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MXene Quantum Lands: Emerging Trends and Breakthroughs

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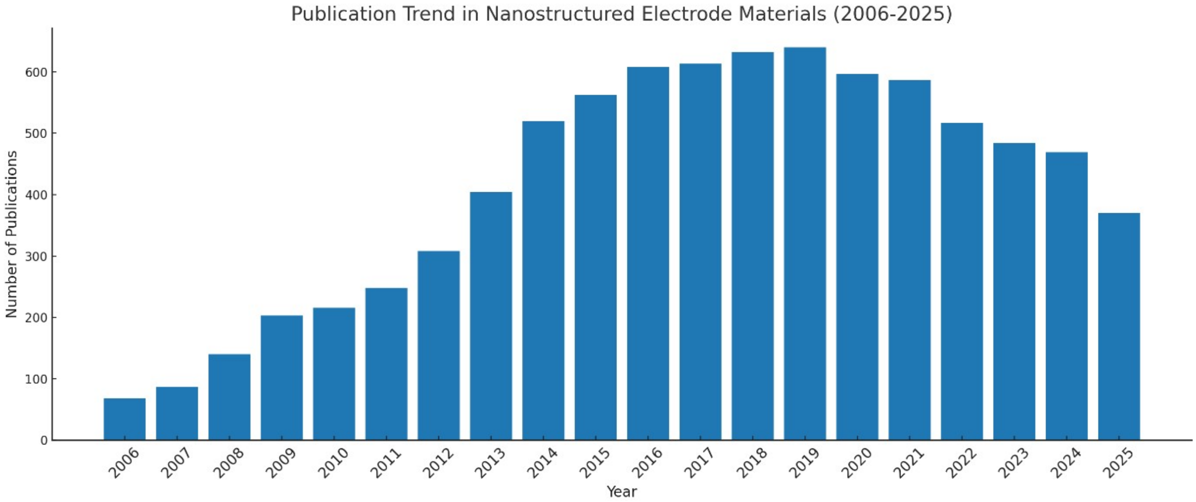

Fig. S1. Annual number of publications on nanostructured electrode materials from 2006 to 2025.

Table S1. Advantages and Limitations of Different MQD Synthesis Methods.

Approach	Advantages	Limitations/Risks
Sonication-Assisted Exfoliation	• Simple, safe, and low-cost process under ambient conditions • Requires minimal reagents or specialized equipment • Compatible with various MXene precursors and solvents	• Low yield and lengthy exfoliation time • Limited control over lateral size and surface termination • Structural degradation due to cavitation-induced defects • Poor reproducibility across large batches
Hydrothermal	• Enables precise control of morphology, crystallinity, and particle size under optimized conditions • Facilitates heteroatom doping and surface functionalization through controlled reaction environment • Operates in a closed system that supports homogeneous nucleation • Offers scalability and compatibility with diverse MXene precursors	• Sensitive to reaction parameters—minor deviations in temperature, pressure, or pH can trigger undesired phase transitions • High probability of surface oxidation and defect formation due to hydrolysis or residual oxygen species • Energy- and reagent-intensive process with long reaction duration • Possible formation of nonstoichiometric or amorphous intermediates in suboptimal conditions
Solvothermal	• Enables size and morphology tuning with selective surface/edge functionalization • Produces stable colloidal dispersions with reduced agglomeration • Applicable for hybrid and doped MQD synthesis • Higher reaction uniformity than hydrothermal method	• Use of toxic organic solvents may pose environmental and safety concerns • Moderate yield and material loss during purification • Requires strict control of solvent polarity and surfactant ratio
Reflux Condensation	• Mild reaction conditions and reduced oxidation tendency • Continuous reaction pathway allows gradual QD nucleation • Suitable for obtaining uniform size in prolonged heating	• Long processing time (up to several hours) • Complex setup and limited scalability • Restricted morphology control and narrow compositional range
Micro-Explosion / Laser Ablation	• Rapid, energy-efficient synthesis under ambient or mild conditions • Free of hazardous chemicals and environmentally benign • Facilitates direct synthesis of ultrafine MQDs from MXene films	• Broad size distribution and limited control over morphology • Multiple purification steps required to remove ablation debris • Low yield per batch and equipment-dependent reproducibility
Microwave-Assisted	• Uniform volumetric heating enables rapid and homogeneous nucleation • Significantly shortened reaction time (minutes) • Reduced oxidation compared to conventional thermal routes	• Risk of non-uniform particle growth and phase instability • Localized overheating may induce structural collapse • Limited scalability and vessel design dependence
Molten Salt	• High crystallinity and precise morphology control • Solvent-free etching medium and allows for the use of non-fluorine containing salts, making it a potentially environmentally benign process	• High temperature and energy consumption • Tedious purification to remove residual salts/by-products • Potential interfacial contamination from molten medium

	• Promotes surface termination control through molten ionic media