Application of Adhesive bonding techniques in Hard Disk Drive head assembly

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Abstract

Current market conditions demand that hard disk drive (HDD) manufacturers adopt advanced technology in every area of drive design to improve drive capacity and performance while simultaneously reduces unit cost. Like all the vendors to the HDD industry, Head stack suppliers for HDD are constantly working on High Density Interconnect (HDI) technologies to provide solutions that enable faster, higher capacity, more economical disk drives. This paper will describe a low cost method to manufacture HDD head using Anisotropic Conductive Film (ACF) bonding for Flex to Flex interconnection. It appears that this type of adhesives can give a very reliable electrical and mechanical interconnection.

Introduction

With manufacturing cost and new technology demands on the rise, disk drive manufacturers are developing advanced manufacturing methods in order to stay competitive. Manufactured in very high volumes, hard disk drive head currently uses either manual bonding process (bump, wire, or TAB) or manual hot bar soldering process to make the electrical connection. Both methods consume expensive cleanroom floor-space and time consuming result in low productivity and yield loss. A low cost method to manufacture HDD head using Anisotropic Conductive Film (ACF) bonding for Flex to Flex interconnection is developed to overcome this drawback.

This paper focuses on the Process selection of ACF bonding method in HDD head application. It starts with a comparison study among the current widely used bonding methods like Ultrasonic Tab bonding, Hot bar soldering process in HDD head manufacturing so as to identify the potential benefits gained from the newly developed ACF bonding technique. The optimal size and shape of the gold bond pads for the interconnected joints are determined by Stress analysis simulation method.

As a result, the current bond pad shape for Ultrasonic Tab bonding was modified to single sided overcoating to give minimum internal stress in ACF bonding method. Reliability evaluations were performed with specific regards to the interface reactions between polymer and metal surfaces in adhesive contacts. The electrical and mechanical performance of the adhesive bonds was studied by evaluating initial contact resistance as a function of time under different reliability testing. Characterization of the ACF bonding critical process parameters such as the heating temperature, bonding pressures, time of duration for optimal conditions is established.
Basic structure of HDD head
Figure 1 shows the components and basic structure of a typical HDD head. It consists of a Head Gimbal assembly (HGA), which is a transducer, the read/write exchange process takes place. The HGA is mounted on an actuator and the electrical connections with passive components are connected via the flexible printed circuit (FPC) assembly. In this paper, we have evaluated the feasibility of applying ACF bonding method for the flex to flex interconnection between the HGA and FPC bond pads. Figure 2 & 3 show the outline and dimensions of the HGA and FPC bond pads.

Process selection
The ACF bonding Technique is compared to the Ultrasonic TAB bonding and traditional hot bar soldering processes which are currently widely used methods of interconnection in HDD industry. The advantages and disadvantages of the bonding methods are evaluated with special regards to the requirements in HDD industries.

Ultrasonic TAB bonding interconnection.
Figure 4 shows cross-section of the interconnected joint by Ultrasonic TAB bonding. The two bond pads, the HGA and the AFC bond pads are bonded together under ultrasonic power and the two surfaces are in close contact. The advantage of this method is short process time (around 300ms) and a clean process, it is a solderless and fluxless process. The main drawbacks of ultrasonic TAB bonding are higher equipment set up cost, limitations in rework and difficulties in quality control and inspection. Micro cracking is used to be the long-term reliability problem in ultrasonic TAB bonding method.

Fig 4 Cross section of joint by Ultrasonic TAB bonding

Hot bar soldering interconnection
Figure 5 shows the cross-section of the joints by Hot bar soldering method. The two bond pads to be jointed are pre-finished with solder. The two terminals are then bonded with a hot bar soldering head, which melts the solder bumps to form an integrated joint. This method gives higher bond strength and reliability. The main disadvantages are contamination from flux residue, solder splashes which are harmful for HDD head yield.

Fig 5 Cross-section of joints by Hot bar Soldering
Anisotropic conductive film bonding
Anisotropic conductive adhesive films are epoxy films of b-stage epoxies or thermoplastics (or blends). They are filled with massive gold particles or gold-coated polymer spheres to an appropriate amount that ensures electrical insulation in all directions before, but electrical conduction in the z-axis only after bonding (up to 20 weight %). The process flow can be divided into three steps.
- Application of the ACF onto the FPC substrate.
- Alignment of the HGA pads to the FPC bond pads.
- Bonding the HGA and FPC bond pads by curing of adhesive.
Coplanarity has a great influence on the reliability of the electrically conductive joint because the conductivity is grounded on the clamping the particles between the two bond pads. Figure 6 shows the cross-section of the ACF bonding interface, the two bond pads are hold together by adhesive with few conductive particles in between for electrical connection.

Stress Analysis
The structure of the bonding surfaces for the Head Gimbal Assembly (HGA) and the Flexible printed circuit (FPC) is illustrated in the below figure 7. The HGA flex and FPC flex structure consists of a Polyimide base layer, adhesive layer, copper trace and Polyimide cover layer.

![](image)

Fig. 7 Structure of Flex to Flex Joint

Table 2 below is the full description of the items in Figure 7.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.025mm polyimide</td>
<td>Coverlayer</td>
</tr>
<tr>
<td>2</td>
<td>0.025mm adhesive</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.018mm copper</td>
<td>Exposed copper shall be covered with 0.43um gold &amp; 7.0um nickel(FPC's pad)</td>
</tr>
<tr>
<td>4</td>
<td>0.025mm polyimide</td>
<td>Baselayer</td>
</tr>
<tr>
<td>5</td>
<td>0.025mm polyimide</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.018mm copper</td>
<td>Exposed copper shall be covered with 0.3um<del>1um gold &amp; 1.2um</del>4um nickel(HGA's pad)</td>
</tr>
</tbody>
</table>

The comparison among different connection methods is summarized in Table 1 below.

<table>
<thead>
<tr>
<th>Connection method</th>
<th>Ultrasonic bonding</th>
<th>Reflow soldering</th>
<th>Anisotropic Conductive Film</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleanliness</td>
<td>Good</td>
<td>Bad</td>
<td>Good</td>
</tr>
<tr>
<td>Stability</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Cycle time</td>
<td>Short(300ms)</td>
<td>Long(20s)</td>
<td>Long(20s)</td>
</tr>
<tr>
<td>Production cost</td>
<td>Middle</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Quality control</td>
<td>Mid-difficult</td>
<td>Easy</td>
<td>Easy</td>
</tr>
<tr>
<td>Process control</td>
<td>Difficult</td>
<td>Middle</td>
<td>Easy</td>
</tr>
<tr>
<td>Reworkability</td>
<td>Rework once only</td>
<td>No</td>
<td>Reworkable</td>
</tr>
<tr>
<td>Application in HAA</td>
<td>Widely used</td>
<td>Will be replaced</td>
<td>First trial</td>
</tr>
</tbody>
</table>

One important consideration for reliable and stable adhesive bonds for HDD head is the internal stress presented after the adhesive bond made. The current FPC bond pad designed for Ultrasonic TAB bonding is evaluated for the suitability for ACF adhesive bonding application. Finite element analysis software ANSYS is applied to calculate various structural internal stress of the current design, it was found that high internal stress of 2760 N/m² presented in the adhesive joints and experiments of actual parts reported open circuit after Aging tests for 1,000 hours.
Original design of FPC for Ultrasonic Tab bonding

The FPC bond pad for Ultrasonic Tab bonding is designed with an opening on cover layer for copper conductive pads exposure. The cover layer, Polyimide is 0.025 mm thick and the copper trace is made of 0.5 OZ Copper.

![Figure 8: Original design of FPC](image)

**Table 3 – Structure of FPC design**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baselayer</td>
<td>0.025mm Polyimide, 0.025mm adhesive</td>
</tr>
<tr>
<td>Trace</td>
<td>0.5oz copper</td>
</tr>
<tr>
<td>Coverlayer</td>
<td>0.025mm Polyimide, 0.025mm adhesive</td>
</tr>
</tbody>
</table>

During ACF bonding using the current FPC design, the coverlayer and baselayer of FPC is under deformation by the press head. Part of the deformation is plastic and part of the deformation is elastic one. When the press head is released, the elastic deformation force tends to restore the adhesive joints to the original shape. The Adhesive joint is now under high internal stress. Reliability tests demonstrate that the internal stress created will cause intermittent or open problem in long term reliability test. The failure mechanism is illustrated in figure 9 below.

![Before Bonding → After Bonding → After Reliability Test](image)

**Figure 9. Failure Mechanism of ACF bonding after reliability test**
Stress Analysis by ANSYS

We then apply Stress analysis software tool ANSYS to design for a new FPC bond pad with minimum internal stress. In the new design, one side of cover layer is removed to give better contact area between the bond pads. Finite element analysis indicates internal stress of only 633 N/m² present in the new design. Figure 10 & 11 show the Finite Element Analysis models of the current FPC design and improved FPC design for ACF application.

Improved design of FPC for ACF bonding

The details of the new design is described as below:
- Partial cover layer is removed to decrease elastic deformation
- To avoid shorting, the HGA trace is shifted 0.2mm and 0.11mm outward respectively and FPC cover layer shifted 0.1mm towards base-plate.
- To enlarge bonding contact area, FPC pads are enlarged 0.175 mm toward base-plate.

Fig. 12 illustrate the ACF bonding with the improved FPC design. The detail structure of the bond layers are shown in the cross-section A-A.

Figure 12: Improved FPC design.

Fig. 13 ACF joints with improved design

Extend FPC trace by 0.175mm
Shift suspension trace 0.11mm outward
Shift suspension bond pad 0.10 mm Towards base-plate
Shift Fpc cover layer 0.1 mm towards base-plate
Shift suspension bond pad 0.10 mm Towards base-plate

Section A-A Improved FPC pad design

Cross- section A-A
ACF Bonding processes

The Anisotropic conductive film is supplied in reel type with width pre-cut to the specified requirement as the width of the bond pads. A release film separates the adhesive layer, which is mixed with conductive particles before processing. A semi-automatic pre-tacking machine (figure 14 & 15) is used to cut the adhesive layer to the right length and to laminate the adhesive film onto the bonding surface of the FPC side. The pre-bonded condition is at temperature 110 degree C, pressure 23 Kg/cm² and duration 1.5 second.

Final bonding for the HGA and FPC interconnection is done by a Hot bar pressure head machine, (figure 16).

The temperature control profile of the hot bar pressure head machine (ACF bonding machine) is shown in below figure 17.
Characterization of critical bonding parameters

Three critical bonding parameters are considered for optimal bonding condition, namely Temperature, Pressure and Time duration.

Temperature and time setting
Among the three parameters, heating temperature is the most important one, as too low heating temperature cannot solidify the ACF adhesive while too high will result in adhesive bond degradation due to the burn of the adhesive and substrate materials. Experiments are carried out to find out the relationship of temperature and time settings for the subject application in Flex to Flex interconnection. Acceptance criteria for complete curing of adhesive are determined at level of more than 85% of adhesive curing. The result is shown in the below figure 18. The epoxy curing percentage is measured by Differential Scanning Calorimetry (DSC).

![Graph showing Epoxy Curing Percentage vs Temperature and Time](https://via.placeholder.com/150)

**Fig 18 Adhesive Curing Percentage Caused by Temperature / time**

**Pressure setting**

Bonding pressure is closely related to the contact resistance of the joint after bonding. Normally, higher pressure increases contact area of the ACF conductive particles between the HGA and FPC bond pads which resulting low contact resistance. Experimental results of bonding pressure and resistance after bonding is shown in figure 19. Pressure at 23 kg/cm2 gives the optimal condition for lowest resistance and hence reliable joint.

**Table 4 below shows peel strength of ACF bonding in HDD Head Assembly.**

<table>
<thead>
<tr>
<th>Item</th>
<th>Peel strength value</th>
<th>Notes:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>155g</td>
<td>1. Sample size=30</td>
</tr>
<tr>
<td>Std deviation</td>
<td>15</td>
<td>2. Perpendicular to bonding surface When testing</td>
</tr>
</tbody>
</table>

The data show peel strength can meet the product specification (min 80g).

![Graph showing Relationship of Pressure and Resistant](https://via.placeholder.com/150)

**Fig 19 the Relationship of Pressure and Resistant**

Even pressure distribution determines to great extent of the stability of the adhesive joints. Uneven pressure creates localized high stress points, which give different deformation rate for the conductive particles, and hence the reliability of the joints is affected. Pressure test paper is used to determine the pressure distribution for the pressure head and the color distribution of the test paper shown the pressure variance across the head. Adjustments are done to ensure even pressure for reliable joints.

**Reliability**

The properties of adhesive joints can be described in the following way:
- Mechanical and adhesive strength of the interconnection.
  This can be evaluated by measuring shear strength as well as performing tensile and peel tests.
- Quality of the electrical contacts evaluated by measuring of contact resistance.
  Peel strength test is carried out under condition that FPC is stripped perpendicular from the bonding surface. The peel strength result of optimal bonding condition is shown in below table 4. It indicates the ACF adhesive bonding method achieves a very reliable joint.
Reability tests performed to confirm the long-term stability of the adhesive joints are Aging life test (temperature, 85 degree C, relative humidity 85%) and Thermal shock tests. The change in contact resistance is monitored at different time intervals up to 1000 hours and the acceptance criteria are less than 0.1-ohm resistance change. Figure 20 & 21 show the reliability test results of 100 samples and all the samples passed the acceptance criteria.

![Fig 20 The Result of Aging Life Test](image)

![Fig 21 The Result of Thermal Shock Test](image)

**Conclusion**

This paper intends to illustrate the application of ACF Adhesive bonding technique to HDD head manufacturing as an alternative to low cost mass production method. Although ACF bonding technique is proved to be a mature process for Chip On Glass (COG) in Liquid Crystal Display (LCD) applications, there are still lots of unknown variables like process parameters and settings, substrate materials properties, effects of operating environment to be understood for applications in HDD head manufacturing. In this report, we have shown the feasibility of the flex to flex interconnection process. The mechanical and electrical properties of the interconnections fulfilled all HDD head requirements.

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**References**


