This article is based on the paper which received the Best Paper Award from Adhesives Age at the SME Adhesives 96 Conference in Rosemount, Illinois, USA.

CASE HISTORIES OF LIGHT CURING ADHESIVES IN ELECTRONICS MANUFACTURING

by

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Abstract

Light radiation cure adhesives, coatings and encapsulants are being used in the electronics manufacturing industry with increasing frequency because their properties and process advantages are a good fit for the manufacturing requirements which are demanded by current industry drivers, such as miniaturisation, environmental and health & safety demands, manufacturing yield improvement and total product cost. Light curing adhesive systems in the electronics manufacturing industry have found applications in strain relief, wire and parts tacking, coil terminating, tamper-proofing, structural bonding, temporary masking, potting, encapsulation, glob topping, conformal coating, and surface mount component attachment.

This paper describes three case histories where photo cure adhesives were introduced to an electronics manufacturing environment, and discusses their rationale, implementation and their economics. The case histories encompass printed circuit board assembly (including surface mount), electronics packaging and microelectronic encapsulation. Production managers and process engineers are given confidence that practical adhesive application can be clean, fast and economical.

Introduction

We all know that the use of adhesives is growing throughout all industries, not just electronics, although it might come as a surprise to know that industry spends more money on materials and accessories for adhesive bonding than for welding[1]. It will not be so many years before one might amend that adage to include soldering as well.

It is said that designers still regard adhesive technology with some suspicion, although this should not be the case in the electronics industry. The construction of the circuit board itself uses adhesive technology, as do most of the components on it. By volume, there is certainly more adhesive and protective resin than metal in a pcb assembly.

However, production managers and process engineers need to be given confidence that adhesives do not need to be applied in either near-laboratory conditions, or, conversely, the electronics factory equivalent to the Augean stables. Practical adhesive application can (and should) be clean, fast and economical.

Industry Drivers

The increasing take up of radiation cure adhesives by the electronics manufacturing industry may in part be explained by the general driving forces which prevail within it. The decisions to go to a radiation cure adhesive in each of the case studies described below were driven by at least one and usually more of the following forces within our businesses:

- Miniaturisation - electronics needs to get a) smaller, b) faster and c) preferably both.

- Environmental demands - implementation of the Montreal Protocol and the banning of ozone depleting substances including CFCs is just the most obvious example of how both legislation about and corporate attitude towards environmental concerns have impinged on manufacturing processes. Restrictions on volatile organic compounds which contribute towards the greenhouse effect, and the discussions about lead replacement are instances of current issues. Companies have espoused the "green" ideal as an ethic.

- Health & safety - almost hand in hand with environmental demands comes the increased responsibilities which companies have to shoulder for the safety of both their work force, and also their customers, in the widest sense of that word.

- Manufacturing yield improvement - high yields are achieved in electronics manufacture (6 sigma plus). The drive is to ensure that this level is routine. New technologies demand this because, for example, inspection and rework processes can become expensive or impossible.

- Total product cost - obviously, the pressure is downwards. To achieve cost improvements, it is important to examine the entire process or product. A new element which is in itself more expensive may have process or performance implications which reduce the total product cost.

- Materials - the emphasis may be swinging from reliability to process-ability. This is not to imply that reliability is not important, or even not paramount. But the need to fit materials into a modern production environment with JIT philosophies means that their processing must be simple and consistent.

- Design for manufacture - a philosophy which encompasses many of the other drivers. In the quest for high functionality, performance and appealing appearance, do not forget that someone has to make it.

Radiation Curing
Adhesives and coatings can be grouped according to the manner in which they change from a "liquid" to a "solid":

- Drying - solvent or water evaporates

- Cooling - hot melt adhesives

- Curing - chemical reaction forming larger molecules or chains

Curing, or polymerisation, can take place by:

- Mixing of two or more components

- Heating

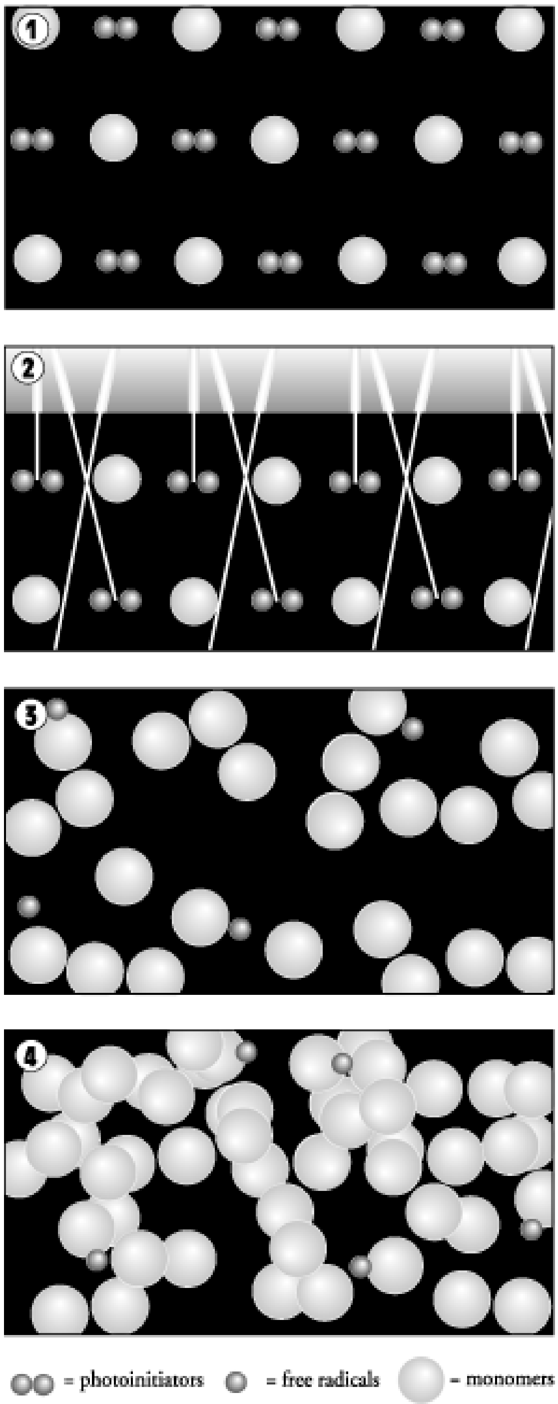
- Altering conditions, e.g. moisture, pH, absence of oxygen

- Exposing to light radiation

Whilst heating and so curing of an adhesive may be achieved by (infrared) radiation, it is this final category on which this paper will concentrate.

Light or Photo Curing
Because of the inherent cost savings possible in faster cure, the technology of cross-linking polymers using photoinitiators which are sensitive to UV light has been the subject of research dating back to the 1950's. In the early 1980's, structural strength UV curing aerobic adhesives were introduced, and in the late 1980's, electronic grade versions were developed which are 100% solids, fast curing and can be used as adhesives or coatings.[2,3]

In simple terms, these materials consist of monomers and oligomers, various agents and modifiers (e.g. wetting agents) and photoinitiators. These elements coexist without reacting with each other, until exposed to light of the correct wavelength and intensity. The photoinitiators turn into free radicals, which initiate the formation of monomer chains. After many propagation steps, the cross linked polymer chains are fully reacted, or cured.



1) In the "liquid" state, monomers and photoinitiators (as well as oligomers, stabilisers, wetting agents, etc.).

2) When exposed to light of the appropriate wavelength, the photoinitiators generate highly energetic species called free radicals.

3) The free radicals initiate the formation of polymer chains. Growth occurs as more monomers add to the active site (propagation).

4) Cross linked polymers in the cured state.

Figure 1 - The light or photo cure process

In the 1990's developments have been made which combined curing with both UV and visible light. This increased the speed and the depth of cure of the adhesives, and also allowed curing through materials which block UV light. The technology has been applied to curing pigmented, black encapsulants for microelectronic "glob tops".[4]

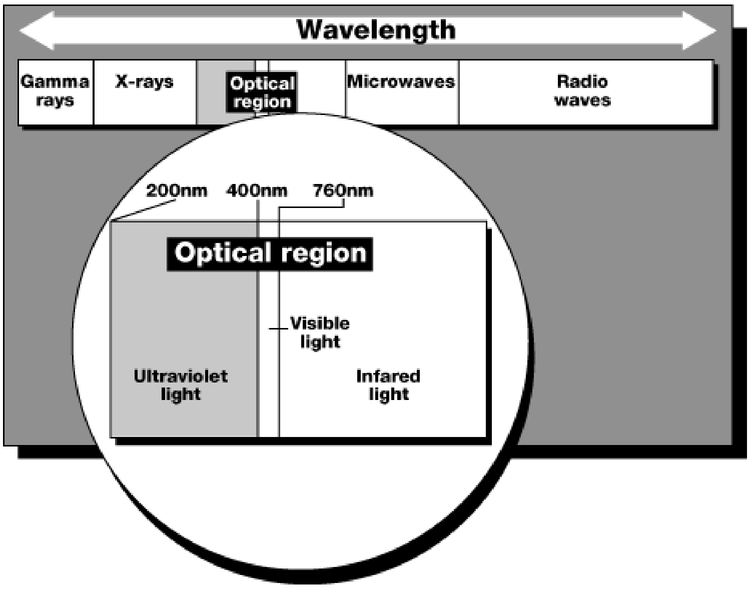


Figure 2 - The electromagnetic spectrum

The light curing process is very fast, cure being effected in many cases almost instantaneously. Many of the benefits of light curing systems in the production environment will be demonstrated in the following case studies.

Electronics Applications
Use has been found in the electronics manufacturing industry for the following applications:

- Strain relief
- Wire and parts tacking
- Coil terminating
- Tamper-proofing
- Structural bonding
- Temporary masking
- Potting
- Encapsulation, glob topping
- Conformal coating
- Surface mount component attachment

CASE STUDY A
Printed Circuit Board Assembly Applications
Wandel & Goltermann (Plymouth, Devon, England) are manufacturers of electronic measurement equipment for the installation, maintenance and testing of telecommunications and data networks. This equipment covers a wide range of applications from rugged hand-held optical power level meters to work-station based ATE systems for manufacturing and conformance testing of telecom modules. Wandel & Goltermann was founded in Germany in 1923, and their Plymouth design and manufacturing division is one of four around the world.

One problem facing Senior Production Engineer Graham Ward was the retention of components during wave soldering. Connectors, switches and other large, unruly or unstable components would fall over or lose their correct alignment between the time they were inserted into the board and the time the assembly came off the soldering machine.

In the past, Wandel & Goltermann had used cyanoacrylate adhesives (CAs), also known as superglues, to tack or stake these components to the pcb. These chemistries polymerise on contact with slightly alkaline surfaces. In general, ambient humidity on the bonding surface is sufficient to initiate cure in thin bond sections. Usually, the

CA adhesive is a thin, low viscosity liquid which is applied inter-facially. In this application, thicker, gel CA is dispensed at the junction where the component meets the pcb. Thus, the normal cure mechanism is insufficient, so an activator has to be sprayed or dripped on to the joint to promote cure.

This process started to become problematical for two reasons:

1) Since the Montreal Protocol, the CA activator has changed. It was common to put the active ingredient into a solvent carrier, and the normal one used was 1,1,1 trichloroethane. The solvent carrier evaporated reasonably quickly, and left a small, controlled amount of activator behind. As 1,1,1 can no longer be used, new formulations have appeared, containing solvents like isopropyl alcohol, acetone or heptane. Whilst environmentally safer, these new formulations raised health & safety issues (e.g. flammability). Wandel & Goltermann also found that the cure time with the new activators was longer than before, greater than 20 seconds, and that the cure was unreliable and inconsistent.

2) The dispensing of the CA adhesive became an issue. Dispensing of CAs is not always easy because of the nature of the cure, which can cause dispensers to clog up. Care must also be taken with them as they easily bond skin. The use of small squeeze bottles for dispensing may lead to occupational diseases like repetitive strain injury (RSI).

Wandel & Goltermann also had a large selection of weights, jigs and other ironmongery based at the wave soldering machine, which were deployed to hold down components during the soldering process. These were time consuming and unreliable.

Graham Ward had first become interested in UV curing in 1992, and it was his idea to overcome the problems by trying this technology. Wandel & Goltermann evaluated a number of photo cure adhesives before deciding on one with the following properties:

- Fast UV cure (1-2 seconds) aerobic acrylic
- 100% solids, solvent-free
- Good adhesion to common pcb construction materials (but see below)
- Thixotropic (viscosity 12,000 cps)
- High flash point (>93°C)
- One year shelf life at room temperature

Wandel & Goltermann purchased a combined dispenser and curing unit. The operator's hand piece contains both the adhesive to be dispensed and the output of the UV light source in one manifold. The high intensity 50 watt bulb is housed in the unit box, but focused into one end of a liquid filled light guide. This transmits the light with minimal losses to the adhesive site.

The adhesive is supplied in a dispensing barrel, which is placed into the hand piece. A luer lock dispensing needle of the appropriate size is screwed into the barrel end, and the air pressure hose is fitted to the other end. The combined dispenser/curing unit has a two-sided foot pedal. The operator positions the needle in the correct location, and pushes on one side of the foot pedal. A pulse of air which is controlled for pressure and time is sent to the adhesive barrel, which pushes the adhesive out of the needle, on to the junction between component and pcb. The repeatability of this dispensed "shot" is high, at least +/- 1%. The operator moves her/his hand slightly, aiming the light guide at the adhesive, and pushes on the other side of the foot pedal. A shutter in the unit box opens, allowing light to go down the light guide and out the end, irradiating the adhesive. This process can be automatically timed if required. The cure takes 1 to 2 seconds.

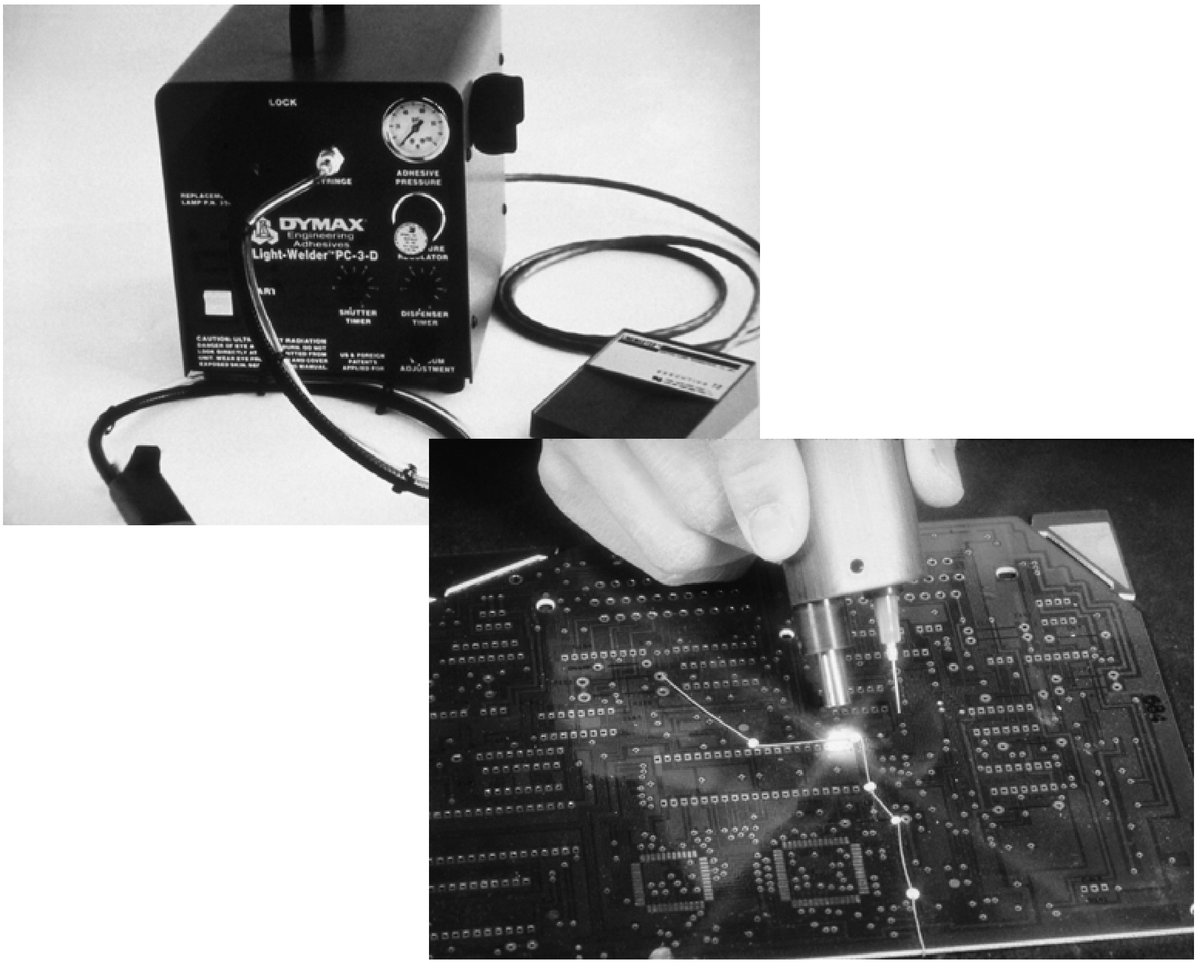


Figure 3 - Combined Dispenser / UV Curing Unit

Benefits
1) The process was now reliable.

2) It was much faster and efficient.

3) The adhesive chosen was easily reworkable should mistakes be made. Whilst uncured, it can simply be wiped off with alcohol. When cured, the bond can be mechanically broken if necessary.

4) The adhesive performance was improved.

Problems to be Resolved
The transition to a photo cure adhesive has gone well, but there were a couple of further issues to resolve.

1) The adhesive contains 2.5-10% acrylic acid, which concerned the health & safety officer at Wandel & Goltermann. Whilst not normally considered a hazard in this concentration (the Material Safety Data Sheet does not specify any exposure controls), and in these small amounts, it was decided to fit local fume extraction at the workplace.

2) The UV curing light source is fitted with a filter to block off the more harmful short (UV-C) and medium (UV-B) wavelengths, leaving safe long wave UV-A and visible light. It is still recommended that operators wear safety goggles or glasses when using the equipment. The bright visible element of the curing lamp can be irritating after a time, and can result in an "after image", much like that experienced after looking at a camera flash bulb go off. It is a temporary sensation, but to be avoided.

Wandel & Goltermann's operators find that wearing the goggles is tiring, and are restricted to 15 minute stints at the curing workstation. Graham Ward is researching the use of a face shield instead of goggles, or a plastic curing box. In this option, the work, the curing unit and the operators hands are encased in a plastic box which in

UV blocking and tinted to prevent visible glare, but still allows good visibility and easy manipulation. An extraction fan could be fitted to assist with the previous issue.

3) As with all UV lamps of this type, the intensity of light will decline with time as the electrodes deteriorate. With high reliability applications or good process control methodology, one may wish to use a radiometer to measure the intensity of the UV light on a regular basis as part of the quality procedure. Wandel & Goltermann will monitor the bulb, and replace it as part of a structured maintenance/quality program, rather than waiting for empirical evidence of low intensity.

Other Applications
As is often the case with photo cure technology, once one application is successfully running and the benefits become clear, other applications spring to mind.

1) Wandel & Goltermann have a number of surface mount technology products to manufacture. One of the new designs is a PCMCIA card (or PC card) which incorporates a 15-way connector on one edge. Without some support, the connector flops forward during reflow soldering. It is hoped to use the same staking adhesive and UV curing system to tack this connector into place prior to infra red reflow.

2) Temporary masking of certain holes and areas on pcb's prior to wave soldering can be achieved with the use of a UV curing temporary solder mask. These materials are viscous gel products which have low adhesion. They can be dispensed and cured from the same combined dispenser/curing unit, the curing time being less than 5 seconds. After soldering, the mask can be peeled off by hand, although there are water soluble varieties available which can be removed in conventional aqueous defluxing processes.

3) Wandel & Goltermann also assemble some small coils with ferrite parts. These need to be bridge bonded together, and they currently use a two part epoxy adhesive, which needs to be mixed, applied and left to cure for many hours. A structural UV curing aerobic acrylic adhesive is being evaluated which will cure in about 15 seconds. This technique has been designated "light welding".[5]

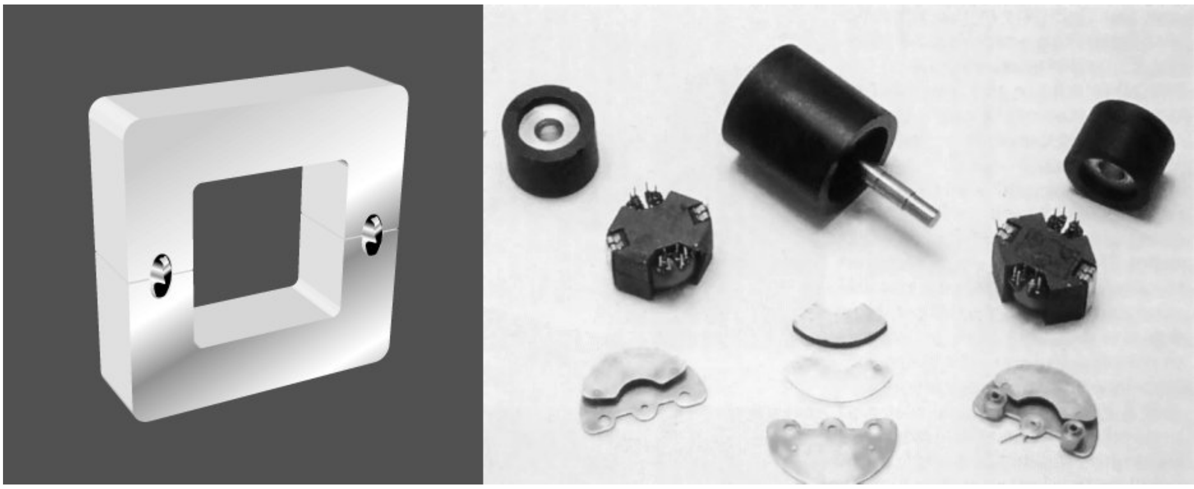


Figure 4 - A "light welded" bridge bond on ferrite cores (left).
Some examples of coils and assemblies which are structurally bonded with aerobic acrylic adhesives (right).

Cost Justification
"What an adhesive costs per litre isn't very difficult to figure out. It is often the only real fact one can count on."[6] Labour and investment costs are more difficult to calculate, as are costs of rework, rejects, storage and the like.

Often, the justification for a capital sum needed to purchase UV curing equipment is a difficult hurdle. However, here is a cost model which shows a short payback period. The costs of the material are assumed to be comparable.

Situation:

Company using cyanoacrylates (with activator) to tack modification wires to a printed circuit board. A UV curing lamp & dispenser is purchased at a cost of $2,700.

Operation time with CAs: 20 seconds
Operation time with UV: 5 seconds
Time saved per assembly: 15 seconds

With 500 pcb assemblies per week, time saved is just over 2 hours per week.

Factory overhead is calculated at $57.50 per hour. Saving in overhead is $115.00 per week.

Payback is 23.5 weeks.

CASE STUDY B
Window Sealing and Bonding
An application which is widespread in electronics packaging is the bonding and/or sealing of windows into frames. The obvious examples are industrial computers and instruments, but all sorts of electronic devices need windows so that the relevant part inside of the package can be seen, whilst still being protected in its box. Analogies can also be drawn with lens mounting and microelectronic packages for opto devices.

A photo cure adhesive is often ideal for this application. Adhesive selection is based on:

- Structural strength - the adhesive must adhere to the two (or more) substrate materials involved. The framework is usually metal, sometimes plastic. The windows are glass or plastic, but sometimes more eclectic (e.g. germanium lens). Coatings and surface treatments need to be taken into account (e.g. anti-glare coatings).

- Sealing - often, a seal against environmental incursion in needed. Environments vary from simple domestic accidents (coffee!), right up to resistance to strong or difficult chemicals (e.g. toluene).

- Thermal - the adhesive must cope with the different thermal expansion rates of the structure. A resilient adhesive is often best.

- Some window materials do not transmit UV light very well. In these instances, an adhesive with a visible light curing mechanism is used.

A case study for this type of application is described below. The company manufactures domestic utility meters, in high volume. A glass window is fitted to the front of a stainless steel housing.

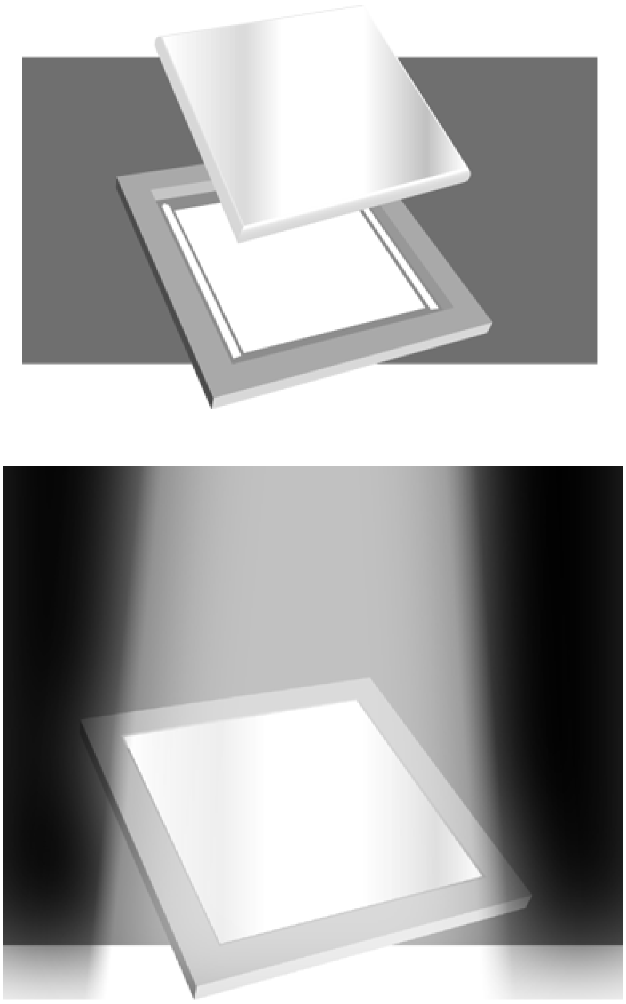


Figure 5 - Window bonding / sealing

History
The company had tried several different adhesives, mostly rubber types, and initially had settled on a two part polysulphide adhesive, albeit with a number of reported problems.

1) The adhesive gave rise to health & safety concerns. Amongst its constituents were MEK and lead oxide. MEK (methyl ethyl ketone, also known as butanone) is a highly flammable solvent, and is difficult to extract.

2) The sulphide smell was a problem, both for the assembly staff, and also for the rest of the factory. Operators began to complain about the smell, despite an extraction system, and there were cases of illness and time off work.

3) It was purchased in two part plastic cartridges with an integral mixer. This is intended to reduce handling and measuring problems, but was seen as an expensive package. The company purchased a machine on to which the cartridges could be placed, and which automatically rotated the integral mixer. However, the system was reported to be problematical.

4) The working pot life of the adhesive was short after mixing.

5) In addition to the dispensing difficulties caused by a limited working pot life, the viscosity of the adhesive was inherently variable after mixing. One attempted solution to this problem was to partially set or cure the material before use so as to get consistent viscosity for dispensing.

6) The material was decanted into 30ml barrels, which were then placed on a X-Y-Z dispensing robot. A high pressure was required to obtain even dispensing results, especially when a partial pre-cure was used. These high pressures precluded the use of other, perhaps larger dispensing cartridges.

7) A bead of adhesive is dispensed on to the stainless steel frame just inside the periphery of the glass window area. The material was difficult to control during dispensing; programs needed to be written which, at the end of the dispense pattern, placed excess stringy extrusions and tails of material into harmless barren land.

8) The glass was then fitted to the steel frame by hand. In order to guarantee a seal, the glass needed to be pushed home firmly. This caused adhesive to be extruded to areas which would be seen by an end user, and therefore cosmetically unacceptable.

9) The full cure time of the adhesive was 72 hours, although the company found that the assemblies could be handled in 24 hours, with care. Storage space was required while this cure took place.

10) After full cure, a process was required to clean the cured components of excess fillets of adhesive, using scalpels, brushes and isopropyl alcohol.

A New Adhesive

There were strong pressures for improvements in this process, headed by the health and safety issues and the very high work in progress (WIP) mandated by the cure schedule. Silicones (condensation cure systems) were considered, but found wanting in their sealing capability. In the past, an engineer had been exposed to UV curing conformal coatings, and this seemed a way forward.

Photo curing adhesives were evaluated from a number of manufacturers. The adhesive which was chosen is an aerobic acrylic system with the following properties:

- It adheres well to glass and stainless steel.

- It offers a resilient nature (Shore D68) which copes with the stresses of thermal cycling between -40° and +80°C.

- It is a single part, fast UV cure material.

- After thermal cycling, it retains an excellent seal (less than 10^7 ml of helium per second, well in excess of specification).

- It is a 100% solids system, with no solvents or volatile content and is safe to handle.

The completed product also has to stand up to twenty years of continuous use. When the company sought approval from their customer, it helped to show that the chosen adhesive is also used in the medical industry for bonding stainless steel cannulae into glass syringes, a high reliability application.

The company had to acquire a means of curing the adhesive, and decided to purchase a high intensity curing lamp with a conveyor. This system copes well with high demand and gives intense UV light of the correct wavelength for fast cure. Full cure of the adhesive occurs under the lamp in a matter of a few seconds.

The benefits of using the new UV cure adhesive are:

1) The operators are not worried by the smell. The new adhesive does not have a noxious odour and a simple extraction system is used. The other health & safety fears (solvents, flammability) were also allayed.

2) The WIP is much reduced. The cure time for the previous adhesive was so long that a new three letter acronym had been coined - WIC stood for "work in cure". The factory space which was used for WIC component storage has been reclaimed for other uses.

3) The mixing and dispensing problems were relieved, which also saved a great deal of time. They now have a day's worth of production in several hours. The new adhesive is much easier to dispense, and can be purchased in different viscosities to assist with this. Future fine tuning of the process will entail evaluating different viscosities of the same adhesive to see if further process improvements can be made. The new

adhesive is purchased in low cost 1 litre containers, and is simply transferred to 180ml cartridges for dispensing on the X-Y-Z robot.

4) The process step of cosmetic rework is no longer required. No pressure on the glass is needed to achieve a seal.

5) The quantity of material used is less. First, there is less wastage with the single part system. Secondly, less adhesive is used in the assembly. It was found that the adhesion and sealing properties required could be achieved with a lesser fillet, and there is no squeeze out. The savings on material use was a benefit which was found after the initial cost justification was calculated, and which would have made the justification easier if it could have been predicted.

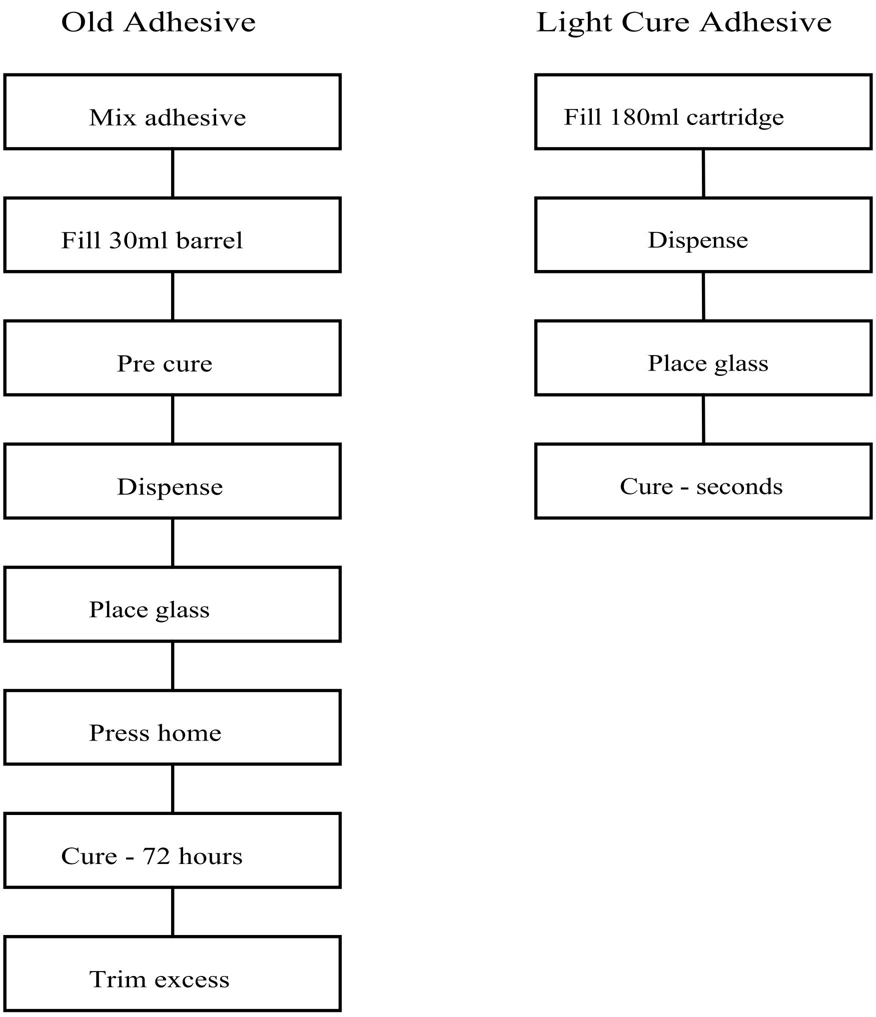


Figure 6 - Reduced process steps in changing from two part adhesive to photo cure

Cost Implications
The photo cure adhesive needed to be cured with a UV oven, and a capital expenditure of approximately $13,500 was required. The justification for this expense follows (all figures approximate):

1) The WIC (work in cure) inventory was reduced from 2,400 units to zero, a saving of $2000.

2) The photo cure adhesive was cheaper than the old two part system, with its special packaging. $9000 per year was calculated to be saved, even before the better material consumption was realised.

3) Time for handling and mixing the old adhesive was estimated at 170 hours per year. At $9.00 per hour, $1530 per year was saved when this process step was eliminated.

4) The labour costs of moving, storing and packing the WIC (it had to be carried up some stairs to a mezzanine area whilst curing) was calculated at an extra 30 minutes per day. $1125 was saved when this was eliminated.

No calculations were included for savings made on reduced health and safety hazards, nor on the release of valuable factory space, and other reduced process steps. In any event, the capital expenditure was justified in approximately twelve months.

CASE STUDY C
Encapsulation
A number of new techniques were used by Custom Interconnect Ltd (Whitchurch, Hampshire, England) in the manufacture of a single chip camera package, which resulted in cost, quality and environmental benefits. Custom Interconnect are a contract manufacturer, specialising in projects where leading edge technologies and an "open-minded approach to design for manufacture can bring success"[7].

Originally, the package used for the component was a windowed ceramic chip carrier. In this new implementation, the single chip camera die is mounted direct to an FR4 printed circuit board (pcb) using chip on board (COB) technology.

The pcb uses a gold flash over nickel finish, allowing aluminium wire bonding from chip to board. A high conductivity silver loaded polymer thick film (ptf) was used for the ground plane, insulated by a ptf dielectric covering the underlying tracks and vias. This meant that a simple doubled sided PTH circuit board could be used instead of a four layer pcb, saving approximately 50% on the cost of the substrate.

The die attach adhesive used is a silver/thermoplastic variety, allowing a cure temperature which is compatible with the ptf materials and existing surface mount devices already soldered on the reverse side of the assembly. The thermoplastic adhesive also has good reworkability, allowing a faulty die to be removed from the underlying polymer thick films if necessary. These technologies reduced overall manufacturing costs, and also enabled significant solder content reduction[8].

Once attached to the FR4 substrate in this manner, and wire bonded, it is imperative that the die be protected from contamination. One of the reasons for going away from a conventional cavity package with a window was that any residual contamination or particulate which remained in the package prior to sealing would eventually find its way on to the die surface, adversely affecting the camera's picture.

A polymer encapsulant was needed. Initially, conventional heat cure epoxies were considered, but it was found that those evaluated had an unacceptable yellow tinge. A photo curing acrylated urethane potting compound was evaluated to encapsulate the die, which was found to have the following advantages:

- It is clear (transparent).
- It is a low viscosity material, which dispenses quickly and self-levels to form a flat surface.
- It can be filtered (3 microns) at the point of dispensing to remove any particulate. This is a key quality issue. Whilst a material can be supplied pre-filtered, there is always the possibility of contamination of that material at any subsequent process step (i.e. at any time that the lid is removed).
- It cures very quickly using a high intensity spot UV light source. The slower the cure, the more chance there is that the surface will be contaminated.
- It has inherently low ionics.
- It has low stress on cure, and survives thermal cycling at 0°C to +65°C.

An acrylic "picture frame" which forms four sides of a low box surrounding the die and wire bonds is glued to the pcb with a UV curable structural aerobic acrylic adhesive. The UV curable urethane encapsulant is filtered and dispensed into the well; it self levels quickly to form a smooth surface.

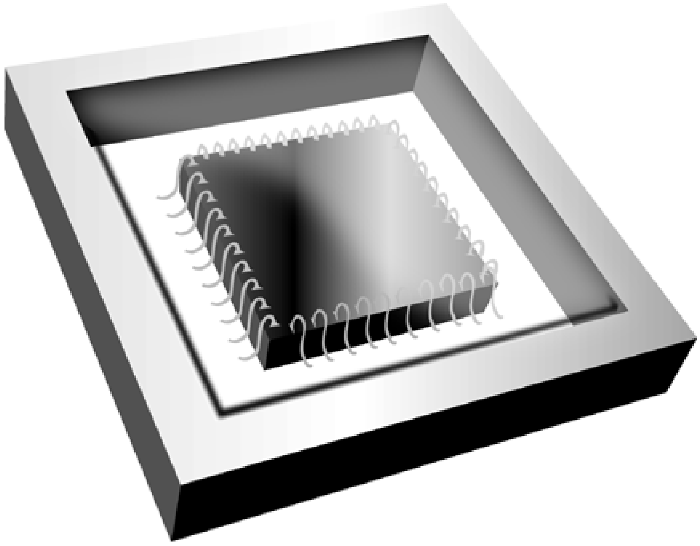


Figure 7 - The FR4 mounted die, wire bonded and awaiting encapsulation

Right up to this point, quality checks can be made to ensure that the die surface is clear and contamination free. If there are any problems or doubts, the encapsulant can easily be removed at any stage prior to cure. In its uncured state, the material can be cleaned with isopropyl alcohol, for example.

If all is well, the encapsulant is then cured in approximately 10 seconds. Because the cure is made at ambient temperature, there are no thermal stresses built into the assembly by a heat cure process at, typically, 150°C.

Demand Cure
This application demonstrates some attractions of one aspect of light curing systems - that of "demand" or "command" cure. This means that the adhesive, coating or encapsulant does not start its polymerisation until it is exposed to the required wavelength and intensity of light, and then it cures very quickly.

In this instance, the *in situ* filtering at the point of dispensing and the ability to cure the encapsulant only when the silicon die and encapsulant are assured to be contamination free were facilitated by the demand cure nature of the material.

Other advantages of demand cure systems include the ability to adjust or align components with the adhesive in place, curing only when the assembly is correctly positioned, e.g. focusing of optical components or aligning of fibre optics.

Summary
Light radiation cure adhesives, coatings and encapsulants are being used in the electronics manufacturing industry with increasing frequency because their properties and process advantages are a good fit for the manufacturing requirements which are demanded by current industry drivers.

References
1) "Adhesives Catch Up Welding", *Eureka*, June 1995

2) "Aerobic Adhesives III, Increasing Quality and Productivity with Customization and Adhesive Process Integration", Andrew Bachman, SME Technical Paper AD90-713, 1990

3) "Ultraviolet (UV) Curable Materials for Specific Military Electronics Applications", Dr Olexander Hnojewyj and Mark Murdock, Navy's Best Manufacturing Practices Workshop, 1989

4) "Low Stress Aerobic Urethanes Lower Costs for Microelectronic Encapsulation", Dr John Arnold and Samuel Forman, Adhesives 95 Conference, 1995

5) *Handbook of Adhesive Technology*, edited by Pizzi & Mittal, Marcel Dekker Inc, 1994

6) *Industrial Adhesives Handbook*, Casco Nobel A/S, 1992

7) Nick Edwards, Managing Director, Custom Interconnect Ltd.

8) "Polymer Thick Film in COB Assembly", *Electronics Manufacture & Test*, September 1994