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FUNDAMENTAL PROPERTIES OF ELECTRICAL CONTACTS

by

Dr. Roland S. Timsit

President
Timron Advanced Connector Technologies

World renowned electrical contact expert, Dr. Roland Timsit, returns to BiTS with a renewed and freshened course that builds on his very popular 2006 BiTS Tutorial. This seminar addresses how contact force and the mechanical properties of contact materials affect both contact resistance and the electrical/mechanical integrity of an electrical contact device.

Dr. Timsit usually teaches this material in a multi-day course, so this tutorial is packed with information for professionals seeking a broad, yet comprehensive understanding, of electrical contacts.

ABSTRACT

An interface between two solids is generated by contact between protruding surface asperities on each of the contacting bodies, so that mechanical contact is actually established at a discrete number of contact spots. Because these spots are tiny, the area of true contact is very small and electrical current passing through the interface is highly constricted at these spots. Constriction of the current gives rise to contact resistance.

The seminar addresses how contact force and the mechanical properties of contact materials affect both contact resistance and the electrical/mechanical integrity of an electrical contact device. Selected contact properties of materials and electroplates such as gold, tin and silver are reviewed. The deleterious effects of contaminant and corrosion surface films, and other mechanisms such as mechanical wear and fretting corrosion, that conspire to eliminate electrical contact spots, are described. The nefarious effects of these mechanisms can often act rapidly, with ensuing catastrophic failure, in devices where the contact force is small such as in MEMS. The effect of signal frequency on contact resistance will also be addressed.

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Fundamental Properties of Electrical Contacts

R.S. Timsit
Timron Advanced Connector Technologies
A Division of Timron Scientific Consulting Inc.
Toronto, ON, CANADA

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Because all solid surfaces are rough on the microscale, two mating solid surfaces make contact only where the peaks of small surface asperities (roughness) touch one another.
TRUE AREA OF MECHANICAL CONTACT

Steel optical flat applied mechanical load rough tool-steel plate

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Steel optical flat after contact with sand-blasted tool-steel, under various loads.

(a) 508 kg

1 mm
Since all contacting asperities deform plastically, then the contact force $F_j$ acting on the surface $A_j$ of the $j$th asperity is

$$F_j = KA_j$$

where $K = \text{“some” yield stress of contact material \ [ kg mm}^{-2} \text{”} \right]$

It turns out $K \rightarrow H = \text{Vickers’ or Knoop microhardness \ [ kg / mm}^2 \text{]}$

($\sim 3 \ Y, Y = \text{yield strength}$)
Fundamental Law of Contacting Surfaces

\[ F = H A \]

or

\[ A = \frac{F}{H} \]

True Contact Area = Applied Contact Load / Hardness

irrespective of contact geometry!
EXAMPLES OF TRUE CONTACT AREA

Area of True Mechanical Contact 3 mm-Radius Ball on a Flat Hertzian Contact copper-copper tin-tin copper-copper nickel-nickel rough contacting surfaces

CONSTRICTION RESISTANCE: MULTISpot CONTACTS

For a multispot contact, the constriction resistance is well approximated as

\[ R_C = \left( \frac{\rho}{2} \right) \left( \pi \frac{H}{F} \right)^{1/2} \]

where

- \( H \) = Vickers’ or Knoop microhardness [ kg / mm\(^2\) ]
- \( \rho \) = average resistivity of contacting materials
- \( F \) = contact load [ kg ]
Contact resistance versus contact load for a copper contact with $H = 120 \text{ kg mm}^{-2}$. Resistivity $\rho = 1.65 \times 10^{-8} \text{ \Omega m}$.

There is also a contact resistance $R_F$ due to the presence of oxide or other contaminant films on the mating surfaces:

$$R_F = \frac{\rho_{\text{cont}} d}{A}$$

where $A = \text{area over of surface film}$
CONTACT RESISTANCE:
METAL-TO-METAL VERSUS FILM-TO-FILM
OXIDE FILM THICKNESS = 2 nm

<table>
<thead>
<tr>
<th>Type of Metallic Junction</th>
<th>Resistance of Metal-to-Metal a-Spot (Ω)</th>
<th>Film Resistance (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cu₂O</td>
<td>Al₂O₃</td>
</tr>
<tr>
<td>copper-copper</td>
<td>1.7 x 10⁻³</td>
<td>0.18</td>
</tr>
<tr>
<td>aluminum-aluminum</td>
<td>2.6 x 10⁻³</td>
<td>23.2</td>
</tr>
</tbody>
</table>

Total contact area = 1 cm²
Radius of a-spot = 10 µm

Total contact resistance
\[ R_T = R_C + R_F \]
\[ R_T = \left( \frac{\rho}{2} \right) \left( \frac{\pi H}{F} \right)^{1/2} + \rho_{cont} \frac{d}{A} \]
$$R_F = \rho_{\text{cont}} d / A$$

**CONTACT RESISTANCE:**

*Cu-Cu Contact Spot 10 μm radius covered with Oxide Film*

- Nickel oxide
- Copper oxide

Contact resistance [ohm] vs. oxide film thickness [nm].
SURFACE OXIDE FILMS

To enhance electrical contact reliability

- do not tolerate surface contaminant films i.e. do not expect conduction through them
- abrade/remove all surface films, in particular oxide layers

Recall $R_C = \left( \frac{\rho}{2} \right) \left( \frac{\pi H}{F} \right)^{1/2}$
For small contact loads, $H$ is the nanohardness
Load depth data for super purity Aluminum with 100nm anodic oxide coating showing deviation from the elastic response at the depth of 20nm.

Effect of anodic oxide coating thickness on the variation in the hardness with the total depth of penetration at the peak load.
**Contact Materials: Silicon Micro Springs**

Example of apparatus used for the measurement of contact resistance between gold layers on Si (Hyman et al, IEEE Trans. CPT, p. 357, vol. 22 1999).

Contact resistance vs. applied force for pure gold micro-contacts using gold layers on Si (Hyman et al 1999).
The data of Hyman et al suggests a higher level of surface contamination of the gold than is the case for the data shown above. The “F^{-1/3}” behavior at very low contact force may stem from adhesion ("stiction").

Contact spot on the gold-coated Si micro-lever after applying a contact force of 500 µN (Hyman et al 1999).
Contact Materials: Silicon Micro Springs

Another example of apparatus used for the measurement of contact resistance between gold and gold layers on Si (Hosaka et al, Proc. MEMS’93, February 1993). Note that only total resistance was measured.

Total circuit resistance vs. applied force for a pure gold pin in contact with a sputtered layer of gold, palladium and silver on glass (Hosaka et al 1993).
Minimum contact loads to achieve specified contact resistance conditions (Hosaka et al 1993).

**BREAKDOWN OF CLASSICAL ELECTRICAL CONTACT THEORY**

For \( a \sim \text{electronic mean free path} \), classical electric contact theory breaks down:

\[
R_C = \frac{\rho}{2a} \text{ no longer holds!}
\]

- electrons behave ballistically within the constriction
- little or no heating in the constriction
The expression for the resistance through a small constriction of radius \( a \) becomes

\[
R_B = \Gamma(K) \left( \frac{\rho}{2a} \right)^2 + C/a^2
\]

where

- \( K = 1/a \) (\( l = \) electron mean free path)
- \( \Gamma(K) = \) varies from 1 to about 0.7 as \( K \) varies from 0 to \( \infty \)
- \( C = \) a constant that depends on the contact material

**Constriction Resistance for Cu**

![Graph showing constriction resistance for Cu](image)
GROWTH OF INTERMETALLIC COMPOUNDS

The width $X$ of an intermetallic layer or an interdiffusion band increases with time $t$ as

$$X^2 = kt$$

with $k = \text{interdiffusion constant} = k_0 \exp\left(-\frac{Q}{RT}\right)$

$Q = \text{activation energy}$  
$R = \text{gas constant}$  
$T = \text{absolute temperature}$

INTERMETALLICS FORMATION

Intermetallics growth at a copper/tin interface.
Growth of interdiffusion bands generated with Zn, Sn and In on brass at 80°C.

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>T (°C)</th>
<th>Interdiffusion Layer Thickness (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 month</td>
<td>20</td>
<td>Zn 0.43  In 1.0  Sn 1.9</td>
</tr>
<tr>
<td>1 year</td>
<td>20</td>
<td>Zn 1.5  In 3.5  Sn 6.7</td>
</tr>
<tr>
<td>1 month</td>
<td>55</td>
<td>Zn 3.4  In 2.8  Sn 3.5</td>
</tr>
<tr>
<td>1 year</td>
<td>55</td>
<td>Zn 11.8 In 9.8  Sn 12.1</td>
</tr>
</tbody>
</table>

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EFFECTS OF INTERDIFFUSION

An SEM photograph of Au-Al intermetallic compound formation (white and fluffy) around the perimeter of the bond and under the grossly deformed ball. Even with its poor appearance, the bond was mechanically strong and electrically conductive.

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EFFECTS OF INTERDIFFUSION

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EFFECTS OF INTERDIFFUSION

The change in contact resistance of multiple Au ball bonds on 1.3 mm Al pads as a function of time at 200°C. The initial bond resistance was a few milliohms. (After Getring [J-7].)

TEMPERATURE IN AN ELECTRICALLY-HEATED CONTACT

A contact spot may be considered a "thermally-insulated" resistor of value R.

1. If the resistor is made of copper and \( R = 10 \times 10^{-6} \text{ ohm} \), it is found that the resistor melts at a current of 43,000 A.

2. If the resistor is made of copper and \( R = 1 \text{ ohm} \), it is found that the resistor melts at a current of 0.43 A.

What is the common factor describing melting of the contact spot?
TEMPERATURE IN AN ELECTRICALLY-HEATED CONTACT

The contact spot temperature depends only on the potential drop across the contact.

CONTACT - SPOT TEMPERATURE

\[
T \quad [^\circ C] = \begin{cases} 
27^\circ C & \text{for } T_0 = 27^\circ C \\
100^\circ C & \text{for } T_0 = 100^\circ C 
\end{cases}
\]

voltage drop across contact [ V ]

contact spot temperature [ ^\circ C ]

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**MAXIMUM VOLTAGE-DROP IN AN ELECTRICAL CONTACT**

Melting of a contact spot is determined by the voltage-drop across the contact, *not the electrical current*

<table>
<thead>
<tr>
<th>Metal</th>
<th>Softening Voltage (V)</th>
<th>Melting Voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Fe</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>Ni</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td>Cu</td>
<td>0.12</td>
<td>0.43</td>
</tr>
<tr>
<td>Zn</td>
<td>0.1</td>
<td>0.17</td>
</tr>
<tr>
<td>Ag</td>
<td>0.09</td>
<td>0.37</td>
</tr>
<tr>
<td>Cd</td>
<td></td>
<td>0.15</td>
</tr>
<tr>
<td>Sn</td>
<td>0.07</td>
<td>0.13</td>
</tr>
<tr>
<td>Au</td>
<td>0.68</td>
<td>0.43</td>
</tr>
<tr>
<td>Pd</td>
<td></td>
<td>0.57</td>
</tr>
<tr>
<td>Pb</td>
<td>0.12</td>
<td>0.19</td>
</tr>
<tr>
<td>60Cu, 40Zn</td>
<td></td>
<td>0.2</td>
</tr>
</tbody>
</table>

**TEMPERATURE IN AN ELECTRICALLY-HEATED CONTACT**

*thermal risetime* \( \tau \) of a contact spot of radius “\( a \)“

\[
\tau = \frac{C a^2}{4 \lambda}
\]

where \( C \) = conductor heat capacity

\( \lambda \) = thermal conductivity

For copper, \( C = 3.44 \text{ J cm}^{-3} \text{ 0C}^{-1} \)

\( \lambda = 4 \text{ W cm}^{-1} \text{ 0C}^{-1} \)

so that \( \tau = 2.2 \times 10^{-7} \text{ s for a contact spot with } a = 10 \mu\text{m} \)
Schematic variation of contact spot temperature associated with variations in voltage-drop across the contact, at a signal frequency of 1 kHz.

CONSTRICION RESISTANCE:
Effect of Signal Frequency

Under conditions of DC current flow:
constriction resistance $R_C = \frac{\rho}{2a}$

$\rho = \text{resistivity}$

constriction of radius $a$
EFFECTS OF FREQUENCY: THE SKIN EFFECT

Under alternating current (AC) conditions, current penetrates into a conductor to an electromagnetic “penetration depth” $\delta$

$$\delta = \left( \frac{\rho}{\pi \mu_0 f} \right)^{1/2}$$

- $\rho$ = resistivity
- $\mu_0$ = magnetic permeability of free space
- $f$ = excitation frequency in Hz

Variation of Skin Depth with Frequency for a Metal of Resistivity $3 \times 10^{-8} \ \Omega \ m$

<table>
<thead>
<tr>
<th>$f$ [Hz]</th>
<th>Skin Depth $\delta$ [\mu m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>11254</td>
</tr>
<tr>
<td>$10^3$</td>
<td>2757</td>
</tr>
<tr>
<td>$10^4$</td>
<td>872</td>
</tr>
<tr>
<td>$10^5$</td>
<td>276</td>
</tr>
<tr>
<td>$10^6$</td>
<td>87</td>
</tr>
<tr>
<td>$10^7$</td>
<td>28</td>
</tr>
<tr>
<td>$10^8$</td>
<td>8.7</td>
</tr>
<tr>
<td>$10^9$</td>
<td>2.8</td>
</tr>
</tbody>
</table>
EFFECTS OF FREQUENCY

\[ R_{\text{ext}} = \text{outer radius of “External” ring} \]
\[ a' = \text{inner radius of “External” ring} \]

\[ R_{\text{ext}} = \frac{\rho}{2\pi\delta}\ln\left(\frac{R_{\text{ext}}}{a'}\right) \]
\[ \delta = \text{electromagnetic penetration depth} \]
\[ R_{\text{ext}} = \text{outer radius of “External” ring} \]
\[ a' = \text{inner radius of “External” ring} \]
\[ \rho = \text{resistivity} \]

Total Connection Resistance = Constriction Resistance + Resistance of “External” Ring
CONSTRICION RESISTANCE
AT HIGH FREQUENCIES

CONSTRICION RESISTANCE
VS.
CONNECTION RESISTANCE
AT HIGH FREQUENCIES

<table>
<thead>
<tr>
<th>Signal Frequency $f$ [Hz]</th>
<th>Constriction Resistance [mΩ]</th>
<th>Connection Resistance [mΩ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^7$</td>
<td>2.2</td>
<td>3.2</td>
</tr>
<tr>
<td>$10^8$</td>
<td>1.4</td>
<td>4.7</td>
</tr>
<tr>
<td>$10^9$</td>
<td>1.0</td>
<td>11.2</td>
</tr>
</tbody>
</table>

\[ \rho = 3 \times 10^{-8} \Omega \text{m} \]
\[ a = 5 \mu \text{m} \]
\[ R_{ext} = 100 \mu \text{m}. \]
### Degradation Mechanisms

- **Thermal Expansion → Stress Relaxation**
- **Temperature Rise → Fretting Wear**
- **Intermetallic Growth → Reaction of Contact → Contact Resistance Rise**
- **Mechanical Vibrations → Oxidation and Corrosion**

### Tribology

**Most common types of wear in metal sliding:**

I. **Abrasive Wear** – relevant only to high power connectors

II. **Adhesive Wear**

III. **Fretting Wear**

IV. **Erosion** – generally not relevant to connectors

V. **Lubricated Wear** – not relevant to connectors
**Adhesive Wear**

![Adhesive Wear Diagram]

Wear rate and electrical contact resistance of a leaded $\alpha / \beta$ brass pin against a hard stellite ring. Note the sharp transition in wear rate.

**Tribology: Adhesive Wear**

![Wear-Load Graph]

Wear rate and electrical contact resistance of a leaded $\alpha / \beta$ brass pin against a hard stellite ring. Note the sharp transition in wear rate.
### Tribology: Adhesive Wear

<table>
<thead>
<tr>
<th></th>
<th>Mild Wear</th>
<th>Severe Wear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal Transfer</td>
<td>small</td>
<td>large</td>
</tr>
<tr>
<td>Wear Debris</td>
<td>small</td>
<td>large</td>
</tr>
<tr>
<td>Contact Wear</td>
<td>relatively symmetrical, depends on sliding frequency</td>
<td>generally unsymmetrical</td>
</tr>
<tr>
<td>Effect on Surface</td>
<td>smoothing, subsurface deformation, little hardening</td>
<td>roughening subsurface deformation, increased hardness</td>
</tr>
</tbody>
</table>

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### Tribology: Adhesive Wear

**Transition Loads**

<table>
<thead>
<tr>
<th></th>
<th>Pure Gold</th>
<th>Hard Gold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean Surface</td>
<td>5 g</td>
<td>10 g</td>
</tr>
<tr>
<td>Contaminated</td>
<td>10 – 50 g</td>
<td>25 – 300 g</td>
</tr>
<tr>
<td>Lubricated</td>
<td>100 – 500 g</td>
<td>500 – 2000 g</td>
</tr>
</tbody>
</table>

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**Tribology: Adhesive Wear**

Wear indices from unlubricated adhesive wear runs: (a), (c) pure gold with and without 2.5 µm Ni underplate; (b), (d) hard cobalt gold, with and without 2.5 µm Ni underplate.

Effect of surface roughness on Wear Index, using solid gold riders:
(a) no underplate
(b) 1.5 µm Ni underplate.
Fretting Wear is generated by small-amplitude movement leading to the formation of small debris particles at a mechanical interface. In electronic connectors, the amplitude of this micromotion ranges from a few µm to about 100 µm.

Micromotion is caused by external vibrations or by changing temperature due to differences in thermal expansion coefficients of the mating materials.

Oxidation of fretting debris leads to increased electrical contact resistance.
**Tribology: Fretting Wear**

(a) Fretting damage on a tin electroplate surface,

(b) Cross-sectional view of (a).

Typical contact resistance variations due to fretting at 50 g and 8 Hz with a 20 µm wipe. Curve I – unacceptable, curve II – acceptable, curve III – best.
Silver is the most stable material in fretting, since it is relatively wear resistant, does not oxidize readily, and does not form frictional polymers. It displays excellent behaviour when mated to itself. Silver is prone to tarnish in the presence of even minute amounts of sulfur and chlorine compounds. This limits the use of silver in electronic connectors.

Silver is widely used as a finish on aluminum busbar contacts.

Contact resistance behaviors due to fretting, in various materials. Load of 50 g, 20 µm displacement at 4 – 8 Hz:

I - solid Ni on Ni-electroplate 2.5 µm thick on Cu
- solid Pd on Pd-clad 5 µm thick on Ni
- solid Cu on solid Cu
II - solid Au on solid Cu
III - solid Au on Ni-electroplate 2.5 µm thick on Cu
- solid Au on Co/Au-electroplate 0.6 µm thick on Ni electroplate on Cu
- solid Ag on solid Ag.
**Tribology: Fretting Wear**

Contact resistance versus fretting cycles, 150 g, 8 Hz, 10 µm wipe.

**Fretting at Tin – Metal Interfaces**

Results of fretting tests conducted on degreased tin, gold, palladium and silver surfaces mated to degreased tin surfaces.

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**Tribology: Fretting Wear**

**Gold**

Gold approaches silver in its stability. Although it is known that has organic materials, aerosols and other contaminant layers accumulate on gold surfaces to increase contact resistance, these contaminants are usually eliminated by rubbing.

*It has been claimed that traces of polymer form when gold contacts are rubbed together in benzene vapor or immersed in an oil. No deleterious effect of this polymer on contact resistance has been detected.*

---

**Effects of Heating**

Thermal stability of contact resistance of 50 μm gold electroplate on copper, aged at 200°C. Effects of Co and Ni additions of 0.25 wt%.
### Oxidation / Contamination in Air

**Copper:** Oxide forms immediately - thickness depends on temperature

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>10^3 h</th>
<th>10^5 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>2.2</td>
<td>4</td>
</tr>
<tr>
<td>55</td>
<td>3.5</td>
<td>17</td>
</tr>
<tr>
<td>85</td>
<td>8.7</td>
<td>69</td>
</tr>
<tr>
<td>100</td>
<td>15.0</td>
<td>130</td>
</tr>
</tbody>
</table>

**Tin:** Oxide growth is initially slow - depends on temperature

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>10^3 h</th>
<th>10^5 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>4.2</td>
<td>6.1</td>
</tr>
<tr>
<td>55</td>
<td>10.3</td>
<td>14.6</td>
</tr>
<tr>
<td>85</td>
<td>18.8</td>
<td>26.0</td>
</tr>
<tr>
<td>100</td>
<td>25.0</td>
<td>36.0</td>
</tr>
</tbody>
</table>

**Nickel:** Oxide growth is self-limiting - weak dependence on temperature

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>10^3 h</th>
<th>10^5 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1.6</td>
<td>15.0</td>
</tr>
<tr>
<td>55</td>
<td>2.1</td>
<td>21.0</td>
</tr>
<tr>
<td>85</td>
<td>2.7</td>
<td>27.0</td>
</tr>
<tr>
<td>100</td>
<td>3.4</td>
<td>34.0</td>
</tr>
</tbody>
</table>

**Silver:** Ag₂S formation - formation of Ag₂O in presence of ozone
Film Formation in a Harsh Environment

Contact resistance due to formation of surface films on Ag, Cu and Ni in N₂-O₂-SO₂-S₈-H₂O mixtures at 30°C.

(a) Optical micrograph
(b) SEM micrograph.

(a) SEM micrograph of scratch marks.
(b) EDX spectrum from entire region shown in (a).
(c) region of EDX spectrum of (b) showing only the 0 - 4.4 kV region.
**Pore Corrosion**

**Electroplate Porosity**

Dependence of pore density on electroplate thickness, for various CLA (Center Line Average) values of Substrate roughness.

Pure gold on 1.5 µm thick Ni underplate on copper.
Galvanic Corrosion

Pore Corrosion

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Pore Corrosion

Example of copper sulfidation through a pore in a gold layer [from Sun, Moffat, Enos and Glauner, Sandia National Labs, IEEE Holm Conf. Electrical Contacts, September 2005].

Connector Testing:
Mixed Flow Gas (MFG) Composition

MFG test conditions for accelerating the effects of environmental classes II, III and IV

|                        | Severity Class |
|------------------------|----------------|----------------|
|                        | II             | III            | IV             |
| Temperature (°C)       | 30 ± 2         | 30 ± 2         | 40 ± 2         |
| Relative Humidity (%)  | 70 ± 2         | 75 ± 2         | 75 ± 2         |
| Chlorine (Cl₂), ppb    | 10 ± 3         | 20 ± 5         | 30 ± 5         |
| Nitrogen Dioxide (NO₂), ppb | 200 ± 50   | 200 ± 50       | 200 ± 50       |
| Hydrogen Sulfide (H₂S), ppb | 10 ± 5       | 100 ± 20       | 200 ± 20       |

ppb = parts per billion of each gas in air.
Class IIa includes 100 ± 20 ppb SO₂ (for Ag)
Class IIIa includes 200 ± 50 ppb SO₂ (for Ag)
Film Formation in a Corrosive Environment

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SIGNIFICANCE OF BURN-IN IN ELECTRICAL CONTACTS

Selected Burn-In Methods

• Pass a large current through contacts
  possible beneficial effects:
  - slight overheating of contact spots, causing negligible metallurgical effect, may soften contact spots and increase the true contact area to reduce contact resistance
  - slight differential expansion in contact region may cause local abrasion of surface contaminant films and reduce contact resistance

• Pass a large current through contacts
  possible deleterious effects:
  - overheating of contact spots with possible metallurgical changes in the contact region
  - increased oxidation
  - overheating of contact springs or connector components with possible decrease in contact force due to stress relaxation or metal-creep
• passing a large burn-in current through some types of contacts, such as those using low melting-point materials, may be particularly deleterious to contact reliability

SIGNIFICANCE OF BURN-IN IN ELECTRICAL CONTACTS

Selected Burn-In Methods

• Reciprocating motion of pin in socket while passing current, but without contact disconnect
  
  major beneficial effect:
  - disperse surface contaminant films and reduce contact resistance
SIGNIFICANCE OF BURN-IN IN ELECTRICAL CONTACTS

Selected Burn-In Methods

- Reciprocating motion of pin in socket while passing current, but without contact disruption possible deleterious effects:
  - generate unwanted mechanical wear on contact surfaces and removal of thin protective electroplates
  - increase a permanent set in receptacle springs
  - possible arcing
  - other effects

SUMMARY

Major Parameters and Mechanisms Affecting Contact Resistance

1. Surface Roughness: Asperity density and shape can optimize connector function

2. Surface Hardness: Hardness determines real contact area

3. Interdiffusion: Usually deleterious to contact performance

4. Electroplates: To modify surface hardness and provide protection against mechanical wear and corrosion; underplates reduce interdiffusion between electroplates and substrate
SUMMARY

Major Parameters and Mechanisms Affecting Contact Resistance

5. Surface Insulating Films: Usually deleterious to contact performance since they add to contact resistance; these films may increase susceptibility to fretting corrosion

6. A-spot Temperature: Controls interdiffusion processes and other mechanisms such as oxidation and corrosion rates; elevated temperatures are usually deleterious to contact performance. Temperature can be evaluated from the V-T relation

7. Signal Frequency: The “skin effect” begins to have a noticeable effect on connection resistance at a frequency of a few MHz

8. Small Contacts: Classical contact theory breaks down for a-spot radii smaller than a few hundred nanometers

9. Contact Degeneration Mechanisms: Oxidation, corrosion, fretting corrosion, intermetallic growth, differential thermal expansion etc.. eventually limit connector life.