

Inkjet and Material-Jetting Deposition of Photocurable Encapsulants for MEMS and Microsensors: Registration, Interfaces and Reliability

Qualification of jetted photocurable encapsulation from droplet placement to barrier, stress and device reliability

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Abstract

Inkjet and material-jetting of photocurable encapsulants for MEMS and microsensors couples droplet placement, cure, interfacial adhesion and package reliability. This review examines registration to small features, deposited-film geometry, wetting, voiding, cure state and thermomechanical stability rather than treating encapsulation as a coating-thickness problem. Reliability studies of inkjet-printed electronic packages show that printed material properties and cure history can control stress and deformation under thermal loading, while UV-LED-curable ink literature defines formulation and jetting constraints relevant to deposited encapsulants.

Qualification is organised around deposited footprint, keep-out compliance, interface integrity, cure/conversion evidence, leakage or insulation function, and environmental/thermal cycling. The objective is to distinguish failures created at deposition from failures created later by cure shrinkage, moisture uptake, modulus mismatch or interfacial degradation.

Keywords: inkjet; material jetting; photocurable encapsulant; MEMS; microsensor; registration; interface; reliability; packaging

1. Significance and scope

Encapsulation around MEMS and microsensors is geometrically constrained: material must cover vulnerable interfaces without flooding moving structures, optical paths, ports or active surfaces. Jetting introduces placement and wetting variability, while photocure introduces shrinkage and modulus evolution. The resulting package should therefore be evaluated as a deposited interfacial structure whose reliability depends on both local geometry and cured material state.

1.1 Corpus boundary

ER-336 owns jet-deposited photocurable encapsulation around MEMS and microsensors. ER-268 retains photodetector/photosensor integration, ER-349 electronic batch records, ER-427 photonic packaging/interconnects, and ER-439 sensor-integrated organ-on-chip platforms. Conductive-ink formulation is outside ER-336 except where it defines an encapsulant interface.

2. Deposition accuracy is not equivalent to package integrity

Drop placement, coalescence and cure determine edge definition, thickness and void formation. Misregistration around bond pads, membranes or sensing windows can create either exposure or mechanical constraint [3].

3. Interfaces dominate many failures

Adhesion, cure shrinkage, thermal-expansion mismatch and moisture transport act at polymer-substrate and polymer-metallisation interfaces. Reliability testing should therefore combine cross-section inspection with electrical or functional monitoring [1].

4. Cure state controls barrier and stress

UV dose, layer count and post-cure can change conversion, modulus, residual stress and permeability. A clear encapsulant can still be an inadequate moisture or ionic barrier if the network is under-cured or cracked.

5. Reliability must be device-relevant

Thermal cycling, humidity, bias, mechanical shock or chemical exposure should be selected according to the microsensor environment. Package-level pass/fail should be tied to drift in the protected device, not just visual appearance [1,2].

6. Qualification architecture

Qualification should map the deposited footprint relative to device keep-out zones, measure film thickness and edge profile, and inspect for voids or incomplete wetting. Cure state and adhesion are then assessed before thermal, humidity or mechanical cycling. Electrical insulation, optical transmission or leak-tightness should be selected according to the sensor function; these functional metrics should be repeated after conditioning to expose interface degradation.

7. Minimum evidence for transfer

Transfer evidence includes substrate surface state, droplet/jetting mode, material identity, deposition passes, cure spectrum/dose description, final thickness profile and interface inspection. Reliability should be reported with thermal and moisture histories rather than as an undifferentiated pass. Comparative packaging work shows that UV-cured printed stacks can develop stress patterns different from conventional packages, making cure-dependent properties part of the manufacturing record [1].

7.1 Evidence hierarchy and transfer

A placement defect and an adhesion defect can produce the same local delamination after cycling, but they require different process action. Pre-cycling footprint and interface imaging should therefore be retained and compared with post-cycling damage. Functional drift should be correlated with where encapsulant geometry or interface state changed.

7.2 Research priorities

Priority work includes registration standards for jet-deposited encapsulants, non-destructive void detection at microsensor scale, and cure-state measurements compatible with thin printed films. Reliability studies should report both package-level outcomes and the local material/interface variables that explain them.

Table 1. Minimum qualification matrix for jet-deposited photocurable MEMS encapsulants.

Encapsulant state	Minimum measurement	Qualification purpose
Deposition	drop spacing, thickness and registration	defines coverage and keep-out zones
Interface	adhesion and void/delamination map	tests mechanical continuity
Barrier	moisture/ionic ingress proxy	tests environmental protection
Stress	warpage or local strain	detects cure/CTE mismatch
Function	device drift during ageing	links package to reliability

8. Interpretation matrix

Encapsulant overflow, edge recession, voiding, delamination and functional drift have distinct likely origins. The diagnostic matrix uses footprint, wetting, cure and interface measurements to separate deposition error from environmental ageing.

Table 2. Diagnostic interpretation matrix for encapsulant registration and reliability failures.

Package observation	Plausible mechanism	Discriminating control
Edge lift after humidity	weak adhesion or swelling	cross-section and adhesion after conditioning
Sensor offset after cure	shrinkage or thermal stress	strain/warpage plus device calibration
Local corrosion under intact film	permeation or ionic contamination	electrochemical/chemical analysis
Nozzle process drifts	viscosity or partial cure in jetting system	drop-volume and rheology monitoring

9. Limitations and evidence gaps

The evidence base includes printed electronics packages and UV-curable ink systems that are not identical to every MEMS application. Device geometry, substrate energy and cure access can change substantially between cases. Accordingly, this review uses those studies to define variables and failure mechanisms, not universal deposition settings or lifetime limits.

10. Conclusions

Photocurable encapsulation by inkjet or material jetting should be qualified as a registered interface, not merely as deposited material. A successful process preserves device keep-out zones, achieves the intended cured state and adhesion, and maintains the required electrical, optical or barrier function after environmental loading. ER-336 therefore connects deposition geometry to interface reliability and keeps MEMS device function distinct from encapsulant manufacture.

References

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Competing interests

The author is Founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L. No comparative product recommendation is made.

Data availability

No new experimental dataset was generated for this review.