"CURING" LOW YIELDS & RELIABILITY ISSUES IN PHOTONICS ASSEMBLY

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ABSTRACT
The desire for high performance photonic components is often at odds with manufacturing process limitations and selection of compatible adhesive materials used in the fiber bonding process. Use of high performance adhesives, while desirable, typically requires longer curing times and higher temperature cure conditions to obtain the best results. Along with selection issues, low yields and reliability concerns are often attributed to adhesive performance and/or the process of curing the adhesive during assembly. Movement during post cure of adhesive joints leads to yield loss. Furthermore, reliability failures are reported highest during temperature cycling, due to improper bonding at the fiber interface. This paper provides an overview of application trials and dedicated development of a rapid curing technique that offers controlled, selective heating of the bond line. The use of microwave energy for curing polymeric adhesives in photonic component assembly has demonstrated cycle time reduction up to 10 to 20 times. Results of rapidly controlling the adhesive cure profile have shown process enhancement potential by minimizing or eliminating fiber joint movement during the adhesive cure cycle. In addition, the ability to selectively heat the bond line only and not the fiber cladding allows cure process temperatures compatible with full adhesive performance properties.

Key words: Fiber Optic Assembly, Adhesive Cure, Microwave, Yield Enhancement

BACKGROUND
With the inevitable market recovery in sight, manufacturers of broadband fiber optic components continue to scramble to improve manufacturing processes to successfully respond to the forecasted growth potential in the industry. This is particularly true as governments around the world and corporations plan for implementing "the last mile" of fiber communications [1]. Over the past year, issues surrounding the opto-electronics manufacturing process have focused on the lack of automation infrastructure and procedures required to increase throughput and reliability while reducing cost [2]. For most manufacturers, automating the assembly process is constrained by the time consuming and arduous

task of precision alignment. Positioning systems required for fiber alignment are expensive, time consuming and remain labor intensive. The automation infrastructure to address this problem is in its infancy and often still ignores the final assembly process. Following alignment, current techniques then require the physical attachment of the fiber while held in precision alignment fixture.

Reliability of Fiber Attach
The predominant method of fiber attachment is adhesive – either high performing epoxy or ultraviolet (UV) activated adhesives, via a precision dispense and then gel stage in-situ, with either UV light, or a hot bar in the case of epoxy. However, to obtain full cure, a subsequent post cure process is usually required in both cases. Adhesive cure profiles vary based on the cure temperature and resulting properties desired from the bond joint. For example, a popular adhesive in the fiber optic market is EPO-TEK 353ND. The adhesive can be "cured" at temperatures ranging from 80? C for one hour up to 150? C for 30 minutes. Higher performance from the adhesive is typically achieved from the higher temperature cure. (Reference: Figure 1)

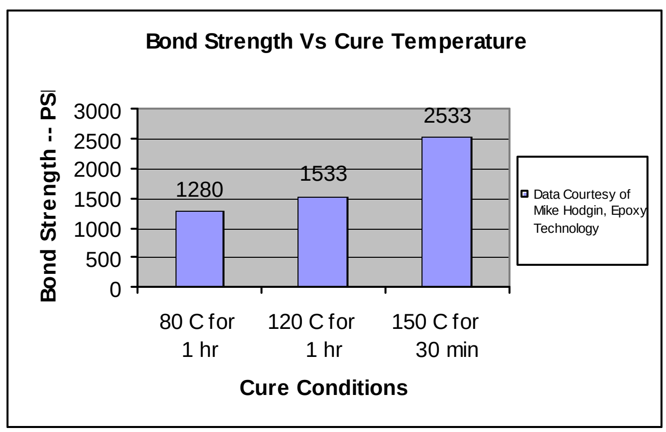


Figure 1: Bond strength versus cure temperature for EPO-TEK 353 ND adhesive (Al/Al, lap shear test)

Independent laboratory reports indicate the highest reliability failures during temperature conditioning tests, in connectors for example, are at the fiber-to-ferrule adhesive interface[3]. It would make sense then, to cure the adhesive at the highest possible temperature to obtain the highest product performance. However, most cladding material used on commercial grade fibers have a maximum temperature tolerance of 80 to 120? C. Hence,

most current adhesive post cure processes are limited to conventional oven cycles at 80 to 110? and are in the 1-hour, plus range. This results in less than optimum adhesive performance.

Yield Loss During Post Cure

Reports of manufacturing yields sometimes less than 50% on many of the key components have been attributed to, among other things, degradation of signal level following post cure of the adhesive joints. Movement or relaxation of the fiber bond joint during the cure process is the typical causes this failure mode. During the long post cure cycle, most adhesives that have been gelled (b-stage) only, will relax as they begin to heat and transform into a fully cross-linked polymer, only after passing through a period of lower viscosity and relaxation. This is discussed further below and highlighted in Figure 5.

Microwave Curing of Polymers

The application of microwave energy for enhancing reaction rates of polymer adhesives is well established[4]. Microwave energy couples to dipolar molecules volumetrically, heating via rotational oscillation. This creates accelerated cross-linking of the polymer material (e.g. adhesive), while producing equivalent properties as convection cure, but often 10 to 20 times faster. The localized heating throughout the material volume provided by microwave is opposed to the equivalent convection cure, which heats from the surface into the material and is dependant upon the thermal transport properties of everything in contact with the material (adhesive) that needs to be cured.

The other key feature of microwave is the inherent selective heating benefit. In a convection oven, everything in the oven reaches the cure temperature of the targeted polymer adhesive. Alternatively, microwave has the ability to preferentially couple to or heat the target polymer material faster than most other surrounding materials. The benefits of microwave heating have also been employed in the electronic and semiconductor-packaging industries for curing structural adhesives, flip chip underfill and glob top liquid encapsulants[5]. By using an advanced microwave technique called variable frequency microwave technique (VFM), the problems of conventional microwave such as hot and cold spots and arcing with metals or circuitry, are eliminated. Curing in reduced time and with selective heating of the polymer adhesive without heating the typical substrate has resulted in reduced stress due to minimizing the coefficient of expansion (CTE) mismatch between the die and substrate material.

As an example, VFM is used in production of RFID tags and smart card assemblies for several polymer cure processes. Figure 2 shows an IR thermal image of a smart card / flip chip assembly immediately after removal from a VFM cure cycle. The chip and underfill material reaches a cure temperature of 100?C while the substrate remains below 40?C. The cure cycle was reduced from 4 hours to just 4 minutes, dramatically increasing throughput, but the selective heating capability of VFM also provided the benefit of optimized adhesive properties when cured at higher temperatures, yet still allowed a product design with low cost substrate material since the substrate does not heat to cure temperature conditions[6].

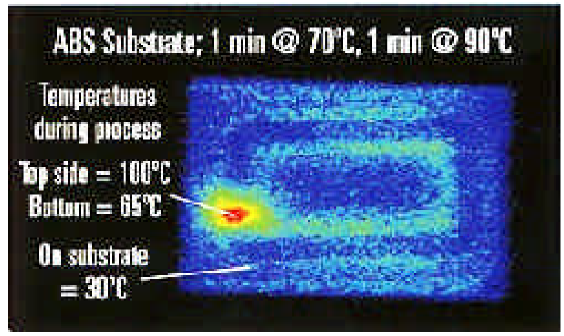


Figure 2: IR thermal image of Smart Card Assembly after VFM processing to cure underfill for flip chip assembly. Only adhesive area around the die heats.

ADVANCED MICROWAVE CURING FOR FIBER OPTIC ASSEMBLY

More recently, the benefits of the VFM technique have been explored for curing adhesives in the assembly of photonic components. The benefits of rapid and selective VFM heating when applied to fiber optic component assembly, offers potential of enhancing automation and throughput while eliminating the compromise between adhesive cure temperature and the constraints of the lower temperature fiber buffer material.

Curing Reliability & Throughput Issues

Adhesive material qualification trials have been conducted to ensure a rapid VFM curing cycle will obtain equivalent material properties to that achieved with conventional curing cycles. Using a range of adhesive materials used in the fiber optic industry, DSC data was collected to compare conventional cure cycles with VFM cycles to obtain equivalent properties. Figure 3 summarizes the test results from this work.

Figure 3: Recommended VFM vs convection cure profiles for standard adhesives

ADHESIVE CURE DATA

ADHESIVE	CONVECTION CURE	VFM CURE
EPO-TEK 353ND	5 MIN. @ 120°C	45 SEC. @ 120°C
EPO-TEK H74	90 MIN. @ 120°C	3 MIN. @ 120°C
EMI 3410	30 MIN. @ 125°C	3 MIN. @ 125°C
EMI 3505-HM	30 MIN. @ 125°C	2 MIN. @ 125°C
TRA-BOND F113SC	15 MIN. @ 120°C	5 MIN. @ 120°C
TRA-DUCT 2919	30 MIN. @ 125°C	2 MIN. @ 125°C
ZYMET F-711	10 MIN. @ 120°C	3 MIN. @ 120°C

In addition, extent of cure data was compared at different cure temperatures to assess the relation to the adhesion properties. The results for the same EPO-TEK 353ND

adhesive, discussed above, are summarized in Figure 4. As anticipated, a full degree of cure (100%) is not achieved at the lower temperature cure profile, independent of the cure time.

Figure 4: DSC data points for EPO-TEK 353 ND at different cure conditions (Time = hold time @ temp.)

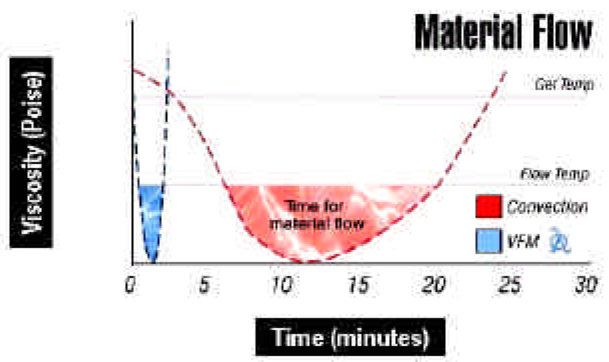
Convection Thermal Cure			
Conditions	% Cure	Conditions	% Cure
95?C for: 30 min	91%	120?C for 3 min	75%
1 hour	94	5 min	96
2 hour	95	10 min	98
VFM Cure			
Conditions	% Cure	Conditions	% Cure
95?C for: 3 min	77%	120?C for 3 sec	99%
8 min	91	-- 10 sec	100
12 min	91	30 sec	100

These qualification trials have shown an equivalent extent of cure between microwave and convection when processed at equivalent temperatures. With the selective heating benefit of VFM, higher cure temperatures and, therefore, improved adhesive performance may be viable for many fiber optic component assemblies. At the higher temperature, the VFM cure profile is just a matter of few seconds, minimizing overall thermal budget constraints.

Curing Low Yields During Post Cure

The rapid heating profiles affordable with VFM cure cycles minimize the resident time a b-stage adhesive spends in low viscosity conditions. By moving rapidly through the full cure process, a significant reduction in time available to experience relaxation effects, fiber movement and subsequent signal loss is accomplished. This is demonstrated by the graphical illustration in Figure 5.

Figure 5: Viscosity vs Cure Time / Profile Comparing VFM at 3 min. vs Convection at 30 minutes.



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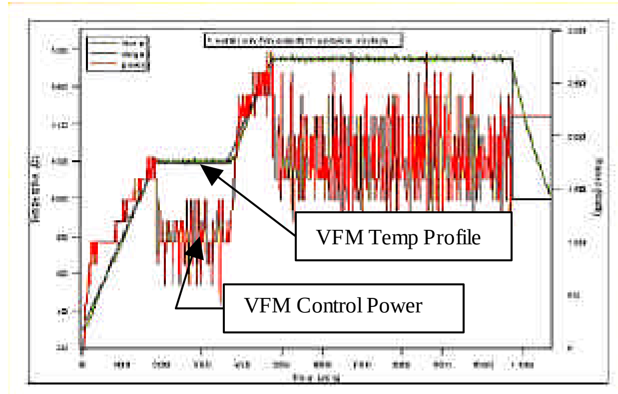
Furthermore, the inherent control features of microwave energy provide capability for very developing accurate cure profiles that can optimize any residual movement at all. Figure 6 shows a typical profile from a VFM production curing process. The rapid transition points and gel stage set points can be controlled and optimized for desired process effects. During VFM development effort for photonic applications, monitoring of signal levels from the fiber optic device is possible and the VFM profile can be tailored in multi-step fashion to control the transition from gel stage to full cure.

Figure 6: Typical VFM cure profile printout from controller with a gel stage and final cure stage cycle.



SUMMARY

A rapid and selective heating process for photonics component assembly has been successfully developed using advanced microwave technology. Application of VFM is now in use for fiber optic assemblies ranging from multi-channel transmitter and receiver vertical cavity surface-emitting laser (VCSEL) devices to transceiver assembly and fiber to ferrule attach for high performance connectors. Preliminary production results confirm significant yield improvement (20 to 50%) through post cure operations and production processes are moving to higher temperature cure which is anticipated to increase reliability of the adhesive bond line. While still early stage of full market implementation, the availability of these advanced process techniques could play a major roll in future production automation, efficiencies and cost reduction.

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