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# Effect of Humidity on Electrical Property of ECA Joints for Dual Stage Micro-Actuator in Hard Disk Drives Applications

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## Abstract

The conductivity of isotropic conductive adhesives (ICA) is the most important property for the ICA functionality. Good ICA must provide the high conductivity or low electrical resistance. In this paper, the electrical resistance of two ICA types, polyimide based (ICA type I) and epoxy based (ICA type II) have been investigated under the humid exposure of 85 °C/ 85% RH from 0 to 384 h. In addition, the degradation mechanisms of conductive adhesive joints were determined. The electrical resistances of both types of ICA joints increased as the exposure time of the humidity test increased. After humidity testing, there was no significant structural change at the interfaces and in conductive adhesive area for both ICA types. However, it is likely that oxidation of copper observed by SEM/EDS causes an increase in electrical resistance. The metal oxidation is the dominant mechanism for the unstable electrical resistance phenomenon during high temperature and high humidity conditions.

**Keywords:** Electrical conductive adhesives, isotropic conductive adhesives, reliability, humidity effect, degradation mechanisms.

#### 1. Introduction

Electrically conductive adhesives (ECA) have been used in many electronic assembly applications due to the environmental friendly issues (Lead-free). Moreover, they do not require high processing temperature or many processing steps. They are able to be used for fine pitch applications such as die attach pad on lead frame, smart cards, surface mount device (SMD) on flex and ceramics, flip chip assembly, flex to liquid crystal display (LCD), printed circuit board (PCB) and LCD drivers (1,2,3). Besides these applications, ECA have been used in the dual stage actuator (DSA) in hard disk drives (HDD) in order to provide an electrical connection from the flexure paddle to the lead zirconate titanate (PZT) micro-actuator as low outgassing properties. Figure 1 shows the hard disk drive components including the DSA.

ECA are composed of a polymer matrix (such as epoxy, polyimide, silicone, or polyurethane) and conductive filler (such as silver, gold, nickel or copper). According to the conductive filler loading, ECA can be classified into isotropic conductive adhesives (ICA) and anisotropic conductive adhesive (ACA). Typically, ICA have a higher loading of conductive adhesive filler (25-30 Vol %) and provides all directional conductivity by incorporating metallic particles within the matrix resin. While the ACA have uni-directional conductivity because they have lower loadings of conductive fillers which is around 5-20 Vol % (1,2,4).

However, one of the major concerns is the reliability of the conductive adhesives at the joints. The factors affecting the reliability are humidity, temperature, and current densities that increase the contact resistance leading to circuit failure. In HDD applications, this failure effected to the reliability of HDD. Many researchers have developed and enhanced the reliability of ECA in terms of mechanical, electrical, and thermal behavior under different conditions (5-9). In addition, ICA may be exposed to various environmental conditions during their working. Moisture is typical issue in environment and one of the critical factors for determining the reliability of adhesives. In this research, the humidity affecting the electrical resistance including the degradation mechanisms of two types isotropic conductive adhesives used in DSA components in HDD were investigated and compared.



Figure 1. Schematic of the dual-stage actuated hard disk drive (4, 5)

## 2. Materials and Methods

#### 2.1 Isotropic Conductive Adhesives (ICA)

Two different matrix based materials of ICA, which were designated as ICA type I and ICA type II, respectively, that used in the DSA in HDD were examined. They are commercial products from Henkel Corporation, (USA, California). Based on the material safety data sheet (MSDS) provided by supplier for two types of ICA as shown in Table 1, ICA type I is polyimide based while ICA type II is epoxy matrix based materials. The resistance and microstructure of both ICA types before and after the tests were characterized by using four point probe (Keithley 24203A) and Scanning Electron Microscope (SEM, Carl Zeiss Ultra 55), respectively.

Parameter	ICA type I	ICA type II
Filler Type	Silver	Silver
Matrix Based	Polyimide	Ероху
Viscosity @ 25 °C	11,600 cP	8,600 cP

 Table 1.
 The properties of ICA type I

#### 2.2 Thermo Gravimetric Analysis (TGA) Table 2.

The weight percent of Ag filler in the conductive adhesive were obtained by using a TGA, Mettler Toledo 851e which use Indium and Aluminum as the reference material. Dynamic heating processes up to 1000 °C at the heating rate 10 °C / min from room temperature in normal ambience were performed.

## 2.3 Preparation of Jointed Samples for Humidity Test

In order to investigate the electrical property of the ICA, the jointed samples were created by two copper strips attached across from each other by ICA as illustrated in Figure 2. The jointed area was 5.0 mm x 5.0 mm. After that, the samples were placed in the oven by setting curing conditions based on Differential Scanning Calorimeter (DSC) result as shown in Table 2. First, the oven was preheated without putting the samples in due to limitations on equipment for isothermal curing. Once, the temperature had reached to the setting point, the samples were put in the oven. Thermal equilibrium was achieved in 1 min.



Figure 2. Schematic of the jointed sample made of two copper strips with ICA

 Curing conditions of isotropic conductive adhesives

ICA	Curing Temperature	Curing Time
	(°C)	(s)
Type I	90	150
Type II	140	194

#### 2.4 Humidity Test Set Up

In this test, the jointed samples after cured were subjected to the humidity to study the reliability dependence on the humidity by using humidity chamber (Espec chamber model PL-2SP). The humid conditions of 85 °C/ 85% RH which is referred to the "85/85" Steady-State Humidity Life Test JEDEC Standard (No. 22-A101) were performed from 0 h to 384 h. At each 96 h, twenty samples were taken out for the electrical resistance measurement with the four-point probe method (Keithley 24203A). The cross section of the jointed interface between ICA and Cu strip area after exposing to humidity conditions was examined by SEM, Carl Zeiss Ultra 55.

## 3. Results and Discussions

#### 3.1 TGA result

The weight percent of Ag filler were studied by TGA. Dynamic heating processes up to 1000°C for both ICA types at the heating rate 10 °C/min were conducted to study the degradation behavior of materials. The TGA results show five weigh loss regions for ICA type I (Figure 3) and three weigh loss regions for ICA type II (Figure 4) in a dynamic heating progress. The weight loss prior to 100°C is associated with solvent evaporation and the other regions denote the degradation of the cured materials. Thus, the weight percent silver of ICA type I is higher than ICA type II which is found at 85% for ICA type I and 79% for ICA type II.



Figure 3. TGA results of ICA type I



Figure 4. TGA results of ICA type II

#### 3.2 Microstructure Characterization

First, the microstructure of ICA type I and type II after cured and before inserting to the jointed area were examined as showed in Figure 5. The sizes of the silver flake particles for both ICA are a mix of particle sizes around 2-10 um and less than 1 um but the sizes of ICA type I is thicker than the ICA type II. In addition, the tiny particles disperse around the big particles, but the ratio of submicron size of ICA type I is greater. Moreover, most of the silver flake particles of ICA type

type I (Figure 3) and three weigh loss regions for ICA II align themselves along the surfaces which may give type II (Figure 4) in a dynamic heating progress. The an advantage to produce lower resistance.

(a) Ag 20 μm 20 μm 20 μm



## 3.3 Humidity affecting the Reliability on Electrical Resistance

In order to evaluate a long-term reliability behavior of the adhesive materials, the jointed samples were exposed to the temperature/humidity conditions (85°C / 85% RH from 0 to 384 h). At every 96 h, the resistances of both ICA types were measured by four-point probe. Before the test, the resistance of ICA type I was higher than ICA type II. Figure 6 shows the comparison of resistance before and after the humidity test. At the initial state of soaking in humidity test for 96 h, the resistances of both cases increased significantly. After that, the resistance gradually increases up to 384 h. The resistance of ICA type I after the test was still higher than ICA type II. ICA type II shows 25% increased from 0.12 ohm to 0.14 ohm while ICA type I shows 28% increased from 0.16 ohm to 0.21 ohm.

The SEM image revealed the microstructure of ICA at the jointed area. The comparison of the ICA type I and ICA type II before the humidity test is illustrated in Figure 7 (a) and Figure 7(c), respectively. The agglomerations of Ag nanoparticles of ICA type I create voids in the ICA matrix that contribute to the decrease in bulk conductivity resulting in higher resistance than the ICA type II. Therefore, the ICA type II is preferred rather than ICA type I used as electrically conductive adhesives used in the dual stage actuator for the HDD.

In order to further examine the degradation mechanisms of the ICA, the microstructure of the jointed interface between Cu strip and ICA of both types after the test were investigated by SEM. There are no significant structural changes on both interfaces and in conductive adhesive area for both ICA types as indicated in Figure 7(b) and Figure 7(d) but the EDS results show that the oxidation of Copper as the oxygen peak was observed at the substrate surface (Figure 8). Since this layer is electrically insulating, the contact resistance is increased. Therefore, it is likely to be that oxidation of copper causes electrical resistance increased for ICA type I and type II during high humidity aging, which is consistent with the resulted reported by Tong et al. (8) and Lu et al. (10) which strongly indicate that electrochemical corrosion between dissimilar metals at the contact interface between the ICA and the non-noble metal is the main mechanism for a contact resistance shift of the ICA in high humidity condition.



Figure 6. Electrical resistance of ICA type I and type II before and after the humidity test as a function of exposure time



Figure 7. Cross sectional micrograph of ICA at the jointed area (a) ICA type I before test (b) ICA type I after the test for 384 h, (c) ICA type II before test, and (d) ICA type II after the test for 384 h



Figure 8. EM-EDS results of the Cu surface (a) before the humidity test and (b) after the humidity test for 384h

## 4. Conclusions

The humidity plays a crucial role on the electrical property of both ICA types. The degradation mechanisms of the joints with ICA type I and type II were characterized in details by electrical resistance measurement and cross-sectional micrograph. Before the test, the resistance of ICA type I is higher than ICA type II. After the humidity test, electrical resistance of ICA type I and type II increased for 28% and 25%, respectively due to the oxidation of copper. After the test, the resistance of ICA type I is still higher than ICA (5) type II. Therefore, The ICA type II is preferred to be used as an electrically conductive adhesives in the DSA for HDD. In addition, the oxidation of copper at the substrate surface after exposing to the high humidity conditions (6) is the main mechanism for contact resistance increased for both types of ICA.

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