Electrostatic Discharge (ESD) Breakdown between a Recording Head and a Disk with an Asperity

Al Wallash and Hong Zhu

Hitachi Global Storage Technologies
San Jose, CA
Outline

• Background
• Purpose
• Experimental Setup
• Results
  • Breakdown behavior with and without asperity
  • Failure analysis: where does breakdown occur?
• Conclusions
Background

- **Electrical breakdown across spark gap**
  - Gap spacing < 5 \( \mu \text{m} \)
  - DC pre-breakdown current: ~ nA
    - Field emission (or tunneling)
      - Fowler-Nordheim equation
  - Transient discharge current: ~ mA
  - Physical damage
    - melting

- **Factors that affect breakdown voltage**
  - Dielectric film properties
    - Thickness and material
  - Electrode
    - Geometry of anode and cathode
      - E-field enhancement at sharp edges
    - Materials: work functions

\[
I = aE^2 e \left( \frac{-b'\Phi^{3/2}}{E} \right)
\]
Purpose

- **Hard disk drive: Head disk interface = spark gap**
  - Thin carbon overcoat (COC) films
    - ~ 3nm head, ~3nm disk
  - Fly height = air gap:
    - <10nm
- **Head-disk contact possible**
  - Asperities
  - Load/unload

- **Study electrical breakdown with head-disk asperity contact**
  - *Electrical breakdown voltage?*
  - *Physical damage to slider air bearing surface?*
  - *Likelihood of ESD damage to read sensor?*
Experimental Setup

- **Modified Guzik XY Spin stand**
  - Float suspension and disk
  - Disk connected to Source/Measure Unit
  - Floating suspension connected to ground through current probe

- **Measurements**
  - Voltage on disk, DC current, transient current (2 GHz bandwidth)
  - Acoustic emission (AE) and thermal asperity (TA) to position sensor over asperity
  - GMR resistance (R), track averaged amplitude (TAA), asymmetry

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**HDD: The Next 50 Years**

[Image of HDD components]
Experimental Setup

- **Heads and media**
  - 40 GMR heads (60 Gb/in²) on a metal AlMag disk; 15k RPM
- **Asperity**
  - Indentation: diamond spherical tip with 50 µm radius
  - Pile-up height ~ 30 nm
- **Test Sequence**
  - Ramp disk voltage: + or -
  - Dwell time: 1 sec
    - Measure R and TAA
  - **Breakdown:** transient current > 1mA

![Graph showing disk voltage and time](image)

**HDD: The Next 50 Years**
Current vs. Voltage

- Increase in DC current, then breakdown
- Breakdown voltage
  - Without asperity (smooth disk): 3.4V
  - With asperity: 1.6V

HDD: The Next 50 Years
Breakdown Voltage

Average breakdown voltage

<table>
<thead>
<tr>
<th></th>
<th>Without asperity</th>
<th>With asperity</th>
</tr>
</thead>
<tbody>
<tr>
<td>+V</td>
<td>3.4</td>
<td>1.7</td>
</tr>
<tr>
<td>-V</td>
<td>-3.3</td>
<td>-2.65</td>
</tr>
</tbody>
</table>

- Both + and – disk voltage
- Significant decrease in breakdown voltage with asperity
Behavior vs. Voltage: No asperity

- TAA increase: electrostatic attraction = spacing decrease
- No TAA or resistance change after breakdown

No asperity (smooth disk)

Breakdown at 3.4V
Behavior vs. Voltage: With asperity

- With asperity positioned over read sensor during breakdown
  - TAA changes
  - Resistance increase
- Read sensor damaged by breakdown over asperity

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HDD: The Next 50 Years
Slider Damage: No Asperity

- Sensor area largely unaffected
- Breakdown to slider body
- Transient current between slider and disk
  - GMR sensor undamaged
Slider Damage: With Asperity

- Breakdown at TiC conductive grains on air bearing surface in center pad
  - Similar to case with no asperity

- Shields and sensor show damage
  - Breakdown between asperity and shields/reader
  - Direct current flow to GMR leads
  - *Severe magnetic damage similar to ESD damage during handling*
## Summary and Conclusions

<table>
<thead>
<tr>
<th></th>
<th>Without asperity</th>
<th>With asperity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Breakdown Voltage (V)</strong></td>
<td>+3.4 / -3.3</td>
<td>+1.7 / -2.6</td>
</tr>
<tr>
<td><strong>Breakdown location</strong></td>
<td>TiC grains on slider</td>
<td>TiC grains <em>and</em> shields/sensor</td>
</tr>
<tr>
<td><strong>Read sensor damage</strong></td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

1. Significant reduction in head-disk breakdown voltage (~50% reduction)
2. Additional damage to shields and sensor area
3. Severe magnetic damage to the read sensor

Important to include asperities in head-disk breakdown reliability testing

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HDD: The Next 50 Years

IDEMA®
Backup slides
Current vs. + and – Disk Voltage

Four different heads and disks

- Negative voltage, no asperity
- No measurable pre-breakdown current

HDD: The Next 50 Years
H45, with asperity, +V on disk, head died

H46, with asperity off sensor, +V on disk, no sensor damage
Optical Slider Damage: Asperity away from sensor
Step edge

Breakdown damage

Step edge