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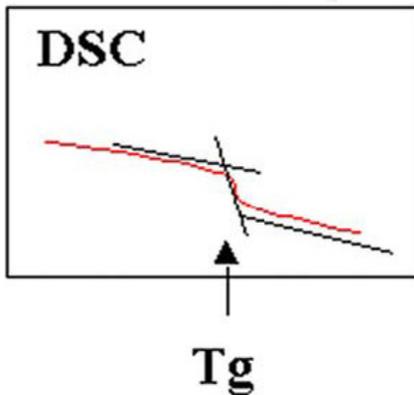
Unparalleled in Polymer Coatings and Adhesives Technology™

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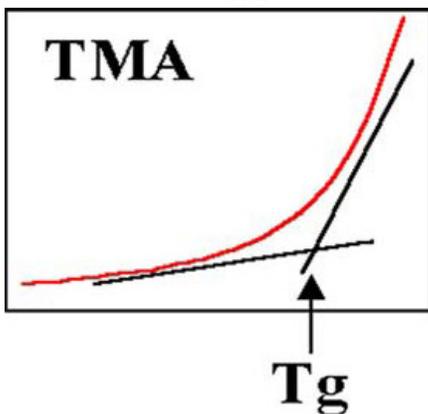
Measuring and Understanding Tg (Glass Transition Temperature)

One of the first pieces of data anyone looks at when evaluating a potential new material for Printed Wiring Board (PWB) applications is its Glass Transition Temperature (Tg). Over the years we have all developed a set of assumptions about Tg that affect how we think about the design and manufacture of boards. Tg's of materials used in our industry run from 115 °C (for old-line difunctional FR-4) to about 250 °C (for high end polyimide materials) with an almost unbroken continuum in between based on various classes of resins, cross-linking agents and blending ratios. We also have two primary ways in which Tg is routinely being measured: Differential Scanning Calorimetry (the "official" method), and Thermo-Mechanical Analysis (TMA).

Glass Transition is a method to characterize a property of a polymeric material. The glass transition is the temperature where the polymer goes from a hard, glass like state to a rubber like state. The best way to envision this type of transition is to put a rubber band (rubber like state, very flexible) into a container of liquid nitrogen. When removed the rubber band is solid and inflexible (glass state) and in fact the rubber band can be shattered. Upon standing and warming to room temperature the rubber band will again become flexible and rubbery (rubber like state).



DSC defines the glass transition as a change in the heat capacity as the polymer matrix goes from the glass state to the rubber state. This is a second order endothermic transition (requires heat to go through the transition) so in the DSC the transition appears as a step transition and not a peak such as might be seen with a melting transition.



TMA defines the glass transition in terms of the change in the coefficient of thermal expansion (CTE) as the polymer goes from glass to rubber state with the associated change in free molecular volume.

Each of these techniques measures a different result of the change from glass to rubber. The DSC is measuring a heat effect, whereas the TMA is measuring a physical effect i.e. the CTE.

Both techniques assume that the effect happens over a narrow range of a few degrees in temperature. If the glass transition is very broad it may not be seen with either approach. This is similar in some ways to comparing inorganic materials with thermoplastics in terms of their melting points: many inorganic materials have sharp melting points that take place within a fraction of a degree of temperature, while most polymers have a much wider melting range depending on the distribution of their molecular weight. Since thermosetting (crosslinked) resins such as the epoxies that are commonly used in our industry do not have melting points, we look at Tg as a measure of change of state, but like their thermoplastic brethren, thermoset resins for a variety reasons of do not all have sharp Tg transitions.

The DSC and TMA often give results that differ from one another by 5-10 °C when used to test a polymer. Moreover, some polymers are more amenable to DSC (epoxies for instance) or to TMA (i.e. some of the first generation polyimides such as Kerimid 601), because the transition is easier to observe using one technique over the other. For example if a polymer has a very large CTE above the glass transition, the polymer may be easier to test with the TMA than with the DSC, where the glass transition may be almost invisible because it is very broad or does not absorb an amount of heat easily detectable by the DSC.

Points to ponder:

1. DSC is the classic and "official" way to determine Tg even though in some cases there are polymeric materials that do not exhibit a sharp Tg by DSC.

2. Tg and Melt Point are distinctly separate phenomena and even when looking at thermoplastic materials such as are part of many laminates (PPO, PPE) their Tg's should not be construed as being melt points and vice-versa.

PTFE for instance has a minor second order crystalline transition at about 19 °C that results in a minor hiccup in the curve of dielectric constant vs. temperature, but is neither a melt point nor a real Glass Transition.

3. Most polymers have Tg's but technically its measurement depends on a crystalline transition so if a polymer is largely or totally amorphous in nature it may not have (or readily exhibit) a Tg.

The traditional wisdom concerning Tg is that higher Tg's confer several distinct benefits in a resin system:

- The higher the Tg, the lower the total amount of Z-direction movement when a substrate is heated (either in use or during process steps such as solder reflow). This translates into reduced stress.

- The higher the Tg the less likely it will be that rework will result in pads or lines detaching from the surface of the substrate. This was a major reason for using polyimide on almost all military PWB's for many years where field repairs were often important. (This is true!)

- The higher the Tg in a PWB resin the less measling (separation of resin from glass weave at the knuckles believed due to differential expansion of the glass vs. the resin) will be experienced. (This is true!)

- The higher the Tg the better will be the long term thermal stability of a material. (This unfortunately is not necessarily true)

So What Do We Need Tg for?

Firstly, it is a good check to make sure that your materials are cured to the proper level. Using Tg as a guideline will quickly detect severe undercure and allow a process to be tweaked to ensure boards with good mechanical integrity.

Secondly, it is a good first order indicator of resistance to process temperatures. As you go to thicker materials higher temperature resins do provide improved resistance and more reliability through thermal cycling. In addition if newer lead-free solders do settle in at higher temperatures than the current systems, higher temp materials will provide an added margin of safety.

Third, Tg as measured by TMA (DSC won't do this) will give you an actual value for Z direction expansion both below and above the Tg inflection point so that you can make judgments as cured materials get thicker about the total amount of movement you can expect and when to plan to switch to a material with higher Tg and therefore less movement.