Thermoplastic Anisotropic Conductive Film Bonding

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Section A: Experimental Handling and Processing of NTP & TP Series Adhesives

General

Section A covers the handling and processing procedures that are suitable for small batch usage of these products. Large-scale production usage of the products requires techniques that are suitable for automatic handling and high speed processing, but require too much setup to be practical for a small scale or experimental application.

Section B covers bonding process development for flip chip applications.

Product Description

TP-1/-2/-3 are advanced ACF adhesives that have electrically/thermally conductive nickel fibers running through the Z-axis thickness of a thin thermoplastic film adhesive. The nickel fibers have an electrically insulative coating that limits electrical conductivity to the Z-axis direction and allows 11 micron pitch with high X-Y plane electrical resistance. The adhesive is produced as a 50-200 micron (0.002-0.008 inch) thick film. It is produced to a specific fiber volume. The second dash number indicates the fiber volume (e.g. TP-2-40 has a 40% fiber volume).

The **NTP-1/-2/-3** series use the same thermoplastic resins as the TP series, however the nickel fibers do not have a special extra electrical insulation coating and, thus, they can be used down to a 200 micron pitch limit with high X-Y plane electrical resistance.

The fibers have a small tilt that allows proper consolidation of the adhesive during bonding. This is typically an angle of 5 degrees off the Z-axis that runs vertically through the thickness of the adhesive film. In order to facilitate alignment of circuits to the adhesive the direction of the tilt is shown on the release paper. There is also a small 45 degree angle cut into the top right corner with the fibers tilting away from the corner along the right edge. The observed tilt angle for a specific lot of film adhesive is shown after the lot number (e.g. Lot 14-175, 5° has an observed angle of 5 degrees).

If the tilt direction indicators are lost the best way to determine the tilt direction is to examine it under a microscope. At 400X with through transmission light, a distinct shadow can be seen attached to the fiber ends in the opposite direction from the tilt. For a reflected light microscope examination, slightly trim two edges that are 90 degrees to each other by placing a single sided razor blade over the adhesive film near the edge and taping the back of the razor to cut a clean edge. When both of these edges are examined at 100X one edge will show the tilt direction with fibers having a very distinct tilt. The other will show fibers straight up and down.

For small quantities the adhesive film typically comes between release papers clamped together in a package. The sheets may be stacked on top of each other.

Storage

TP/NTP adhesive films are storable in a controlled environment at room temperature.

Like all thin adhesives, the adhesive may warp and pucker if stored free standing. It should be stored between two sheets of release paper with a light dead weight on top or returned to the same clamping box it was shipped in with the original bubble wrap plies top and bottom. Carefully putting the adhesive between two sheets of release paper and putting a dead weight on top normally eliminates any puckering or warping.

Handling

Read the MSDS before handling. Powder free gloves should be worn to avoid contamination of the bond line.

The adhesive is subject to distortion and splitting if handled improperly. The adhesive can be easily cut by tapping on a one sided razor placed over it. This should be done on a clean surface such as glass, plastic or release paper. Like all adhesive films it will pick up dirt from any surface it touches.

Experimental Bonding

The surfaces to be bonded should be clean enough to meet normal electronic assembly standards. TP/NTP will accommodate the surface flatness of most common electronic assemblies. Thicker versions of the film may be required for large bonding areas or surfaces with poor flatness.

TP/NTP has been designed to accommodate local intrusions (from flex circuit traces, die pads, etc.) up to 15% of the Z-axis thickness without compromising Z-axis conductivity. For example, 100 micron (0.004 inch) thick film can be successfully bonded to a 15 micron thick trace (with a flat substrate on the other side) or to a 10 micron thick trace on one side and a 5 micron pad on the other side. However these intrusions cause the nickel fibers to tilt over further so alignment compensation is needed for small pad connections. 100 micron (0.004 inch) thick TP/NTP with 5 degree fiber tilt has a 9 micron offset from top to bottom - that increases to ~40 microns when connecting flat pads and consolidating the bond line by 10% during bonding. This offset increases to 65 microns when connecting a 15 micron thick trace (height above the substrate) to a flat (same level as substrate) pad.

The bonding process is a function of temperature and pressure and is affected to a lesser degree by heatup rate, surface area, surface flatness and substrate material. Because temperature is usually the easiest variable to measure and control, we recommend starting your bonding experiments at a nominal point (such as 125-130°C, 50 psi for **TP-1/NTP-1**; 150-155°C, 50 psi for **TP-2/NTP-2**; and 185-190°C, 50 psi for **TP-3/NTP-3**) and varying the temperature at a constant pressure until suitable bonds are produced. All these bonding temperatures are the actual resin temperature and must be verified with a thermocouple attached to the film during bonding.

We recommend using two pieces of glass microscope slides to verify that full resin wet-out is produced at the temperature/pressure bonding conditions prior to experimenting with real test packages. Higher temperature produces higher consolidation of the adhesive and would be the direction to go if incomplete bonding is observed. **The thermoplastic resin will start to degrade during bonding if heated above 150°C for TP-1/NTP-1; 170°C for TP-2/NTP-2 or 210°C for TP-3/NTP-3** (all ok for solder reflow exposure). Lowering the temperature will reduce excessive consolidation as observed by less squeeze-out of the adhesive around the bond edge. If temperature can't be varied easily, pressure variation can be used. Again, higher pressure produces higher consolidation, lower pressure less.

A suitable bond will have wetted out both surfaces and won't show squeeze-out of the adhesive around the edge. This can be determined by: (1) bond line compression that is ~10% of the original adhesive film thickness (for example, 0.004" film will compress down to ~0.0036"); (2) Z-axis electrical conductivity meets your requirement; and (3) die shear testing shows >500 psi bond strength. Some applications may need to trade higher pressure for lower temperature (>200 psi at ~135°C for a **TP-2/NTP-2** example) or, to lower pressure, use a higher bonding temperature (165-170°C at 35 psi for a **TP-2/NTP-2** example).

The temperature and pressure should be applied for long enough to ensure that the adhesive film and both substrates reach the proper temperature range **as confirmed with a thermocouple attached to the film during bonding.** The bond line should be cooled 30-40°C before releasing pressure.

Tacking the adhesive film to one of the substrates prior to bonding is the best way to assure proper film positioning for some applications. This can be accomplished by putting the adhesive film on release paper, putting the substrate on top, heating them on a hot plate (within 20-30°C of normal bond temperature) and applying light fingertip pressure to the substrate before removing it from the hot plate. The adhesive film should stick to the substrate enough so that it can be trimmed around the edges if desired.

Non-alignment Bonding

Bonding pressure for laboratory experimental applications that do not require precision alignment is most easily accomplished with a simple spring fixture with a block attached to a ball joint on the end (Figure 1 below). A film such as Kapton is sometimes used under the block to protect the substrate. We use this type of fixture in our own lab…due to thermal absorption it takes about 15 minutes to reach ~150°C bond line temperature (for **TP-2/NTP-2** applications) and 3 minutes to cool down below 120°C.

Pressure application with a dead weight is not recommended because the weight must be much larger than the bond area to get enough pressure. This leads to tipping of the weight, which creates a bond that is over compressed on one edge and debonded on the other. Very large bond areas of >6 cm^2 (1 in^2) are best bonded with a heated vacuum press or autoclave.

The bond is reworkable by exposing it to 15-25°C above the bond temperature and separating the bond line. The film can be scraped off the substrates at this temperature or removed at lower temperature with isopropyl alcohol. New film must be used for a new bond.

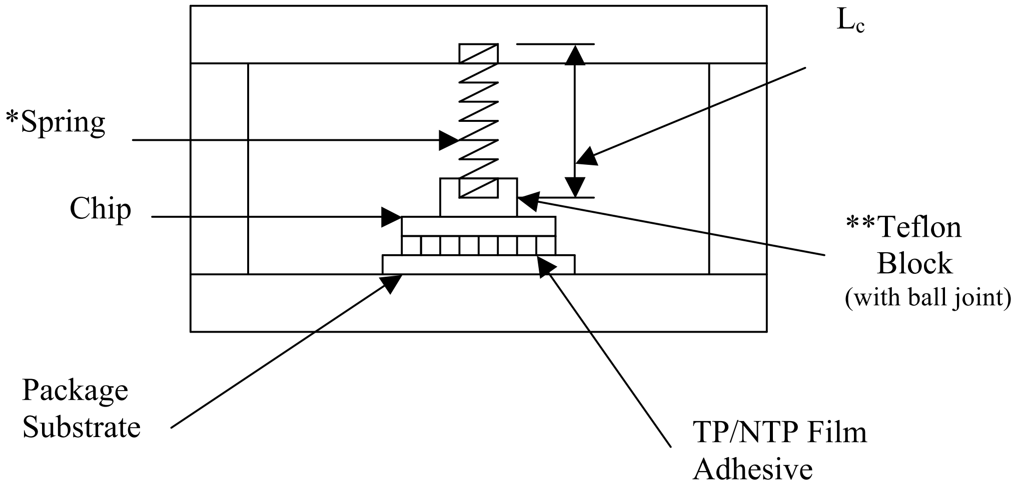


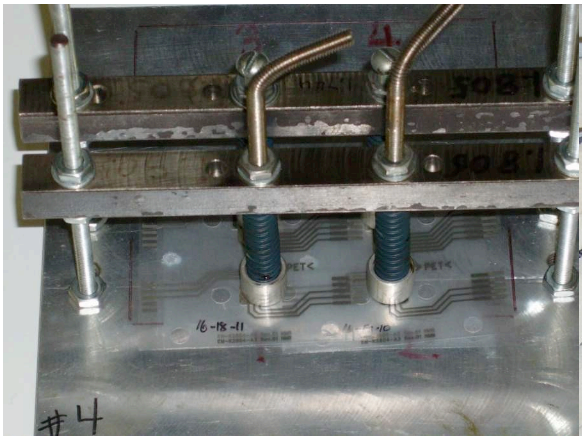
Figure 1. Typical Spring Bonding Fixture

$$L_c = L_f - (\sigma \cdot A)/k$$

Where:

L_c = length of compressed spring, mm (in)
L_f = free length of uncompressed spring, mm (in)
σ = bonding pressure, MPa (psi)
A = bond area, mm^2 (in^2)
k = spring rate N/mm (lbs/in)

*We use a steel die spring, 3/8in OD, 3/16in ID, 1.5in length, 42 lbs/in (McMaster-Carr 9573K12).
**An aluminum block faced with Kapton tape has also been used.



Section B: Flip Chip Bonder Process Development for NTP & TP Series Adhesives

Note: TP-2 is used here as an example and is the basis for all temperatures mentioned in this Section B. *These process development guidelines can be modified for* ***TP-1/NTP-1*** *(125°C resin bonding temperature) and* ***TP-3/NTP-3*** *(190°C resin bonding temperature) by adjusting all TP-2 process temperatures by the difference in the TP-1/NTP-1 or TP-3/NTP-3 resin bonding temperature with* ***TP-2/NTP-2*** *(150°C resin bonding temperature).*

Flip Chip Bonder

- Heated bond head (up to 200°C) with vacuum pickup.
- Bond head pressure capability >5 kg per cm^2 of bond area, maintain X-Y axis alignment <10 microns.
- Heated work stage (>180°C).
- Split optical alignment capability.

Experimental Components

- Die
  - non-bumped, pads <5 microns higher than non-conductive surface coating; pads >70 microns. For smaller pads see the Experimental Components Bonding section for pre-bonding alignment information.
  - individual pad connections to substrate, no daisy chain design.
- Substrate
  - conductive surfaces <5 microns higher than non-conductive surface coating.
  - external fiducials (location markings) to check for post-bonding alignment.

1st Stage Bonding Practice

- Two <400μ microscope glass slides cut to experimental die size
- Use TP-2 with <75μ thermocouple inserted. Bond head at 175°C, work station at 130°C, 3.5 kg per cm^2. Maintain heat/pressure until thermocouple reads ~150°C thermoplastic resin temperature. If decreased bond time is desired, then increase both bond head and work station temperatures and measure time to reach ~150°C resin temperature.
- Inspect bond area. If properly bonded there will be no visible voids on the two glass surfaces (due to low pressure and/or temperature) and no TP-2 squeeze-out around any outside edge (due to high pressure and/or temperature). There will be voids around the thermocouple. Fiber ends are visible on a voided surface but are covered with resin. Shiny metallic fiber ends will be visible on properly bonded surfaces. Another test is to measure the bond line thickness decrease…it should have gone down about 10-15% (for example from 100μ to ~90μ).

- Continue glass slide bond trials until proper bonding is achieved.

2nd Stage Bonding Practice

- Experimental substrate and one <400μ microscope glass slide cut to experimental die size.
- Start with successful bonding parameters (bond head temperature/pressure, work stage temperature, bonding time) developed during **Initial Bonding Practice** and refine them as needed to account for the difference in thermal conductivity between the glass substrate and the experimental substrate. Once again a <75μ thermocouple inserted into the TP-2 is used to verify that the resin reaches ~150°C.

Experimental Components Bonding

1st Step….Baseline Bonding Parameters

- Experimental substrate and die.
- **Pre-bonding die alignment for pads <50 microns:** The nickel fibers' angle increases (starts at 5°) as the TP-2 thickness decreases during bonding. For example, 100μ film will decrease to 85-90μ after proper bonding…this tilts the fibers at the die interface ~30 microns along the X-axis and must be compensated for pads < 50 microns. These smaller pads will need X-axis position adjustment to properly make Z-axis connections. Two techniques can be used: (1) for bond heads with X-Y axis restraint the die should be aligned with an offset of ~30 microns along the X-axis (this increases to 50 microns if both die and substrate pads are 5 microns higher than the non-conductive surface coating); and (2) for bond heads with only Y-axis restraint the die pads will follow the fibers as they tilt during bonding and no pre-bonding alignment offset is required.
- Start with successful bonding parameters (bond head temperature/pressure, work stage temperature, bonding time) developed during **2nd Stage Bonding Practice** and refine them as needed to account for the difference in thermal conductivity between the glass "die" and the experimental die. Once again a <75μ thermocouple inserted into the TP-2 is used to verify that the resin reaches ~150°C.
- Check alignment with external fiducials to ensure no post-bonding X-Y axis shift.
- Use acoustical scanning to confirm lack of bond voids.
- Use a micrometer to confirm proper bond line thickness.

2nd Step….Destructive Inspection

- Experimental substrate and die.
- Use the final bonding parameters from the **1st Step** to perform a normal bond without a thermocouple inserted in the TP-2. Pry the die and substrate apart (a reasonable pry force is needed for a good bond) and inspect both surfaces. A good bond will have TP-2 attached to portions of both the die and the substrate. Exposed TP-2 film will have the correct fiber tilt (15-20° from Z-axis) and fiber ends visible on the surface. Also there will be no signs of TP-2 squeeze-out from the bond area.

3rd Step….Electrical Testing

- Use the successful bonding parameters (bond head temperature/pressure, work stage temperature, bonding time) verified in the **2nd Step** to bond several sets of die/substrate and measure the electrical resistance of all Z-axis pad pairs.

4th Step….Reduce Bond Time

- Both bonded surfaces (die and substrate) and the TP-2 resin must reach ~150°C for proper bonding. Substrates that are not pre-heated can take a long time to reach ~150°C on the bonded surface when heated by a work stage. For example, a 330 micron thick (0.013") FR4 PCB takes ~12 seconds to reach 150°C when placed on a 165°C hot plate.
- Decreasing the bond time successfully used in the **3rd Step** means that the temperatures of both the bond head and the work stage need to be increased. Increasing bond head pressure can also help if the temperature increase alone does not sufficiently lower the bond time.
- Other techniques for lowering the bond time include using die or substrates with the TP-2 already laminated in place or pre-heating the substrate bonding surface just prior to the actual bonding.

Ideal Production Component Configuration

- Die is non-bumped, pads are no more than a few microns higher than non-conductive surface.
- Substrate conductive surfaces are a no more than a few microns higher than non-conductive surface.
- TP/NTP film adhesive has been vacuum laminated to either the die (on the wafer before dicing) or the substrate (for example flex circuits before singulating). This will reduce the bonding temperatures and pressure required for final package assembly.

  Vacuum lamination equipment options:

  (1) heated vacuum press.....every PCB shop uses this type of equipment.

(2) vacuum drawer laminator (example Dynachem EN-2400, ~$65k new, used equipment available).....fairly common piece of equipment for wafer producers....more capability and more costly than needed for TP/NTP application.

(3) air cooled laminator used for making solar panels.... www.eets.co.uk ~$35k new. These machines are very simple so many companies build their own.

Example: the basic vacuum lamination production process for wafers:

- tack a piece of TP/NTP to the wafer with a heated plate (outside plate diameter is slightly smaller than the wafer)
- run a scribe around the outside of the wafer to trim off excess adhesive film and expose the dicing streets
- vacuum laminate the TP/NTP to the wafer
- dice with a 4-6 micron particle diamond saw (or use laser dicer)