White Paper

Thermal Spot Curing of Adhesives with Photonic Energy; a novel fiber delivery method of radiant heating to accelerate the polymerization of thermally active adhesives

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Background

Adhesives are often used in the microelectronics industry and have been used since its early days for applications as simple as wire tacking to replace mechanical tie-downs to more complex applications such as mechanical elements of Multichip Modules (MCM); as underfills for BGA's or LGA's; as electrically or thermally conductive components of printed circuit board assemblies and as the interface connection between optical and electrical networks for Fiber To The Home (FTTH) applications. Adhesives are versatile in that they can be applied as liquids, pre-applied as films, post-applied as wicking liquids and can be formulated to provide a variety of physical properties. Adhesives are formulated with different modulus of elasticity to address structural needs and they can be made with glass transition temperatures appropriate to differing application requirements. The market pressure towards mass accessible consumer electronics has also put pricing pressures on the assembly of microelectronic assemblies. This pressure in a highly competitive environment is one of the reasons why specialty adhesive companies have fine-tuned their formulations to specific tasks using the latest reactive chemistries available.

All of these adhesives have one function in common. They must all "cure" or more precisely, they must polymerize and change state from a liquid phase (gel, film, liquid) to a final solid state at a rate that is appropriate for the application but yet does not interfere with the automated needs of high volume or high precision assemblers of consumer electronics. Even B-stage and film adhesives are pre-cured to a certain degree before completing the final polymerization during the electronic assembly process.

Although the much broader market of industrial adhesive users (carton sealing, automotive engine or body bonding, furniture bonding) can tolerate a variety of curing methods depending on the final result desired, the desire for speed and control in fine assembly processes of small components has driven microelectronic manufacturers towards fast reactive mechanisms to accelerate the cure of adhesive assemblies. These reactive mechanisms often result from the mixing of two-part chemistries (where the adhesive is in two parts to isolate a base monomer from a catalyst); from the use of frozen-when-stored glue formulations of adhesive (where the adhesive reactive mechanism is prevented from activation through cold storage at -40C or similar temperatures); from the mixing of photoinitiators in a resin (where the polymerization is initiated in those glues by exposure to light at specific wavelengths, generally ultraviolet or visible light, and in many cases where the complete polymerization can be completed through exposure to these wavelengths); from the thermal and pressure activation of B-stage film adhesives; and from other atmospheric (moisture-cures or oxygen-cures) or surface pH dependent cure mechanisms (such as can be found with the cure of instant adhesives).

The remainder of this paper will deal with the adhesive cure mechanism most often found in the microelectronics industry; the thermal activation and cure of adhesives that are most commonly based on epoxy backbones. The use of heat is already prevalent in the microelectronics industry as most printed circuit board assemblies use some element of this thermal energy (reflow ovens for example) during the component soldering and assembly stage or during their burn-in stage (convection ovens).

Therefore it is not surprising that the most popular adhesives for applications in microelectronics; from die-bonding and MCM assembly through chip to leadframe assemblies use thermally cured epoxies – whether unfilled or filled with thermal or electrically conductive particles. Requirements for fast throughputs and requirements for more complex assemblies using smaller and smaller chips (such as those used for radio frequency identification or RFID chips) or complex multi-layered die assemblies strain the current thermal curing techniques of reflow ovens, convection ovens, conduction plates or hot air systems as these methods were initially developed to handle larger masses and less precise alignment requirements.

New thermal heating methods have also been developed using variable frequency microwave (VFM) energized systems to vibrate the molecules in epoxies to their thermal kick-over point. Although effective for a variety of substrates and configurations, these VFM systems tend to take up a footprint that is sometimes beyond the capability of the current assembly line. Many die-bonding assembly stations may also incorporate conductive heating pads or infrared ovens to pre-heat or post-heat assemblies within the glue dispensing station. This is also effective but may not be as precisely controlled as desired unless extensive and complex feedback mechanisms are built-in.

Innovative Thermal Spot Curing of Adhesives with Radiant Energy
The newest thermally curing system for microelectronics assembly uses the power of photonics (light energy) from a short arc source focused on an innovative fiber bundle that transmits through to the mid infrared spectrum of light (see figure 1) to create a broad spectrum of electromagnetic radiation ranging from long ultraviolet through the visible spectrum and into the infrared spectrum. This combination of light energy focused into a tight area translates into extremely high irradiance values and for most microelectronic substrates, this translates into high conversion of photonic energy from light; radiant heat into internal heating. A very important part of this innovative thermal curing system is the light transport pipe or fiber delivery bundle. This novel bundle is composed of fluoride glass fibers with low attenuation along the full spectrum of light that is emitted by the light source through to previously unreachable mid infrared limits allowing the full power of the light source to be focused as radiant energy with low losses on to the target area.

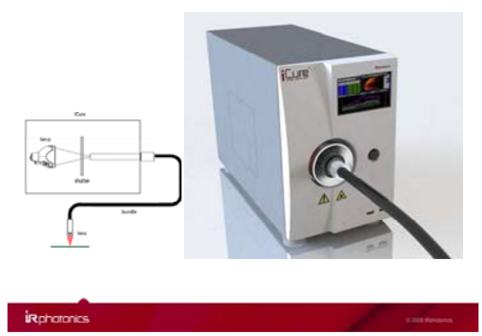


Figure 1. Thermal Spot Curing System – iCure AS200 (photo courtesy of IRphotonics Inc.)

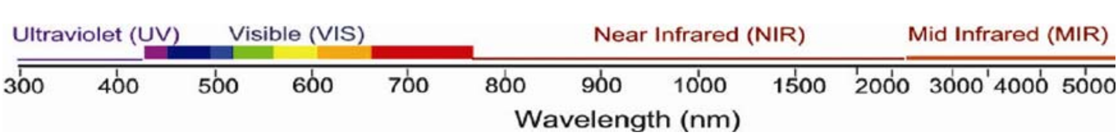


Figure 2. Spectrum of emission of iCure AS200 Thermal Spot Curing System (courtesy of IRphotonics Inc.)

The power distribution along the spectrum of emission as shown by figure 2 is particularly interesting for the microelectronics industry as different segments of this radiant energy can be responsible for generating heat using simple thermodynamic principles. For example, wavelengths below 750nm (composed of ultraviolet and visible energy) absorb particularly well into opaque surfaces commonly found in microelectronics assemblies. The transformation of light into heat is particularly rapid due to the power of low wavelengths but paradoxically this heat generation is concentrated on the surface layers of the substrates or adhesive.

However, wavelengths above 750 nm transmit particularly well through deeper layers of substrates and adhesives. This region of the spectrum is the near and mid infrared region which is also absorbed and transformed into heat very quickly by many of the fillers and form modifiers used in epoxy formulations such as silica, silver and aluminum, some of which are also used in solder pastes (see figure 3 for a graphical view of the near infrared absorption of metals that are found in solder paste formulations and how this absorption in the near infrared allows these solder pastes to be melted with lasers of the appropriate wavelengths). In addition, wavelengths in the mid infrared above 2500nm are particularly important for their heating effect resulting from the vibrational energy of the C-H and O-H bonds in the typical epoxy formulations. Figure 4 shows the FTIR scan of a typical microelectronics adhesive and the absorption of this unfilled adhesive to certain wavelengths.

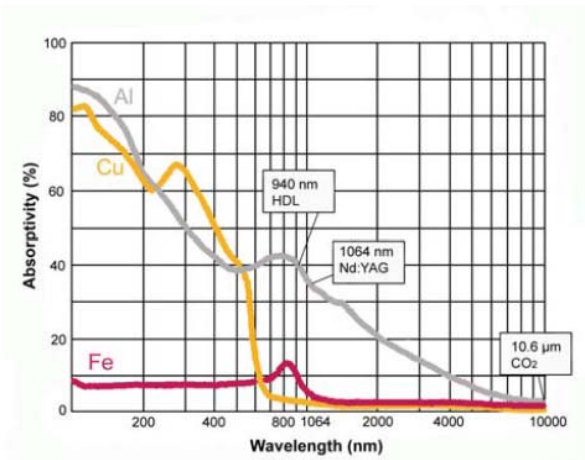


Figure 3. Absorption of metal components in typical solder paster (courtesy of EFD Inc)

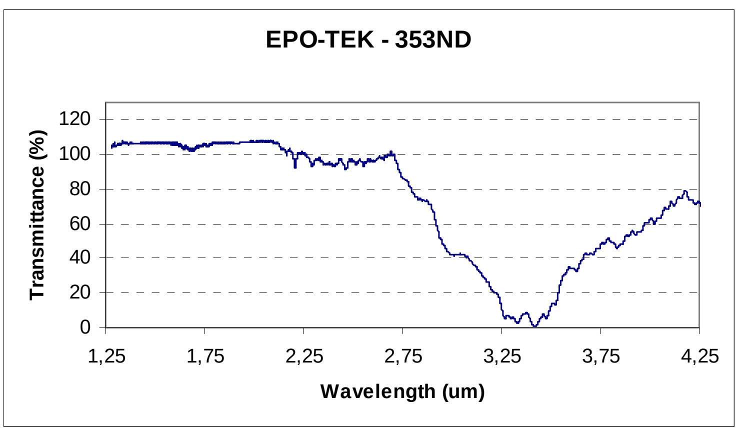


Figure 4. FTIR scan of Epotek 353ND provided by Epoxy Technology Inc (testing courtesy of IRphotonics Inc).

Process Considerations During Thermal Spot Curing

All adhesive operations involve the adhesive and the effect of the adhesive on the substrate and of the substrate on the adhesive. This is a very synergistic relationship and when the principles of using photonic energy to accomplish spot curing is used, then it becomes critical as the thermal effects from the substrate will play an important role in the heat retention and conduction through to the adhesive. Silicon plays a disproportionate role in microelectronics assembly as the substrate of choice for micro-circuits. Light energy that hits silicon is partially transmitted at certain wavelengths, absorbed at other wavelengths, and also partly reflected. This can be particularly interesting as incident light can warm the chip without overheating and yet long wavelengths in the infrared region can transmit through to the adhesive location. See figure 5 for a graphical description of the effect of light energy on a silicon substrate. While most of these silicon components as dies are not always present as bare silicon substrates and are more frequently found with 30-50um layers of imprinted circuitry or with multilayers, they may also be "saturated" with conductive traces and paths. The sum of all the effects is that there will be a certain amount of preferential heating of the epoxy bonding layers when bonding silicon-based microelectronic components.

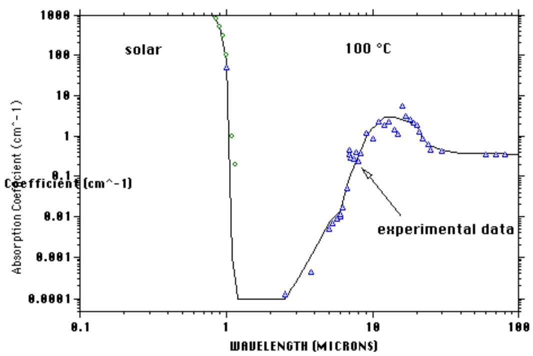


Figure 5. Absorption and transmission of different wavelengths of light through a silicon substrate (courtesy of Jet Propulsion Laboratories)

Heating without control of the output energy can be easily performed with any focused infrared lamp system. This has been previously demonstrated with infrared soldering systems used in some segments of the microelectronics industry. However, the integration of multiple control systems within a focused curing system with a very flexible fiber light guide allows the end user to precisely control the amount of radiant heat generated, where it is sent and the rate of this heat generation. (Figure 6 shows a display showing the ability to control the time of exposure, the photonic power emitted, and the ability to generate cure profiles; spectral control is also possible but not shown on the display.)

This control of heating is important for a bonded assembly because the adhesive layer and its adjacent surfaces (for example a die to a board) can be locally heated at a controlled rate to the thermal initiation temperature of the adhesive This also controls excessive flow-out of the adhesive by driving it to the gel point more rapidly and reliably. Controlling the length of time at a set temperature, a temperature profile can be generated that cures the adhesive in a low stress environment.

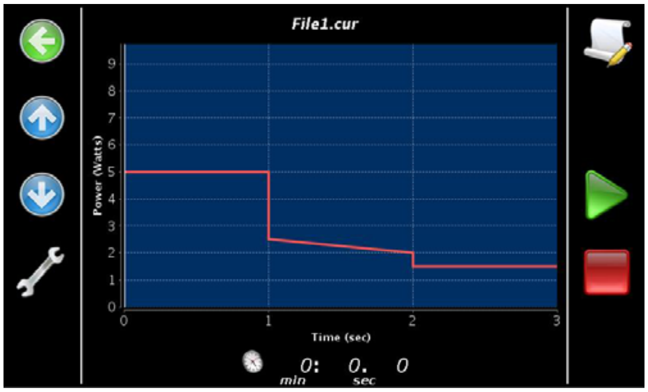


Figure 6. Display of Profile generating capability of iCure AS200 Thermal Spot Curing system.

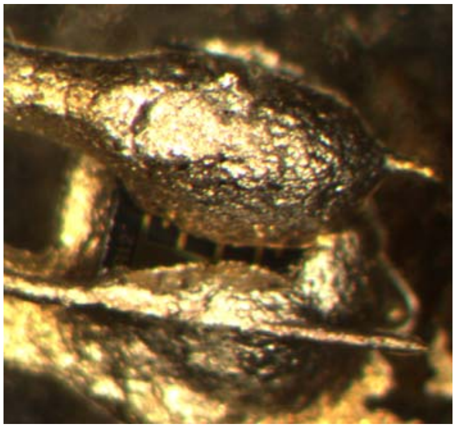
The innovative photonic radiant manner of curing needs comparison to traditional curing methods since it is not as widely adopted in the microelectronics industry as it is by medical device manufacturers for the integration of micro-optics and micro-electronics into their health care devices. Comparisons are industry-specific and applications-specific but there are some basic elements that can be benchmarks of performance. For example the degree of cure of a thermally curing adhesive can be determined through differential scanning calorimeters (DSC) among other techniques. Other metrics such as electrical conductivity measurements are also used when the epoxy formulation is heavily loaded with conductive fillers and when the need for low electrical resistance is the main driver in the use of this type of epoxy.

Previous work by IRphotonics, Montreal Canada, has been performed to validate that the cure resulting from a focused photonic curing system led to equivalent degrees of cure for set samples. Table 1 compares degrees of cure using a conventional thermal cure with the cure obtained with the spot thermal curing system. It is important to keep in mind that the results are valid only for the set conditions as actual manufacturing conditions, substrate conditions; epoxy quantity will impact the speed of cure, the time to reach cure temperatures, and the resultant degree of cure.

Samples	Curing Conditions	Residual Exotherm (J/g)	Percentage Cure (%)
Ref. Epotek[1]	Oven 120°C – 1 hr	-8.67	98.3
Ref. Epotek[1]	Oven 120°C – 2 hr	-0.8	99.8
Ref. IRphotonics A1[2]	DSC 120°C – 1 hr	-6.71	98.65
Ref. IRphotonics A2[2]	DSC 120°C – 2 hr	-5.02	98.99
Ref. IRphotonics B1[2]	iCure 3W – 30 s	-6.17	98.8
Ref. IRphotonics B2[2]	iCure 3W – 30 s	--	100

Table 1. Comparing Curing Methods and Degree of Cure achieved (Reference [1] courtesy of Epoxy Technology Inc testing; reference [2] is courtesy of IRphotonics Inc white paper)

This type of photonic curing has also been done for applications involving electrically conductive adhesives (silver-filled) as used in the microelectronics industry. The specialty formulation of one of these adhesives provided by Epoxy Technology Inc., Billerica, MA, generates rapid curing at elevated temperatures. In addition, a stable distribution of metallic particles makes it attractive as an alternative to soldering for lower temperature curing than solder, for linking non-metallic substrates and acting as a conductive trace for microelectronic applications. Figure 7 shows a typical application where a 42 gauge wire was bonded to a conductive pad on a thermally sensitive substrate and the thermal curing profile that was used to cure the glue. On another thermally sensitive substrate shown in figure 8, the polyimide tube needed to be filled with an electrically conductive adhesive and cured without affecting the substrate. The curing profile is shown in addition to the cured part



iCure Specifications:
P = 7.0 W (100%) with no spectral filters (300nm – 3600nm).
Optical component: Biconvex lens.
Beam spot size: 2.4 mm.
Working distance (WD): 8mm.
Interval tested: 5 minutes, 1 minute, 30 seconds.

Figure 7. Wire bonding application with iCure AS200 from IRphotonics Inc. and H20E epoxy from Epoxy Technology Inc.

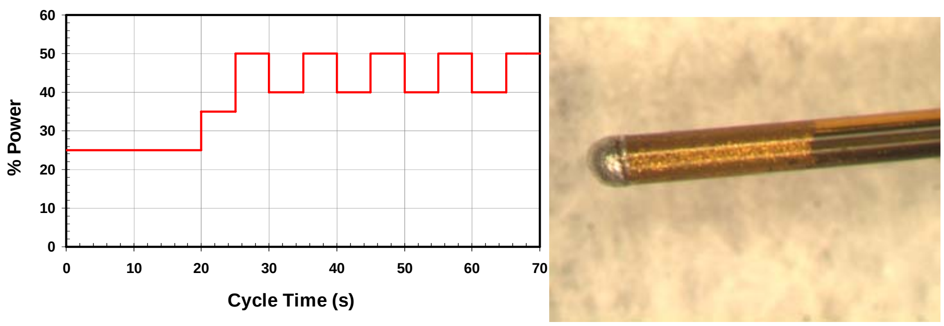


Figure 8. Curing of H20E from Epoxy Technology Inc with iCure AS200 from IRphotonics Inc on temperature sensitive substrate – polyimide tubing.

Both of the specialty epoxies described in the applications, Epotek 353ND and Epotek H20E use a very reactive catalyst that is tuned to rapid polymerization of the epoxy as the temperature is increased to 150C for a set time. As the epoxies are complex mixes of various components in liquid form, their thermal absorption and conversion of photonic energy and the effect of the substrates are important parameters to control. It is important to control the photonic energy from the thermal spot cure system so that the polymerization point is reached but not exceeded to the point of reaching thermal decomposition temperatures. All experiments involving this exciting new way of fiber-driven local thermal activations are performed using external temperature monitoring systems such as fine-gauge thermocouple monitors or infrared thermal imaging equipment. In this way, the curing of the adhesives and the heating of the substrates can be monitored to mitigate risks of thermal degradation of the adhesive or the substrates but yet achieve low-stress rapid bonded assemblies.

This paper reviewed the use of adhesives, the types of heat curing assembly adhesives that are commonly used in microelectronics and went through some simple case studies of spot curing using radiant energy with an innovative fiber light guide spot curing system. The adoption of this fiber driven type of thermal spot cure system in the microelectronics industry will help drive the end user towards finer control of thermal curing epoxy curing profiles. It will leverage and increase the use of fast curing reactive epoxies in the microelectronics industry, in the consumer electronics industry and increasingly across the various other embodiments of microelectronics in our everyday lives…anywhere where electrons and photons meet.

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