

Second Generation Die and Substrate Attach Flexible Film Adhesive

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Abstract

Flexible paste and film epoxies have been proven to provide stress-relief for large die and substrate attaches for over 10 years. They are particular useful for systems using materials with die and substrate or both with highly mismatched CTEs. With the ever increasing power density, level of integration, and circuit speed at subsystem levels, the requirements of high flexibility at low temperature range of -65°C as well as high thermal transfer efficiency are becoming even more important for reliable electronic packaging. Die and substrate attach film adhesives with good bond strength, outstanding thermal stability and conductivity, and fast bonding speed for in-line manufacturability will be presented and examples demonstrated. These film adhesives have been proven to have outstanding reliability for exposure from -65 to 150°C, HAST and 85°C/85%RH stresses, and provide less than 0.3°C-sq.cm./W thermal impedance for high power device of over 35 watts per square cm.

Key words: flexible, film, adhesive, die-attach, substrate-attach, stresses

Introduction

Paste epoxy adhesives for use in microelectronics applications have more than 25 years of history. They have been proven to have helped lowering the cost of manufacturing of semiconductor devices. With the advances of high performance plastic substrates for use in the traditionally ceramic hermetic packages such as CPU and other high power density devices, organic adhesives are becoming even more important in the manufacturing of electronic devices.

Film adhesives uses the traditional tools and equipment similar to that of the eutectic or solder bonding with a definite requirement of applying pressure during bonding process. This particular requirement of pressure during bonding is one of the reason preventing film adhesives to be widely adopted. Paste adhesives can flow easily under placement pressure. The bonding process can be achieved with heat provided in box ovens for off-line curing or belt oven for in-line processing.

With the requirements for faster bonding processes, even the fastest curing epoxies adhesives are still too slow for the push in higher productivity. Properly engineered film adhesives may be induced to flow and form bonds within milli-seconds with proper temperatures and pressures. Successful high productivity have been achieved with lead-on-chip

packaging for DRAM during the last 5 years. Infrastructure such as equipment and tooling have been developed and available for both monolithic and multichip module using film adhesives. Table 1 is a summary for the various differences involved in using film and paste adhesives.

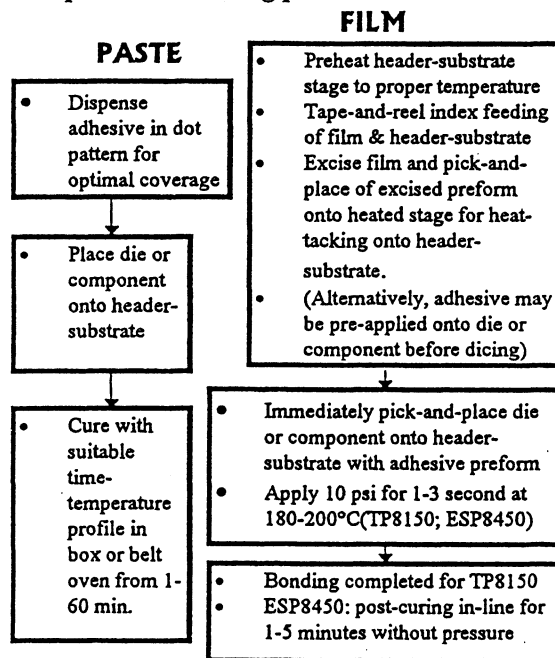
Table 1: A table of summary for the differences in using paste and film adhesives

	PASTE ADHESIVE	FILM ADHESIVE
Dispensing	Needle with or without positive displacement capability depending on viscosity	Pick-and-place of adhesive on heated parts with equipment with or without excise capability depending on preform or tape-reel
Curing-Bonding	100-200°C for 5-100 min. after parts have been seeded with placement pressure	100-350°C for 0.1 to 100 seconds depending on thermoplastic or thermosetting adhesives
Post Curing	Some may be needed	Generally not required
Equipment-Infrastructure Cost	Relatively low for both high and low volume production	Relatively high upfront capital investment
Space and Labor Cost	Increases with increasing volume	Relatively low
Chemical & Safety Concern	Good ventilation and safety logistics are required	Very little concern with almost no special safety precautions required
Material Cost	\$0.02/sq.cm. (2 mil bondline) bonding	May reach same pricing at higher volume
Overall Cost of Manufacturing	\$0.04 per sq. cm. bonding area	\$0.04-0.2 per sq. cm. bonding area

The use of thermoplastic film adhesive have been well proven in the production of low cost DRAM using the Lead-on-Chip format of die-attach[1]. The advantage is the extreme high speed of in-line processing. One of the main draw-backs preventing the wider use of this technology is the extreme temperature and pressure of processing.

Another yet to resolve problem is to incorporate high enough thermal and/or electrical conductivity for it to be useful for those chip requiring substantial thermal dissipation and electrical drain. In the case of the second generation thermoplastic film adhesives described herein, the bonding can be performed at 180-200°C with nominal pressure of 10 psi for dwell time of less than one second[2]. They can be electrically insulating with high thermal conductivity or inherently electrically conductive. It should be clear from Figure 1 below that the process flow are substantially different for the use of film adhesive and paste adhesive[3].

Figure 1: A schematic flow of the different operations in using paste and film adhesives



From the illustration of both Figure 1 and Table 1, it is quite clear that film adhesive requires a higher start-up cost but can be extremely effective for both die and module attaches when the volume of through-put is high enough.

Reliability of Adhesive Bonding in Microelectronics Applications

Failures of electronic devices may be attributed to temperature run-away (50%); vibration

(25%); and moisture(25%)[4]. In those cases of electronic failures can be attributed to the adhesive bonding, almost all of the temperature and vibration failures may be attributed to the stress problems if proper bonding processing have been used.

The first group of factors relate to the physics of adhesive bonding. One of most easily forgotten aspect of adhesive bonding verses soldering is the fact that they are not intermetallic joints. Instead they are bonded together with Van Der Waal forces that are dipolar in nature. In order that dipolar attraction be effective, the adhesive molecules must be able to couple with the bonding surfaces with molecular intimacy[5]. Thus good liquidous flow must be present during some part of the bonding process. In the case of film adhesives, some pressure must be exerted to induce adequate flow in its molten state.

Another important factors in the first group that commonly missed in the designing of manufacturing processes is the assurance of contamination free surfaces. Most of the surfaces of materials used in electronic device are high in surface energy if no organic contaminants are present[6]. However, during many of the chemical processes that are directly involved in preparing such parts or performed adjacent to such parts tends to impart organic onto the surfaces. They may be weak interfacial liquid or hard-to-adhere molecular structures. All such contaminants must be removed for proper bonding. In the case of hard-to-adhere materials, their surface characteristics must be modified by methods such as corona discharge, chemical etching, flame-oxidation or other methods to increase its molecular polarity for easier bonding. Materials that form weak oxide surfaces will be limited to the strength of the oxide surfaces for its long-term bond strength and reliability. Once all of these factors have been properly considered and engineered with proper preparation protocols, bonding will be successful in the short term.

Long-term reliability of bonded structures will depend on two additional factors: proper internal stress management[7,8] and chemical stability of the surfaces, adhesives, and inherent ionic cleanliness of the parts and adhesives[9].

Assuming that all surfaces of the adherends to be bonded are void of contaminants and weak oxide or coatings, most properly formulated adhesives will be able to adhere them with success in the short term. The long-term reliability will depends on the internal stresses built up during the process or during the temperature excursion from the zero stress point of the assembly. The zero stress

point of an bonded structure is the temperature whereby the adhesive changes from liquidous state to solid state. This temperature may be the curing temperatures of an cross-linked adhesives such as epoxy. In case of solders, inorganic glasses, or hot-melt like adhesives, the zero stress temperatures are the solidification temperatures that may or may not coincide with the melting temperatures. The internal stresses that are inevitable in adhesive bonding represents that second group of factors that affect the reliability of the microelectronics assemblies.

The extent of the stress build up is determined by the curing temperature above its normal operating condition, the operating temperature ranges, the modulus of elasticity of adhesive, CTE mismatches of adhesive and adherends, the thickness and area of bonding, and in lesser extend the ability of adhesive to withstand fatigue under high strain condition[10,11]. The ability of the adhesive to survive long-term usages without delamination or other failure is determined by the above factors in combination as a function of temperature in the operating temperature range of -65 to 150°C and the intrinsic strength and toughness of the adhesives and adherends.

The third group of factors that may affect the long-term reliability of bonded microelectronics are the thermal stability against long-term high temperature exposures of 150°C and sometimes up to 225°C of the adhesive and adherend surfaces, the ionic cleanliness of the adhesives that may cause corrosion related failures, the stability under moisture at high temperature and concentration, and the chemical resistance of the adhesives under special operating environment such as salt-fog, fuels, and solvents. These three groups of factors have to be fully accommodated in designing and developing adhesive for reliable bonding of microelectronics devices (summarized in Table 2).

Table 2: Factors Affecting Adhesive Reliability

Factors	Adverse Factors	Favorable Factors
Molecular Intimacy	Oil & Contaminants	Low surface tension adhesive
	Weak Oxides	Good adhesive flow
	Low surface energy	High adherend surface energy
Internal Stresses	High modulus adhesive	Low adhesive modulus
	High CTE mismatch	Low CTE mismatch
	High adhesive Tg or Tm	Low Tg
Operation Environments	Ionic impurities	Ionically clean
	High moisture	Low moisture absorption
	High temperatures	High temperature stability

Tg and Second Generation Film Adhesives

Most of the organic adhesives have a distinct glass transition temperature (Tg) at which the polymers changes from a rigid and sometimes

brittle material into a flexible and rubbery phase. The mobility of the molecule is freed when temperature increases through its Tg. Most of the common epoxy adhesives and thermoplastics have glass transition from 60 to 220°C. Table 3 is a summary of the relevent properties of common adhesives used in microelectronics bonding.

Table 3: Tensile moduli, CTEs, and Thermal Stability of Common Electronic Adhesives

	Tg (°C)	Tensile Modulus (psi)	CTE (ppm/°C)	Thermal Stability, TGA/Long-term (°C)
Typical Epoxy (Unfilled)	60-200	2,000K/20,000	60/200	350/150
1st Generation Flexible Epoxy (Alumina filled)	-20	1,000K/20,000	40/110	450/150
2nd Generation Flexible epoxy (Alumina filled)	-60	1,000K/20,000	40/110	450/180
Polyurethane (unfilled)	-40	1,000K/10,000	60/200	300/125
Rigid-rod polymer (unfilled)	>250	10,000K/1,000K	5/20	500/250
Solder (60/40, Tm)	220	10,000K	26	NA/Tm
Indium (Tm)	156	10,000K	30	NA/Tm
Gold Eutectic(Tm)	350	10,000K	15	NA/Tm
Silver-Glass	350	10,000K	15	NA

Most of the polymers used in adhesive applications have a planar zig-zag conformation that generally moves and expand at a rate of 50-60 ppm/°C when they are rigid and changes to 100-200 ppm/°C when they becomes rubbery in conformational arrangement. The molecular freedom is directly related to the stress required to induce a unit strain on the adhesive. The modulus of elasticity typically changes from a rigid state of 1,000,000 psi to 10,000 psi in the rubbery state. The Poisson ratio also changes from a typical elastic material of 0.33 to closer to 0.50 for liquidous material. The material strength also changes from high of 30,000 psi to flexibility of 5,000 psi[12,13].

Moduli of Elasticity and Tg of Organic Adhesives

Modulus of elasticity of polymeric adhesive for the first order is elastic in nature and are related to the molecular structure and its conformational characteristics. For a traditional epoxy, the basic Tg is generally above ambient and are thus known for its strength and high rigidity. While the molecular structure and its response to stress may differ significantly, their modulus of elasticity generally fall in the range of 1-5 million psi and 20-30K psi below and above its Tg respectively[12,13]. Unless the molecular structures are very distinct like that of

rigid rod or liquid crystal polymers that are very difficult to process and use as adhesives[14,15], the conformational characteristics and differences yield very little differences in modulus of elasticity when they are above or below their respective T_g as illustrated in Figure 2 for different adhesives.

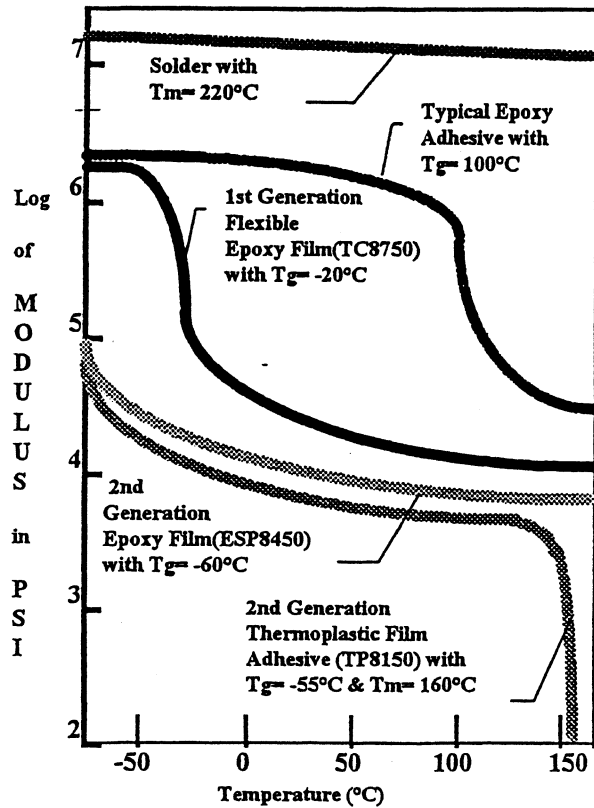


Figure 2: Glass Transition Temperatures and Moduli of Elasticity of Epoxy and Thermoplastic Adhesives

Poisson Ratios and T_g

Typical Poisson Ratio of amorphous elastic solid is approximately 0.33 when they are in its rigid glassy state. When the glassy material becomes rubbery and soft, the stress transfer characteristics approaches that of the incompressible liquid of 0.4 to 0.5[12,13]. The filled adhesives behave in much the same way unless they exhibit substantial anisotropy or orientation of high aspect ratio fillers.

Thermal Expansion Coefficients and T_g

Moduli of elasticity change at T_g is that of second order phase transition. Thermal expansion coefficients also change from a typical value of 50-60 ppm/°C in its glassy state to 100-200 ppm/°C in its rubbery state[12,13]. Figure 2 is a plot of typical CTE as a function of temperatures. The change of T_g from 100°C to -60°C merely shift the curves of transitional characteristics.

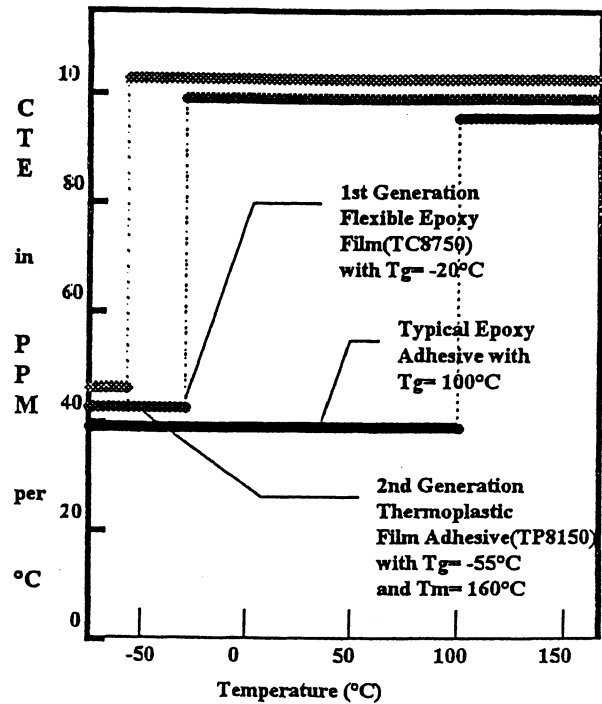


Figure 5: T_g & CTE of Epoxy and Thermoplastic Adhesives

Internal Stresses and T_g

Internal stresses are defined as either compressive, tensile or shear stresses exerted between different similar parts in any assembly. In the case of adhesive bonded structures, they arise from the expansion differences between the adhesive and adherends that they joined together. In the case of most electronic assembly, the adhesives typically expand and contract at higher rate than that of the adherends as shown in Table 3. Depending on the solidification or curing temperature, the stress level can be as high as thousands of psi. In a simple 1-dimensional model, the level of stress trapped can be easily calculated as below in Figure 4.

In the actual usage, the stress level will depends on the dimension of the bonded area and the thickness of the adhesive used. The thicker the bondline in relation to the area of bonding will decreases the stress level based on a 3-dimensional model by Suhir[10]. In the case of rigid epoxy adhesive with T_g of 100°C, the internal stress will be very high from 100°C and below. For the same bonding, flexible adhesive with T_g of -20°C or lower will only accumulate internal stress from -20°C and thus at a much lower level.

While internal stresses will weaken the bond strength initially, they may not be enough to cause failures. Most adhesive failures occurred at the corners or intrinsic flaws of either in the adherends

or adhesive. Internal stress when coupled with the stress-concentration or stress-intensifying factor of sharp edges, or flaw may exceed that the intrinsic strength of the material as described by Griffith's criteria[16,17]. Sharp corners and flaws will yield localized stress concentration of 3 or more times that of the average applied stresses.

$$\begin{aligned} \sigma_{Si} &= \epsilon_A \times E_A = (\alpha_A - \alpha_{Si}) \Delta T \times E_A = \sigma_A \\ &= 42 \times 10^{-6} \times 125 \times 1.0 \times 10^6 \text{ psi} \\ &= 5,250 \text{ psi (Rigid Adhesive-Solder)} \end{aligned}$$

$$\begin{aligned} \sigma_{Si} &= (\alpha_A - \alpha_{Si}) \Delta T \times E_A = \sigma_A \\ &= 100 \times 10^{-6} \times 125 \times 20,000 \text{ psi} \\ &= 250 \text{ psi (Flexible Adhesive-Solder)} \end{aligned}$$

where σ_{Si} = Stress on Silicon die
 ϵ_A = Strain of Adhesive
 σ_A = Stress on Adhesive
 E_A = Modulus of Adhesive
 α_A = CTE of Adhesive
 α_{Si} = CTE of Silicon
 Compressive Stress on Die

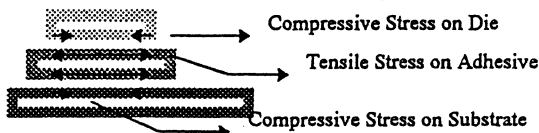


Figure 4: Stress Estimation of Joint Cooled From Curing

Thermal Conductivity and Thermal Resistance

Thermal conductivity in single crystal is well understood in quantum mechanical phonon transport theory[18]. In the case of amorphous materials, only phenomenological understanding is possible [19]. In the case of filled adhesive system, the transport phenomena will include: elastic phonon transport within the crystallites, the amorphous transport through the matrix adhesive resin, and the scattering between the interfaces of the crystallites and adhesive matrix. Because of the significant scattering of phonon transport, the combined thermal conductivity of filled system are 2 orders of magnitude below that of the crystallites.

In addition to the thermal conductivity and the thermal impedance resulting from the transport through the adhesive, there are also interface resistance between the adhesive material and the adherend surfaces. That is the total thermal impedance of the joint is:

$$\begin{aligned} \Theta_t &= \Theta_{a1} + \Theta_m + \Theta_{a2} \\ &= \Theta_{a1} + \Theta_{a2} + 100 t/k \end{aligned}$$

where Θ_{a1} and Θ_{a2} are the thermal resistances between adhesive and adherend 1 and 2,

respectively; and t is the thickness in cm, and k is the thermal conductivity in W/m-°K

The interface resistance between adhesive and adherends can be treated to be similar to that of electromagnetic waves with reflection and scattering losses. Figure 4 is a systematic measurement of thermal resistance of various greases and materials tested in the same contact area of 1 sq. in.[20].

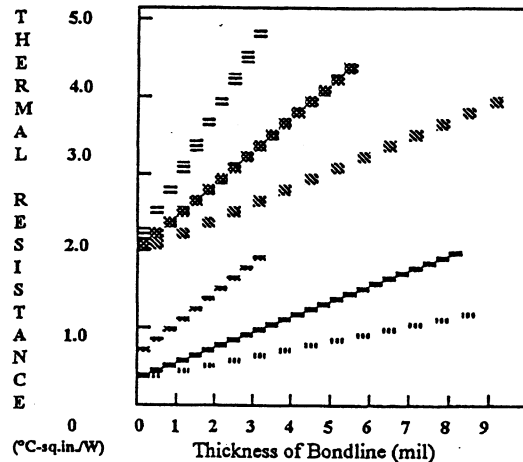


Figure 4. Thermal Resistance As a Function of Thickness for Different Species of Thermal Interface Materials

It is clear from Figure 4 that: (1) interface resistance is dependent on specific interface material for any specific adherend surfaces[21]; (2) to the lesser extent, different adherends may have different impedance characteristics for the same adhesive.

Material	Thermal Conductivity (k, W/m-°K)	Thermal Impedance for 2-mil Interface (t/k, °C-sq.cm/W)	Estimated Impedance with 2-mil & 0.30°C-sq.cm/W Interface Resistance	Estimated Impedance with 2-mil Interface & 1-mil "Delamination"	Estimated Impedance with 2-mil Interface & 1-mil "Delamination"
Air	0.026	19	20	20 (100%)	20 (100%)
Adhesive (No fillers)	0.30	1.7	-2.0	2.4 (5%)	3.5 (20%)
Adhesive (ESP7455)	1.8	0.28	0.58	1.0 (5%)	2.4 (20%)
Adhesive (ESP8450)	6	0.084	0.38	0.84 (5%)	2.2 (20%)

Thermal failures are caused by thermal impedances increase and growth with either interfacial delamination or voiding by depletion of grease binder. Voiding of any kind in the interface can increase the thermal resistance by several orders[22] as illustrated in the above Table.

Electrical Resistivity and Electrical Resistance

Electrical conductivity in a filled polymer is achieved and maintained as long as the apparent volume fraction of the conductive fillers exceed the percolation threshold of the system to allow

quantum mechanical hopping of electrons from one grain to the next[23]. In a typical system, the volume changes in temperature range of interests from -65 to 150C is relatively minor and thus showed very nominal resistivity changes. Electrical resistance of joint may increase over thermal cycling induced delamination micro-cracking or along the interfaces. As long as some contacts remained, the electrical resistance is relatively an insensitive measure of the joint integrity[8].

Molecular Structures and Thermal Stability

There is a difference between flexibility with lower mechanical strength and the adhesive's ability to withstand high temperature exposures. While molecular structures may be flexible, as long as they have high inter-atomic bonding, they will also be stable when exposed to high temperatures. Figure 5 is a summary of the dynamic weight loss analysis (TGA) results of representative adhesives.

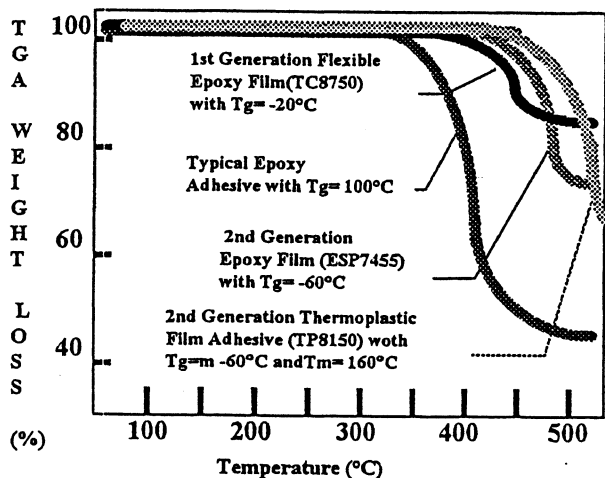


Figure 5: Thermogravimetric Analysis(TGA) of Dynamic Thermal Stability of Second Generation Epoxy and Thermoplastic Adhesives

References

- [1] W.C. Ward, "Volume Production of Unique Plastic Surface-mount Modules for the IBM 80-ns 1Mb DRAM chip by area wire Bond Techniques", 38th ECC Proceeding, 1989.
- [2] AIT Product catalog, p.III-5, III-6, III-7, 1997.
- [3] S. Takeda et. al., "A Novel Die Bonding Adhesive-Silver Filled Film", ECTC Proceeding, pp.518-524, 1997.
- [4] E. Suhir, "Predicted Failure Criterion for Moisture-Sensitive Plastic Packages", ECTC Proceeding, pp. 266-190, 1995.
- [5] J.F. Padday, "Surface Tension", pp.39-251, Surface and Colloid Science, Vol.1, Wiley-Interscience, 1969.

- [6] G.S. Ganesan, G.L. Lewis, T. Anderson, and H.M. Berg, "Organic Contamination in IC Package Assembly and It's Impact on Interfacial Integrity", ECTC Proceeding, pp.68-70, 1996.
- [7] L.M. Leung and K.T. Chung, "Zero-Stress Film Adhesives fro Substrate Attach", Hybrid Circuits, No.18, P.22, 1989.
- [8] K. Chung et.al., "Z-axis Conductive Adhesive for TAB and Fine Pitch Interconnects", ECTC Proceeding, p.345-354, 1991.
- [9] D.E. Riemer, "Material Selection and Design Guidelines for Migration Resistant Thick-Film Circuits with Silver Bearing Conductors", pp. 287-292, CH1671-7/81 0000-0287, IEEE 1981.
- [10] E. Suhir, " Calculated Thermally Induced Stresses in Adhesive Bonded and Soldered Assemblies", ISHM Proceeding, p. 383, 1986.
- [11] W.T. Chen and C.W. Nelson, "Thermal stresses in bonded joints", IBM J. Res. Develop..., Vol.23, No. 2, 1979
- [12] C.L. Segal et. al., "Polymers in Space Research", pp.181-356, Marcel Dekker, 1970.
- [13] G.M. Bartenev and Y.V. Delenev, "Relaxation Phenomena in Polymers", John Wiley & Sons, 1974.
- [14] T. Miwa, T. Ikeda, S. Numata, "A New Polyimide for a Multi-Level Planar Dielectric Layer", 4th International SAMPE Electronic Conference, pp. 468-480, 1990.
- [15] J.H. Jou and C.S. Chung, "Curing Effect on the Relaxation Modulus and Thermal Expansion Coefficient of Rodlike Polyimide Films", Macromolecules, 25, pp. 6035-6039, 1992
- [16] A.A. Griffith, Phil. Trans. Roy. Soc. London, Ser.A 221, pp.163, 1921.
- [17] G.C. Sih and H Liebowitz, "Mathematical Theories of Brittle Fracture", Fracture-An Advanced Treaties, Academic Press, pp.67-190, 1968.
- [18] H.B.G. Casimir, Physica 5, pp.495, 1938.
- [19] C.E. Inglis, Trans. Roy. Inst. Naval Architects, Vol. 60, pp. 219, 1913.
- [20] H. Hinshaw, Thermally Corp., Private Communication, 1996.
- [21] C.P. Chiu, G.L. Solbrecken, and Y.D. Chung, "Thermal Modeling of Grease-Type Interface Material in PPGA Application", 13th Semi. Thermal Measurement and Management Symposium Proceedings, pp.57-63, 1997.
- [22] R. Viswanath and C.P. Chiu, "Organic PGA-A Performance Comparison with Ceramic PGA", 13th Semi. Thermal Measurement and Management Symposium Proceedings, pp.119-130, 1997.
- [23] D.A.G. Bruggeman, Ann. Phys. Leipz., 24, pp.636, 1935.