

In-Can Stability, Latency and Premature Cationic Polymerisation in Light-Curable Formulations: Photoacid Generators, Counterion Chemistry, Impurities, Pigments, Fillers and Stabilisation Strategies

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

3Dresyns Engineering Review ER-81 · Version 0.3 · 24 August 2026 · No proprietary formulation composition disclosed

Statement of Significance

Commercial cationic photocuring is not stabilised by the same logic used for radical acrylates. The formulation must retain a photoacid generator that is inactive during storage yet capable of producing sufficient acid under the intended wavelength; the generated acid and oxonium centres may then persist and continue reacting in darkness. Counterion, monomer, water, basic contaminants, sulfur-containing species, pigments, fillers, sensitizers, package contact and temperature can each change a different step. This review therefore treats in-can stability as a coupled balance among unintended acid generation, acid neutralisation, ion-pair reactivity, mass transport and the retained cure response of the aged formulation.

Keywords: cationic photopolymerisation; photoacid generator; PAG; onium salt; counterion; dark cure; oxonium; epoxy; oxetane; vinyl ether; in-can stability; acid scavenger; proton trap; humidity blocker; pigment; filler; package compatibility

Abstract

Cationic photopolymerisation is commercially established in coatings, inks, adhesives, release coatings, photoresists and selected additive-manufacturing formulations, but its storage and latency controls differ fundamentally from those of free-radical systems. A cationic formulation can fail before intended exposure through thermal, photochemical or redox activation of the photoacid generator; after even a short exposure it can continue through dark cure because protonic or oxonium centres may remain active. The same ingredient may increase intended cure while reducing shelf stability, or suppress acid migration while decreasing conversion and cure depth. This review develops a mechanism-led qualification framework for epoxy, oxetane, vinyl-ether and related cationically curable formulations. It compares onium-cation and counterion choices; reversible proton traps, acid scavengers, photobuffers, humidity blockers, microencapsulation, initiator purity and two-component supply; and the conditional use of radical inhibitors when a radical-promoted acid-generation route exists. Particular attention is given to water, hydroxyls, amines, sulfides, ionic contaminants, pigments, dyes, silica, clays, carbonaceous fillers, package contact and optical attenuation. Public commercial documentation is segregated from peer-reviewed evidence. No universal stabiliser, optimum counterion, shelf-life threshold or transferable dosage is proposed. The required output is a formulation- and package-specific stability window that preserves both storage integrity and the complete intended cure response.

1. Scope, terminology and evidence boundary

ER-81 is restricted to light-triggered cationic polymerisation and related photoacid-driven network formation. The principal monomer classes are cycloaliphatic epoxides, glycidyl ethers, oxetanes and vinyl ethers. Chemically amplified photoresists are used only where they provide transferable evidence on acid generation,

buffering or diffusion; their development and imaging chemistry remain outside the main scope. Photobase-mediated and truly anionic systems are reserved for ER-82. The broader taxonomy of 2D, 2.5D and 3D photocuring chemistries and processes is reserved for ER-83.

The central distinction is among four states: (i) unexposed storage, (ii) unintended low-level activation during storage, (iii) intended illuminated cure and (iv) post-exposure dark reaction. A formulation can pass one state and fail another. For example, an acid scavenger may prevent overpolymerisation or acid migration during imaging while also reducing through-cure; a highly active counterion may improve conversion but narrow the thermal-storage margin. Claims must therefore identify the exact state, package and acceptance criterion.

Table 1. Evidence terminology used in ER-81.

Evidence class	Definition	Permitted use
Direct cationic storage evidence	The formulation or initiator is aged under declared time, temperature, light and package conditions, then re-tested.	Supports only the tested formulation and failure criterion.
Cationic mechanistic evidence	The study resolves acid generation, proton capture, oxonium persistence, counterion, impurity or filler effects.	Supports mechanism and test design, not a universal shelf life.
Adjacent photoresist evidence	Acid generation, base quenching or diffusion is measured in chemically amplified imaging materials.	Supports acid-control principles only; coating or VPP performance must be revalidated.
Manufacturer documentation	A supplier identifies product chemistry, application, wavelength, storage or compatibility claims.	Supports product identity and stated positioning, not independent generalisation.
Proposed qualification requirement	A control or descriptor introduced by this review.	Must be labelled as proposed and cannot be presented as a standard.

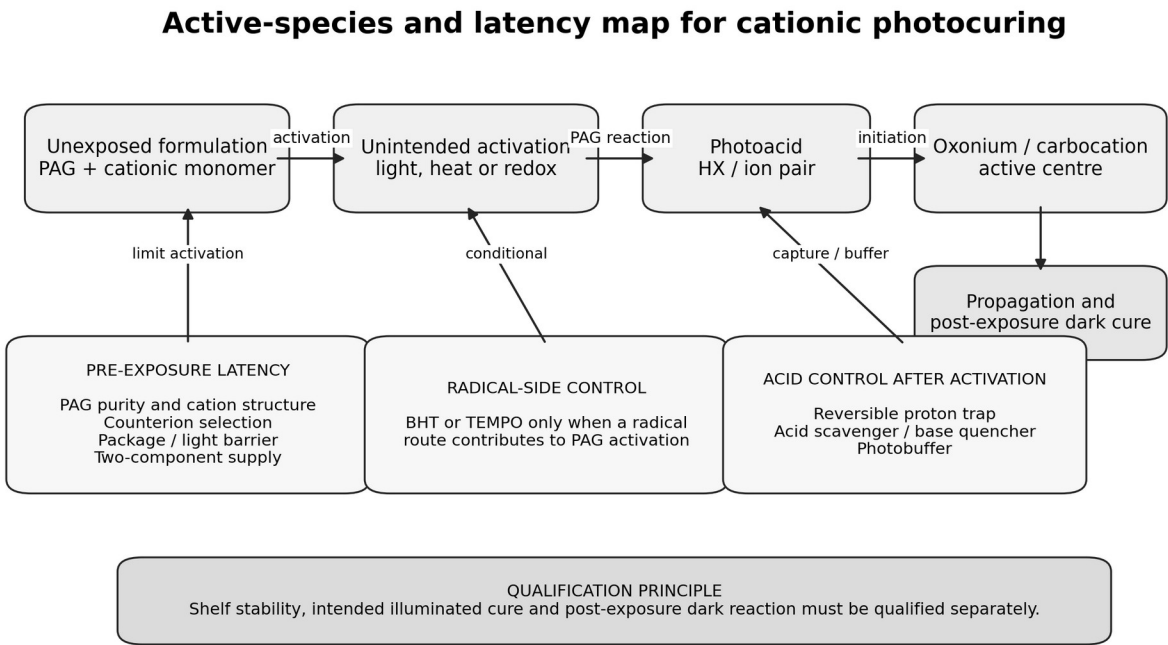


Figure 1. Active-species and latency map for cationic photocuring.

2. Cationic active species and the origin of dark cure

2.1 Photoacid generation and initiation

Direct photolysis of onium salts, sensitised electron transfer and free-radical-promoted cationic polymerisation can all generate the initiating acid or cationic species [1,2,11,20-22]. These routes are not interchangeable from a storage perspective. Directly absorbing sulfonium or iodonium salts can be activated by stray wavelengths that overlap their absorption. Sensitised and radical-promoted systems add donors, dyes, photoinitiators or silanes whose excited-state, redox and peroxide chemistry create additional routes to premature acid generation [2,18,20].

The initial photochemical event and the propagating species must be separated. A radical may be required to reduce or oxidise an onium salt, yet the subsequent polymerisation is cationic. Conversely, a radical inhibitor can suppress that upstream route without directly neutralising an already generated proton or oxonium centre. This is why BHT, TEMPO or MEHQ cannot be classified as universal cationic stabilisers. Epoxide structure also changes propagation and conversion independently of PAG activity, so storage and cure comparisons require the same monomer family and composition [10].

2.2 Persistent centres and post-exposure reaction

Sipani and Scranton shuttered the initiating light during the cationic polymerisation of phenyl glycidyl ether and monitored continued reaction in darkness, using the long lifetime of the active centres to obtain kinetic constants [3]. The industrial consequence is that the end of illumination is not necessarily the end of material evolution. Dark conversion, modulus development, shrinkage, heat release and stress may continue after exposure, especially when the formulation remains warm and mobile.

A shelf-stable formulation therefore needs two different controls: no significant activation before intended exposure, and a quantified post-exposure dark reaction after intended exposure. Suppressing the second by adding base may also suppress the first few micrometres or the full depth of intended cure. The acceptable dark-cure window is application-specific rather than intrinsically good or bad.

3. Photoacid-generator families and commercial latency architecture

3.1 Sulfonium, iodonium and related onium salts

Triarylsulfonium and diaryliodonium salts remain the principal commercial onium families. Sulfonium grades are often selected where one-component storage stability is important, whereas iodonium grades can provide strong sensitisation but may show poorer storage stability in cationically polymerisable resins, according to current supplier documentation [M1-M4]. Research has also examined pyrylium, oxonium, selenonium, telluronium, bismuthonium and stibonium structures [12,13]. The cation controls absorption, reduction potential, fragmentation, solubility and thermal stability; the anion controls ion pairing, acid expression, nucleophilicity and hydrolytic behaviour.

Taschner and co-workers reported a sulfonium borate initiator with high reactivity and more than 30 days of storage stability at 50 °C in a BADGE formulation containing 1.0 mol% sulfonium salt alone [5]. The sensitiser and EDAB superacid scavenger used in their printing formulation were not part of that storage formulation. The study therefore supports PAG-level storage design and a separate process-control use of EDAB, not a claim that EDAB produced the reported 30-day shelf stability.

3.2 Wavelength extension and the stability trade-off

Long-wavelength initiation can be achieved by covalently integrating chromophores into iodonium salts or by adding external sensitizers and radical donors [2,20-22]. Zivic and co-workers developed a naphthalimide-based one-component iodonium salt active under 365-395 nm LEDs [21], while Topa and co-workers

developed coumarin-based iodonium salts for visible-LED cationic polymerisation and 3D-printing-related IPN formulations [22]. These systems reduce dependence on short-wave UV, but each added chromophore or donor changes storage photochemistry, colour, solubility and spectral competition with pigments and dyes.

Commercial product selection reflects this trade-off. San Apro distinguishes low-absorption grades for thick films from higher-absorption grades for 365/405 nm sensitivity [M1,M2,M9]. IGM positions Omniscat 250, an iodonium PF₆ formulation in propylene carbonate, for thick and highly pigmented epoxy or oxetane systems [M5]. These claims identify intended use; they do not establish a universal storage-stability ranking.

4. Counterion chemistry: activity, hydrolysis and compatibility

Counterions are not passive labels. Their nucleophilicity and coordinating ability affect the lifetime and reactivity of propagating cations; their hydrolysis and ion-pair behaviour influence corrosion, colour and storage. Toba, Saito and Usui showed that onium tetrakis(pentafluorophenyl)borates support direct and sensitised cationic photopolymerisation, with kinetics linked to sensitiser electron transfer and thermal loss of generated acid [11]. Taschner, Liska and Knaack used tetrafluoroborates to compare a broader set of onium cations, while explicitly recognising solubility and possible HF-release limitations [13].

The commonly repeated order $\text{SbF}_6^- > \text{AsF}_6^- > \text{PF}_6^- \gg \text{BF}_4^-$ is useful only as a qualitative acid-strength or non-nucleophilicity guide. It is not a complete performance ranking. Arsenic-containing salts are historical rather than preferred contemporary design choices. Antimony-free borate systems can provide high cationic activity, but solubility, molecular mass, hydrolysis, wavelength response and package compatibility remain formulation-specific.

Table 2. Counterion qualification matrix. Ratings are qualitative and must be revalidated in the exact formulation.

Counterion family	Potential advantages	Principal cautions	Required verification
BF ₄ ⁻	Commercial availability; simple ion exchange; useful research benchmark.	More nucleophilic; lower expressed activity in many systems; hydrolysis/HF concerns.	PAG solubility, water content, corrosion, fresh/aged cure.
PF ₆ ⁻	Widely used commercial balance; available in iodonium and sulfonium products.	Fluoride/hydrolysis considerations; activity depends on cation and medium.	Package contact, water, colour, through-cure.
SbF ₆ ⁻	Very weakly coordinating; high cationic activity and post-cure.	Antimony content, potential corrosion and regulatory burden.	Exact SDS, leachables, corrosion and disposal route.
B(C ₆ F ₅) ₄ ⁻ and related borates	Antimony-free strong-acid route; selected commercial grades claim low corrosion and hydrolysis resistance.	High molecular mass; solubility and proprietary-anion dependence.	Identity, purity, solvent, wavelength and aged cure.
Proprietary special anions	Can target low corrosion, low colour or selected wavelength response.	Structure and mechanism may not be publicly disclosed.	Use only manufacturer-stated claims; no structural inference.

Qualitative counterion design space

BF ₄ ⁻	PF ₆ ⁻	SbF ₆ ⁻	Borates
Acid expression Moderate	Acid expression High	Acid expression Very high	Acid expression High; structure-dependent
Typical advantage Availability; easy synthesis	Typical advantage Common commercial balance	Typical advantage Strong cationic cure	Typical advantage Antimony-free; tunable solubility
Principal cautions Lower activity Hydrolysis / HF risk	Principal cautions Hydrolysis Fluoride / corrosion	Principal cautions Antimony content Corrosion burden	Principal cautions High molecular mass Proprietary structures
NO UNIVERSAL RANKING Performance depends jointly on the onium cation, monomer, sensitiser, residual water, temperature, solvent and package.			

Figure 2. Qualitative counterion design space.

5. Stabilisation and latency-control strategies

5.1 Initiator purity, cation structure and solution form

Public commercial documentation places substantial emphasis on PAG purity and cation structure rather than on a separate universal stabiliser. San Apro attributes the storage stability of its CPI sulfonium grades in cationically polymerisable monomers to high-purity monosulfonium cations produced by a proprietary process [M1-M3]. The formulation engineer should treat this as a supplier-specific product claim and verify the final monomer/PAG/package combination. Trace bis-sulfonium species, ionic impurities, residual synthesis acids or bases and solvent quality can all alter latency.

5.2 Reversible proton traps

Finson, Jury and Crivello demonstrated a cyclic azodioxide that captures photogenerated initiating protons at lower temperature, suppressing cationic polymerisation, and releases them after thermal conversion of the trap [4]. This is a true reversible-latency strategy rather than a permanent neutralisation. Its applicability depends on the trap-to-acid stoichiometry, temperature programme, monomer and desired post-exposure response. It is not evidence for a universal commercial additive dosage.

5.3 Acid scavengers and base quenchers

Taschner and co-workers used ethyl 4-(dimethylamino)benzoate (EDAB) at 0.12 mol% as a superacid scavenger in a sensitised printing formulation to neutralise migrating acid and reduce overpolymerisation [5]. Its function was spatial cure control, not the separate 30-day storage result. In chemically amplified photoresists, Pawloski, Christian and Nealey showed that base quenchers can do more than stoichiometrically neutralise acid: they may also alter deprotection, dissolution and induction behaviour [24]. This adjacent evidence warns that a base cannot be treated as a single-function stabiliser.

5.4 Photobuffers

Ma and co-workers used weakly basic photobuffers to sequester PAG-generated protons until additional light dose consumed the buffer and enabled cationic polymerisation [6]. This supports dose-programmed latency

and mechanism switching. It is not a passive shelf-life study, and the photobuffer must not be presented as a universal in-can stabiliser without dark-storage data.

5.5 Humidity blocking and hydroxyl management

High humidity can inhibit cationic photopolymerisation, yet hydroxyl-containing additives may accelerate epoxide conversion through chain transfer or an activated-monomer pathway [7,9,23]. Chen and co-workers combined a hydrophobic epoxy-siloxane humidity blocker with hydroxy-functional reactive diluents to obtain more consistent conversion across humidity conditions [7]. This illustrates why “water is bad” and “hydroxyls are good” are both over-simplifications: external water, internal alcohol, monomer structure and transport act differently.

5.6 Microencapsulation and physical separation

Komarova, Ren and Neckers encapsulated a visible-light cationic photoinitiator in polystyrene to increase thermal stability [12]. Physical separation, controlled release and two-component supply are therefore legitimate latency architectures. They introduce new variables: particle size, optical scattering, diffusion, release kinetics, mixing uniformity and the possibility of local acid concentration gradients.

5.7 Radical inhibitors: conditional use only

Radical inhibitors may be useful only where a radical route contributes to unwanted onium activation, parasitic radical homopolymerisation or peroxide chemistry. In the silane/iodonium redox system reported by Wang and co-workers, TEMPOL and selected inorganic salts were used to extend the gel-time window, while the authors also reported storage stability in epoxide resin [18]. This is formulation-specific control of an upstream radical/redox route. In free-radical-promoted cationic polymerisation, the intended acid-generation route itself depends on oxidisable radicals [2,18,20]. BHT, TEMPO, TEMPOL or related inhibitors can therefore improve one side reaction while slowing the intended cationic cure. No source retained in this review establishes any of them as a direct universal inhibitor of protonic or oxonium propagation.

5.8 Commercial light stabilisers compatible with acidic systems: a separate function

Commercial non-basic hindered-amine light stabilisers provide an important terminology boundary. BASF positions Tinuvin 123 as a non-basic N-OR HALS for acid-catalysed coatings and states that it does not interact with acidic ingredients such as catalysts, biocides and pigments [M10]. Clariant positions Hostavin 3058 LIQ as a non-basic HALS for acid-catalysed and oxidative systems and states that it does not interact with photoinitiator radicals during UV curing [M11]. These products are designed primarily to protect the cured coating against long-term photooxidative degradation. They are not evidence of PAG shelf-life stabilisation, proton trapping or suppression of cationic dark cure. Conversely, a basic HALS or amine-containing light stabiliser can neutralise acid and must not be substituted without cure and storage validation.

Table 3. Stabilisation strategies and interpretation boundaries.

Strategy	Primary controlled event	Direct evidence retained	Main penalty or confounder
High-purity / thermally stable PAG	Unintended acid generation during storage.	Supplier positioning; BADGE storage study [5,M1-M3].	Absorption, solubility and activity may narrow.
Counterion selection	Ion pairing, acid expression, hydrolysis and corrosion.	Onium borate and BF ₄ studies [11,13].	No universal ranking; package and water dependence.
Reversible proton trap	Temporary capture of photogenerated acid.	Azodioxide system [4].	Thermal trigger and stoichiometry required.
Acid scavenger / base quencher	Migrating or excess acid.	EDAB printing system [5]; photoresist adjacency [24].	Conversion, depth and development effects.
Photobuffer	Dose-gated proton sequestration.	Mechanism-switching thermoset system [6].	Not passive shelf-life evidence.

Strategy	Primary controlled event	Direct evidence retained	Main penalty or confounder
Humidity blocker / internal OH source	External humidity and chain-transfer balance.	Epoxy-siloxane / hydroxyl system [7].	Hydroxyls alter network and kinetics.
Microencapsulation / physical separation	PAG contact and thermal activation.	Encapsulated pyrylium initiator [12].	Scattering, release and spatial heterogeneity.
Radical inhibitor	Upstream radical or peroxide side route.	TEMPOL-controlled silane/iodonium redox system and FRPCP evidence [2,18,20].	May suppress intended photoacid generation.
Two-component packaging	Premature contact among reactive components.	Commercial metallic cationic ink practice [M8].	Mixing ratio and user-process variability.

Stabilisation strategy atlas: controlled event and principal trade-off

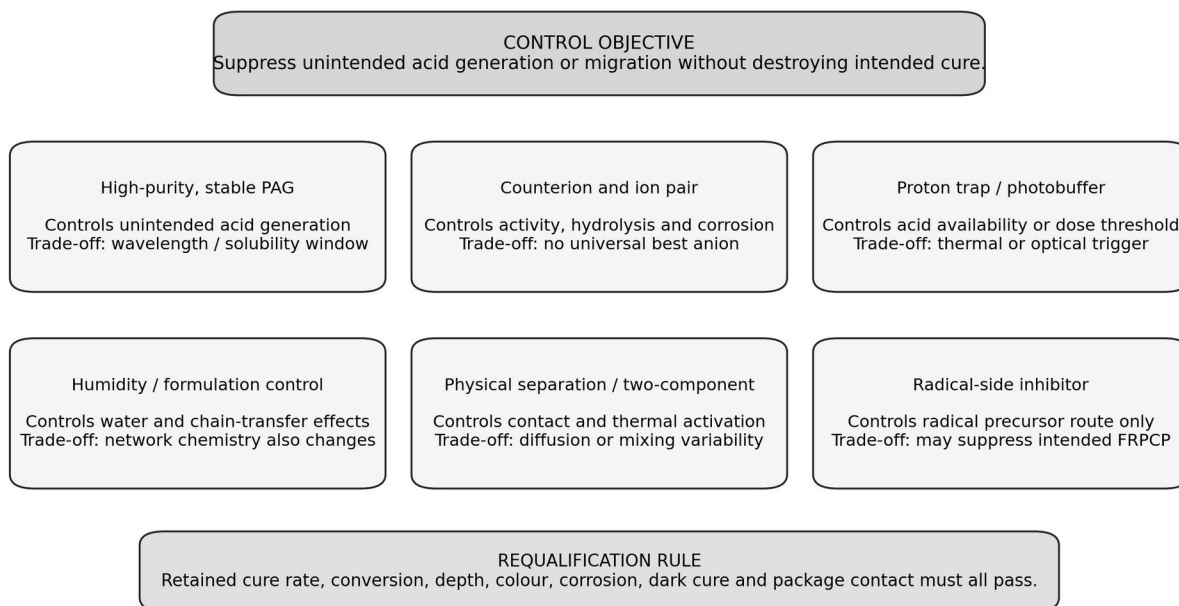


Figure 3. Stabilisation strategy atlas.

6. Residuals and impurities

6.1 Water and humidity

Water can solvate protons, participate in chain transfer, change ion pairing and inhibit or redirect epoxide polymerisation. Its effect depends on concentration, monomer hydrophobicity, hydroxyl content and temperature [7]. A single Karl Fischer value is useful but not sufficient; water should be tracked in the complete mixture, after filler addition and after package conditioning. Humidity exposure of a thin coating and water absorbed into a filled bulk formulation are different states.

6.2 Alcohols and hydroxyl-functional impurities

Alcohols are not universally inhibitory. Benzyl alcohols markedly accelerated onium-salt-initiated epoxide polymerisation by combining an activated-monomer pathway with radical participation [9]. Hydroxylbutyl vinyl ether can react through both active-chain-end and activated-monomer mechanisms [23]. Residual alcohol from synthesis, solvent, dispersant or package extractable can therefore shorten latency or change network architecture rather than simply quench acid.

6.3 Amines, bases and alkaline residues

Amines and bases are the most direct acid-neutralising contaminants. Sources include dispersants, pigments, aminosilanes, urethane catalysts, cleaning residues, alkaline fillers and amine-containing package components. Their effect depends on basicity, mobility and phase distribution. A low average concentration may still create local dead zones on filler surfaces or at interfaces. The Resino cationic ink documentation explicitly warns that water and amines inhibit the system [M8].

6.4 Sulfides, thiols and phosphorus-containing species

Falk, Zonca and Crivello showed that dialkyl sulfides strongly inhibit and diaryl sulfides retard onium-salt-induced cationic epoxide photopolymerisation, proposing sulfonium intermediates [8]. Sulfur-containing pigments, accelerators, antioxidants, chain-transfer agents or package extractables should therefore be treated as mechanism-specific risks. Thiols and phosphines may also alter redox or coordination chemistry; their compatibility cannot be inferred from performance in radical systems.

6.5 Peroxides, radicals and metal contaminants

Sensitised and FRPCP systems add radical and redox chemistry upstream of cationic propagation [2,18,20]. Hydroperoxides, transition-metal residues and radical-forming impurities can therefore alter acid-generation rates even when the final network forms cationically. The correct control is not merely “add antioxidant”: compare fresh and aged PAG decomposition, radical contribution, acid generation and cationic conversion with matched inhibitor controls.

6.6 Ionic impurities, halides and synthesis residues

Halides, residual ion-exchange salts, unreacted sulfonium or iodonium precursors, acid, base and polar solvent can change PAG solubility, ion pairing and corrosion. Conductivity alone is non-specific, but it can be useful as a batch screen when linked to ion chromatography or targeted analysis. Purification history should be recorded for laboratory PAGs, while commercial grades should be identified by exact lot and solution form.

Table 4. Residual and impurity effects requiring specific controls.

Residual / impurity	Possible effect	Discriminating measurement	Interpretation limit
Water / humidity	Proton solvation, chain transfer, inhibition or spatial gradients.	Karl Fischer; humidity-conditioned cure; fresh/aged conversion.	Effect depends on monomer and internal hydroxyls.
Alcohol / hydroxyl species	Activated-monomer acceleration, chain transfer, network change.	Targeted GC/HPLC; OH value; kinetic comparison.	Not automatically a stabiliser or inhibitor.
Amine / base	Acid neutralisation and dead zones.	Acid titration; extractables; cure-map around filler/interface.	Average bulk concentration can hide local poisoning.
Sulfide / sulfur species	Strong inhibition or retardation depending on structure.	Compound-specific spike study; RT-FTIR.	Do not transfer one sulfide result to the whole class.
Peroxide / radical precursor	Premature FRPCP activation or competing radical chemistry.	Peroxide assay; radical-inhibitor control; PAG decomposition.	Relevant mainly to sensitised/redox systems.
Metal / ionic residue	Redox, corrosion, colour, PAG decomposition or adsorption.	ICP/IC; package blank; spectral and corrosion test.	Elemental identity alone does not define effect.
Residual solvent	Solubility, mobility, evaporation, phase separation.	GC; mass loss; viscosity and cure at fixed solvent content.	Supplier solution grades must be treated as formulations.

Impurities, pigments, fillers and additives alter different parts of the cationic system

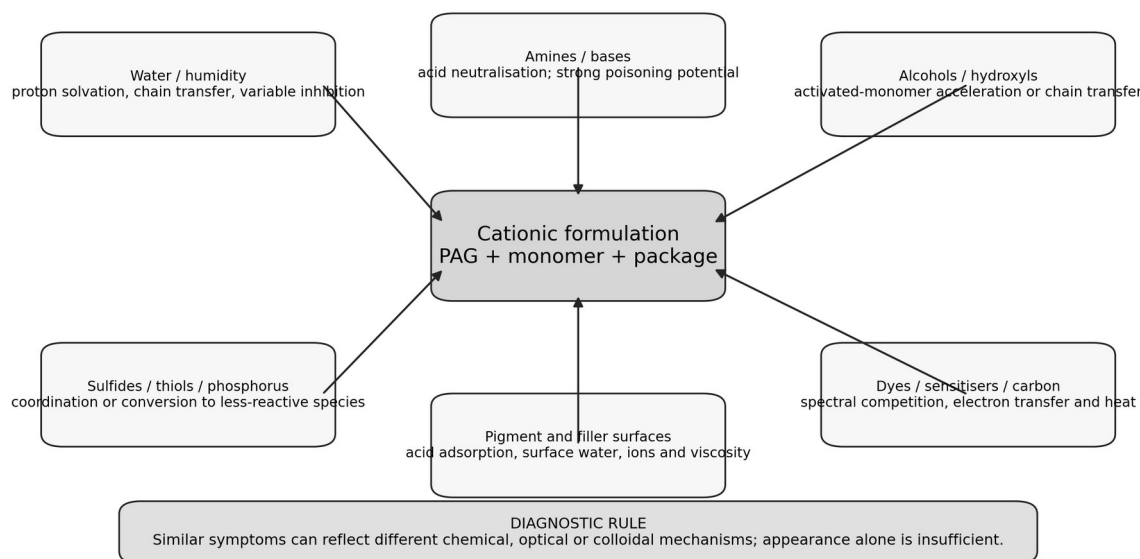


Figure 4. Impurity, pigment, filler and additive interaction map.

7. Pigments, dyes, fillers and formulation additives

7.1 Optical and photochemical effects

A pigment, dye or carbonaceous filler can reduce cure through absorption or scattering, but it may also sensitise the PAG, participate in electron transfer or convert light to heat. One-component chromophoric iodonium salts demonstrate that a coloured chromophore can be part of the initiation architecture rather than only an optical blocker [21,22]. The correct question is therefore whether the commercial grade changes the complete spectral, redox and transport balance, not whether its nominal colour is “good” or “bad”.

7.2 Silica and silanol-containing surfaces

Silica is not chemically inert in every cationic system. In SU8 formulations, low silica-nanoparticle loadings with surface silanol groups increased cure rate and conversion, whereas higher loading reduced crosslink density through aggregation [14]. Functionalised silica studies show that surface chemistry and dispersion control both kinetics and final nanocomposite properties [15,17]. A current commercial example, Evonik NANOPOX C 620, is documented as 40 wt% of 20 nm nanosilica in a cycloaliphatic epoxy resin for cationic UV coatings, with 10-20% as-supplied recommended addition and at least 18 months of shelf life in unopened packaging at 4-40 °C [M12]. This is supplier documentation for one predispersed nanocomposite, not evidence that silica universally improves cationic storage or cure. Silica grade, surface treatment, adsorbed water and agglomeration state must therefore be specified.

7.3 Clays, minerals and surface water

Bongiovanni and co-workers found that natural and organically modified clays caused significant changes in rate and final conversion, and that only a suitable montmorillonite after suitable pretreatment matched the neat-resin rate while increasing conversion [16]. Clay identity, modifier chemistry and water content are inseparable variables. A generic “organoclay” or “nanoclay” label is not a sufficient formulation descriptor.

7.4 Carbonaceous and opaque fillers

Carbon black, graphite, graphene, nanotubes and carbon fibres strongly alter optical penetration and heat transfer. Gachet and co-workers used a photoactive sulfonium salt plus a latent thermal sulfonium salt to

sustain a thermal front through carbon-filled and carbon-fibre epoxide systems [19]. This is a dual photo/thermal architecture, not evidence that ordinary cationic VPP will cure through opaque filler. Carbon grade, surface oxygen, metal residues, particle size and thermal conductivity require separate controls.

7.5 Dispersants, surfactants and adhesion promoters

Dispersants and adhesion promoters can contain amines, phosphates, sulfur groups, acids, hydroxyls or metal ions. They may improve colloidal stability while poisoning or accelerating the cationic reaction. A dispersion that remains visually uniform can still lose cure because the PAG or acid adsorbs at the particle surface. The minimum control is a matched clear resin, a filler-only resin and a filler-plus-dispersant resin tested at the same optical dose and thickness.

Table 5. Pigment, filler and additive effects in cationic formulations.

Component class	Potential stabilising or useful effect	Potential destabilising or cure-limiting effect	Minimum control
Organic pigment / dye	Spectral sensitisation; optical confinement.	Photon competition, electron transfer, residual amines or salts.	Absorption/emission, redox and grade-specific spike study.
TiO ₂ / metal oxides	Opacity, reinforcement, possible surface acidity.	Scattering, photocatalysis, basic treatment, adsorbed water.	Surface treatment, water, radical/acid controls.
Silica / alumina	Reinforcement, rheology, proton-donor surfaces in selected systems.	PAG/acid adsorption, water, aggregation.	Untreated vs treated grade; supernatant and dispersion cure.
Clay / organoclay	Rheology and barrier properties.	Modifier basicity, surface water, variable conversion.	Drying/pretreatment matrix and exact grade.
Carbon black / graphite / graphene / CNT	Electrical/thermal function; photothermal contribution.	Severe attenuation, surface radicals, metal residues, high area.	Optical depth, extractables and thermal-front control.
Metal / ceramic filler	Functional conductivity, dielectric or mechanical properties.	Corrosion, ionic extractables, basic surfaces, sedimentation.	Package/filler blanks, ion analysis, depth-resolved cure.
Dispersant / surfactant	Prevents settling and optical heterogeneity.	Amine, phosphate, sulfur or hydroxyl interference.	Filler-only vs filler-plus-dispersant comparison.

8. Package, storage and process architecture

Package compatibility is part of the formulation. Glass, HDPE, polypropylene, coated metal, liners, seals, pumps and transfer tubing can introduce ions, bases, plasticisers, sulfur compounds or water. Transparent or translucent containers also change the stray-light dose. A package screen should therefore compare formulation held in the intended container with an inert reference under the same temperature, headspace and light history.

Storage temperature must be treated as a kinetic variable, not a simple pass/fail condition. A formulation may remain unchanged at 23 °C but activate during transport excursions, or it may show slow acid formation without visible viscosity change. Conversely, a highly viscous filled system may hide early conversion. Small-vial results cannot be transferred directly to drums or IBCs because heat removal, headspace, wall area, package permeability and mixing history differ.

Two-component supply is an established commercial control where one-component stability is inadequate. Resino states that gold and silver cationic UV inks are poorly stable and therefore supplies the ink as two components mixed shortly before use [M8]. This is strong evidence for a practical storage architecture, but it does not identify the proprietary destabilising species or provide a transferable composition.

9. Commercial implementation context

The following examples are included only to show how commercial suppliers implement cationic initiation and latency. Product pages can support exact identity, anion, solution form, wavelength, application and supplier-stated storage claims. They are not independent evidence of universal performance, toxicological superiority or suitability in a different resin, pigment package or printer.

Table 6. Public commercial implementation examples reviewed for ER-81.

Commercial example	Publicly stated function	Latency or compatibility relevance	Boundary
San Apro CPI-100B(40) / CPI-110B	General-purpose sulfonium borate PAG; supplier states excellent storage stability in cationic monomers.	High-purity monosulfonium cation and borate are supplier-attributed design factors.	Verify exact monomer, lot, solvent and package [M2].
San Apro CPI-101A	Sulfonium SbF_6 PAG in propylene carbonate; supplier states storage stability and low coloration.	Antimony benchmark for activity and colour.	Requires exact hazard, corrosion and disposal assessment [M3].
San Apro IK-20B / IK-1FG	Iodonium PAGs for sensitised longer-wavelength use.	Supplier states lower resin-storage stability than sulfonium grades but larger sensitiser effect.	Not a universal iodonium ranking [M4].
San Apro ES-1B / CPI-410B	Borate sulfonium PAGs with 365/405 nm sensitivity and low-corrosion positioning.	Shows wavelength, anion and application trade-offs.	No standalone stabiliser claim [M9].
IGM Omnica 250	Iodonium PF_6 solution for epoxy/oxetane, including thick and highly pigmented systems.	Commercial evidence that pigmented cationic systems are formulated.	No public shelf-life claim [M5].
IGM Omnica 320	Triarylsulfonium SbF_6 solution for epoxy, oxetane and vinyl ether; high cure speed and post-cure.	Illustrates strong post-cure and counterion choice.	Not evidence of low toxicity or low corrosion [M6].
Evonik TEGO Photo Compound 1467	Solvent-free photocatalyst for cationic silicone release coatings; supplier states long shelf life.	Application-specific commercial cationic photocatalyst.	Silicone release formulation, not general epoxy PAG evidence [M7].
Resino RESUCAT 213-14	Two-component metallic cationic UV flexo-ink system.	Component separation used to improve storage stability.	Proprietary ink system; mechanism not inferred [M8].
BASF Tinuvin 123	Non-basic N-OR HALS for acid-catalysed coatings.	Designed to avoid interaction with acidic coating ingredients.	Cured-film weathering stabiliser, not an in-can cationic inhibitor [M10].
Clariant Hostavin 3058 LIQ	Non-basic HALS for acid-catalysed and oxidative systems.	Supplier states no interaction with photoinitiator radicals during UV cure.	Cured-film light stabiliser, not PAG latency evidence [M11].
Evonik NANOPOX C 620	40 wt% of 20 nm nanosilica predispersed in cycloaliphatic epoxy resin for cationic UV coatings.	Commercial filled cationic formulation component with declared storage and addition guidance.	Filler compatibility example, not a universal stabiliser [M12].

10. Qualification architecture

10.1 Required material states

Every qualification should distinguish: fresh unexposed formulation; aged dark formulation; aged stray-light formulation; intentionally exposed specimen at light-off; and the same specimen after a declared dark-cure interval. Filled materials additionally require top, middle and bottom sampling or a validated homogenisation procedure. A single fresh working curve or one clear-vial photograph cannot represent these states.

10.2 Minimum accelerated-ageing matrix

A practical matrix varies temperature, time, package, headspace, light leakage, humidity or water, pigment/filler grade and stabilisation strategy. The matrix must include true replicates, a fresh control, a package blank and a positive degradation or activation control where feasible. Accelerated conditions should be selected below obvious runaway or package-failure regimes and should not be converted to a room-temperature shelf life without a validated kinetic model.

10.3 Retained-cure endpoints

The aged formulation must be tested for its intended function, not only for absence of gel. Recommended endpoints include viscosity or rheology, soluble/insoluble fraction, PAG or acid-state indicator where available, onset and peak reaction rate, final conversion, dark conversion after light-off, cure depth or feature response, colour, corrosion, extractables and final mechanical or functional performance. Acceptance criteria should be declared before testing.

Table 7. Minimum cationic in-can qualification design.

Block	Minimum variables	Minimum controls	Required outputs
Identity	Monomer family, PAG cation/anion, solvent, sensitiser, stabiliser, additive and lot.	Exact fresh formulation and supplier documents.	Traceable formulation state without proprietary disclosure beyond authorisation.
Storage stress	Time, temperature, dark/stray light, humidity, package, headspace.	Fresh, dark blank, package blank, positive control.	Declared exposure history and failure criterion.
Filled system	Pigment/filler grade, surface treatment, loading, dispersant, water and sampling depth.	Clear resin, filler-only, filler-plus-dispersant.	Separation of colloidal, optical and chemical effects.
Chemical state	Water, PAG/acid indicator, targeted ions or extractables.	Method blank and recovery check.	Mechanism-supporting evidence, not appearance alone.
Cure response	Onset, peak rate, conversion, dark conversion, depth or feature response.	Fresh formulation at identical optical and thermal conditions.	Retained cure window and uncertainty.
Final performance	Relevant geometry, conditioning, mechanical/functional and corrosion endpoints.	Matched post-processing and specimen state.	Application-specific decision, not universal ranking.

Minimum accelerated-ageing and retained-cure qualification architecture

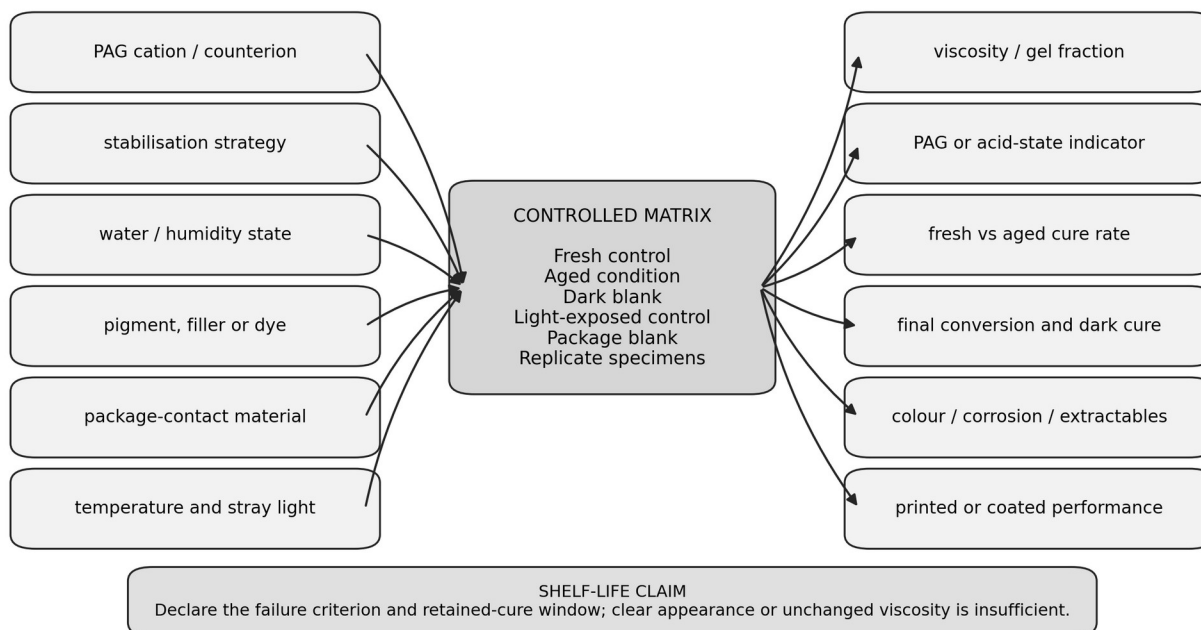


Figure 5. Minimum accelerated-ageing and retained-cure qualification architecture.

11. Proposed reporting aids

The following quantities are proposed as reporting aids, not standards. Their purpose is to make the material state and denominator explicit. They should be accompanied by the raw curves, uncertainty, sample count and the exact illumination and thermal histories.

Table 8. Proposed reporting aids for cationic storage and dark-cure studies.

Quantity	Definition	Required declaration	Interpretation boundary
$\Delta X_{\text{dark}}(t)$	$X(t \text{ after light-off}) - X(\text{light-off})$.	Conversion method, light-off time, temperature and observation window.	Measures post-exposure continuation, not in-can stability.
$R_{X,\text{aged}}$	$X_{\text{final,aged}} / X_{\text{final,fresh}}$.	Fresh and aged optical/thermal conditions and final-time criterion.	A value near 1 can hide a slower rate or longer dark cure.
$R_{r,\text{aged}}$	$r_{\text{max,aged}} / r_{\text{max,fresh}}$.	Rate extraction method, smoothing and replicate uncertainty.	Peak rate alone does not establish adequate conversion or depth.
Δt_{onset}	$t_{\text{onset,aged}} - t_{\text{onset,fresh}}$.	Operational onset criterion and detection limit.	Positive or negative shifts require mechanism-specific interpretation.
$t_{\text{fail,storage}}$	First time at which a declared failure criterion is exceeded.	Criterion, interval censoring and test schedule.	If no failure occurs, report right-censored, not infinite shelf life.

12. Failure modes and interpretation errors

Table 9. Common failure modes in cationic stability studies.

Observation	Possible interpretation error	Required response
No visible gel after ageing	Shelf life declared from appearance alone.	Measure retained cure, conversion, PAG/acid state and viscosity.
Aged resin cures eventually	Latency loss missed because final conversion is	Compare onset, peak rate, dark cure and

Observation	Possible interpretation error	Required response
	similar.	exposure required.
Base additive improves resolution	Additive labelled an in-can stabiliser.	Separate printing formulation from storage formulation and test both.
BHT improves one formulation	BHT called a cationic inhibitor.	Determine whether it suppresses an upstream radical route or the intended acid-generation pathway.
Pigmented resin cures poorly	Pigment colour blamed generically.	Test optical attenuation, surface water, basic extractables, adsorption and dispersant separately.
Silica increases conversion	All silica grades declared catalytic.	Report surface treatment, silanol density, water, loading and aggregation.
Two-component ink is stable	Component separation treated as intrinsic resin stability.	Report mix ratio, induction time, mixed pot life and user-process sensitivity.
Strong counterion gives fastest cure	Counterion declared universally superior.	Include hydrolysis, corrosion, colour, package and aged-cure evidence.
Same PAG code, different supplier or lot	Identity assumed equivalent.	Lock supplier, lot, solution form, purity and storage history.

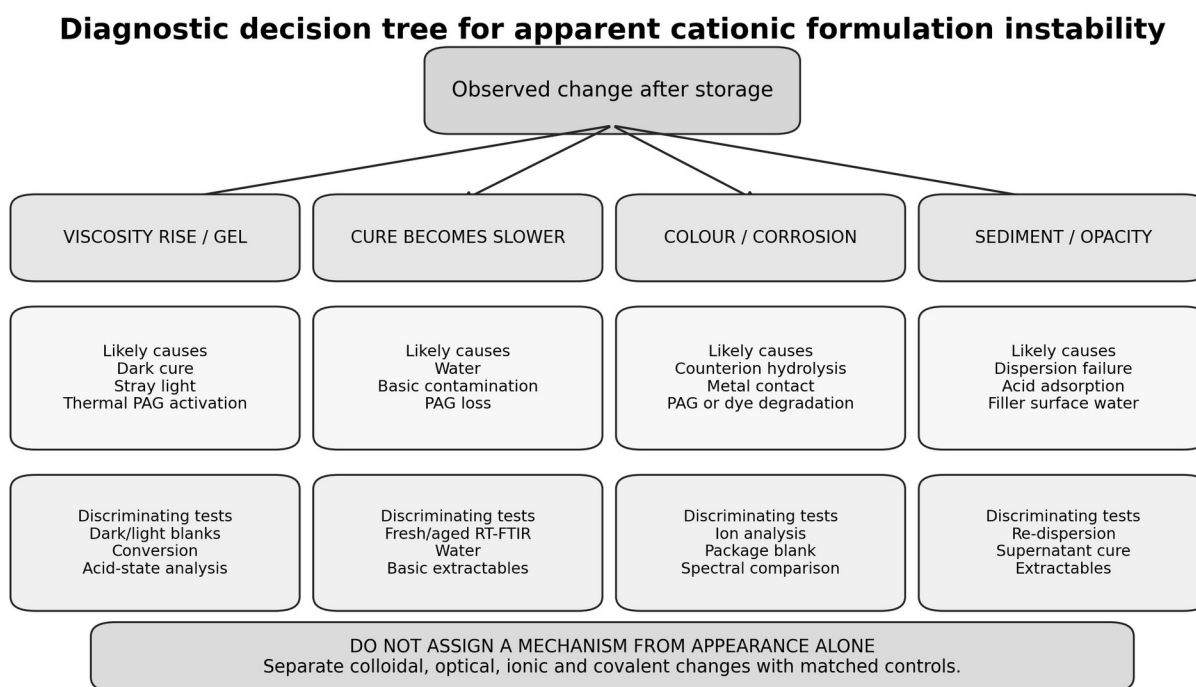


Figure 6. Diagnostic decision tree for apparent cationic instability.

13. Safety and scale-up boundary

Photoacid generators, superacids, fluorinated counterions, antimony-containing salts, sensitizers, amines, sulfur compounds and proprietary commercial mixtures require exact-identity SDS review. This review does not infer hazard from a generic PAG class and does not treat antimony-free, borate, low-corrosion or low-outgassing positioning as a toxicological conclusion. Hydrolysis products, metal corrosion, extractables and package compatibility must be evaluated for the intended application.

Accelerated ageing and frontal or dark cationic polymerisation can generate heat, pressure and rigid gel. Tests should use small quantities, compatible containers, temperature limits, remote monitoring and abort criteria. Scale-up must account for heat-removal area, package wall, headspace, filler thermal conductivity and the possibility that a formulation stable in a thin film becomes self-heating in bulk.

14. Scope boundaries within the Engineering Review series

Shared measurement conventions, evidence levels and disclosure boundaries are defined in RP-02 [R1]. ER-81 states only the topic-specific content.

ER-80 addresses radical in-can instability, hydroperoxides, phenolic inhibitors, nitroxides, metal-mediated redox and pigment-coupled radical chemistry. ER-81 refers to radical inhibitors only where a radical side route contributes to cationic acid generation [E1].

ER-82 will address photobase-mediated, anionic and base-catalysed systems. Acid scavenging in ER-81 must not be transferred as a base-stabilisation strategy [E2]. ER-83 will provide the broader taxonomy of 2D, 2.5D and 3D photocuring chemistries and processes [E3].

ER-32 addresses storage, reuse and the open-vat state, including contamination, light leakage and repeated printing. ER-81 is restricted to cationic mechanism, latency and package-contact chemistry [E4].

ER-30 addresses oxygen inhibition and surface-cure effects. ER-81 discusses oxygen only when it changes an upstream radical or redox route in a cationic initiating system [E5]. ER-27 addresses conversion metrology; ER-81 uses conversion-based reporting aids but does not define a conversion method [E6]. ER-61 addresses gelation, vitrification and mobility arrest during network formation; ER-81 treats gel as a storage-failure endpoint and dark cure as a time-dependent cationic reaction [E7].

15. Conclusions

- Cationic in-can stability is a coupled problem of PAG integrity, unintended activation, counterion chemistry, acid neutralisation, water, transport, additives and package contact.
- Dark cure is an intrinsic post-exposure state and must be measured separately from unexposed shelf stability.
- Sulfonium versus iodonium, and BF_4^- , PF_6^- , SbF_6^- or borate counterions, cannot be ranked without the exact monomer, sensitiser, water, temperature and package.
- Direct latency strategies include high-purity stable PAGs, reversible proton traps, acid scavengers, photobuffers, humidity blockers, microencapsulation and component separation. Each can penalise intended cure.
- BHT, TEMPO and related radical inhibitors are conditional controls for radical side routes. They are not universal inhibitors of protonic or oxonium propagation.
- Water, hydroxyls, bases, sulfides, ionic residues, pigments, dyes, silica, clays, carbonaceous fillers and dispersants can accelerate, inhibit or redirect different parts of the system.
- Commercial documentation more often embeds stability in PAG design, counterion, solution form or two-component supply than it identifies a universal standalone cationic stabiliser.
- A shelf-life claim requires a declared package, ageing history, failure criterion, retained-cure window and uncertainty. Unchanged appearance or viscosity alone is insufficient.

Limitations

This is a mechanism-led engineering review, not a systematic review or product-ranking study. The direct literature on long-duration storage of complete commercial cationic formulations is smaller than the literature on initiation and cure kinetics. Several stabilisation concepts are demonstrated in laboratory formulations, photoresists or process-control experiments rather than in packaged industrial products. Commercial product pages were checked on 24 August 2026 and may change. Proprietary anions, purity specifications and formulations are not inferred. No universal shelf life, stabiliser dosage, counterion ranking, acceptable dark conversion or application qualification is proposed.

Author contributions

Juan Segurola: conceptualisation, literature synthesis, engineering framework, commercial-document boundary, writing, review and editing.

Competing interests

The author is founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L. Commercial 3Dresyns products are not used as evidence in this review. Third-party product documentation is included only to identify publicly stated commercial implementations and is segregated from peer-reviewed evidence.

Data availability

No new experimental dataset was generated. Scientific statements derive from the cited literature; commercial examples derive from public manufacturer documentation. The figures and proposed reporting aids are original synthesis tools and do not represent measured product data.

Company information

Legal company name: 3Dresyns by Resyner Technologies S.L.

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

VAT number: ESB24827511

Contact email: info@3Dresyns.com

Company website: www.3Dresyns.com

References

- [1] Sangermano, M.; Razza, N.; Crivello, J. V. Cationic UV-Curing: Technology and Applications. *Macromolecular Materials and Engineering* 2014, 299(7), 775-793. DOI: [10.1002/mame.201300349](https://doi.org/10.1002/mame.201300349).
- [2] Tasdelen, M. A.; Lalevée, J.; Yagci, Y. Photoinduced Free Radical Promoted Cationic Polymerization 40 Years after Its Discovery. *Polymer Chemistry* 2020, 11(6), 1111-1121. DOI: [10.1039/C9PY01903K](https://doi.org/10.1039/C9PY01903K).
- [3] Sipani, V.; Scranton, A. B. Dark-Cure Studies of Cationic Photopolymerizations of Epoxides: Characterization of the Active Center Lifetime and Kinetic Rate Constants. *Journal of Polymer Science Part A: Polymer Chemistry* 2003, 41(13), 2064-2072. DOI: [10.1002/pola.10750](https://doi.org/10.1002/pola.10750).
- [4] Finson, S.; Jury, J. M.; Crivello, J. V. Azodioxides as Inhibitors and Retarders in Photoinitiated Cationic Polymerization. *Macromolecular Chemistry and Physics* 2013, 214(16), 1806-1816. DOI: [10.1002/macp.201300300](https://doi.org/10.1002/macp.201300300).
- [5] Taschner, R.; Koch, T.; Wolff, R.; Stampfl, J.; Liska, R.; Knaack, P. Evaluation of Sulfonium Borate Initiators for Cationic Photopolymerization and Their Application in Hot Lithography. *ACS Applied Polymer Materials* 2023, 5(4), 3023-3033. DOI: [10.1021/acsapm.3c00191](https://doi.org/10.1021/acsapm.3c00191).
- [6] Ma, Y.; Dreiling, R. J.; Recker, E. A.; Kim, J.-W.; Shankel, S. L.; Hu, J.; Easley, A. D.; Page, Z. A.; Lambert, T. H.; Fors, B. P. Multimaterial Thermoset Synthesis: Switching Polymerization Mechanism with Light Dosage. *ACS Central Science* 2024, 10(11), 2125-2131. DOI: [10.1021/acscentsci.4c01507](https://doi.org/10.1021/acscentsci.4c01507).
- [7] Chen, Z.; Zhang, Y.; Chisholm, B. J.; Webster, D. C. A Humidity Blocker Approach to Overcoming the Humidity Interference with Cationic Photopolymerization. *Journal of Polymer Science Part A: Polymer Chemistry* 2008, 46(13), 4344-4351. DOI: [10.1002/pola.22754](https://doi.org/10.1002/pola.22754).

- [8] Falk, B.; Zonca, M. R., Jr.; Crivello, J. V. Modification of Photoinitiated Cationic Epoxide Polymerizations by Sulfides. *Journal of Polymer Science Part A: Polymer Chemistry* 2005, 43(12), 2504-2519. DOI: [10.1002/pola.20726](https://doi.org/10.1002/pola.20726).
- [9] Crivello, J. V.; Acosta Ortiz, R. Benzyl Alcohols as Accelerators in the Photoinitiated Cationic Polymerization of Epoxide Monomers. *Journal of Polymer Science Part A: Polymer Chemistry* 2002, 40(14), 2298-2309. DOI: [10.1002/pola.10311](https://doi.org/10.1002/pola.10311).
- [10] Bulut, U.; Crivello, J. V. Investigation of the Reactivity of Epoxide Monomers in Photoinitiated Cationic Polymerization. *Macromolecules* 2005, 38(9), 3584-3595. DOI: [10.1021/ma050106k](https://doi.org/10.1021/ma050106k).
- [11] Toba, Y.; Saito, M.; Usui, Y. Cationic Photopolymerization of Epoxides by Direct and Sensitized Photolysis of Onium Tetrakis(pentafluorophenyl)borate Initiators. *Macromolecules* 1999, 32(10), 3209-3215. DOI: [10.1021/ma981860r](https://doi.org/10.1021/ma981860r).
- [12] Komarova, E. Y.; Ren, K.; Neckers, D. C. Influence of Microencapsulation on the Stability and Reactivity of 2,4,6-Triphenylpyrylium Tetrakis(pentafluorophenyl)gallate as a Cationic Photoinitiator. *Langmuir* 2002, 18(11), 4195-4197. DOI: [10.1021/la025648z](https://doi.org/10.1021/la025648z).
- [13] Taschner, R.; Liska, R.; Knaack, P. Evaluation of Suitable Onium Tetrafluoroborates for Cationic Polymerization of Epoxides. *Polymer International* 2022, 71(7), 804-816. DOI: [10.1002/pi.6330](https://doi.org/10.1002/pi.6330).
- [14] Cho, J.-D.; Ju, H.-T.; Park, Y.-S.; Hong, J.-W. Kinetics of Cationic Photopolymerizations of UV-Curable Epoxy-Based SU8-Negative Photoresists With and Without Silica Nanoparticles. *Macromolecular Materials and Engineering* 2006, 291(9), 1155-1163. DOI: [10.1002/mame.200600124](https://doi.org/10.1002/mame.200600124).
- [15] Chemtob, A.; Croutxé-Barghorn, C.; Soppera, O.; Rigolet, S. Cationic Photopolymerization in Presence of Functionalized Silica Nanoparticles. *Macromolecular Chemistry and Physics* 2009, 210(13-14), 1127-1137. DOI: [10.1002/macp.200900083](https://doi.org/10.1002/macp.200900083).
- [16] Bongiovanni, R.; Turcato, E. A.; Di Gianni, A.; Ronchetti, S. Epoxy Coatings Containing Clays and Organoclays: Effect of the Filler and Its Water Content on the UV-Curing Process. *Progress in Organic Coatings* 2008, 62(3), 336-343. DOI: [10.1016/j.porgcoat.2008.01.014](https://doi.org/10.1016/j.porgcoat.2008.01.014).
- [17] Crivello, J. V.; Mao, Z. Preparation and Cationic Photopolymerization of Organic-Inorganic Hybrid Matrixes. *Chemistry of Materials* 1997, 9(7), 1562-1569. DOI: [10.1021/cm960595q](https://doi.org/10.1021/cm960595q).
- [18] Wang, D.; Garra, P.; Fouassier, J. P.; Lalevée, J. Silane/Iodonium Salt as Redox/Thermal/Photoinitiating Systems in Radical and Cationic Polymerizations for Laser Write and Composites. *Polymer Chemistry* 2020, 11(4), 857-866. DOI: [10.1039/C9PY01819K](https://doi.org/10.1039/C9PY01819K).
- [19] Gachet, B.; Lecomère, M.; Croutxé-Barghorn, C.; Burr, D.; L'Hostis, G.; Allonas, X. Highly Reactive Photothermal Initiating System Based on Sulfonium Salts for the Photoinduced Thermal Frontal Cationic Polymerization of Epoxides: A Way to Create Carbon-Fiber Reinforced Polymers. *RSC Advances* 2020, 10(68), 41915-41920. DOI: [10.1039/D0RA07561B](https://doi.org/10.1039/D0RA07561B).
- [20] Crivello, J. V. A New Visible Light Sensitive Photoinitiator System for the Cationic Polymerization of Epoxides. *Journal of Polymer Science Part A: Polymer Chemistry* 2009, 47(3), 866-875. DOI: [10.1002/pola.23203](https://doi.org/10.1002/pola.23203).
- [21] Zivic, N.; Bouzrati-Zerrelli, M.; Villotte, S.; Morlet-Savary, F.; Dietlin, C.; Dumur, F.; Gigmes, D.; Fouassier, J. P.; Lalevée, J. A Novel Naphthalimide Scaffold Based Iodonium Salt as a One-Component Photoacid/Photoinitiator for Cationic and Radical Polymerization under LED Exposure. *Polymer Chemistry* 2016, 7(37), 5873-5879. DOI: [10.1039/C6PY01306F](https://doi.org/10.1039/C6PY01306F).
- [22] Topa, M.; Hola, E.; Galek, M.; Petko, F.; Pilch, M.; Popielarz, R.; Morlet-Savary, F.; Graff, B.; Lalevée, J.; Ortyl, J. One-Component Cationic Photoinitiators Based on Coumarin Scaffold Iodonium Salts as Highly Sensitive Photoacid Generators for 3D Printing IPN Photopolymers under Visible LED Sources. *Polymer Chemistry* 2020, 11(32), 5261-5278. DOI: [10.1039/D0PY00677G](https://doi.org/10.1039/D0PY00677G).
- [23] Sangermano, M.; Tasdelen, M. A.; Yagci, Y. Photoinitiated Curing of Mono- and Bifunctional Epoxides by Combination of Active Chain End and Activated Monomer Cationic Polymerization Methods. *Journal of Polymer Science Part A: Polymer Chemistry* 2007, 45(21), 4914-4920. DOI: [10.1002/pola.22239](https://doi.org/10.1002/pola.22239).
- [24] Pawloski, A. R.; Christian; Nealey, P. F. The Multifunctional Role of Base Quenchers in Chemically Amplified Photoresists. *Chemistry of Materials* 2002, 14(10), 4192-4201. DOI: [10.1021/cm0200947](https://doi.org/10.1021/cm0200947).

Manufacturer documentation

- [M1] San Apro Ltd. Product Information: Photo Acid Generator (Photo-Initiator for Cationic Polymerization), CPI and IK Series. Accessed 24 August 2026. Source: <https://www.san-apro.co.jp/en/products/>.
- [M2] San Apro Ltd. CPI-100B(40) / CPI-110B Ionic Photoacid Generator, Photo-Cationic Polymerization Initiator (Sulfonium). Accessed 24 August 2026. Source: <https://www.san-apro.co.jp/en/products/acid-uv/cpi-100b-110b/>.
- [M3] San Apro Ltd. CPI-101A Ionic Photoacid Generator, Photo-Cationic Polymerization Initiator (Sulfonium). Accessed 24 August 2026. Source: <https://www.san-apro.co.jp/en/products/acid-uv/cpi-101a/>.
- [M4] San Apro Ltd. IK-20B Ionic Photoacid Generator, Photo-Cationic and Thermal Cationic Polymerization Initiator (Iodonium). Accessed 24 August 2026. Source: <https://www.san-apro.co.jp/en/products/acid-uv/ik-20b.html>.
- [M5] IGM Resins. Omnicat 250: Iodonium Hexafluorophosphate Blend in Propylene Carbonate. Product page, accessed 24 August 2026. Source: https://www.igmresins.com/en/product/omnicat_250.
- [M6] IGM Resins. Omnicat 320: Mixed Triarylsulfonium Hexafluoroantimonate Salts in Propylene Carbonate. Product page, accessed 24 August 2026. Source: https://www.igmresins.com/en/product/omnicat_320.
- [M7] Evonik. TEGO Photo Compound 1467: Cationic Photocatalyst for TEGO RC 1400 Silicone Release Series. Product page, accessed 24 August 2026. Source: https://www.evonik.com/en/products/ou/pr_52014081.html.
- [M8] Resino Inks A/S. RESUCAT 213-14 Series: Metallic Base for Cationic UV Flexo Inks. Product page, accessed 24 August 2026. Source: <https://resino-inks.com/resucat-213-14-series/>.

- [M9] San Apro Ltd. ES-1B Ionic Photoacid Generator, Photo-Cationic Polymerization Initiator (Sulfonium). Accessed 24 August 2026. Source: <https://www.san-apro.co.jp/en/products/acid-uv/es-1b/>.
- [M10] BASF. Tinuvin 123: Non-Basic HALS for Acid-Catalyzed and Oxidative Curing Coatings. Product page, accessed 24 August 2026. Source: <https://products.basf.com/global/en/ed/30486716>.
- [M11] Clariant. Hostavin 3058 LIQ: Non-Basic Hindered Amine Light Stabilizer for Acid-Catalyzed and Oxidative Systems. Product page, edition 12 dated 25 April 2024; accessed 24 August 2026. Source: <https://www.clariant.com/en/Solutions/Products/2014/06/17/07/48/Hostavin-3058-liq>.
- [M12] Evonik Operations GmbH. NANOPOX C 620: 40 wt% of 20 nm Nano-Silica Particles in Cycloaliphatic Epoxy Resin for Cationic UV Coatings. Technical Data Sheet dated 26 October 2025; accessed 24 August 2026. Source: https://products.evonik.com/assets/or/ld/NANOPOX_C_620_TDS_EN_EN_TDS_PV_52022511_en_GB_WORLD.pdf.

Engineering Review series references

- [R1] Segurola, J. RP-02 - Evidence-to-Decision Qualification Framework for Vat Photopolymerisation. 3Dresyns Engineering Publications, version 0.1, 2026. Concept record. DOI: [10.5281/zenodo.22048032](https://doi.org/10.5281/zenodo.22048032)
- [E1] Segurola, J. ER-80 - In-Can Stability and Premature Polymerisation in Light-Curable Formulations. 3Dresyns Engineering Publications, in preparation, 2026.
- [E2] Segurola, J. ER-82 - Photobase Latency and Premature Reaction in Anionic and Base-Catalysed Photocuring Systems. Planned Engineering Review, 2026.
- [E3] Segurola, J. ER-83 - Major and Emerging Photopolymerisation and Photocuring Material Systems for 2D, 2.5D and 3D Manufacturing. Planned Engineering Review, 2026.
- [E4] Segurola, J. ER-32 - Photopolymer Storage, Reuse and Open-Vat State: Evidence Boundaries and Qualification Requirements. 3Dresyns Engineering Publications, 2026. Concept record. DOI: [10.5281/zenodo.22048038](https://doi.org/10.5281/zenodo.22048038)
- [E5] Segurola, J. ER-30 - Oxygen Inhibition and Surface-Cure Effects in Vat Photopolymerisation. 3Dresyns Engineering Publications, 2026. Concept record. DOI: [10.5281/zenodo.22048034](https://doi.org/10.5281/zenodo.22048034)
- [E6] Segurola, J. ER-27 - Conversion Metrology and Spatial Cure Heterogeneity in Vat Photopolymerisation: From Exposure to Network State. 3Dresyns Engineering Publications, 2026. Concept record. DOI: [10.5281/zenodo.22017523](https://doi.org/10.5281/zenodo.22017523)
- [E7] Segurola, J. ER-61 - Gelation, Vitrification and Mobility Arrest in Vat Photopolymerisation. 3Dresyns Engineering Publications, in preparation, 2026.