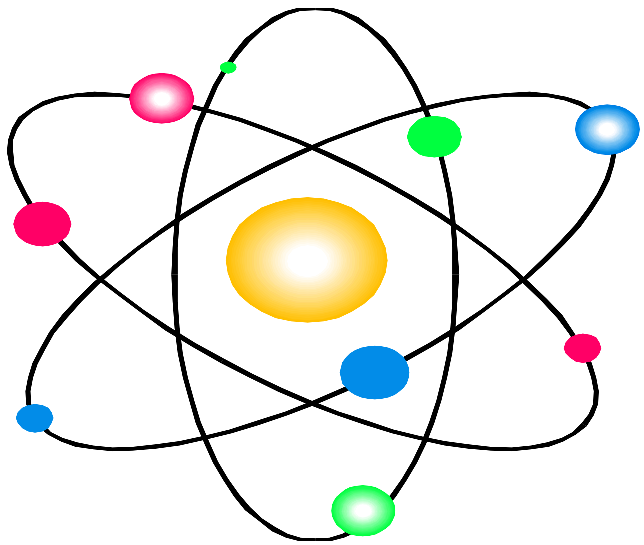
INTRODUCTION
TO
PHYSICS OF CONTACT RESISTANCE



Presented by

January Kister

INTRODUCTION TO PHYSICS OF CONTACT RESISTANCE

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- Introduction
- Elements of Contact Resistance
- Material Transfer in Contacts
- Contact Resistance Effects in Probing Applications

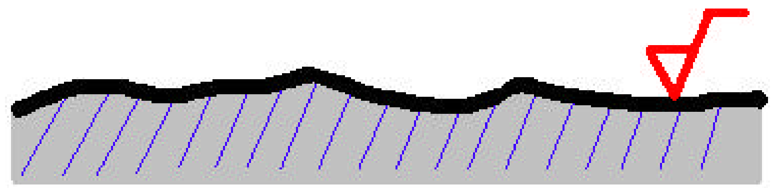
Introduction

- **Contact Resistance:**
- **Occurs between bodies in contact**
- **Creates losses in electrical and thermal systems**
  - **Contact of probe tip and the I.C. pad**
- **Probe Card as a micro-contactor**

Elements of Contact Resistance

- Topography of Clean Surfaces
- Apparent vs.. Real Contact Area
- Constriction Resistance
- Film Phenomena
  - Thin & Thick Films
- Constriction Thermal Effects

Clean Surface Topography



- **Practical Surfaces are not smooth due to manufacturing operations/material nature**
- **Probe-tip surface roughness ~3 micron, Typ.**

Ave. amplitude of asperity:

Polished - 0.1 mic; clean drawn - 1.0 mic; ground - 6mic; turned-10mic.

Typ. radius of asperity curvature = 3-100 X its height.

Typ. slope of asperity < 5deg.

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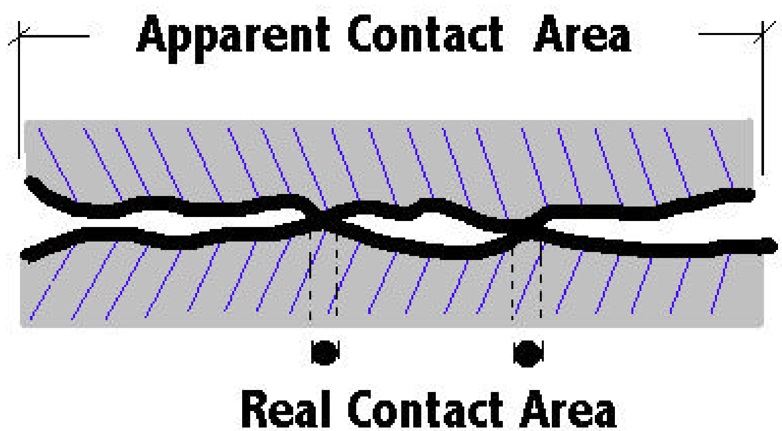
Apparent vs. Real Contact Area



- **Surface Contact = Contact of a few Asperities**
- **Real Contact Area << Apparent Contact Area**

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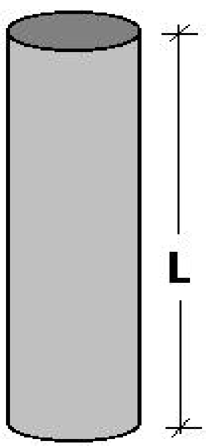
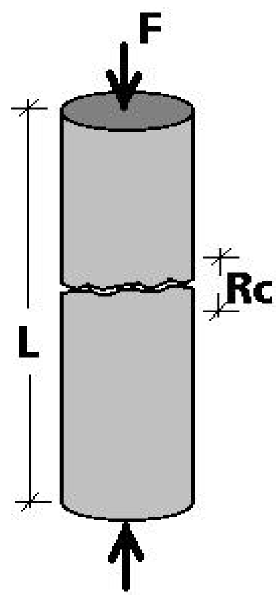
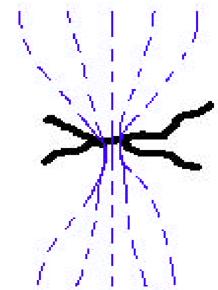
Constriction Resistance

- **Clean Surfaces**







Constriction in Current flow due to Asperities

R=rho*L/A

R=rho*L/A + Rc

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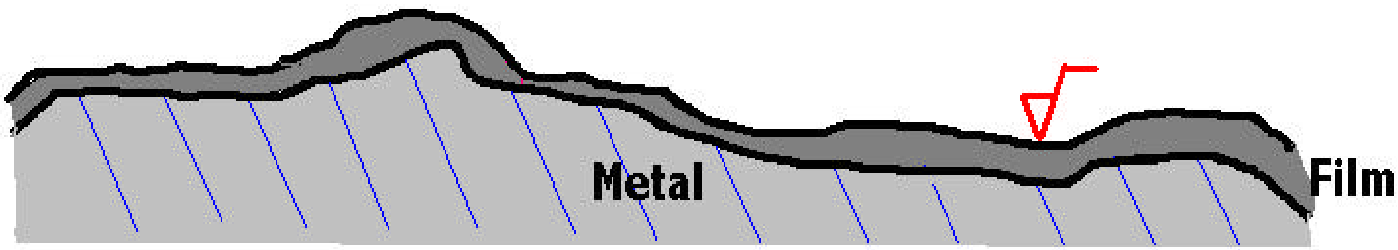
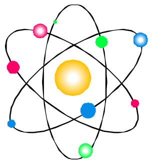
Film Phenomena



- **Metal surfaces are covered with films**
  - **Thin Films (Chemisorbed Oxygen atoms to Au, W, Ag...)**
    - **Up to Average 20 Angstrom thickness**
    - **Easily fractured mechanically**
    - **Conduct electricity by Tunnel effect when U>=30mV**
  - **Thick Films (Tarnish films: Oxides, Sulfides...)**
    - **Thickness >Average 100 Angstrom**
    - **Conductivity by Fritting when 10^5-10^6 V/cm**
    - **Practically insulating**



Rate of Metal Oxide Formation

Time t	Au	Ag	Cu	Pt	Ni	W	Al
20 sec			1.0-2.5				7.0
1-2 min		0.3	0.5-4.0	3.0	0.5	1.7	
10 min	0-1.0		10.0				
1-2 h			6.0		2.0	2.0	
2 days	1.0		2.0-10.0		2.0		

- **Number of chemisorbed atomic layers of Oxygen in time**
- **Initially clean metal surface exposed to Air**
- **All data averages**
- **Room temperature**
- **Compiled data from different sources and measurement methods**

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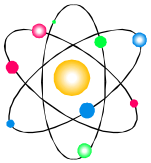
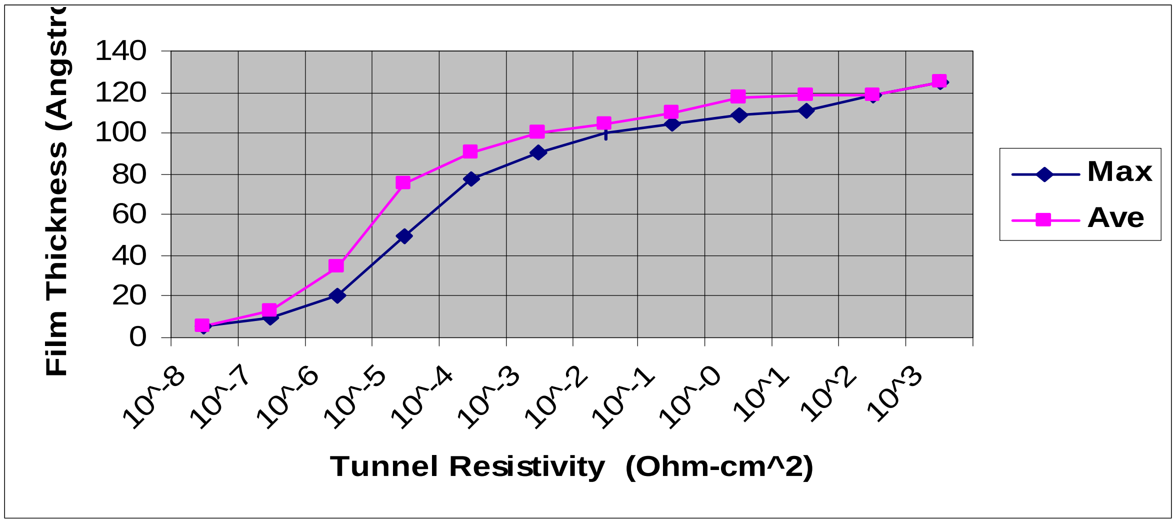


Film Thickness Vs. Tunnel Resistivity



From I.Dietrich "Z. Physiks..." p. 132

- **At 25 deg.C Al2O3 can grow to ~60 Angstroms**
- **A few seconds exposure of Al to Air generates**

  ~20 Angstroms of Al2O3
- **Tungsten develops ~50 Angstroms thick oxide at R.T.**

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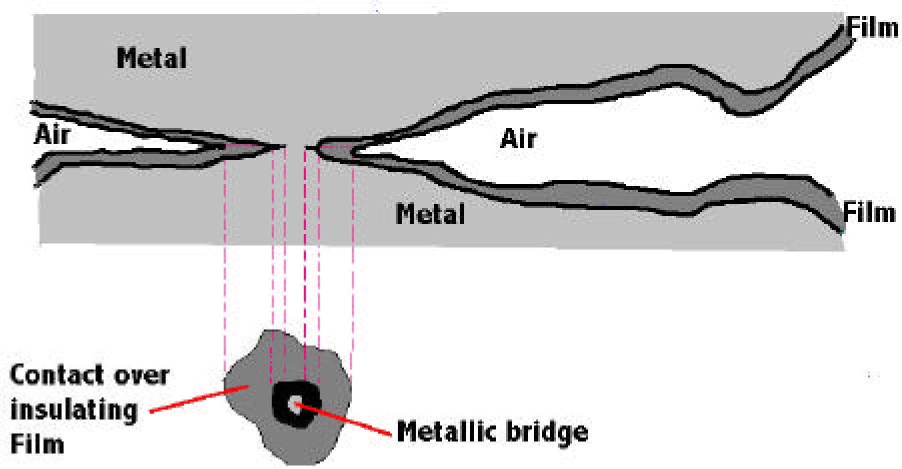
Contact Between Surfaces Covered with Film



- **Films covering surfaces need to be electrically or mechanically fractured before metal-to-metal contact is formed**
- **Probe wiping action**
- **Rough surface helps breaking oxide film**
- **Extremely smooth probe tip can produce high contact resistance!**

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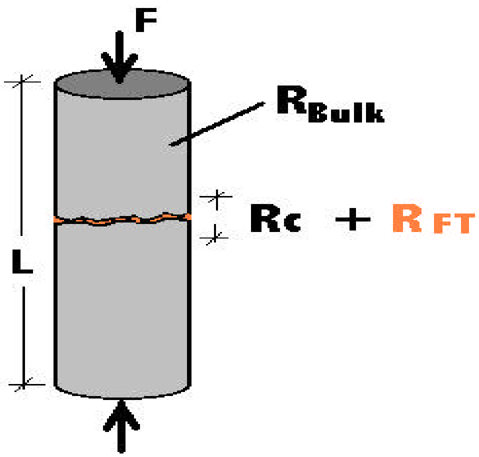
Contact Resistance of Practical Surfaces



$$RT = RB + RC + RFT$$

- RT= Total Resistance
- RB= Bulk Resistance
- RC= Constriction Resistance
- RFT= Film Tunneling Resistance

Material Transfer in Static Contacts

- **Cold micro-weld (Press-weld)**
- **Thermal micro-weld (Resistance-weld)**

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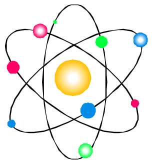
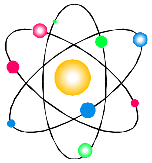


Cold Micro-Weld (Press-Weld)

- **Requires clean metal-to-metal contact**
- **Forms at Room Temperature**
  - **Hard metals (e.g.Tungsten)**
    - **weld by covalent bonds**
    - **bind with force=3-8eV**
    - **time needed to reach full strength**
    - **sliding weld much weaker than bulk material - wear and sliding proceeds in initial contact surface**
  - **Soft metals (e.g. Al, Cu)**
    - **weld by metallic bonds**
    - **bind with force=0.5-2eV**
    - **form immediately**
    - **weld capable to tear out debris from bulk material**

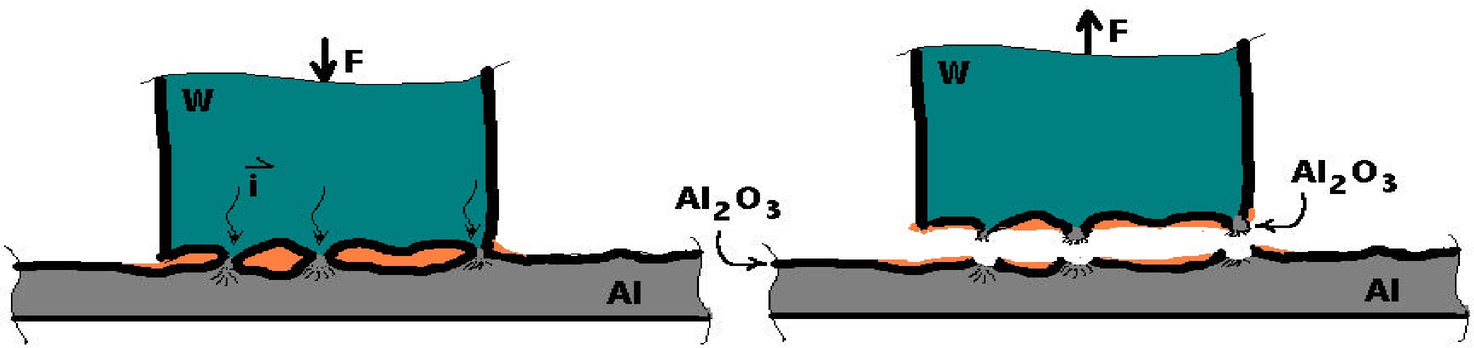


Thermal Micro-Weld (Resistance-Weld)

- **Elevated temperature due to Joule's heating softens metal around the contact**
- **Load generates increased contact surface**
- **Metallic contact spots form when film cannot follow the metal expansion and breaks open. Plastic deformation.**
- **A condition for adherence: contact voltage must attain the softening voltage of the harder member**
- **The strength of thermal weld reaches Tensile Strength of base metal**

		SOFTENING VOLTAGES FOR VARIOUS METALS					
MATERIAL	Fe	Cu	Ag	W	Pt	Au	Al
Adherence begins at			0.1		0.35		
Uadhere	0.35	0.1	0.24	0.6	0.4	0.06	0.1

Material Transfer in Contacts



- Touch down ... wipe films off ...
- Clean metal to metal contact ... Test ...
- Cold/thermal weld ...
- Lift-off ... Weaker material tears out ...
- Newly Exposed material oxidizes...
- Touch down ... Cres increases

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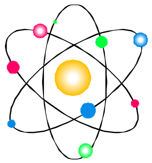

Summary

- **Presented concepts have been adopted from the field of micro-contactor design developed in 1950's**
- **Quality of contact resistance relies on contactor's ability to penetrate the insulating surface films and form metal-to-metal contact spots that carry the majority of flowing current**
- **The necessity to clean the probe tips arises from the fact that direction of material transfer is from soft (Al pad) to hard (W probe) contact component and soft material forms non-conductive film**