Electrostatic Measurement Issues and SEMI E43

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Overview

• General comments on electrostatic measurements and measurement methods.
  – Charge, voltage and electric field
  – Measuring charge - coulombmeter and Faraday cup
  – Measuring voltage - electrostatic voltmeters
  – Measuring electric field - electrostatic fieldmeters

• Review of E43 - 0301
  – what it contains
  – what areas are in need of review and additions
  – what has been done so far
Why measure charge?

• Charge measurement may serve as semiconductor characterization tool (work function of materials, mobile charge density, doping density, etc.)

• Measurements in semiconductor manufacturing:
  – Electrostatic discharge (ESD) hazard detection
    • integrated circuits, reticles
Why measure charge (cont.)?

- ESD may also cause an electromagnetic interference (EMI) problems
  - Equipment process interruption
- Prevent contamination via electrostatic attraction
  - Wafers, flat panel displays (FPD)
- Restrict damage due to field induced migration of material
  - Wafers
  - Reticles
How to measure charge?

• Measurements in electrostatic systems require very high input impedance of the measuring instrument:
  – Charge is limited,
  – Electrical state of the measured object has to be preserved.
• Input impedance of the meter has to be much higher than that of the object being measured.
High input impedance techniques

- Non-contacting methods:
  - Lack of physical contact assures that the input impedance is high
- Instruments:
  - The Faraday cup (pail) with a coulombmeter,
  - Fieldmeters,
  - Induction probes,
  - Electrostatic voltmeters
- Contacting methods:
  - Electrometers
Charge measurement techniques in E43 - Coulombmeter

- Technique allowing for direct measurement of the charge – use of coulombmeter/electrometer
- Not always convenient and/or feasible
- Measures the net charge

\[ Q = C \cdot V \]
Fieldmeter measurements

- Measures electric field $E$
- Need to know the object-to-ground capacitance $C$
- Charge $Q$ can be calculated
- Spatial resolution not too good
- Arc-over hazard if the meter is too close to the measured object

$$Q = C \cdot E \cdot d$$
Fieldmeter measurements, cont.

- If the capacitance is not known, the surface charge still can be theoretically approximated (assuming uniform distribution):

\[
Q = \frac{2\varepsilon_0 \cdot E \cdot A}{\left(1 - \frac{H}{\sqrt{R^2 + H^2}}\right)}
\]

\[d\]

\[
\text{fieldmeter sensor}
\]

\[
\text{surface area A "seen" by the sensor}
\]

\[
\text{surface under test}
\]

\[
H
\]

\[
2R
\]
Fieldmeter measurements, cont.

Fieldmeter may distort the original electric field.
Electrostatic voltmeter measurements

- Measures voltage, not field. Field can be calculated, if necessary
- Good spatial resolution
- No arc-over hazard, the sensor is at the potential of the measured surface

\[ Q = C \cdot V \]
Electrostatic voltmeter measurements, cont.

\[ V = V_{\text{surface}} = V_{\text{probe}} \]

\[ V = \frac{Q}{C_1 + C_p} \]
Electrostatic voltmeter measurements, cont.

 Equipotential lines

[Diagram showing equipotential lines with a legend indicating object with non-uniform surface charge distribution in nC/cm²]
Comments on field and voltage measurements

Table 1 – Recommended Equipment Electrostatic Levels

<table>
<thead>
<tr>
<th>Year</th>
<th>Electrostatic Discharge, nC</th>
<th>Electrostatic Field, V/cm</th>
<th>V/inch</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000 180 nm</td>
<td>2.5–10</td>
<td>200</td>
<td>500</td>
</tr>
<tr>
<td>2002 130 nm</td>
<td>2.0</td>
<td>150</td>
<td>375</td>
</tr>
<tr>
<td>2003 100 nm</td>
<td>1.5</td>
<td>125</td>
<td>300</td>
</tr>
<tr>
<td>2004 90 nm</td>
<td>1.0</td>
<td>100</td>
<td>250</td>
</tr>
<tr>
<td>2006 70 nm</td>
<td>0.6</td>
<td>80</td>
<td>200</td>
</tr>
<tr>
<td>2007 65 nm</td>
<td>0.5</td>
<td>70</td>
<td>175</td>
</tr>
<tr>
<td>2009 50 nm</td>
<td>0.3</td>
<td>55</td>
<td>140</td>
</tr>
<tr>
<td>2010 45 nm</td>
<td>0.25</td>
<td>50</td>
<td>125</td>
</tr>
<tr>
<td>2013 32 nm</td>
<td>0.125</td>
<td>35</td>
<td>88</td>
</tr>
<tr>
<td>2015 25 nm</td>
<td>0.08</td>
<td>28</td>
<td>70</td>
</tr>
<tr>
<td>2018 18 nm</td>
<td>0.04</td>
<td>20</td>
<td>50</td>
</tr>
</tbody>
</table>

- Recommended equipment electrostatic levels in E78 are based on 10 pF capacitance.
Proposed changes to E43

- Change in the title and scope (much broader: electrostatic measurements instead of electrostatic charge measurements)
- New section added: “Electrostatic discharge measurements”
  - Describes methods and instrumentation for the discharge measurements
- Structure changes, i.e. “Performance verification” of instrumentation moved to “Measurement” section
- New related information sections with examples
Related information – new additions

• Electric field, voltage and charge
  – discussion of generalized cases for the charge, electric field and voltage measurements on flat surfaces
  – advantages and disadvantages of each of the test methods

• Correlation between electric charge, electric field, and electric potential
  – basic information on dependencies between field, voltage and charge
Conclusions

• E43 should become a charge measurement guide referenced by other SEMI standards (E78, E129).
• Your feedback in that matter is very much needed and appreciated!
• Please participate in the E43 review process, meeting of the EOS/ESD TF on Tue., March 6th, 1:30-4:30 p.m.