

Photoluminescent Photopolymers in Vat Photopolymerisation: Fluorescence, Phosphorescence, Cure-Spectrum Coupling, Reabsorption, Scattering and Qualification

Juan Segurola, PhD

3Dresyns by Resyner Technologies S.L.

Registered tax address: General Etxague 15B, 20003 Donostia / San Sebastián, Gipuzkoa, Spain

VAT number: ESB24827511

Correspondence: info@3Dresyns.com · Website: www.3Dresyns.com

Statement of Significance

Photoluminescent vat-photopolymerised parts are often described simply as fluorescent or phosphorescent, yet those labels do not establish spectral efficiency, lifetime, afterglow, colour stability or compatibility with the printing exposure. The same additive that creates useful emission may absorb the printer wavelength, alter cure depth, self-absorb emitted light, aggregate, scatter, photobleach or change response after post-curing. This review separates the photochemical state used to manufacture the network from the optical excited-state behaviour used to qualify the finished part, and proposes a reporting architecture for fluorescence and phosphorescence in SLA, DLP and LCD/MSLA photopolymers.

Keywords: vat photopolymerisation; photoluminescence; fluorescence; phosphorescence; emission; excitation; photoluminescence quantum yield; lifetime; afterglow; reabsorption; scattering; photobleaching; DLP; SLA; qualification

Abstract

Vat photopolymerisation can embed molecular dyes, organometallic emitters, carbon dots, nanoparticles and aggregation-induced-emission systems into three-dimensional polymer networks. Primary studies demonstrate fluorescent photopolymer objects with tunable absorption and scattering, phosphorescent DLP resins, red-emitting carbon-dot additives, photoluminescent printed waveguides, and fluorescence changes that can track network formation. These demonstrations do not make photoluminescence a single material property. Excitation spectrum, emission spectrum, photoluminescence quantum yield, prompt or delayed lifetime, afterglow decay, concentration, aggregation state, optical path length, scattering, reabsorption, cure wavelength and post-cure history can all change the observed signal. The strongest VPP-specific evidence also shows that fluorescent absorbers can strongly perturb penetration depth and critical exposure, so optical function and manufacturability must be qualified together. This review develops a state-based framework that separates fluorescent emission, phosphorescent or persistent emission, radiation scintillation and photochromic colour change; maps the principal VPP formulation and measurement couplings; proposes minimum reporting and failure-discrimination requirements; and treats 3Dresyns fluorescent and phosphorescent colouring additives only as manufacturer implementation examples. No quantum yield, lifetime, afterglow duration, spectral peak, photostability or device performance is inferred from their product names or commercial descriptions.

1. Scope and boundaries

ER-56 addresses light-excited photoluminescence in cured or printed photopolymer networks made by vat photopolymerisation. It includes conventional fluorescence, phosphorescent emitters, persistent or delayed emission where it is actually measured, fluorescent nanoparticles and AIE-type luminogens. The engineering question is how emissive function survives formulation, optical exposure, network formation, post-processing and service conditioning.

The scope excludes four neighbouring domains. ER-55 controls passive waveguide propagation and coupling; ER-19 controls radiation-functional materials and scintillation under ionising radiation; ER-44 controls photoabsorbing fillers and cure-depth control more generally; and high-security/photochromic materials remain a separate information-display or anti-counterfeiting topic. A luminescent material may intersect those domains, but ER-56 does not absorb them.

Photoluminescence is also distinct from visual colour. A specimen can be strongly coloured and weakly emissive, or nearly colourless under ambient light and strongly emissive under excitation. Therefore a colour name, fluorescent appearance or glow photograph is not a quantitative photoluminescence qualification.

2. Fluorescence, phosphorescence and persistent emission are not interchangeable

Fluorescence is prompt radiative emission following optical excitation, normally characterised by an excitation/emission spectrum, intensity or quantum yield and a short excited-state lifetime. Phosphorescence involves longer-lived emissive states and can persist after excitation is removed. Persistent luminescence or afterglow can additionally involve trapping and detrapping processes whose decay may extend far beyond the intrinsic molecular lifetime. In printed composites, observed decay can therefore reflect both emitter photophysics and the surrounding network or particle environment.

A defensible paper or datasheet should report the actual measured endpoint rather than using “fluorescent”, “phosphorescent” and “glow-in-the-dark” as synonyms. If afterglow is claimed, the excitation dose, excitation wavelength, delay before measurement, observation window and decay model or intensity-versus-time data are required.

Table 1. Photoluminescence quantities that must not be conflated

Quantity	What it measures	What it does not establish
Excitation spectrum	Wavelength dependence of emission generation under a defined detection condition.	Not the resin cure spectrum and not an absorption spectrum by definition.
Emission spectrum	Spectral distribution of emitted light under a defined excitation.	Not total efficiency or lifetime.
PL quantum yield	Emitted photons relative to absorbed excitation photons under a defined method/state.	Not brightness in an arbitrary geometry or afterglow duration.
Prompt lifetime	Decay timescale of an emitting excited state.	Not persistent afterglow where traps or multiple states dominate.
Afterglow decay	Emission intensity after excitation is removed as a function of time.	Not captured by a single photograph or colour description.
Absorbance / attenuation	Loss of incident light through absorption and, depending on method, scattering.	Not identical to emitter concentration or PL efficiency.
Apparent brightness	Signal measured by a given optical geometry/detector.	Not an intrinsic material constant without calibration and geometry control.
Colour coordinates	Perceived/emitted colour under a defined illuminant or emission measurement.	Not quantum yield, lifetime or spectral stability.

3. VPP evidence: fluorescent materials can be printed, but optical state is formulation-specific

Ruiz et al. used masked stereolithography to manufacture fluorophore-doped photopolymer structures with tuned absorption and reduced scattering. They printed multiple fluorophore systems and showed that spectral behaviour and relative emission yield depend on the manufactured optical matrix [1]. The study is important because it treats fluorescence together with absorption and scattering rather than as an isolated colour property.

Maturi et al. incorporated long-chain surface-modified red-emitting carbon dots into two vat-photopolymerisable resin formulations and obtained red-emitting printed objects [2]. The work directly measured absorption, emission, photoluminescence quantum yield and lifetime, and it also demonstrates why dispersion chemistry matters: the carbon-dot surface was modified to improve compatibility with the resin phase. Emitter identity alone is therefore insufficient; dispersion and matrix affinity are part of the realised optical state.

Frascella et al. covalently incorporated a photoluminescent dye into DLP-printed polymer waveguides and splitters [3]. In ER-56 the study is used as evidence that emissive chemistry can survive photopolymerisation and remain responsive in the solid network. Waveguide transmission and propagation-loss questions remain delegated to ER-55.

4. Phosphorescent DLP resin: a useful proof of concept with an important correction history

Maturi et al. reported a bio-based DLP resin containing phosphorescent cyclometalated iridium complexes and demonstrated rigid and flexible printed structures [4]. This is direct primary evidence that phosphorescent functionality can be integrated into a photocurable resin. It is not evidence that every phosphorescent pigment or powder will disperse, cure or retain its optical performance in the same way.

The 2020 article has published correction notices in 2020 and again in 2026 [5,6]. The 2026 notice clarifies the schematic representation of the PPGIV polyester backbone and explicitly states that the clarification does not affect interpretation of the results or conclusions. ER-56 therefore cites the original article together with both correction records rather than silently citing the unqualified original record.

5. Cure-spectrum coupling is a first-order engineering variable

A luminophore can compete with the photoinitiator for the same photons used to cure the resin. The degree of coupling depends on the printer emission spectrum, photoinitiator absorption, luminophore absorption, concentration, optical path length and scattering. A formulation that emits strongly under one excitation wavelength may still print poorly if it attenuates the manufacturing wavelength.

Chandler et al. provide strong mechanistic evidence from VPP plastic-scintillator formulations: fluorescent dopants changed light penetration depth and critical energy dose, demonstrating that an emissive additive can materially alter the working curve [7]. ER-19 owns the scintillation and radiation-detection endpoints; ER-56 uses this study only for the narrower optical-manufacturing conclusion that fluorescent absorbers can alter VPP cure behaviour.

Accordingly, luminescent VPP systems need paired measurements: the optical emission function of the cured part and the cure response of the liquid formulation. Neither can substitute for the other.

Table 2. Coupled formulation variables in photoluminescent VPP

Variable	Potential benefit	Primary failure risk
Emitter concentration	Higher absorption and potentially stronger emitted signal.	Inner-filter/self-absorption, aggregation quenching, colour shift, cure attenuation.
Emitter absorption at printer wavelength	Efficient excitation can be useful in some systems.	Competition with photoinitiator; shallower cure; higher critical exposure.
Particle size / aggregation	Can enable persistent or nanoparticle-based functions.	Scattering, sedimentation, z-gradient, roughness, local cure heterogeneity.
Covalent attachment	Reduces migration and can stabilise spatial distribution.	Network chemistry and local mobility may alter spectra/lifetime or cure.
Matrix polarity / rigidity	Can tune solvatochromism, AIE and non-radiative relaxation.	Printed-state emission may differ from liquid-screen result.
Post-cure dose	Raises conversion and may stabilise mechanics.	Further excitation/bleaching, chromophore change, spectral drift.
UV stabiliser / absorber	May improve long-term matrix stability.	Can attenuate excitation or emission and reduce apparent brightness.

6. Concentration, self-absorption and inner-filter effects

Photoluminescence intensity does not necessarily increase linearly with emitter concentration. At higher optical density, excitation may be absorbed near the specimen surface, emitted photons may be reabsorbed before leaving the part, and molecular or particle aggregation can create non-radiative loss. These effects are geometry-dependent: a thin coupon and a thick three-dimensional object can show different apparent brightness at identical composition.

For this reason, concentration-response studies should retain specimen thickness and optical geometry, and emission data should be accompanied by absorption or attenuation data. Integrating-sphere PLQY, calibrated front-face emission or other validated geometries are preferable when reabsorption and scattering are substantial. Arbitrary camera photographs should be treated as qualitative illustrations only.

7. Dispersion and spatial homogeneity

Particle-based emitters such as carbon dots, persistent phosphors or other luminescent fillers introduce a spatial-distribution problem in addition to photophysics. Agglomeration changes local scattering and emission; sedimentation can create height-dependent composition during a long build. The carbon-dot work of Maturi et al. explicitly used surface chemistry and ultrasonication to improve incorporation in the resin matrix [2].

ER-36 controls generic rheology, dispersion and sedimentation methodology. ER-56 requires only the luminescence-specific consequence: if the emitting phase is nonuniform, optical output may vary with position even when the printed geometry is dimensionally correct. A qualification coupon should therefore sample the spatial direction most vulnerable to settling or segregation.

8. Network state can change emission

The liquid-resin spectrum is not necessarily the printed-part spectrum. Polymerisation can change polarity, free volume, molecular mobility, aggregation and local refractive environment. Covalently incorporated dyes may experience different conformational freedom than dissolved dyes; AIE systems can become brighter as intramolecular motion is restricted; phosphorescent emitters can be affected by oxygen accessibility and matrix rigidity. Consequently, screening only the liquid formulation is insufficient.

The minimum state sequence is: liquid formulation → partially converted green part → washed/dried part → post-cured part → conditioned service-state part. Emission spectrum, quantum yield or relative intensity should be measured at the state relevant to the intended claim. If the claim concerns long-term function, the same optical endpoint must be repeated after ageing.

9. Post-processing and photobleaching

Washing can extract unbound dye or low-molecular-weight emitter, while post-curing adds optical dose and can change both matrix conversion and chromophore state. Ambient UV/visible exposure may then bleach some emitters or yellow the host network. These effects can move in opposite directions: conversion may improve mechanical stability while optical exposure decreases emitted intensity.

A “stable fluorescent print” claim therefore requires a defined stability endpoint. Useful tests include repeated excitation cycles, cumulative light dose, post-cure comparison, solvent/water conditioning where relevant, temperature/humidity exposure, and spectral or PLQY retest. ER-72 controls generic environmental ageing; ER-56 specifies the luminescence endpoint that must be retained.

10. Measurement architecture

Table 3. Minimum measurement architecture for a photoluminescent printed part

Layer	Minimum record	Why it matters
Manufacturing light	Printer spectrum or nominal wavelength, irradiance/exposure and layer conditions.	Defines spectral competition between PI and luminophore.
Formulation optical state	Absorption/attenuation around cure and excitation bands; emitter identity/loading.	Predicts cure coupling and excitation penetration.
Printed state	Wash/dry/post-cure sequence; specimen thickness and orientation.	Network and geometry alter the measured optical state.
Emission	Excitation wavelength, emission spectrum and calibrated signal or PLQY.	Separates colour from efficiency.
Time response	Lifetime and/or afterglow decay with acquisition window.	Separates prompt fluorescence from delayed/persistent emission.
Spatial uniformity	Multiple positions/heights or mapped signal where particles are used.	Detects settling, aggregation or cure gradients.
Retention	Repeated optical endpoint after defined ageing or cycling.	Needed for stability/service claims.

11. Fluorescence, phosphorescence and scintillation must remain separated

Optical photoluminescence under UV or visible excitation is not the same endpoint as scintillation under ionising radiation. A material can fluoresce strongly yet be a poor scintillator because radiation energy transfer, light yield, timing and pulse-shape behaviour are separate. Conversely, fluorescent dopants developed for scintillators can still be useful mechanistic evidence for cure attenuation if that conclusion is explicitly separated from detector performance.

ER-19 therefore remains the controlling review for scintillation, shielding, neutron absorption and dosimetry. ER-56 does not infer radiation detection from fluorescence, and it does not infer photoluminescence quantum yield or lifetime from a radiation-response result.

12. Fluorescence and passive waveguiding must remain separated

A photoluminescent waveguide may generate light throughout its volume and then guide some fraction of that emission. This is not equivalent to a passive waveguide illuminated only at an input facet. Reabsorption, emission spectrum and spatial generation can dominate the apparent output. ER-55 therefore controls propagation loss, insertion loss, coupling and modal behaviour; ER-56 controls the emissive state. A device paper that combines both should report both sets of quantities rather than collapsing them into total output power.

13. Proposed qualification levels

Table 4. Evidence levels for photoluminescent VPP materials

Level	Evidence required	Permitted conclusion
L0 · Visual screen	Observed emission under named excitation.	Luminescent response observed; qualitative only.
L1 · Spectral confirmation	Excitation/emission spectra in cured printed state.	Defined fluorescence/phosphorescence spectral claim.
L2 · Quantified optical state	PLQY or calibrated intensity + lifetime/decay where relevant + geometry.	Quantitative emission claim in tested state.
L3 · Process coupling	Working curve/cure response with emitter loading + spatial homogeneity.	Printable luminescent formulation demonstrated.
L4 · Retention	Repeated optical endpoint after post-cure, cycling and defined ageing.	Condition-specific retained luminescence.
L5 · Device qualification	Application geometry, interfaces, illumination and detector/readout validated.	Device-level optical claim within tested configuration.

14. 3Dresyns implementation boundary

The controlled 3Dresyns catalogue contains a Fluorescent Yellow Colour and a Phosphorescent Yellow-Green Colour, both positioned as colouring additives for SLA, DLP and LCD resin systems [M1,M2]. Their existence provides relevant manufacturer implementation context because it demonstrates that fluorescent and phosphorescent colour functionality is represented in the commercial formulation toolbox.

ER-56 does not infer emitter chemistry, concentration, excitation maximum, emission maximum, quantum yield, fluorescence or phosphorescence lifetime, persistent afterglow duration, photobleaching resistance, cure-depth effect or compatibility with every base resin from those product descriptions. Those properties require product-specific measurement after incorporation into the intended formulation and completion of the full printing/post-processing workflow.

15. Minimum reporting checklist

- emitter identity/class and whether it is dissolved, covalently bound, dispersed as particles or generated in situ;
- emitter loading and complete base-resin formulation information to the extent disclosure permits;
- printer wavelength/spectrum, exposure, layer thickness and photoinitiator system;
- absorption/attenuation around both printer wavelength and intended excitation band;
- cure-depth/critical-exposure or equivalent printability response versus emitter loading;
- printed specimen geometry, thickness, orientation and spatial sampling position;
- complete wash, dry and post-cure history before optical measurement;
- excitation wavelength/bandwidth, emission spectrum and detector geometry;
- PLQY or calibrated intensity when a quantitative efficiency claim is made;

- fluorescence lifetime, phosphorescence lifetime or afterglow decay according to the actual mechanism claimed;
- scattering/haze or other optical-background descriptor where it materially affects signal;
- spatial homogeneity and sedimentation/agglomeration check for particle-based emitters;
- repeated measurement after defined UV/visible dose, thermal/humidity/fluid exposure or service cycling for stability claims;
- clear separation of photoluminescence from scintillation, photochromism, passive waveguiding and visual colour.

16. Failure-mode and discrimination matrix

Table 5. Common observations and discriminating evidence

Observation	Competing explanations	Discriminating evidence
Weak printed emission	Low PLQY; emitter extraction; quenching; insufficient excitation penetration; reabsorption.	Compare liquid/green/post-cured spectra; mass balance where possible; PLQY; absorption; thickness series.
Strong top surface, weak interior	Excitation absorbed near surface; sedimentation; cure gradient.	Depth-resolved sectioning/map; absorption coefficient; build-height sampling.
Emission drops with higher loading	Aggregation quenching; inner-filter effect; self-absorption; cure change.	Concentration series with PLQY, spectra and working curve.
Colour shifts after post-cure	Photochemistry; matrix polarity/rigidity change; selective bleaching.	Pre/post-cure spectra and controlled additional-dose study.
Apparent long afterglow in photograph	Camera integration/exposure; true delayed emission; ambient-light contamination.	Time-resolved decay with controlled excitation shutoff and detector settings.
Good fluorescence but print failure	Competition with PI; excessive attenuation/scattering.	Printer-spectrum overlap + working curve + cure-depth map.
Good coupon, poor device	Geometry, optical path, coupling or environmental state differs.	Application-geometry optical test and retained-state qualification.

17. Research and standardisation priorities

- VPP-specific round-robin photoluminescence specimens with controlled thickness and post-cure state;
- paired working-curve and PLQY datasets across emitter concentration;
- protocols separating absorption, scattering, reabsorption and true non-radiative loss in printed specimens;
- spatial luminescence mapping through build height for particle-filled systems;
- direct comparison of dissolved, covalently bound, nanoparticle and AIE emitter strategies in the same resin platform;
- afterglow reporting that includes excitation dose, delay, decay window and calibrated intensity;
- post-cure and long-term photobleaching studies with repeat spectral/PLQY measurements;
- cross-wavelength studies where printer wavelength and service excitation wavelength differ strongly;
- clear correction-aware bibliographic reporting when source papers have published errata or clarifications;
- minimum evidence rules separating qualitative glow, quantitative photoluminescence and application-device performance.

18. Conclusions

Photoluminescent VPP materials are not defined adequately by a fluorescent or phosphorescent label. Their realised function emerges from an emitter–matrix–cure–geometry system in which the same optical species can both provide emission and perturb photopolymerisation. Primary literature demonstrates successful fluorescent, phosphorescent and nanoparticle-based printed materials, but also shows that absorption, scattering, matrix compatibility, concentration and network state materially affect both manufacture and optical output.

The minimum defensible claim architecture is therefore: emitter identity and state + printer/cure spectrum + printed/post-cured specimen state + excitation/emission spectra + calibrated efficiency or PLQY when quantitative + lifetime/afterglow where relevant + spatial homogeneity + retention after the intended conditioning. A glow photograph or commercial colour designation is only an initial screen.

For 3Dresyns implementation, the fluorescent and phosphorescent colour products provide formulation routes that can motivate application-specific testing, but they are not substitutes for the optical qualification described here. The scientific endpoint belongs to the finished, processed and conditioned photoluminescent part.

Limitations

This review is a literature-based engineering synthesis and reports no new photoluminescence experiments. The retained studies use different emitters, matrices, printers, wavelengths and measurement geometries, so numerical quantum yields, intensities, lifetimes and cure parameters are not pooled or ranked across studies. Scintillator evidence is used only for VPP cure-spectrum coupling and is not transferred into radiation-performance claims. The Maturi 2020 phosphorescent-resin paper is cited together with its published correction records.

No ISO or ASTM standard identified in this review directly qualifies photoluminescence of a vat-photopolymerised part. General photoluminescence and colorimetry methods may provide adjacent measurement architecture, but they do not address emitter-cure coupling, printed-state spectral change or spatial homogeneity through build height.

Author contributions

Juan Segurola: conceptualisation, literature synthesis, engineering framework, writing and critical review.

Competing interests

The author is founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L. Manufacturer documentation is included only as implementation context and is separated from independent scientific evidence.

Data availability

No new experimental dataset was generated for this review. Scientific statements derive from the cited literature; manufacturer examples derive from controlled 3Dresyns documentation.

Company information

3Dresyns by Resyner Technologies S.L. · General Etxague 15B, 20003 Donostia / San Sebastián, Gipuzkoa, Spain · VAT ESB24827511 · info@3Dresyns.com · www.3Dresyns.com

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