White Paper

Common Reliability Problems in Opto-Electronic Packaging: Epoxies

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This is the first of a series of perspectives on common, but avoidable, problems that I have encountered in the development and qualification of components for use in high reliability opto-electronic applications. Some of these problems may appear intuitive, and therefore absurd, to engineers with specific academic or established telecom OEM backgrounds, where projects run for many years and are supported by significant past experience and/or applied research. However, the proliferation of start-ups, radical shortening of development cycles, general dilution of knowledgeable engineers (both in vendors' product development and customers' reliability assessment groups), constant cost reduction pressure from customers, and outsourcing/offshore production have all colluded to promote quick, ill-informed design and process decisions. One of the key value propositions of DfR Solutions is to provide guidance during the design and development phases, in order to avoid expensive and reputation-damaging mistakes in the future.

The use of epoxy is common in the opto-electronic components industry for many reasons, the most important being limiting attachment-induced residual stresses and their impact on optical alignment. There is a wide array of epoxy chemistries to choose from, including filler-reinforced adhesives that exhibit much better mechanical, thermal, and/or electrical properties, as well as a similarly broad group of epoxy manufacturers in terms of size, maturity, and markets served.

Unfortunately, many 'telecom' adhesives were developed and optimized for other markets and uses; in some cases, they are acceptable for network applications with sufficient process development, but more often than not may introduce new failure modes (debonding, creep, residual moisture, optical surface contamination, etc.) that take substantial engineering resources and time to solve. A common misconception is that epoxies allow greater process flexibility (lower process temperatures, easier rework, less intensive capital equipment costs, etc.) than solder or welding solutions, when in fact they require something close to religion in terms of consistency of manufacturing practices and controls. The following are common mistakes in epoxy selection and process development:

- ***Epoxies are often not optimized for the materials being bonded or the required properties*** (low stress attachment; long term stability; outgassing; thermal performance; etc.)
  - Selection is often based on past experience of an employee in bonding very different materials
  - Particle reinforced epoxies may be optimal for stability, but may induce stress birefringence
  - "Room temperature" curing epoxies help to minimize residual stresses, but are significant sources of contaminants & non-volatile residues and prone to long term creep deformation
- ***Manufacturers' data sheets are often misleading***
  - Mechanical & thermal properties are *heavily* dependent on the curing conditions and actual component application/geometry
  - Users are often looking for quick & inexpensive solutions and accept the data sheet recommendations without scrutiny; process development for new epoxies is unavoidable
  - Optimal curing conditions are often at much higher temperatures and times than listed in the data sheets, since the requirements for opto-electronics are often more severe than standard structural applications
  - "UV only" epoxies often require some elevated temperature curing to complete cross-linking reactions; varying access of UV light to the bondline also has a significant impact
  - Listed properties may not be obtained even when using comparable dispense and cure methods
- ***Elevated temperature curing is immediately and often incorrectly associated with increased component stress***
  - Step-curing (multiple exposures to progressively increasing temperatures) can lock in stress at low temperatures and yet complete curing & obtain optimal properties
  - In cases where bonding stresses are unavoidable, non-operational burn-in (typically temperature cycling, not annealing) can substantially reduce them through stress relaxation; furthermore, burn-in prevents such relaxation and associated performance changes from occurring in the field
- ***Surface preparation is critical to adhesive strength and is often overlooked***
  - Most telecom epoxies are targeted for bonding to native oxides (glasses, ceramics, adsorbed oxides on Ni, Ti, Al, etc.)
  - Ag, Au, and Pt metallizations (particularly on ceramic substrates and packages where solder attachments are also used) are problematic; without special additives, adhesion will generally be quite poor and highly variable
  - Solution-based cleaning methods often leave organic residues that inhibit strong bond formation

- ***Lot-to-lot variability in adhesive chemistry requires strict quality assurance procedures***
  - Adhesive manufacturers often focus on viscosity as the process control variable, and may make slight changes to the chemistry to achieve consistency
  - These changes can result in variable working time, adhesion, and outgassed species
  - Lot acceptance testing is strongly encouraged; such testing may range from simple die shear tests to more elaborate chemical characterization like FTIR spectroscopy and/or differential scanning calorimetry
- ***Epoxies are often used past their effective working times and expiration dates***
  - Effective working time for individual vials of epoxy can be characterized by simple wetting angle or die shear measurements
  - At least limited qualification testing should be performed for expired vials; alternatively, storage at lower than specified temperatures (typically -40ºC) can be used to extend the useful life
  - Refreezing of partially used vials should be discouraged

DfR can provide guidance with respect to adhesive selection, cure process development, storage & usage guidelines, process monitoring tests, and additional characterization methods to enable reliable long-term performance of your components.