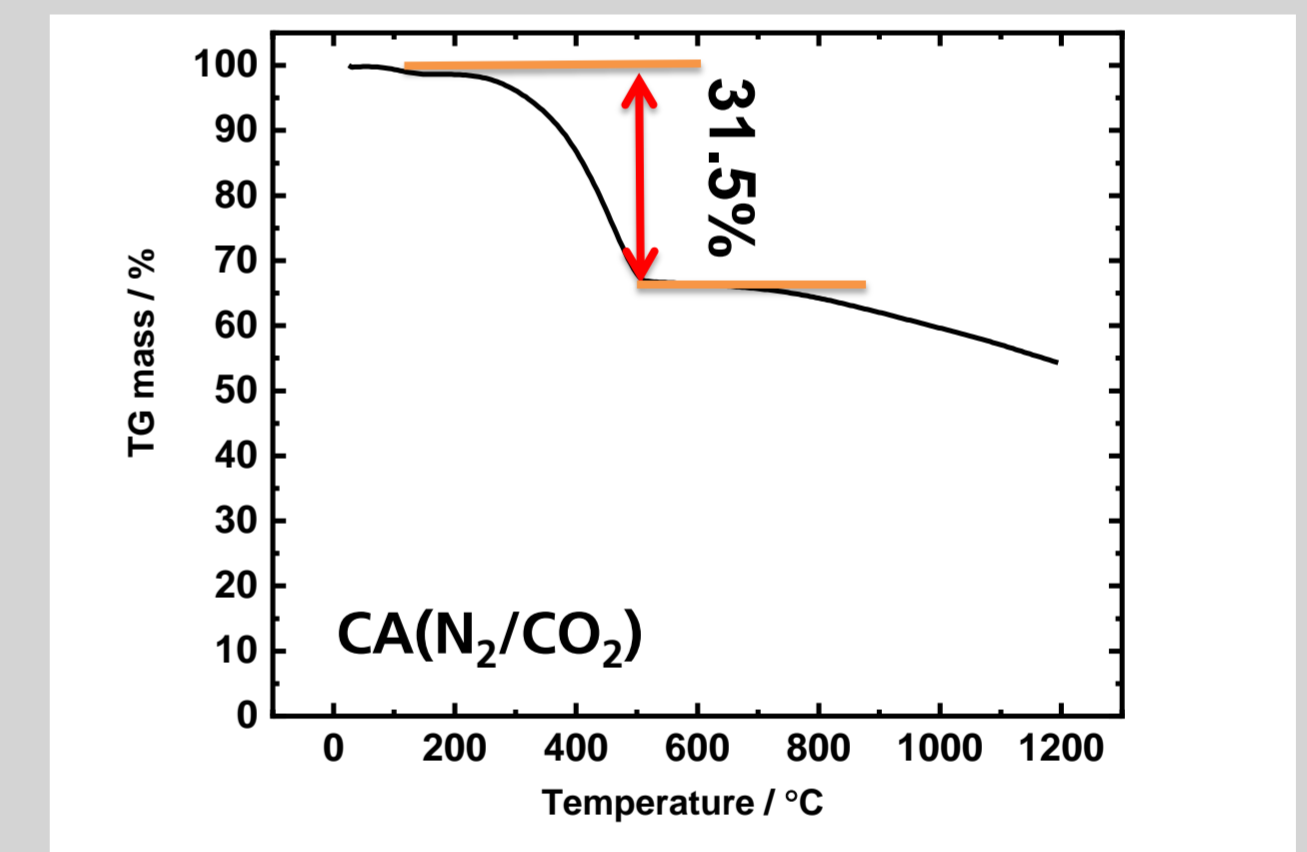
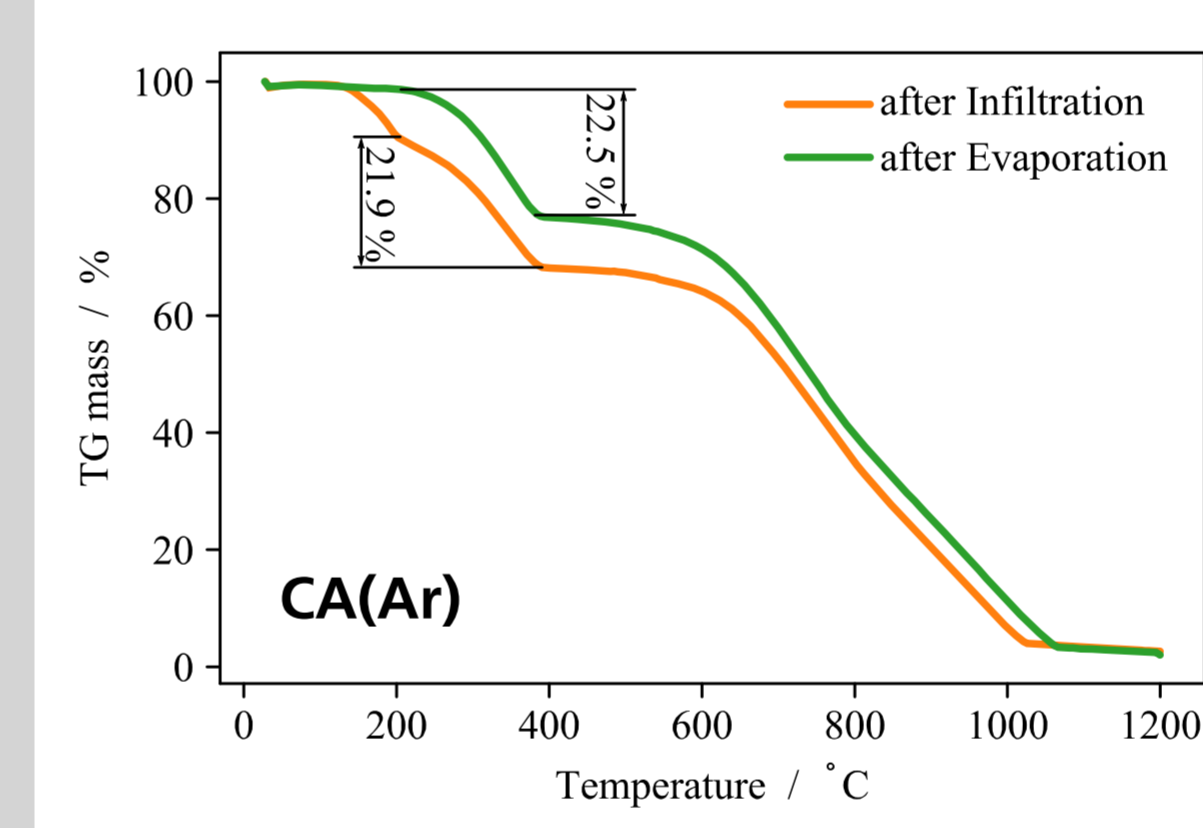
INFILTRATION

Two-step infiltration process:

- Gas Phase Infiltration
 - 600°C (6h) under vacuum in a sealed glass ampule
 - evaporated sulfur enters the micropores (< 2nm)
- Evaporation of excessive sulfur from aerogel surface
 - 330°C (1.5h) under argon in glass tube with condensation trap
 - increases electrical conductivity of carbon
 - prevents undesired reactions with electrolyte



Thermogravimetric analysis



Higher microporosity leads to higher sulfur loading

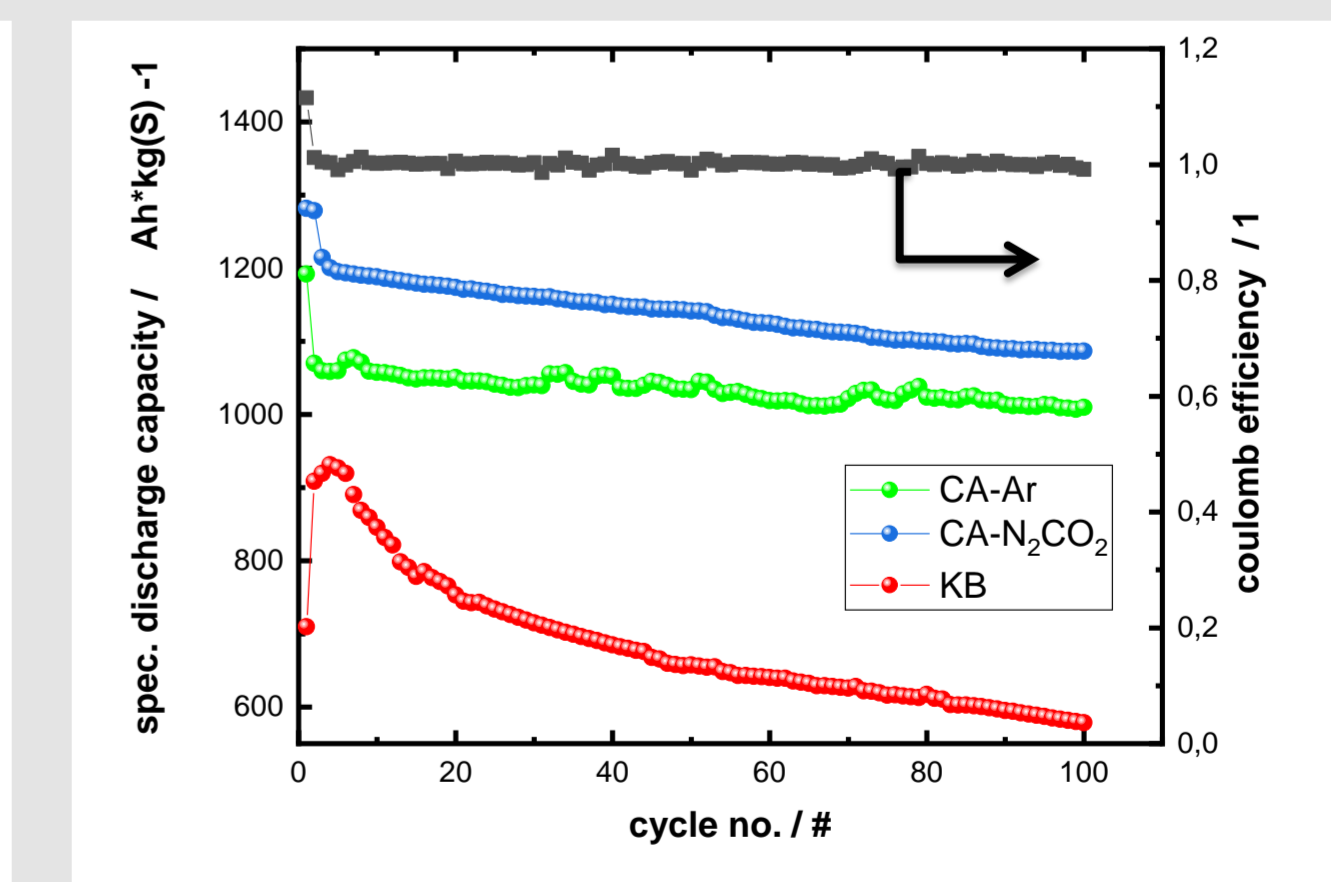
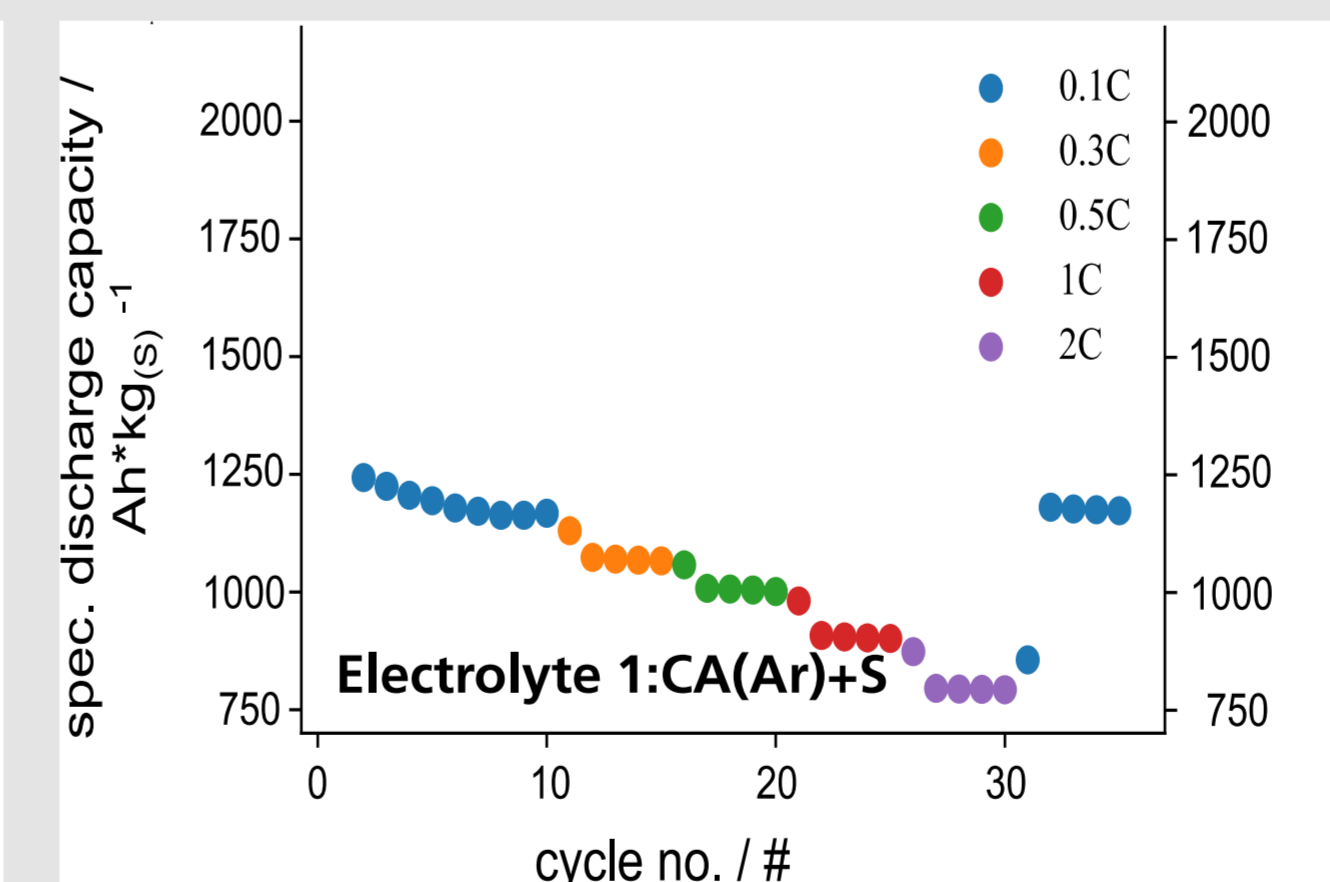
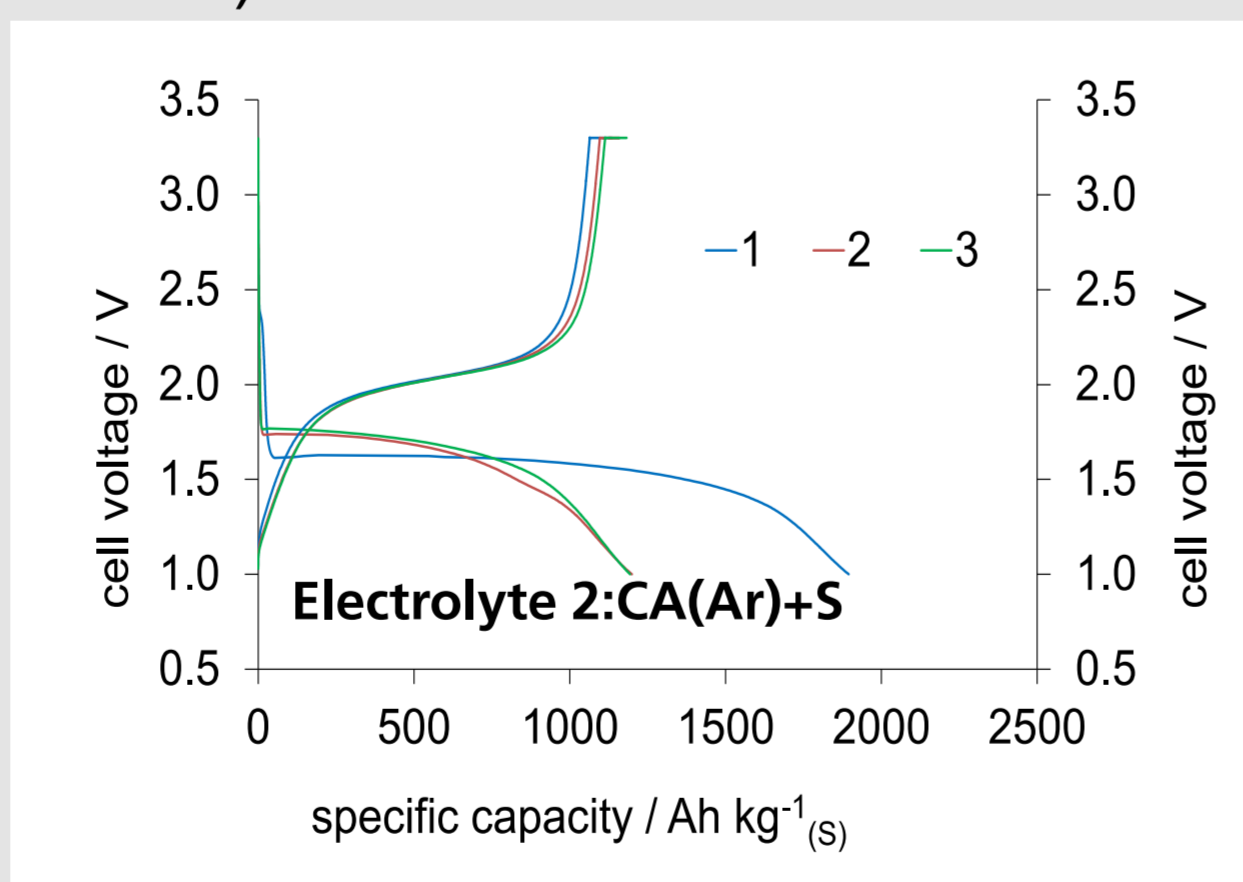
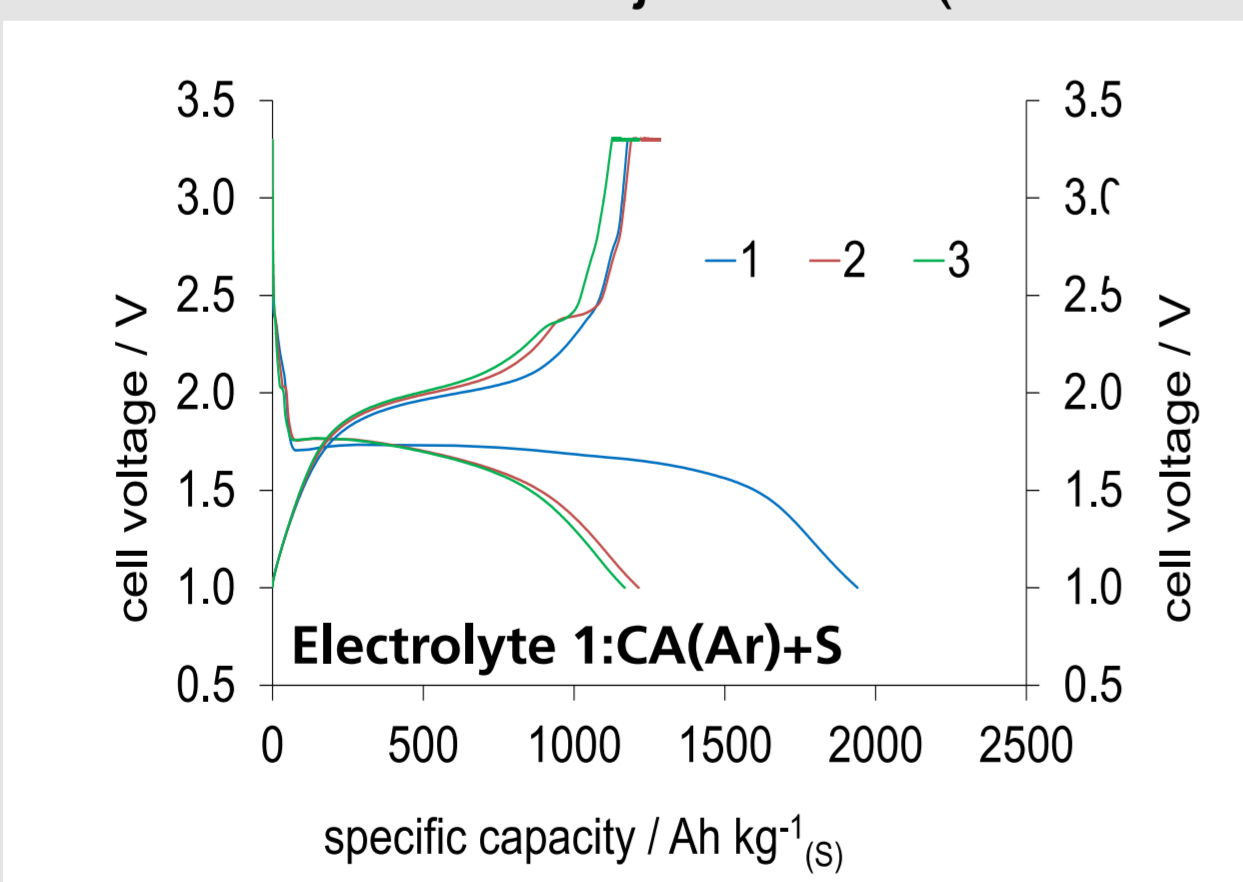
PERFORMANCE

Cell Parameter:

Cell type: Swagelok
 Electrolyte 1: 1M LiTFSI (lithium bis(trifluoromethylsulfonyl)imide in DOL/DME (1,3-dioxolane / dimethoxy ethane), 25 °C
 Electrolyte 2: 1M LiPF₆ (Lithiumhexafluorophosphat) in EC/DEC (ethylene carbonate / diethylene carbonate), 25 °C
 Sulfur-loading: 0.7–0.8 mg_S/cm²
 KB: Katjenblack (reference material)

Results:

- Suppression of polysulfide shuttle effect using CA:S electrode
- Stable discharge capacity in both carbonate- and ether-based electrolytes for CA:S
- High specific capacity and coulombic efficiency for CA:S cathode materials
- No irreversible losses in rate-capability test for CA:S cathode materials
- CA(N₂/CO₂):S exhibits even higher specific capacity as compared to CA(Ar):S



CONCLUSION

- Synthesis of the CAs with controlled and defined pore sizes and structures
- Increased surface area due to carbonization with N₂/CO₂
- Increased micropore volume in aerogel structure due to carbonization with N₂/CO₂
- Infiltration of short chain sulfur in the micropores through gas phase process
- Higher sulfur loading in CA (N₂/CO₂) due to higher micropore volume
- Higher cyclability of the Li-S cell via the encapsulation of sulfur in carbonate- and ether-based electrolytes

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