Application of adhesive bonding techniques in hard disk drive head assembly

C.F. Luk a,1, Y.C. Chan b,*, K.C. Hung b

a SAE Magnetics (H.K.) Ltd., SAE Tower, 38-42 Kwai Fung Crescent, Kwai Chung, N.T., Hong Kong
b Department of Electronic Engineering, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon, Hong Kong

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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 and simultaneously reduce unit cost. Head stack suppliers in HDD industry are constantly working on high density interconnect technologies to provide faster and higher capacity and cheaper head stack components for disk drives. A low cost method to manufacture HDD head using anisotropic conductive film (ACF) bonding for flex-to-flex interconnection has been developed. This paper describes the process selection work among the current and the newly developed ACF bonding technologies. Bond pad design for ACF process using the finite element analysis method is introduced. Critical process bonding parameters are identified and characterized to give the optimal bonding conditions. Reliability evaluations on the final assemblies indicated that ACF bonding could give a very reliable electrical and mechanical interconnection.

1. 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, either manual bonding process or manual hot bar soldering process to make the electrical connection for hard disk drive (HDD) head is used. Both methods consume expensive cleanroom floor-space and time resulting 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 [1] is developed to overcome this drawback.

This paper focuses on the process selection of ACF bonding method in HDD head application. It starts with the comparison among the currently widely used bonding methods like ultrasonic TAB bonding and 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 finite element method, stress analysis tools with verification of computation results by actual prototype build samples. As a result, the current bond pad shape designed for ultrasonic TAB bonding was modified to single sided over-coating to reduce minimum internal stress when it is bonded by 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 and time of duration for optimal conditions is established.

*Corresponding author. Tel.: +852-2788-7130; fax: +852-2788-7579.
E-mail addresses: cfluk@sae.com.hk (C.F. Luk), eeyc-chan@cityu.edu.hk (Y.C. Chan).
1 Tel.: +852-2612-8888; fax: +852-2480-4757.
2. **General description and bonding method comparison**

2.1. **Interconnection**

Fig. 1 shows the basic structure of a typical HDD head for hard disk drive. The major component parts consist of a head gimbal assembly (HGA), which is a transducer where the read/write exchange process takes place, a mechanical actuator for the mounting and movement of the HGA. The electrical connections with the pre-amplifier (IC), passive components, connector, etc. are connected via the flexible printed circuit (FPC) assembly. In this paper, we have evaluated the feasibility of applying ACF bonding method to the flex-to-flex interconnection between the HGA and FPC bond pads. The typical shape and dimensions of the HGA and FPC bond pads are shown in Figs. 2 and 3 respectively.

In most HDD products, traditional ultrasonic TAB bonding or hot bar soldering processes are currently, widely used methods for HGA and FPC interconnection and they are done either by manual or semi-automatic process only. The newly developed ACF bonding technique is compared to the ultrasonic TAB bonding and hot bar soldering processes. The pros and cons of all the bonding methods are identified and evaluated with special regards to the unique requirements in HDD industries.

2.2. **Ultrasonic TAB bonding interconnection**

The two bond pads, the HGA and the FPC bond pads are bonded together under ultrasonic power and the two bonded surfaces are in close contact. The advantage of the method is short process time (around 300 ms) and is
a clean process because it is a solder-less and flux-less process.

The main drawbacks of ultrasonic TAB bonding are higher equipment setup cost, limitations in rework and difficulties in quality control and inspection. Micro-cracking used to be the long-term reliability problem in ultrasonic TAB bonding method. Fig. 4 shows the cross-section of the joint by ultrasonic TAB bonding.

2.3. Hot bar soldering interconnection

The two bond pads to be joined are pre-finished with solder. The two bonding pads are then bonded by 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 and solder splashes and both are detrimental to the HDD head yield. Fig. 5 shows the cross-section of the finished joints by hot bar soldering method.

2.4. Anisotropic conductive film bonding

Anisotropic conductive adhesive films are epoxy films of b-stage epoxies or thermoplastics (or blends) [2]. They are filled with massive gold particles or gold-coated polymer spheres to an appropriate amount that ensures electrical insulation in all directions before bonding but
electrical conduction in the z-axis only after bonding (up to 20 wt.%).

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 of the bond pads has a great influence on the reliability of the electrically conductive joint [3] because the conductivity is grounded on the clamping of the particles between the two bond pads.

Fig. 6 shows the cross-section of the ACF bonding interface, the two bond pads are held together by adhesive with few conductive particles in between for electrical connection.

The critical process factors of the three interconnection methods, ultrasonic TAB bonding, hot bar soldering and ACF bonding, are compared and summarized in Table 1.

ACF bonding method has shown good performance in cleanliness and joint stability. As a result of fewer process steps, the overall production cost for ACF process is the lowest among the three. Quality and process control for ACF bonding is also relatively easy too.

3. Modelling and experimental verification

3.1. Bonding surface structures

The HGA and the FPC bonding surface structures are illustrated in Fig. 7. The HGA and FPC flexible substrate structures consist of a polyimide base layer (0.025 mm thick), an adhesive layer (0.025 mm thick), copper trace (0.018 mm thick) and a polyimide cover-layer (0.025 mm thick). The HGA and FPC bond pads are with gold plated finish. The detail descriptions of the HGA and FPC flexible substrate structure items are summarized in Table 2.
3.2. Internal stresses prediction using finite element analysis computation

The current FPC bond pad designed for ultrasonic TAB bonding is evaluated for the suitability for ACF bonding application. The cover layer of the FPC is designed with a rectangle opening for the gold plated copper pads as shown in Fig. 8. The FPC bond pads are aligned and pressed against the HGAbond pads during the adhesive bonding process.

One important consideration for a reliable and stable adhesive bond for HDD head is the internal or mechanical stresses, which are incorporated during the adhesive bonding [4].

Finite element analysis (FEA) method ANSYS structural stress analysis tool [5] is adopted to predict the internal stress of the final ACF bonded HGA/FPC joints. The modeling work is briefly introduced below:

1. The thickness of the FPC is considered far less than its size and force is being evenly applied to FPC along the thickness direction.
2. The cross-section of the bonding area between the FPC and HGA is taken as analysis target.
3. The length direction is defined as the x-axis and the thickness direction is defined as the y-axis.
4. According to symmetrical theory, \( u = u(x, y) \), \( v = v(x, y) \) and they are function of \( x \) and \( y \), the displacement in z direction is zero.
5. According to deformation geometry theory, 
   \[ \varepsilon_c = \frac{\partial w}{\partial z} = 0, \]

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Table 1
Comparison of different interconnection methods for HDD head assembly

<table>
<thead>
<tr>
<th>Interconnection method</th>
<th>Ultrasonic TAB bonding</th>
<th>Hot bar soldering</th>
<th>ACF</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 (300 ms)</td>
<td>Long (20 s)</td>
<td>Long (20 s)</td>
</tr>
<tr>
<td>Production cost</td>
<td>Middle</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Quality control</td>
<td>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>Not reworkable</td>
<td>Reworkable</td>
</tr>
<tr>
<td>Application in HDD</td>
<td>Widely used</td>
<td>Will be replaced</td>
<td>First trial</td>
</tr>
</tbody>
</table>

Table 2
Descriptions of HGA & FPC flexible substrate structure

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.025 mm polyimide</td>
<td>Cover layer</td>
</tr>
<tr>
<td>2</td>
<td>0.025 mm adhesive</td>
<td>Exposed copper shall be covered with 0.43 μm gold and 7.0 μm nickel (FPC’s pad)</td>
</tr>
<tr>
<td>3</td>
<td>0.018 mm copper</td>
<td>Base layer</td>
</tr>
<tr>
<td>4</td>
<td>0.025 mm polyimide</td>
<td>Exposed copper shall be covered with 0.3–1 μm gold &amp; 1.2–4 μm nickel (HGA’s pad)</td>
</tr>
<tr>
<td>5</td>
<td>0.025 mm polyimide</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.018 mm copper</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 7. Structure of flex to flex joint.
6. The structure can be simplified into plane strain model and strain in $x$- and $y$-axes exist and they are function of $x$ and $y$.

7. The adhesive layer is comparatively soft (Young’s modulus is around $0.3 \times 10^6$ Pa). It is assumed that the adhesive provides nothing but bonding force and it is ignored in the analysis structure model.

The final FPC target area for stress analysis is shown in Figs. 9 and 10. FEA software ANSYS is then applied to calculate various structural internal stresses of the current bond pad design. When the press head moves downward the FPC bond pads will be forced to contact with the HGA bond pads. The stress build up in the
joint will be gradually increased as the two contact surfaces come closer and closer until the joint is finally set. The movement of the FPC can be simulated in N steps with repeated cycles for the internal stress prediction. The computation result has shown high internal stress of 2760 N/m² presented in the adhesive joints. During the ACF bonding process, the cover layer and base layer of FPC are under deformation by the press head. Part of the deformation is plastic and part of the deformation is elastic. When the press head is released, the elastic deformation force tends to restore the adhesive joints to the original shape. It is likely that the joint will become open when the stress on FPC is larger than that of the ACF bonding force.

A new FPC bond pad structure design is then developed to reduce the internal stress in the adhesive joints. In the new design as shown in Fig. 11, one side of the cover layer is removed to decrease the elastic deformation and to give better contact area between the FPC and HGA. FEA results indicated that the new design gives internal stress of 633 N/m² only.

The FEA models of the current and improved FPC bond pad structure designs for ACF bonding are shown in Figs. 12 and 13.

3.3. Experimental verification of FEA computation

In order to verify the FEA result, 60 samples with the current and new FPC bond pad structure design are then fabricated respectively under the standard bonding condition. The experimental result are found good agreement with the FEA model data. Aging tests of both types of samples for 1000 h demonstrated that the restored deformation in the current design will cause intermittent or open problem in long term reliability while the new design shown a stable adhesive joint.
The failure mechanism of the current design is proposed in Fig. 14. Under severe conditions, the restored stress in the adhesive joint is too large that it separates the adhesive jointed bond pads from contact and hence open or intermittent phenomenon result.

4. ACF bonding process

The ACF 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.

Basically, the ACF bonding process consists of two process steps, i.e. ACF pre-tacking and ACF final bonding.

A semi-automatic pre-tacking machine as shown in Figs. 15 and 16 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 ACF is pre-bonded onto the FPC substrate with a thermode as shown in Fig. 17. The pre-tacking process condition as recommended in ACF supplier data sheet is at temperature 110 °C, pressure 2.3 kg/cm² and duration of 1.5 s.

Final bonding for the HGA and FPC interconnection is done by a hot bar pressure head machine as shown in Fig. 18. The bonder has a pulse-heated thermode, which made it possible to use a temperature profile as indicated in Fig. 19. The indicated temperature is the setting temperature of the thermode. It is measured that the real adhesive temperature is about 15 °C lower than the thermode setting temperature (at 200 °C).

The temperature control profile of the hot bar pressure head machine (ACF bonding machine) is shown in Fig. 19. It consists of a ramp up, bonding and cooling zone. The final curing of the ACF epoxy is set in the bonding zone.

Special attention has been paid to the thermode. The thermode must be clean, flat and parallel to the substrate. The flatness and parallelism is controlled with pressure sensitive paper.

5. Results and discussion

5.1. Characterization of critical bonding parameters

In ACF bonding, temperature, pressure and time duration are the critical bonding parameters for optimal
bonding conditions. The process window of bonding parameters for optimization is discussed in detail in the following paragraphs.

5.1.1. 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 temperature 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 percentage of epoxy curing is measured by differential scanning calorimetry measurement technique. It is shown in Fig. 20 that process condition with curing temperature set at 200 °C and time duration of 20 s gives the most cost-effective solution for ACF bonding.

5.1.2. 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 and result in low contact resistance. Experimental results of bonding pressure as a function of resistance after bonding are shown in Fig. 21. Pressure setting at 2.3 kg/cm² gives the optimal condition for lowest resistance and hence a reliable joint.

Fig. 18. ACF bonding machine.

Fig. 19. Temperature profile of ACF bonding cycle.

Fig. 20. Adhesive curing percentage as a function of temperature/time.

Fig. 21. Relationship of pressure and resistance.
Even pressure distribution determines to great extent of the stability 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 shows the pressure variance across the head. Adjustments are done to ensure even pressure for reliable joints.

5.2. Reliability testing

It must be noted that the influence of parameters like bonding force and bonding time can only be determined after reliability tests.

The properties and quality of adhesive joints [6] can be described in the following way:

1. Mechanical and adhesive strength of the interconnection: this can be evaluated by measuring shear strength as well as performing tensile and peel tests.
2. Quality of the electrical contacts: it is evaluated by measuring of change of contact resistance with time under severe conditions.

5.2.1. Peel strength test

Peel strength test is carried out under condition that FPC is stripped perpendicular from the bonding surface. The peel strength result for 30 samples bonded under the optimal bonding condition have shown high peel strength with mean value of 155 g and standard deviation of 15 g with the HDD product specification for the HGA/FPC joint is at least 80 grams for peel strength requirement, it indicates that the ACF adhesive bonding method achieves a very reliable joint.

5.2.2. Contact resistance changes

Reliability tests performed to confirm the long-term stability of the adhesive joints are aging life test (85 °C, 85% RH) and Thermal shock test. The change in contact resistance is monitored at different time intervals up to 1000 h and the acceptance criteria are less than 0.1 Ω resistance change. The reliability testing results of 100 samples are shown in Figs. 22 and 23 and all the samples passed the acceptance criteria with contact resistance change in the range of −0.02 to 0.04 Ω.

6. Conclusions

In this paper, we have shown that

- The feasibility study of using an ACF to make the flex-to-flex interconnection between the HGA and FPC bonding pads for a HDD head assembly.
- FEA software tools ANSYS is used to predict the internal stress of the ACF bonded joints and computation results shown high internal stress of 2760 N/m² presented in the original FPC pad design, hence a new design is developed with minimum stress of 633 N/m².
- Actual ACF bonded samples with the original and new FPC pads are built to witness the FEA computation results and the failure mechanism of the original design is proposed.
- ACF bonding process is with fewer steps. It consists of two processing steps, the ACF pre-tacking and ACF final bonding. Estimation of the total costs showed that the application of ACF bonding technique to HDD head manufacturing could be an alternative low cost mass production method.
- The mechanical and electrical properties of the interconnections fulfilled all HDD head requirements. The mean peel strength of the ACF joint is 155 grams and standard deviation is 15 grams. The contact resistance change of the ACF joint after aging life test and thermal shock test for 1000 h is less than 0.1 Ω.

Although the ACF bonding technique is proved to be a mature process for chip on glass in liquid crystal display applications, there are still lots of unknown variables like process parameters settings, substrate materials properties and effects of operating environment to be understood for applications in HDD head manufacturing. Ongoing research is being carried out to study the long-term reliability of these HDD products.
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