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Percolation Threshold Effects on the Electrical Contact Resistance and Adhesion of Microelectromechanical Systems Thin-Film Materials

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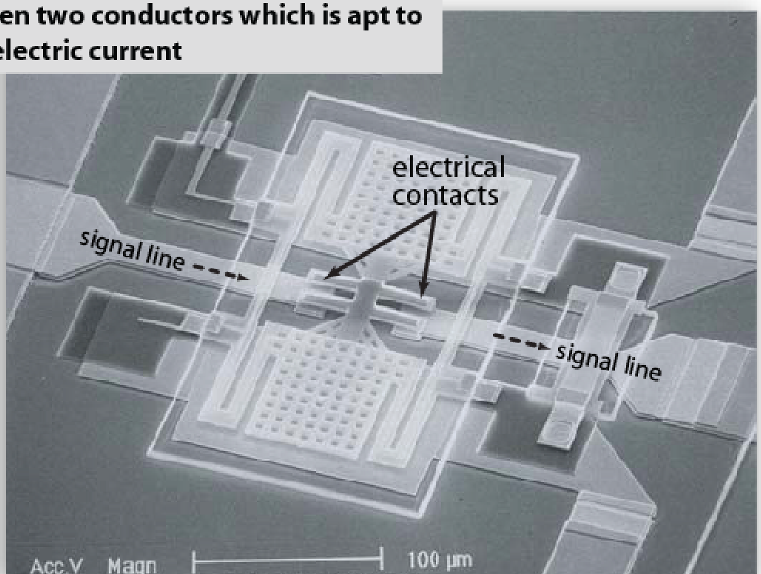
Presentation Outline

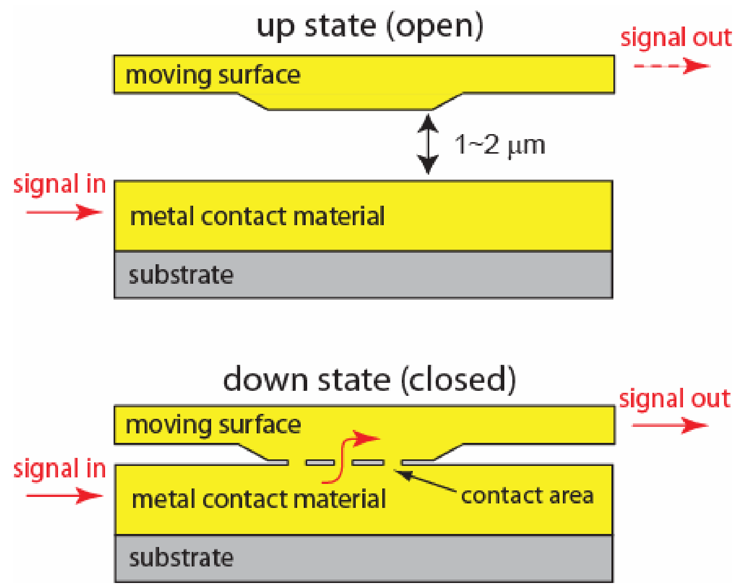
- MEMS Electrical Contacts
- Degradation Mechanisms
- Composite Electrical Contact Materials
- Experimental Results
- Percolation Threshold

MEMS Electrical Contacts

electrical contact **: a reasonable junction between two conductors which is apt to carry electric current**



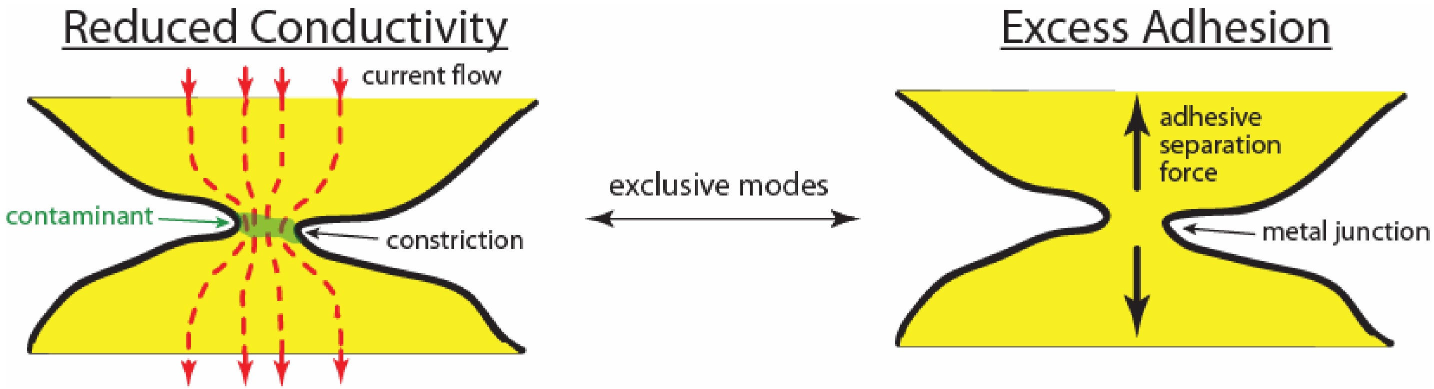
Rockwell RSC MEMS switch

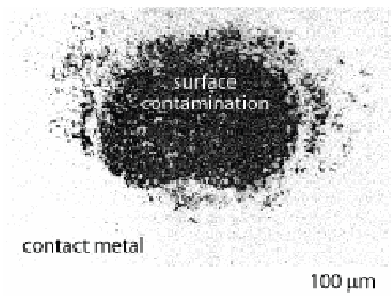


Metal-contact MEMS electrical devices are capable of operating over a wide range of signal frequencies and posses distinct advantages over larger solid-state components: (e.g., size, low insertion loss, high isolation, low power consumption)

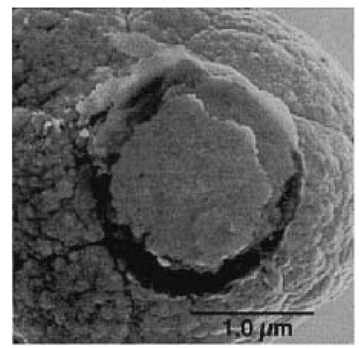
However, the performance and reliability of metal-contact MEMS devices depends critically on the *quality* of the electrical contact interfaces which can change over time

Degradation Mechanisms





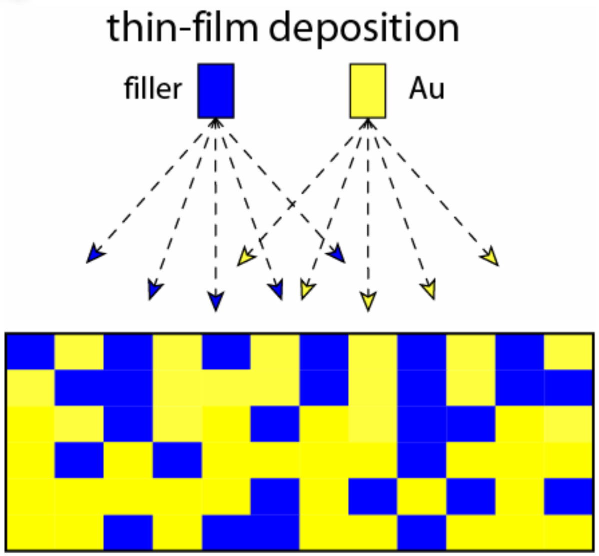
Tamai, T., 1995, "Effect of Silicone Vapour and Humidity on Contact Reliability of Micro Relay Contacts," IEEE Transactions on Components, Packaging, and Manufacturing Technology – Part A, 19(3), pp. 329-338.

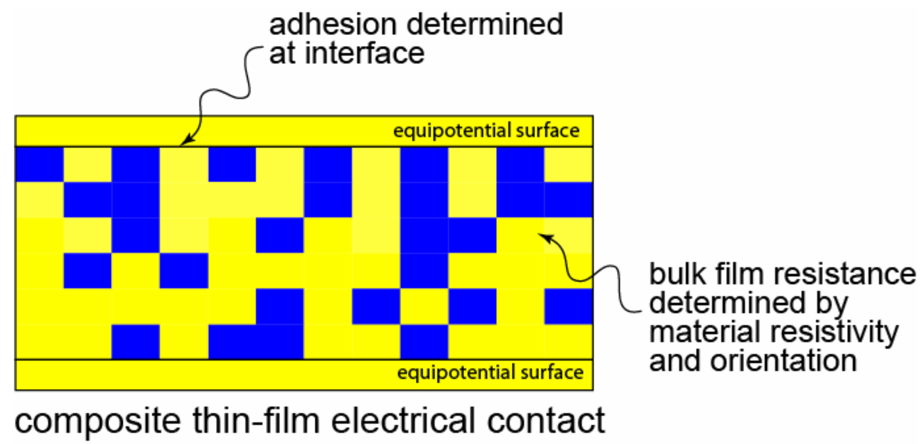


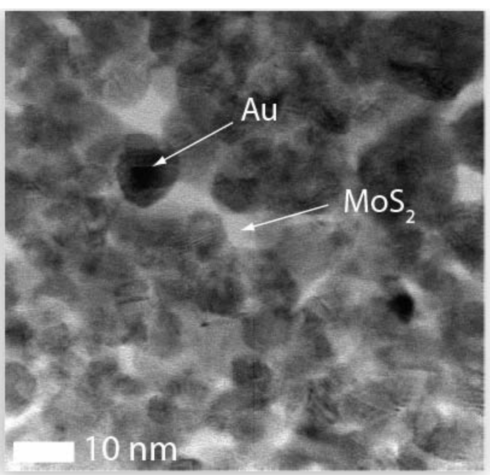
Hyman, D., and Mehregany, M., 1999, "Contact Physics of Gold Microcontacts for MEMS Switches," IEEE Transactions on Components and Packaging Technology, 22(3), pp. 357-364.

Proper operation of MEMS electrical contacts is predicated on the balance of sufficient interfacial conductivity and off-state separability of the surfaces

Composite Electrical Contact Materials



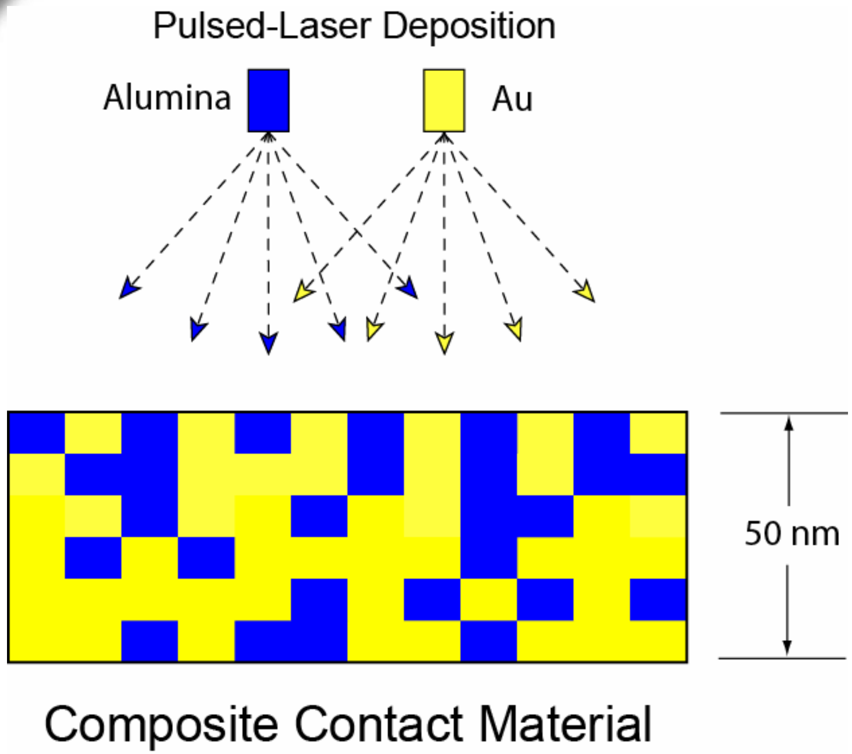


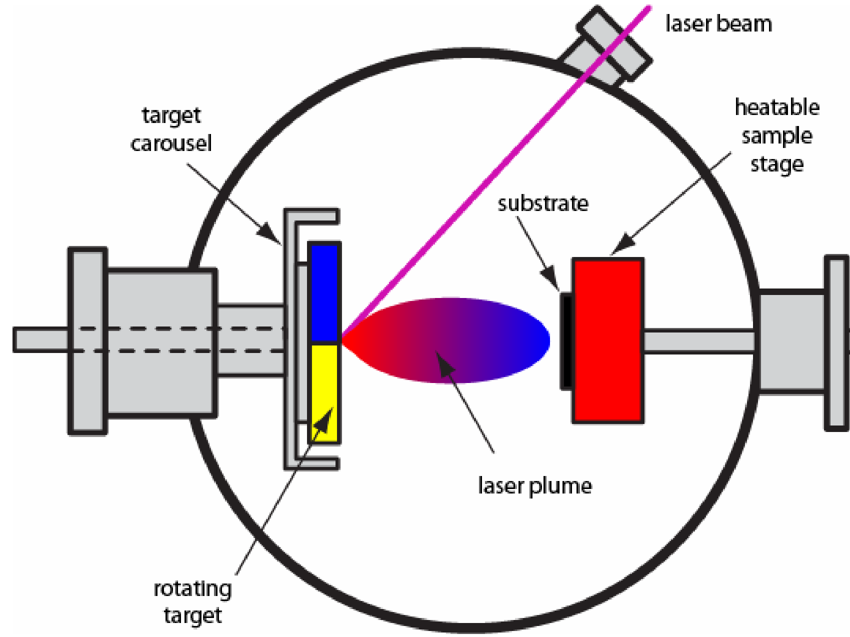


- J.R. Lince, "Tribology of co-sputtered nanocomposite Au/MoS2 solid lubricant films over a wide contact stress range", *Tribology Letters*, Vol. 17, No. 3, 2004

A co-deposited electrical contact material with intermixed phases of high-conductivity and low-adhesion constituents should satisfy the concurrent operational requirements of low resistance and reduced adhesion

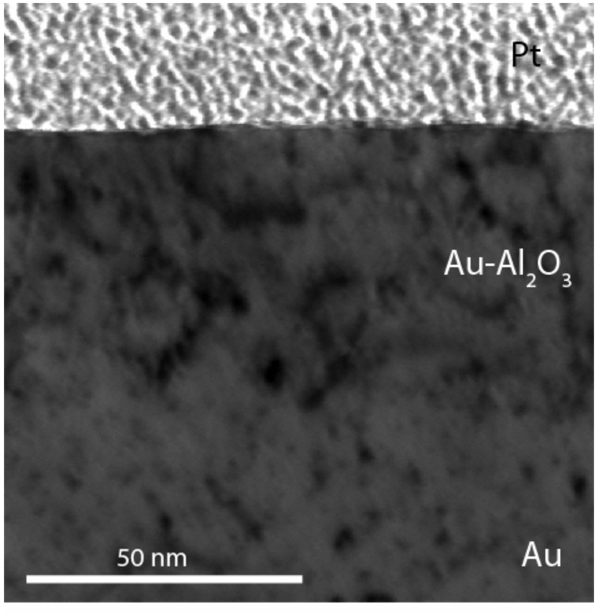
Composite Material Deposition



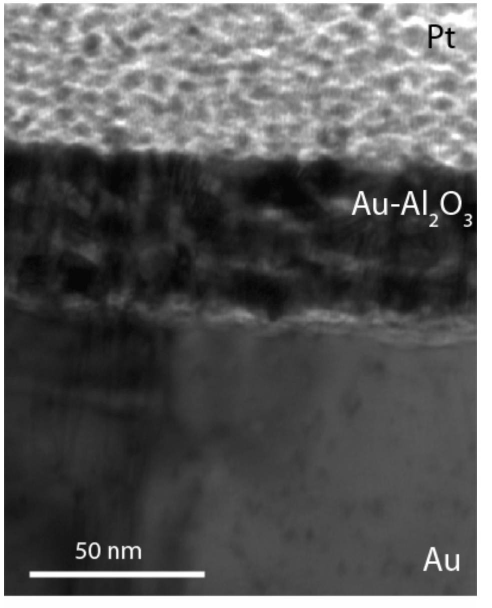


Pulsed-laser deposition (PLD) was used to create thin Au-Al_2O_3 electrical contact film composites of varied composition

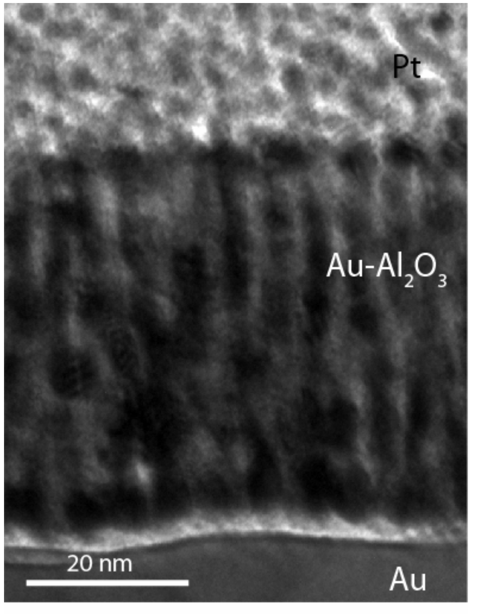
Au-Al_2O_3 TEM Imagery



90% Au



50% Au



20% Au

Transmission Electron Microscopy (TEM) imagery of the gold-alumina composites shows evolving morphology within the composite film as gold content decreases

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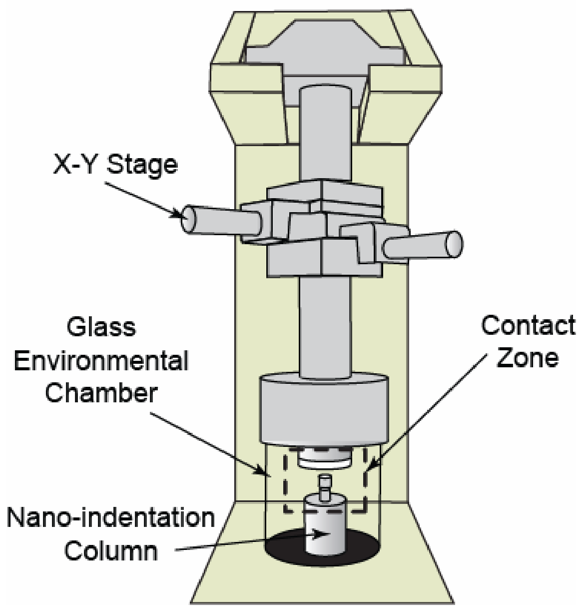
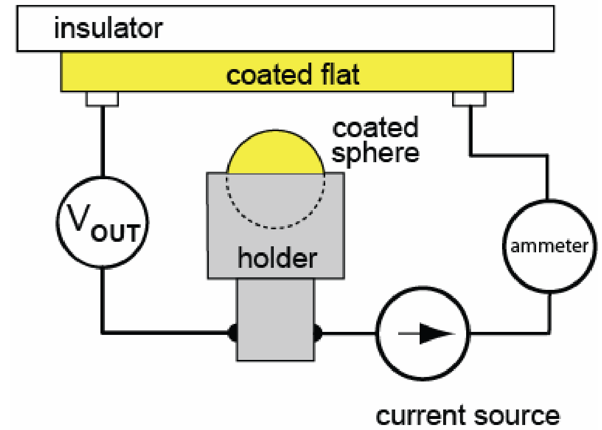
Experimental Apparatus

Apparatus Schematic



Contact Zone Schematic

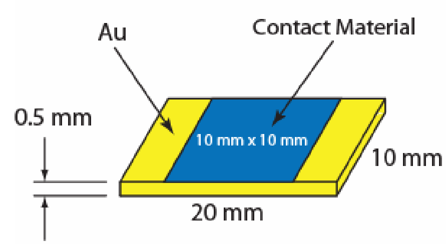


Conditions

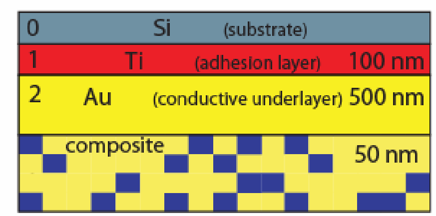
$F_n = 100\,\mu N\ (\pm 1\ \mu N)$

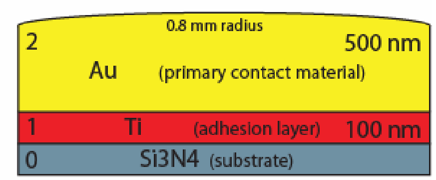
$V_{open} = 1\ V\ (\pm 1\ \mu V\ @\ 1\ V)$

$I_{source} = 1\ mA\ (\pm 1\ nA\ @\ 1\ mA)$



coated flat





coated sphere

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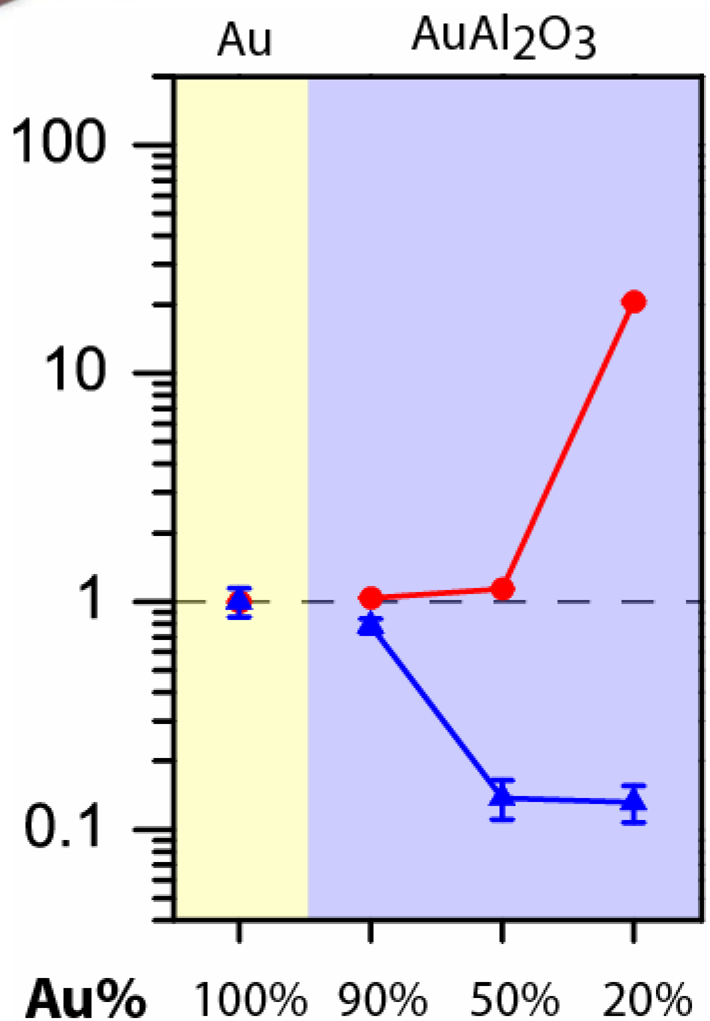
Experimental Results



● Normalized Resistance

▲ Normalized Pull-off Force

Normalization Values

$R_{AuAu} = 533 \pm 7\ m\Omega$

$F_{po_{AuAu}} = 253 \pm 36\ mN$

Experimental Conditions

Fn: 100 μN

current: 1 mA

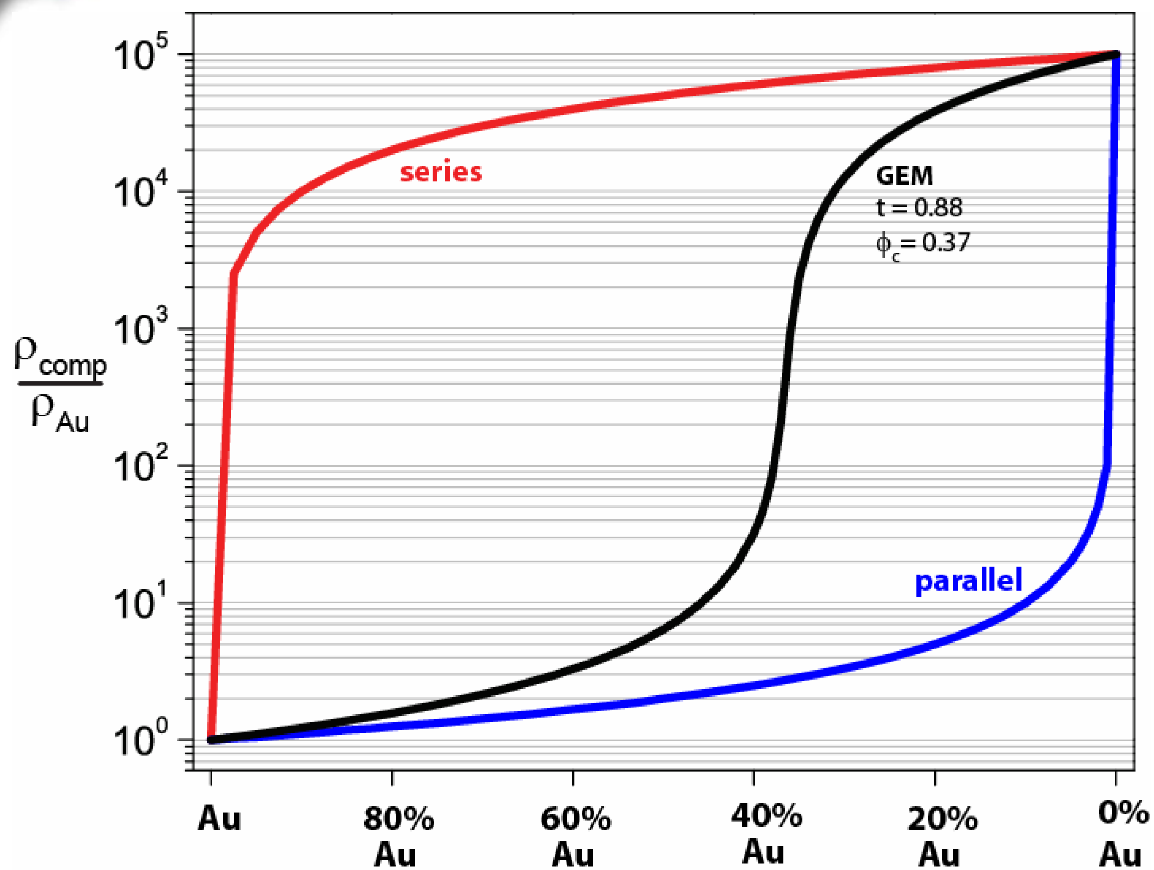
laboratory air

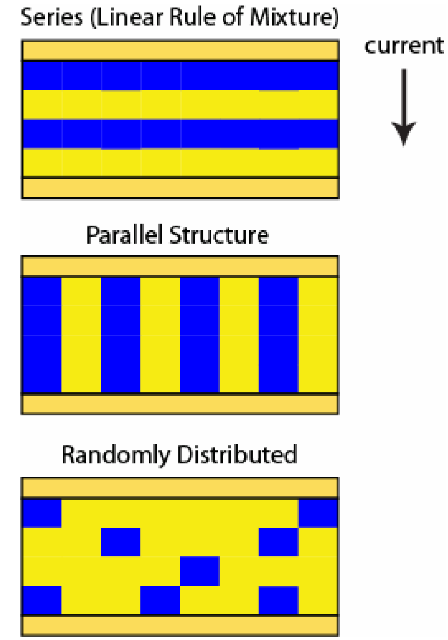
22 °C

RH 20% ± 5%

Initial experimental results showed that reduction in adhesive pull-off force did not immediately coincide with increases in measured contact resistance

Percolation Threshold





General Effective Media
(McLachlan 1987)

$$\frac{(1-\phi)\left(\rho_m{}^{1/t}-\rho_h{}^{1/t}\right)}{\rho_m{}^{1/t}+\rho_h{}^{1/t}\left(\frac{1-\phi_c}{\phi_c}\right)}+\frac{\phi\left(\rho_m{}^{1/t}-\rho_l{}^{1/t}\right)}{\rho_m{}^{1/t}+\rho_l{}^{1/t}\left(\frac{1-\phi_c}{\phi_c}\right)}=0$$

unknown parameters
ρ_m -- composite resistivity

known parameters
ρ_l -- low resistivity phase
ρ_h -- high resistivity phase
ϕ -- volume fraction

free parameters
t -- percolation exponent
ϕ_c -- critical volume fraction

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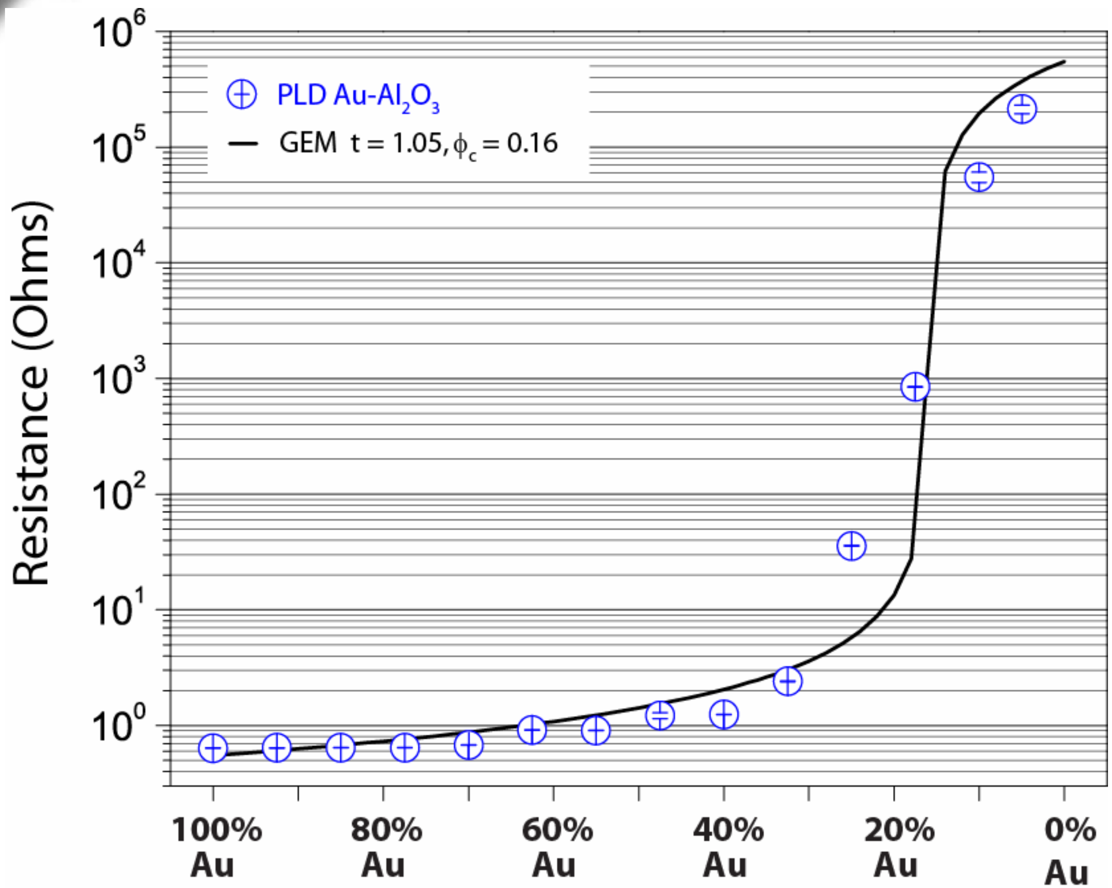
Percolation Threshold



Subsequent testing of composites created with increased compositional resolution showed a distinct threshold where contact resistance increases sharply with small increase in filler percentage

General Effective Media (McLachlan 1987)

$$\frac{(1-\phi)\left(\rho_m{}^{1/t}-\rho_h{}^{1/t}\right)}{\rho_m{}^{1/t}+\rho_h{}^{1/t}\left(\frac{1-\phi_c}{\phi_c}\right)}+\frac{\phi\left(\rho_m{}^{1/t}-\rho_l{}^{1/t}\right)}{\rho_m{}^{1/t}+\rho_l{}^{1/t}\left(\frac{1-\phi_c}{\phi_c}\right)}=0$$

unknown parameters

ρ_m -- composite resistivity

known parameters

ρ_l -- low resistivity phase

ρ_h -- high resistivity phase

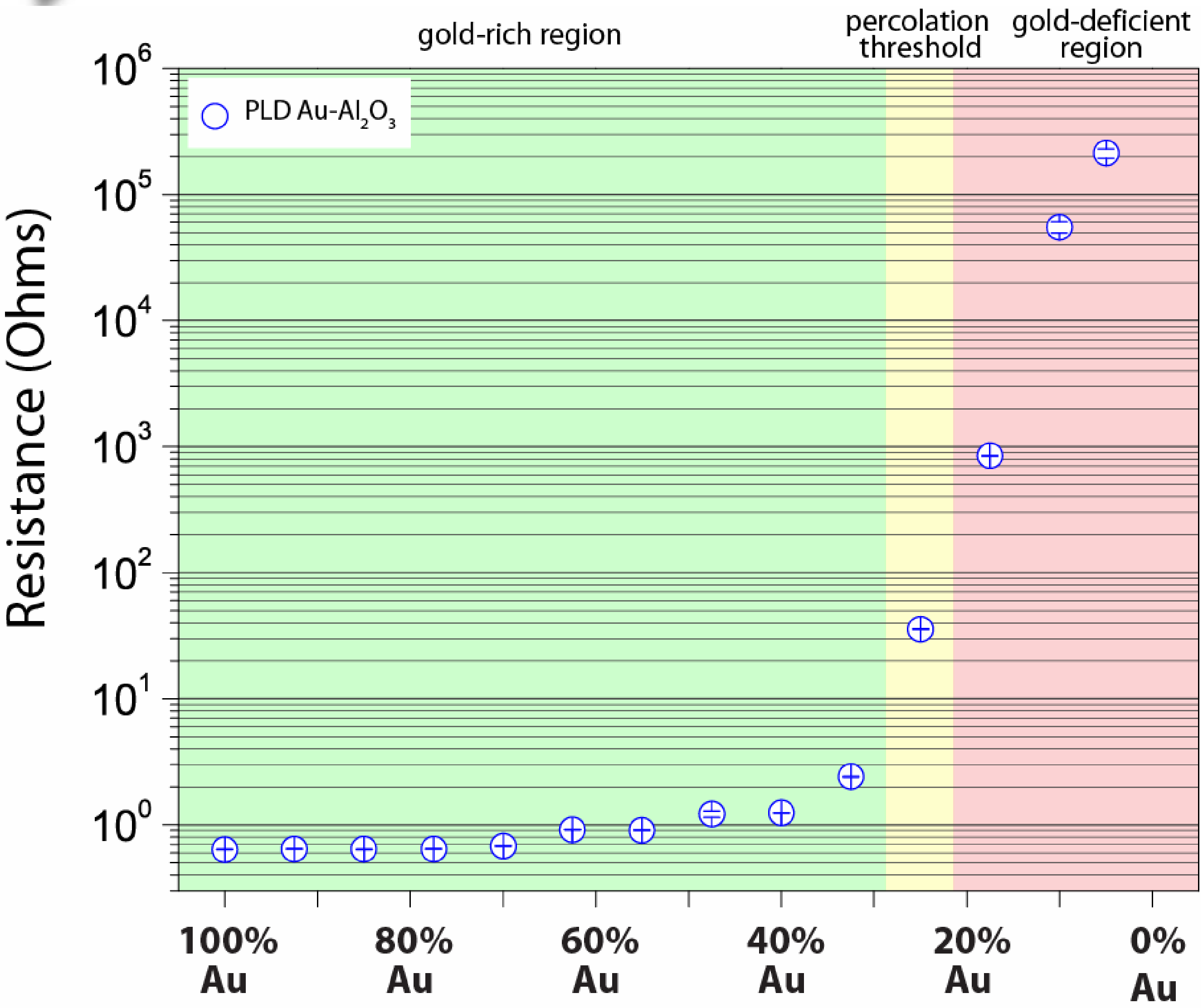
ϕ -- volume fraction

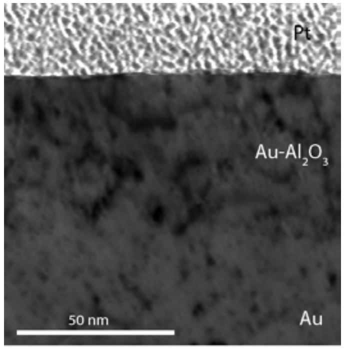
free parameters

t -- percolation exponent

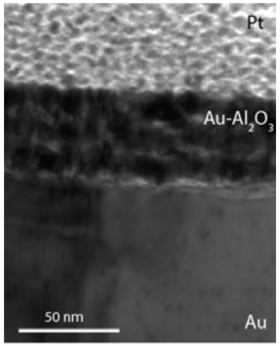
ϕ_c -- critical volume fraction

Percolation Threshold

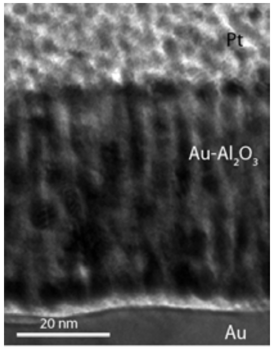




90% Au



50% Au



20% Au

Conclusions

- Co-deposited thin film electrical contact composites can be created which simultaneously exhibit good conductivity and reduced adhesion compared to a self-mated purely metallic contact
- The nano-scale structural morphology of the composite film strongly determines the effectiveness of the composite at conducting electrical current (percolation limit)
- Significant freedom exists in the deposition methods (co-sputtering, evaporation, etc.) used to create the composite films, as well as the materials available for use
- Significant refinement and optimization of the deposited film structure could lead to highly conductive, non-adherent electrical contact materials for high-reliability MEMS devices (!)

Acknowledgements and Questions

Sandia National Laboratories

Michael T. Dugger
James. A. Knapp
David M. Follstaedt

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