VIABILITY OF PLASMA CLEANING FOR THE REMOVAL OF SMEAR AND SOFT CARBON CONTAMINATION ON HEAD GIMBAL ASSEMBLY

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ABSTRACT

The existing cleaning method of head gimbal assembly (HGA) is ultrasonic cleaning, which has limitations when removing thin contaminants such as smear and soft carbon due to its mechanical cleaning mechanism.

To address this challenge, this paper examines plasma cleaning as an additional cleaning method for HGA. Due to its chemical cleaning mechanism, plasma cleaning is effective to remove organic particulate contamination such as smear and soft carbon. To assess its effectiveness, Scanning Electron Microscopy (SEM) analysis was conducted on the HGA. The results demonstrate that plasma cleaning effectively removes smear contamination, and partially removes soft carbon on HGA. To ensure functionality, angular and electrical measurements, and visual checking were performed before and after plasma cleaning. No changes in angular and electrical data were observed, and no visual defects. Therefore, plasma cleaning is a viable cleaning method for HGA without affecting functionality. Further evaluation at hard disk drive (HDD)-level is recommended to assess the operational feasibility and determine its impact on reliability and cost of HDD.

1. 0 INTRODUCTION

The hard disk drive operation relies on the rotation of a magnetic disk driven by a motor. As the disk rotates, it generates a thin air cushion that enables the HGA to glide over its surface at a minimal distance, called flying height, as shown in Figure 1. To maximize the data storage efficiency of HDD, the flying height has decreased to less than ten nanometers. However, any contaminants on the head can result in head crashes, erratic head movement, and ultimately HDD failure. Therefore, it is important to ensure the cleanliness of components before installing them inside the HDD.

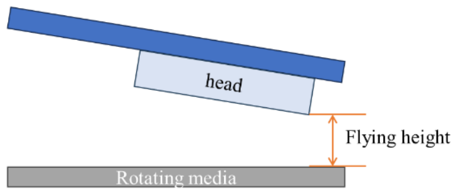


Figure 1. Schematic diagram of a head flying over a rotating media

A typical HDD manufacturing process is shown in Figure 2. The HGA are initially assembled along with other components to create the head stack assembly (HSA). Subsequently, the HSA is installed inside the HDD.

Figure 2. HDD manufacturing process flow

One contamination control is cleaning of components before proceeding to the next process. It is crucial that the cleaning method not only removes contaminants but also preserves the functionality of the component. Existing cleaning method for HGA is ultrasonic cleaning which is performed at the HSA level. After cleaning, functionality check is also performed at the HSA level. Ultrasonic cleaning method uses sound waves in a liquid to create microscopic bubbles that dislodge particles from the surface. The bubbles must penetrate the gap between the particle and surface for effective cleaning [1]. While ultrasonic cleaning is effective for removing most particulate contamination, it does not adequately address very thin particulate contamination, such as smear, and soft carbon as demonstrated in Figure 1. The small cavity between the thin particle and the surface hinders bubble penetration, making particle removal difficult.

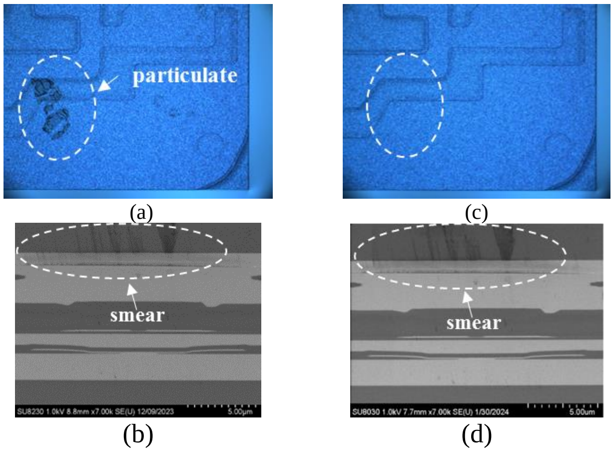


Figure 3. Optical inspection and SEM images of heads showing removable particulates and non-removable smear before (a~b) and after (c~d) ultrasonic cleaning of HGA.

Contamination on the HGA, such as smear and soft carbon, can be analyzed using SEM and/or Auger Electron Spectroscopy (AES). These methods allow analysis of contamination in order of decreasing size.

Smear contamination, often too thin to be analyzed using SEM and AES, is composed of carbon and/or nitrogen elements, as shown in Figure 4. Smear is suspected to be an organic particulate contaminant from media lubricant based on its appearance and composition. On the other hand, soft carbon, shown in Figure 5, appears black, surface-attached, and is thinly spread on the surface.

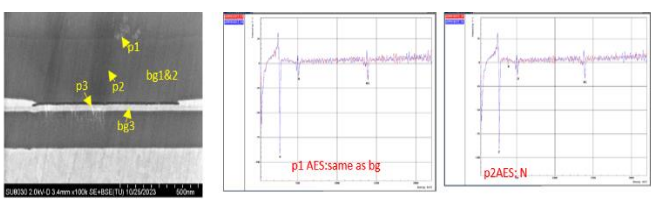


Figure 4. SEM and AES analysis of a smear contaminant on the head

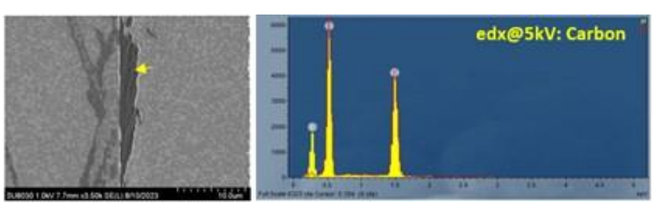


Figure 5. SEM analysis of soft carbon contaminant of the head

Plasma cleaning is one method used in semiconductor industry for the removal of organic contamination. This is a chemical cleaning method which applies ionized air to a surface. The energy from the ionized air breaks down the bonds of the particle and dislodges it from the surface, making it particularly effective for organic contamination due to the weak bonds in organic materials [2]. HGA samples with smear and soft carbon contaminant were subjected to plasma cleaning, and effectiveness was measured based on the removability of contamination using SEM. Functionality checks, including visual inspection, angular and electrical assessments, were performed both before and after the plasma cleaning process. By examining both contaminant removal and functionality, this study aims to determine the viability of plasma cleaning as an additional cleaning method for HGA.

2.0 REVIEW OF RELATED WORK

2.1 Types of Contamination

HDD can be affected by different types of contamination, namely particulates, outgassing contamination, and ionic contamination.

Particulate contamination is the presence of tiny particles on the surface of HDD components, causing physical damage. Particulates can come from different sources like the air, factory workers, or machine [3]. Smear and soft carbon are both particulate contaminants.

Another type of contamination is outgassing that refers to the process where gas, once held within a material, is released and settles on hard drive components which triggers chemical reactions that slowly degrade the performance of the hard drive [4].

The last type of contamination is ionic contamination which refers to the presence of charged substances such as salts and acids that can cause corrosion or other reactions, affecting the drive's reliability and lifespan [5].

These contaminants can adhere to the surface of hard drive parts with the help of an adhesion force governed by van der Waals forces, capillary forces, electrostatic forces, and specific chemical forces [6].

2.2 Contamination Removal Methods

In Table 1, different cleaning methods of HDD components were presented. The effectiveness of cleaning relies on applying external forces greater than the adhesion force of the contaminant [7]. Hence, cleaning effectiveness varies depending on the type of contamination.

Table 1. HDD Component Cleaning Methods

Method	Cleaning Mechanism	Target contaminants			Advantage	Disadvantage
		Particulate	Outgassing	Ionic		
Chemical Wiping	Solvent cleaning	o	o	o	> Quick evaporation > Disinfecting properties	> Potential material damage > Health risk
Ultrasonic Washing	Thermal, mechanical and emulsification	o	o	o	> Efficiency > Life span	> Transducer efficiency > Temperature sensitivity
Tapping	Hydraulic and mechanical process	o	x	x	> Versatility > Precision > Efficiency	> Tool wear > Breakage risk
Air Knife	Physical and	o	x	x	> Efficiency	> Transducer

	mechanical process				> Drying > Uniform airflow	efficiency > Temperature sensitivity
Vacuum	Physical and mechanical process	o	x	x	> Efficiency > Versatility	> Electricity consumption > Handling > Noise
CO2 (Dry Ice) Spray Cleaning	Thermal, mechanical and solvent interaction	o	x	x	> Efficient cleaning > No residue > Environmental benefits	> Requires special equipment > Limited effectiveness > Safety concern

The existing HGA cleaning method involves ultrasonic washing. As shown in Figure 6, the mechanism produces sound waves that create bubbles as they move through the water—a phenomenon called cavitation. These bubbles penetrate the crevice between the particle and the surface. As the bubbles collapse, they exert pressure that dislodges the adhered particle from the surface [1]. With the right settings, ultrasonic cleaning can be effective and not cause surface damage [8]. However, it cannot effectively remove thin contaminants such as smear and soft carbon because the small crevice between the particle and the surface hinders bubble penetration [9]. Another factor for ineffective ultrasonic might be due to reaction of the particle with the surface, where no crevice exists and there is no space for the bubbles to penetrate, as shown in Figure 6. Lu's study found that chemical cleaning can help remove these particles [1].

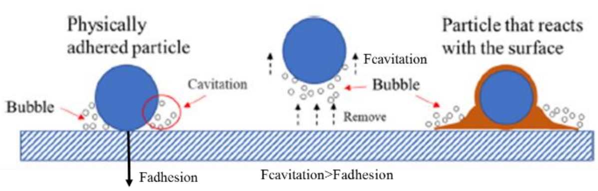


Figure 6. Mechanism of particle removal by ultrasonic washing [1]

2.3 Contamination Removal by Plasma Cleaning

Plasma cleaning is a chemical and physical cleaning method. Plasma is an ionized gas that can be created from argon, oxygen, and mixtures of air and hydrogen/nitrogen using high-frequency voltages [10, 11, 12]. In plasma cleaning, the surface is exposed to plasma. Through chemical reaction and ionization, the energy from the ionized gas breaks down the intermolecular and adhesion forces of the contaminant molecules, producing lighter and volatile components, as depicted in Figure 7 [2]. These are then easily removed by a vacuum pump.

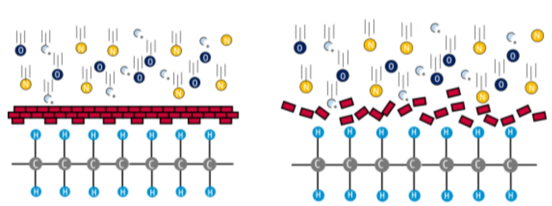


Figure 7. Mechanism of contamination removal by plasma cleaning using air

Effective plasma cleaning requires a physical force that is stronger than the force of adhesion of the particle and surface. Intermolecular forces also affect cleaning effectiveness since its mechanism is to break down the particle into smaller molecules. With this, it is effective for organic contaminants since the forces acting on these particulates are covalent bonds and van der Waals, which are weaker and easier to break [13]. On the other hand, metallic and inorganic particles are more difficult to remove due to their strong ionic and metallic bonds. These bonds require higher energy to break, which ions and radicals from plasma may not be able to provide. Additionally, metallic particles are the most difficult to remove by plasma cleaning due to their dense electron cloud which shields the metal ions and reduces plasma interactions [14].

Plasma cleaning is used in the electronics industry for surface preparation, surface activation, etching, de-smearing, de-oxidizing, and removing contaminants such as flux, solder residue, dust particles, oils, and grease from circuit boards, glass substrates, and semiconductor wafers [15]. Remarkably, plasma only affects the surface layer without altering the bulk molecular structure, making it suitable for component reuse [16, 17].

3.0 METHODOLOGY

The study was divided into two main parts, namely contaminant removability evaluation and functionality evaluation.

3.1 Contaminant Removability Evaluation

The evaluation was performed to check the effectiveness of plasma cleaning to remove smear and soft carbon contaminants on the HGA.

3.1.1 Analysis before plasma cleaning

Nine (9) HGA samples with smear contamination and three HGA (3) samples with soft carbon contamination were used in the removability evaluation. The contamination severity was described in Table 2. SEM-energy dispersive x-ray spectroscopy (SEM-EDX) was performed to gather initial image of the contamination. Imaging utilized a 1~2 kV acceleration voltage and an 8.2 mm working distance, while elemental analysis used a 3~15 kV acceleration voltage.

Table 2. The severity of contaminants on HGA samples used for the removability evaluation.

Sample	Contamination	Severity
1	Smear	Light
2		Light
3		Light
4		Light
5		Moderate
6		Severe

7		Light
8		Light
9		Light
10	Soft carbon	Light
11		Moderate
12		Severe

To simulate mass production cleaning procedures, the samples were attached to an actuator block (ACB) as shown in Figure 8.

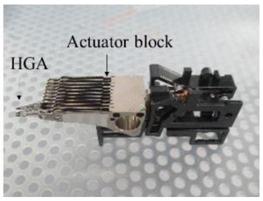


Figure 8. HGA attached to ACB

3.1.2 Plasma Cleaning

Plasma cleaning was conducted using Plasmatreat equipped with Plasma Jet RD1004 and Plasma Generator FG5001. This equipment is an air plasma, which produces plasma using dry compressed air by creating an atmospheric pressure high-voltage discharge within the jet's reaction chamber. The resulting discharge exits the jet nozzle at high velocity onto the sample.

Air plasma cleaning was conducted in a non-cleanroom environment as shown in Figure 9. The sample was placed on the stage at an 8 mm distance from the nozzle with a 20 mm diameter. The nozzle was aimed at the HGA. Upon turning on the plasma source, the stage was manually moved sideways using a toggle at 2 m/min speed for 5 passes.

Figure 9. Plasma cleaning setup of ACB with HGA

3.1.3 Analysis after plasma cleaning

After plasma cleaning, the samples were again subjected to SEM-EDX using the same equipment and settings used in the analysis before plasma cleaning.
Image comparison was performed before and after plasma cleaning to judge the removability of the contaminant.

3.2. Functionality Evaluation of HSA

Aside from cleanliness, it is important to ensure the functionality of HGA after being subjected to plasma. In the functionality evaluation, plasma cleaning of HGA was performed at the HSA level followed by functionality checking at the HSA level to simulate the mass production process. Functionality tests include measurement of angular and electrical properties and checking of visual appearance.

Ten (10) HSA samples with smear contamination were collected. Angular and electrical property checking, and visual inspection were performed before plasma cleaning with the quantity shown in Table 3 to ensure good condition of units.

Table 3. Quantity of H SA samples used in functionality evaluation

Check Item	**Qty.**
Visual inspection	10
Angular checking	10
Electrical checking	10

Angular properties such as pitch static attitude (PSA) and roll static attitude (RSA), bend, gram load and swage position were checked to assure good positioning of HGA on media and the flatness and absence of deformation on the HGA. On the other hand, electrical properties such as voltage peak to peak (VPP), asymmetry, and resistance were checked to assure correct connections of terminals and non-presence of cuts, and shorted or open lines. Visual appearance was also checked to confirm that there were no defects on the units such as dents, scratches, and misaligned HGA.

Air plasma cleaning of HGA was conducted in a non-cleanroom environment as shown in Figure 10. Then, angular and electrical property checking, and visual inspection were performed again after plasma cleaning.

Figure 10. Plasma cleaning setup of HSA

Statistical analysis using 2 sample T-Test was performed to check for any significant difference in angular and electrical parametric data before and after plasma cleaning.

4.0 RESULTS AND DISCUSSION

4.1 Contamination Removability Result

SEM images of HGA before and after plasma cleaning were shown in Figure 11. Based on the results, 9 out of 9 HGA samples showed that complete removal of smear contamination after plasma cleaning. However, 3 out of 3

HGA showed only partial removal of soft carbon. Compared to ultrasonic cleaning as shown in Figure 12, plasma cleaning is more effective.

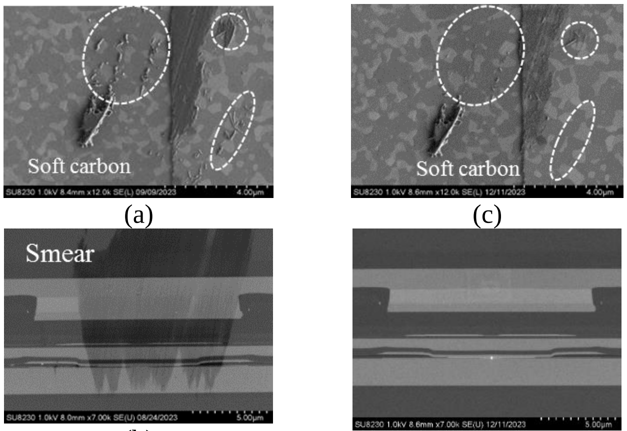


Figure 11. SEM images of soft carbon and smear contamination on HGA before (a~b) and after (c~d) plasma cleaning

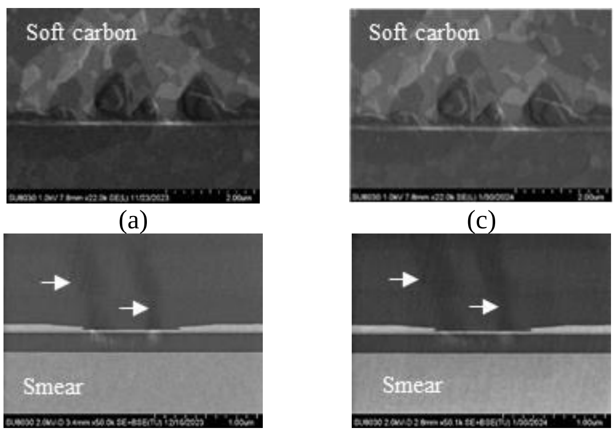


Figure 12. SEM images of soft carbon and smear contamination on HGA before (a~b) and after (c~d) ultrasonic cleaning

4.2 Functionality Test Result

Following the assessment of contamination removal effectiveness, functionality check was proceeded.

It was hypothesized that plasma cleaning has no significant impact to the electrical and angular properties, and visual appearance of the HGA. This is based on the established practice of using plasma cleaning in the semiconductor industry, where it is known not to alter the bulk material. To test the hypothesis, 2 sample T-Test was proceeded at 0.05 significance level. If the resulting p value is less than 0.05, Ho is rejected, indicating that plasma cleaning does indeed have a significant impact to the the electrical and angular properties of HGA.

For angular properties such as PSA, RSA, bend, gram load and swage position, the p-value of 2 sample T-Test were shown in Figure 13. Since $p>0.05$, it can be concluded based on 2 sample T-test that there is no significant difference in mean of all angular properties comparing before and after plasma cleaning.

On the other hand, the p-value of 2 sample T-Test for electrical properties such as voltage peak to peak (VPP), asymmetry, and resistance were shown in

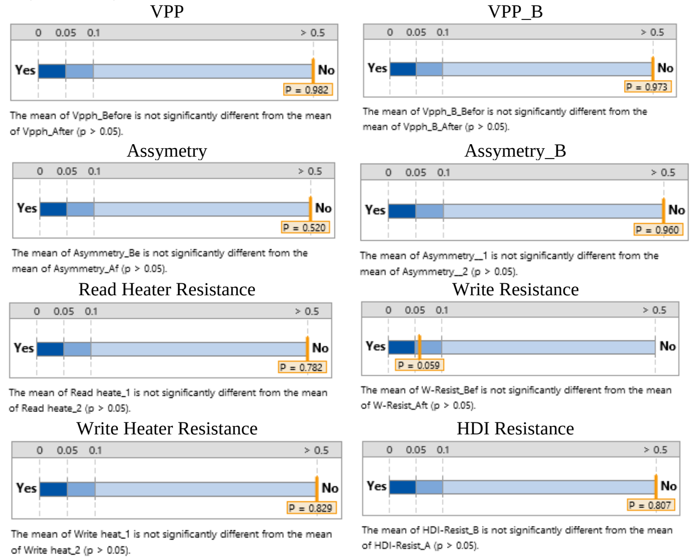


Figure 14. Since $p>0.05$, it can also be concluded based on 2 sample T-test that there is no significant difference in mean of all electrical properties comparing before and after plasma cleaning.

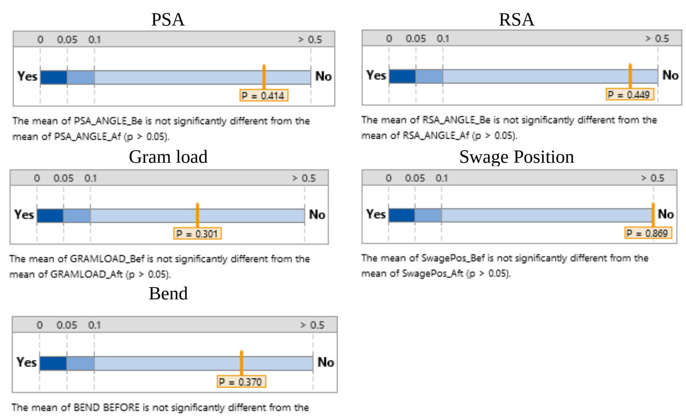
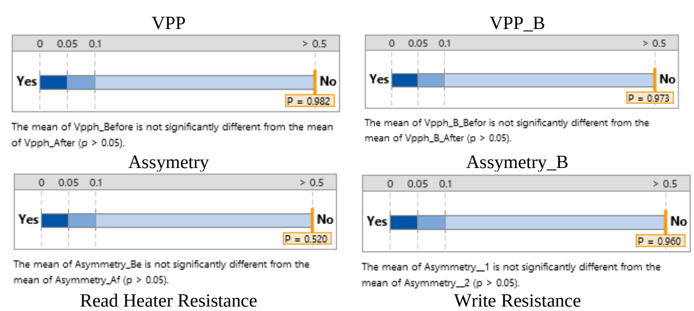


Figure 13. 2 Sample T Test results of HSA angular properties



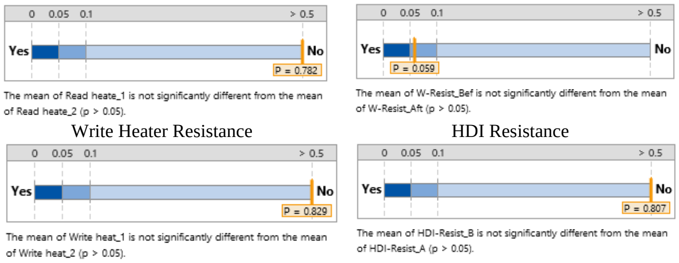


Figure 14. 2 Sample T Test results of HSA electrical properties

Lastly, visual inspection of HGA showed no defects such as dents, scratches, and misaligned HGA, as shown in Figure 15.

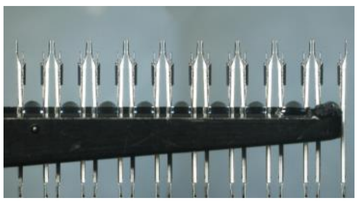


Figure 15. Sample of HGA with good visual appearance

Overall, all HSA samples passed the functionality test, as shown in Table 4, indicating their readiness for installation inside the HDD.

Table 4. Summary of functionality check results

Check Item	Result
Visual inspection	10/10 Passed
Angular checking	10/10 Passed
Electrical checking	10/10 Passed

5.0 CONCLUSION

The complete removal of smear contamination and partial removal of soft carbon contamination using plasma cleaning was proven in this study.

Also, visual inspection, electrical and angular property checking indicate that plasma cleaning has no significant impact on the functionality of HSA. Therefore, plasma cleaning can effectively remove contamination that cannot be removed by ultrasonic cleaning, while preserving the functionality of HSA.

Thus, plasma cleaning of HGA to remove smear and soft carbon contamination is viable and can be further studied for operational feasibility.

6.0 RECOMMENDATIONS

To verify the long-term viability and operational feasibility, it is advisable to conduct an HDD-level assessment. It is also recommended to study the impact on HDD reliability and cost.

Tailoring the plasma cleaning process based on parameters like distance, speed, and number of passes must be considered for optimal cleaning, such as complete removal of soft carbon. It is also recommended to explore potential applications of plasma cleaning to other components and different types of contamination.

7.0 ACKNOWLEDGMENT

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