

Photopolymer-Derived Battery Components: Electrodes, Separators, Current Collectors, Cure Residuals and Cell Qualification

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Abstract

Vat photopolymerization can generate battery electrodes, separators, electrolytes, current-collector architectures and sacrificial precursors with geometric freedom unavailable to planar coating. The enabling resin, however, also introduces a coupled chemical history: photoinitiator fragments, unreacted species, binder or carbonization residue, pore-forming domains and post-processing products can persist at interfaces that control transport and stability. This review defines a qualification architecture for photopolymer-derived battery components. It separates the printed precursor from the final electrochemical state, distinguishes active-material performance from current-collector and separator functions, and requires component evidence to survive assembly into a relevant cell. The central conclusion is non-compensatory: successful printing or attractive half-cell capacity cannot compensate for inadequate ionic transport, unstable interfaces, residual chemistry, unsafe separator behaviour or weak full-cell retention.

Keywords: vat photopolymerization; batteries; electrodes; separators; current collectors; gel polymer electrolytes; cure residuals; electrochemical qualification; additive manufacturing

1. Significance and scope

Battery performance is produced by a coupled stack rather than by any single printed object. Vat photopolymerization has already been used for LiCoO₂ cathodes, NMC111 precursor-derived electrodes, hard-carbon negative electrodes, porous separators and polymer electrolytes [1-6]. Each route transforms a photocurable feedstock into a different electrochemical function, and the transformation may involve washing, extraction, pyrolysis, sintering, electrolyte uptake or in-situ synthesis. ER-265 owns the qualification of battery components and their integration into electrochemical cells. ER-264 retains general electrochemical-electrode architecture and cycling logic outside the battery-specific stack; ER-266 retains supercapacitor architectures.

1.1 Corpus boundary

Published incumbents retained as corpus boundaries are ER-07 for electrically functional photopolymer resins, ER-36 for rheology and dispersion of highly filled VPP suspensions, ER-76 for optical attenuation and cure-profile physics in particle-filled vat photopolymerisation, ER-86 for analytical extractables and leachables, ER-92 for residual reactants and manufacturing conversion, ER-95 for photoinitiator migration and residual species, ER-99 for dispersant chemistry, ER-149 for lithography-based metal manufacturing where filled-photoresin cure/loading, debinding and sintering physics are the relevant process boundary, ER-156 for nano/micron raw materials, ER-157 for electrically and thermally functional fillers, and WP-27 for conductive composites. ER-261 retains generic printed conductors and resistive elements, ER-263 retains dielectric breakdown and insulation ageing, ER-264 retains general electrochemical-electrode qualification, and ER-266 retains supercapacitor-specific architectures. These forward identifiers define scope only and carry no evidentiary authority for ER-265.

2. The printed object is often a precursor

A printed green electrode can differ profoundly from the final active component. In precursor-based NMC111 printing, metal salts are incorporated into a photocurable resin and the electrochemically active oxide is formed only during thermal post-processing [2]. In hard-carbon printing, the polymer-containing printed state is converted to a conductive carbonaceous network after thermal treatment [3]. The qualification record must therefore preserve the state chain from resin formulation through printing and all post-processing steps to the object actually placed in the cell. Dimensions, mass, porosity and chemistry should not be transferred across those states without measurement.

3. Electrodes: active loading, conductive continuity and binder fate

Composite-resin electrodes require a compromise among printability, light transport, active-material loading and electronic connectivity. Martinez and co-workers showed direct LiCoO₂ loading in a UV-sensitive resin, while the NMC111 precursor approach avoids initial particle scattering by forming the active phase later [1,2]. These are different manufacturing mechanisms and should not be pooled. A qualified electrode should report active mass, conductive additive if used, final porosity, electronic resistance, accessible area and the fate of the photopolymer-derived phase. Capacity normalized only to total printed mass can obscure inactive resin or current-collector contributions.

4. Separators: porosity is necessary but not sufficient

Projection micro-stereolithography has been used to make nanoporous HDDA separators by polymerization-induced phase separation, with the printed morphology tuned by resin composition and exposure history [4]. A separator must simultaneously prevent electronic contact, permit ionic transport, retain dimensional integrity, wet reproducibly and remain chemically compatible with the electrolyte and electrodes. Porosity alone is therefore not an acceptance criterion. Thickness distribution, tortuosity or a transport surrogate, electrolyte uptake, ionic resistance, puncture or dimensional stability, and full-cell behaviour should be considered together.

5. Solid and gel polymer electrolyte architectures

SLA-printed solid polymer electrolytes and more recent vat-photopolymerized gel polymer electrolytes show that geometry can be used to alter transport path length and interface area [5,6]. Their performance depends on solvent or plasticizer state, salt concentration, network conversion, residual monomer, interfacial contact and dimensional stability. Ionic conductivity should be reported with temperature, composition and test method. A high bulk conductivity does not prove low cell impedance if electrode contact is poor, nor does a low initial impedance prove cycling stability.

6. Current collectors and interconnects

Battery current collection can be provided by an external foil, a deposited conductor, a carbonized printed scaffold or a hybrid architecture. The relevant property is not nominal conductivity alone but distributed electronic resistance under the actual current path. Contact resistance, coating adhesion, geometric necking and corrosion can dominate local current density. When the photopolymer route creates a carbon current collector through pyrolysis,

shrinkage and connectivity after conversion must be measured. ER-261 remains the controlling location for generic printed-conductor percolation and contact-resistance mechanisms.

7. Cure residuals and electrochemical compatibility

Photoinitiator fragments, residual monomer, oligomer, wash residue and products created during thermal conversion can contact electrolyte or active material. Their significance is chemistry-specific: a residue may be electrochemically inert in one voltage window and reactive in another. Consequently, the resin formulation and cure/post-cure history are part of the electrochemical material state. Extractables analysis, mass-loss tracking or targeted spectroscopy should be used where residual chemistry could plausibly affect gas generation, interphase formation, ionic conductivity or self-discharge. Absence of visible residue is not analytical evidence.

8. Cell-level transfer and non-compensatory qualification

A component-level result must ultimately survive integration into an electrochemical cell. Half-cell capacity can be useful for isolating electrode behaviour, but practical qualification should also examine the relevant counter-electrode, electrolyte, areal loading, N/P balance where applicable, separator thickness, pressure and current-collector geometry. Rate capability, Coulombic efficiency, impedance and retention should be interpreted together. A favourable metric in one axis cannot compensate for a safety-critical or transport-critical failure in another.

Gate	Required evidence	Blocking failure
G1 State chain	Resin/feed, print, wash, cure, thermal conversion and final state traced	Electrochemical object cannot be reproduced
G2 Function	Component-specific electrical/ionic/mechanical function measured	Printed geometry has no demonstrated battery role
G3 Residual chemistry	Relevant residuals or conversion products bounded	Uncontrolled interface chemistry
G4 Integration	Representative cell assembly and interfaces documented	Component evidence not transferable to cell
G5 Cycling	Rate, efficiency, impedance and retention under declared protocol	Initial performance mistaken for durability
G6 Safety boundary	Separator integrity, voltage window and thermal/chemical constraints declared	Performance claim exceeds safe operating state

9. Minimum reporting set

Report resin and all electrochemically relevant additives, printer and wavelength, layer thickness, exposure strategy, build orientation, washing/extraction, post-cure, pyrolysis or sintering schedule when used, final dimensions and mass, porosity or density, active-material loading, conductive additive, current-collector architecture, separator thickness, electrolyte composition, cell format, electrode areas and loadings, test temperature, voltage window, C-rate or current density, formation protocol, impedance method, every cycle count supporting retention claims and the normalization basis for capacity or energy.

10. Knowledge boundary

The literature establishes feasibility of several vat-photopolymerization battery-component routes, but it does not establish a universal resin composition, residual threshold, porosity target or cycle-life criterion [1-7]. The correct transfer unit is the complete state-and-test protocol. Performance values should remain attached to their chemistry, geometry and cell configuration.

11. Conclusions

Photopolymer-derived battery components must be qualified from printed precursor to cell-tested state. Geometry is valuable only when electrochemical function survives the accompanying polymer chemistry and post-processing. Electrodes require verified active loading and electronic continuity; separators require coupled transport and isolation evidence; polymer electrolytes require ionic and interfacial qualification; current collectors require distributed resistance and stable contact. The acceptance decision belongs to the weakest relevant gate, not to the most attractive single performance number.

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