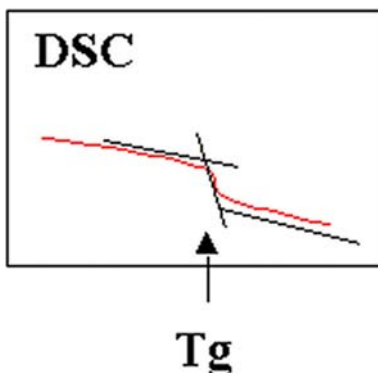


Measuring and Understanding Tg (Glass Transition Temperature)

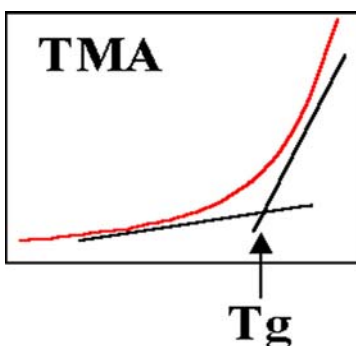
One of the first pieces of data anyone looks at when evaluating a potential new material for Printed Wiring Board (PWB) applications is its Glass Transition Temperature (Tg). Over the years we have all developed a set of assumptions about Tg that affect how we think about the design and manufacture of 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 of reasons 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 PWB is heated (either in use or during process steps such as solder reflow). This translates into reduced stress on plated through holes (PTH's) during processing, reduced risk of hidden or intermittent PTH defects, and therefore better board reliability.

- The higher the Tg the less likely it will be that rework will result in pads or lines detaching from the surface of the PWB. 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 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 -- See "The Ups and Downs of Continuous Operating Temperature in the July 2001 Newsletter.)

The question of plated through hole reliability and CTE_Z is more complicated than being simply a roughly linear function of Tg. That would be OK and works out reasonably if you are always comparing PWB's with the same construction, fabric reinforcement and resin content, all of which contribute in some way to the CTE values.

And it is a mistake to equate thermal stability with Tg because the two involve totally different phenomena. The most thermally stable epoxy we ever used was in the old 1102 Burn-In material that we sold for many years until operating temperatures started making demands on it that were beyond its capability. Yet its Tg was only about 105°C. Because it had very low levels of flame retardant it didn't have the tendency to decompose when heated.

So What Do We Need Tg for?

Firstly, it is a good check to make sure that your PWB's 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 and thicker boards (12 layer MLBs and up) higher temperature resins do provide improved measling resistance and more reliability of PTH's 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.

Thirdly, there are applications in which rework or repair temperatures may put surface features (pads, lines) at risk, and higher Tg materials do not soften and "let go" of Copper foils as readily.

Fourth, 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 judgements as your boards 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.

The attached chart showing the difference between a polyimide (Blue Line -- Arlon's 35N) and a high Tg Epoxy (Black Line -- Arlon's 45N) shows how the point of inflection makes a large difference in total Z direction expansion between room temperature and solder reflow temperature (i.e. 250°C even where the rate of expansion below and above the Tg's is essentially the same.

