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Quantitative evolution of electrical contact resistance between aluminum thin films

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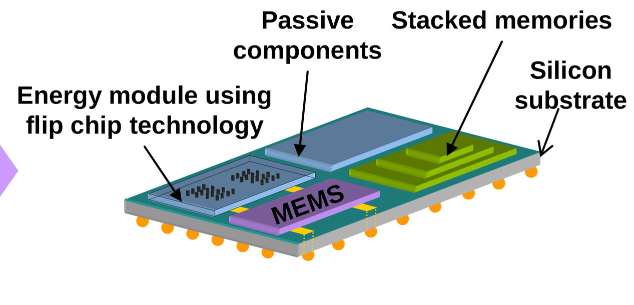
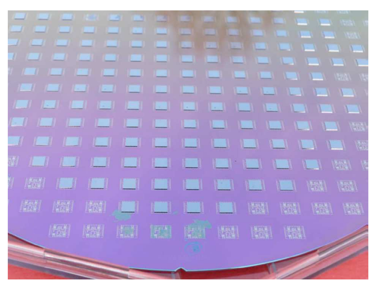
3D Integration



System On Wafer

High integration of systems by vertically stacking and connecting various technologies and functional components together.

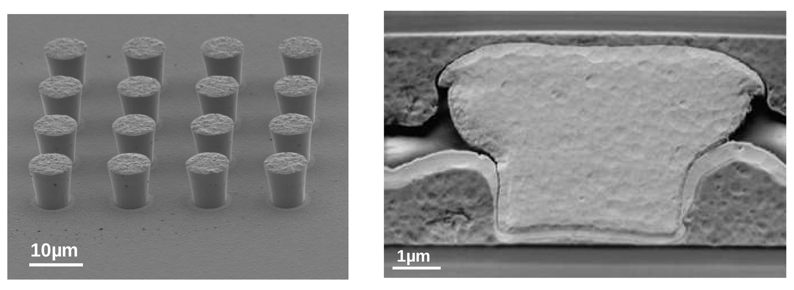
Flip-chip process


Assembled wafer and die components connected on a 200mm wafer [1].

Flip chip interconnection technology is a solution for high packaging demand.
Smaller chip size, higher speed electrical performance and bigger I/O density.

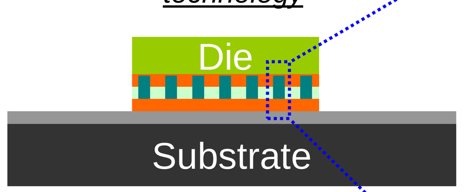
Micro-insert technology

Electrical connection are realized through **micro-insert technology**.

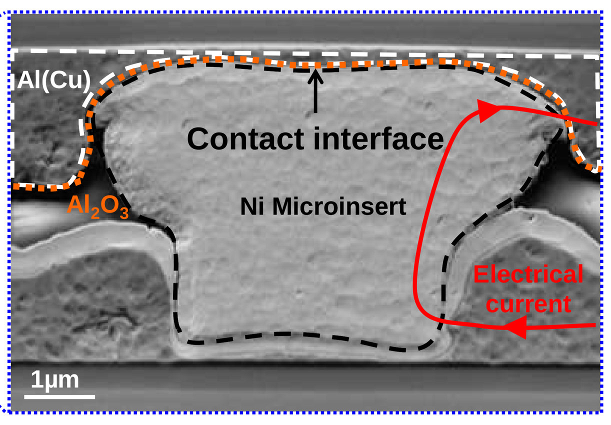


(a) (b)
SEM views of micro-inserts (a) before and (b) after assembly (with mechanical cross section and FIB cutting) [1].

3-D silicon die stacked package using flip chip micro-insert technology



➔ 2 main goals :
- *Electrical connection*
- *Mechanical maintain*

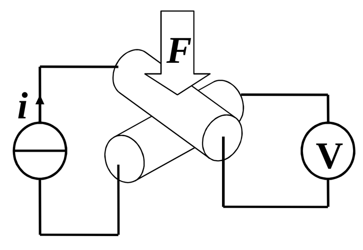
Die


Substrate

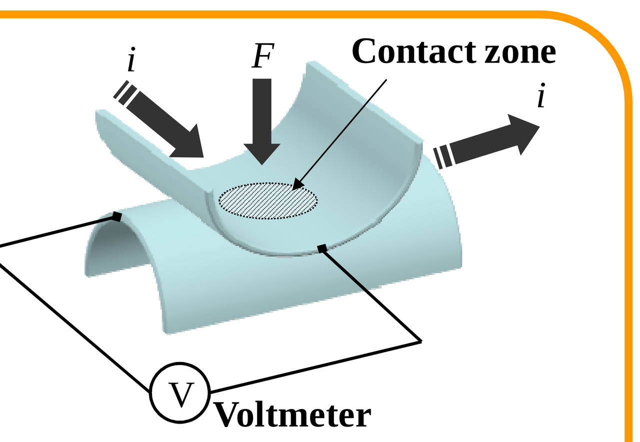
Goal of this work

Mechanisms of the **electrical contact establishment** between Al thin film and Ni microinsert ?
&
Role of the native Al_2O_3 layer ?

How ?

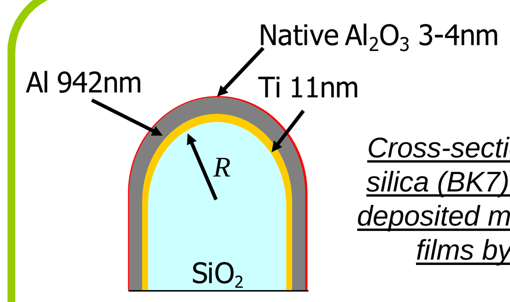


Crossed rods experiments [2]
(Hertzian contact)

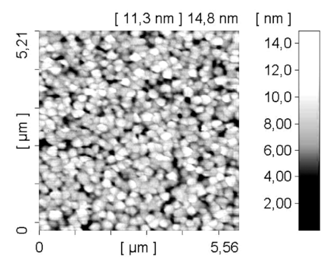


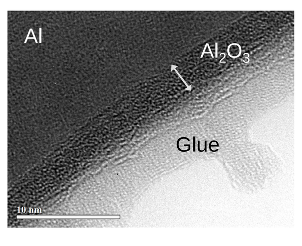
Compression of 2 Al thin films (~1µm) with electrical measurement.

Samples



Cross-section of the silica (BK7) lens with deposited metallic thin films by PVD


AFM observation of the Al thin film surface



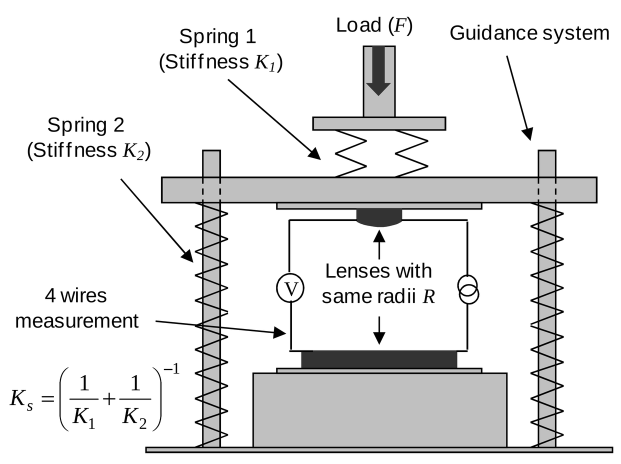
TEM cross section of Al film with native Al_2O_3

	Young's modulus (E) (GPa)	Hardness (H) (GPa)	Poisson's coefficient (ν)
BK7	81 ± 1	7.5 ± 0.5	0.21 [3]
Al thin film	68 ± 1	0.8 ± 0.1	0.34 [4]

Mechanical properties of Al thin film and BK7

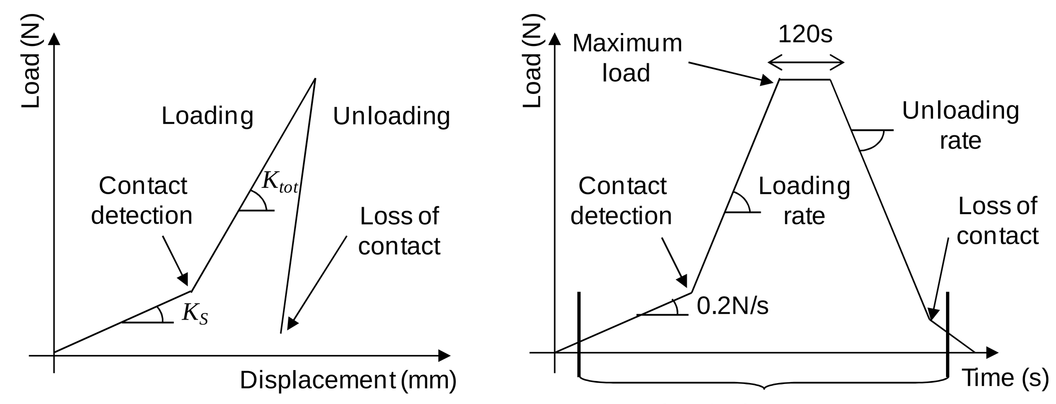
Experimental details

A specific guidance system designed to avoid any vibration and slipping effect

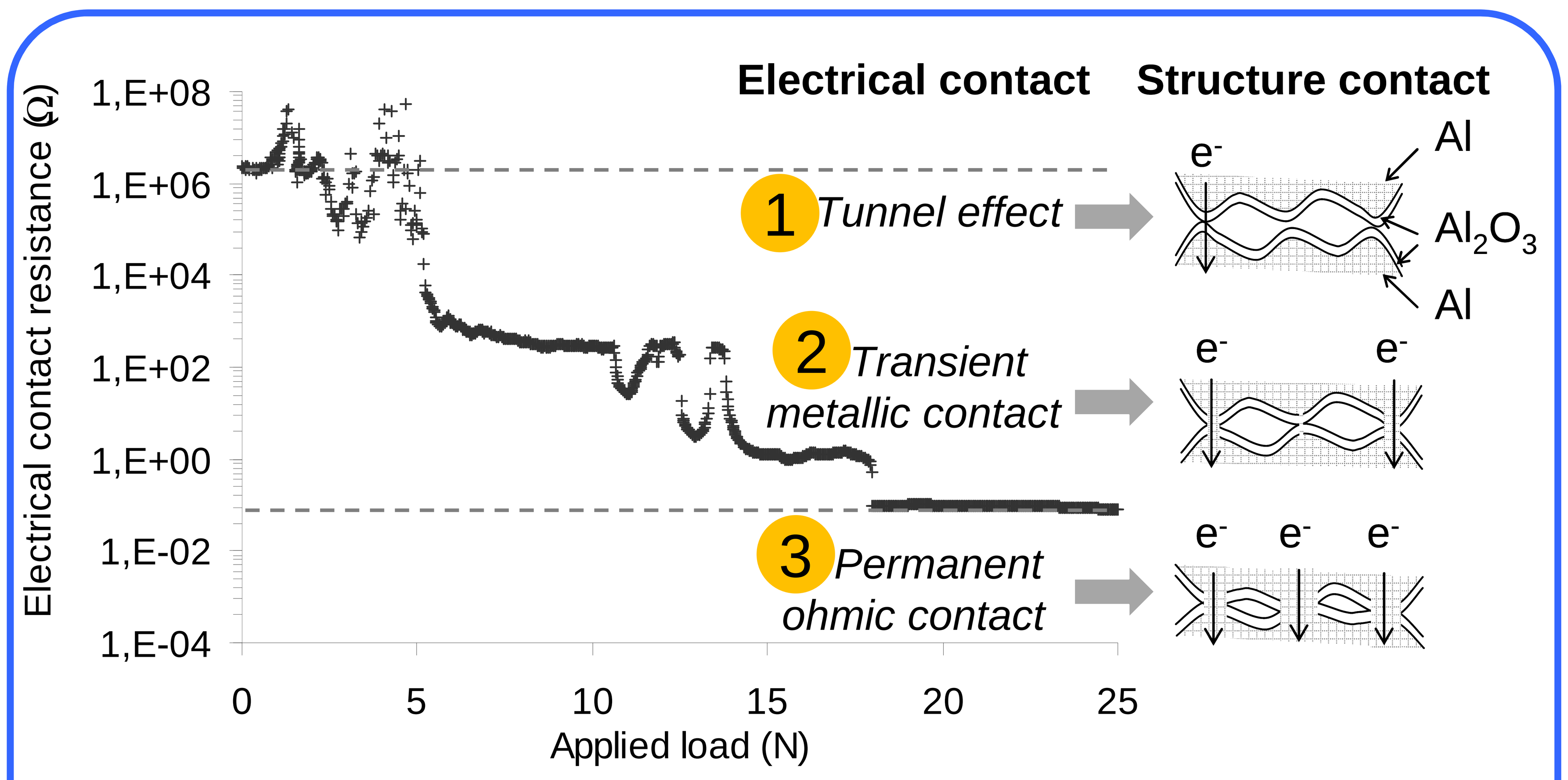


Electrical parameters :
- 4 wires measurement
- Constant voltage (±5mV)
- Compliance current : 500mA
- Data acquisition frequency : 10Hz

Mechanical parameters :
- Maximal load : 50N
- Loading rate : 0.1, 0.2 and 1 N/s
- Load resolution : 50mN



Electrical result

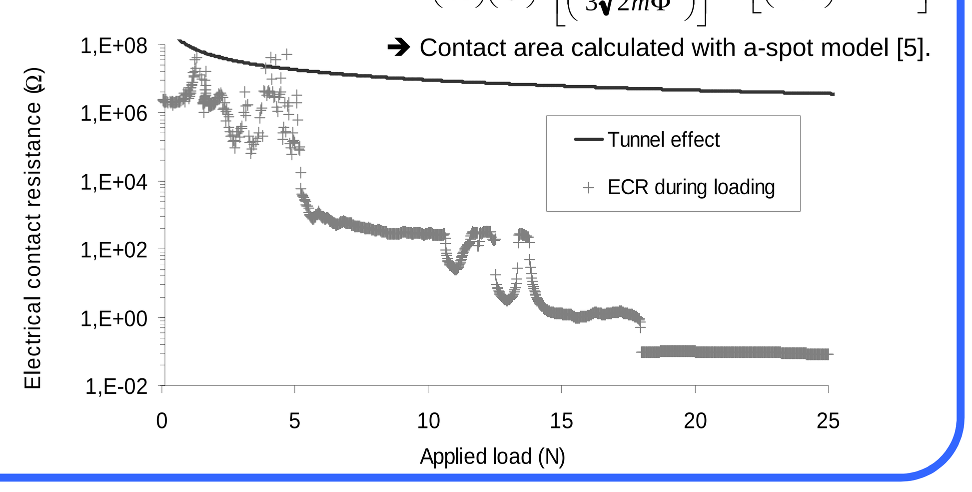


Hypothesis : Electrical contact is formed through cracks into native alumina [5].

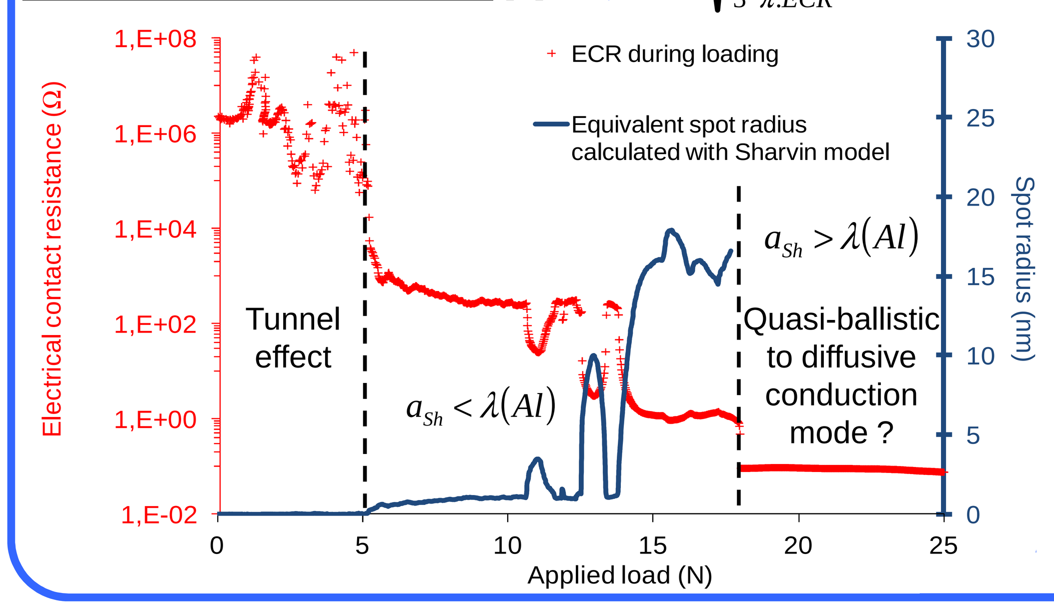
1 Low loads

Tunnel Effect [6] ➔ $R_f = \left(\frac{t}{A}\right)\left(\frac{h}{e}\right)^2\left[\left(\frac{2}{3\sqrt{2m\Phi}}\right)\right]\exp\left[\left(\frac{4\pi t}{h}\right)\sqrt{2m\Phi}\right]$

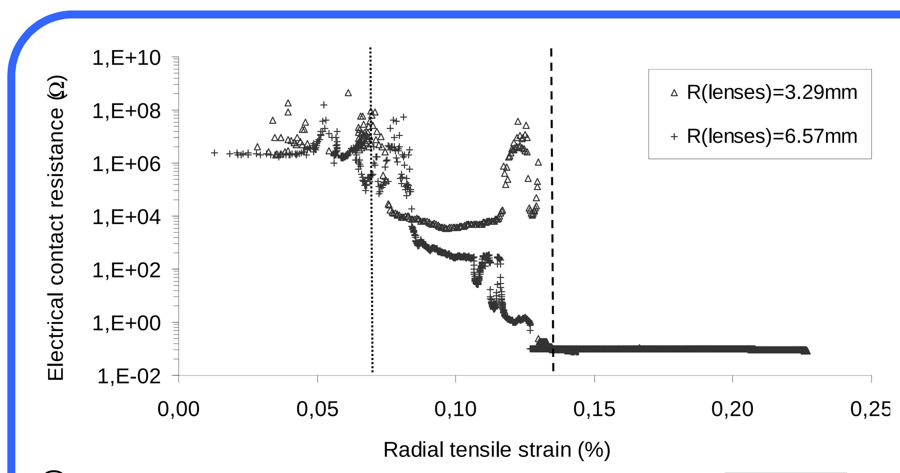
➔ Contact area calculated with a-spot model [5].

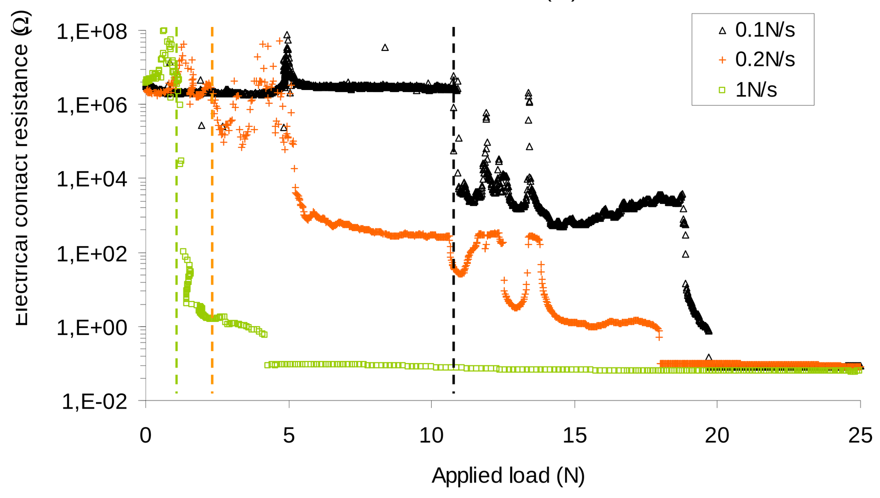


Ballistic conduction mode [7] ➔ $a_{Sh} = \sqrt{\frac{4}{3}\frac{\rho.\lambda}{\pi.ECR}}$ with $\lambda(Al) = 16nm$



2 Transient metallic contact





Parametric studies

≠ loading rate → *High influence of load rate on ECR evolution.*

≠ radii of lenses → *No major influence of the lens radius.*

Hyp. *: Alumina strain is imposed by silica lens.*

➔ ***Hertzian elastic contact theory***

Calculation of fracture strains [8]

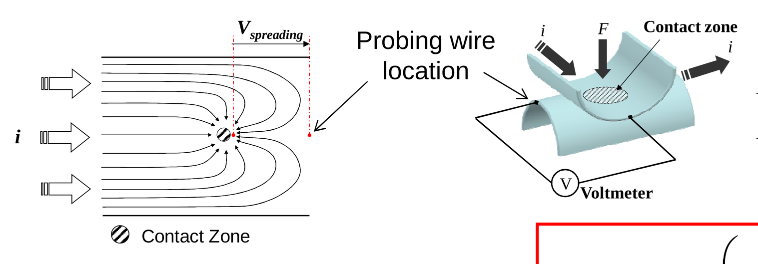
$$\varepsilon_{rupt}(r = a_e) = \frac{(1-2\upsilon)}{2E}\frac{F_{rupt}}{\pi a_e^2}$$

$$\sigma_{rupt} = \varepsilon_{rupt}(r = a_e).E_{Al2O3}$$

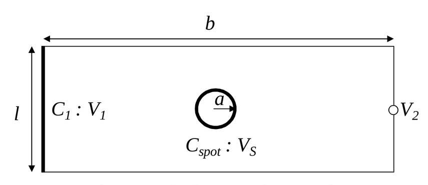
	Loading rate	0.1N/s	0.2N/s	1N/s
Exp.	F_{rupt}	10.7N	2.5N	1.2N
Exp.	ε_{rupt} (r=a_e)	1.1 10^{-3}	6.7 10^{-4}	5.1 10^{-4}
Litt.	ε_{rupt} (r=0) [9]	3.5 10^{-4} - 5.0 10^{-4} N. B. : loading rate not given		
Litt.	ε_{rupt} [10]	1-3 10^{-4}		
Calc.	σ_{rupt} (r=a_e)	100 to 210 MPa (with E=200Pa)		

3 High loads

Ohmic contact at high loads controlled by spreading and crowding effects → FEM simulations

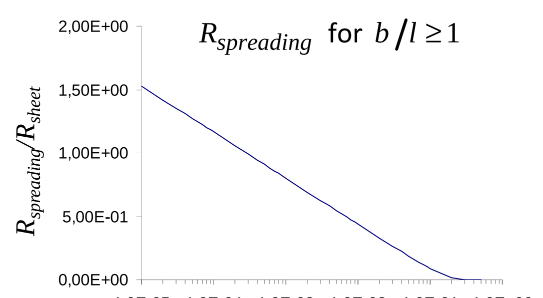


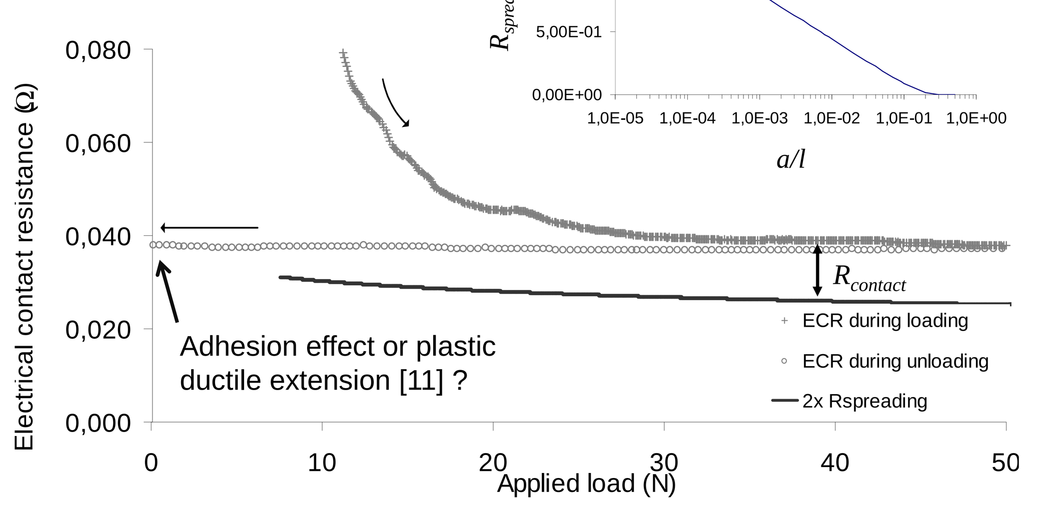
$ECR = \frac{\Delta V}{i} = \frac{\Delta V_{contact} + 2V_{spreading}}{i}$
$ECR = R_{contact} + 2R_{spreading}$



Schematic lens plane view

➔ $R_{spreading} = \left(k_1 \ln\left(\frac{a}{l}\right) + k_2\right).R_{sheet}$





➔ *A value of $R_{contact}$ ≈ 13mΩ is extracted at high loads, which corresponds to an equivalent circular constriction with* **Ø=1.8µm** (only ≈1% of elastic contact).

Conclusion

- 3 ≠ steps observed during the evolution of ECR in function of load :
  - → Low load : Tunneling effect (~MOhm),
  - → Transient: Metallic contacts formation through cracks in alumina with a ballistic conduction mode,
  - → High load: Ohmic contact (<100 mOhm), controlled by geometry and resistivity of the thin film.
- Mechanical characterization of native alumina ➔ $\sigma_{rupt}(Al_2O_3) = 100 - 210MPa$.
- Extraction of real electrical contact resistance corrected with FEM simulations.

Outlook

- Crossed rods compression between different lenses (thin film of Ni and Al).
- Intermetallic compounds formation.
- Study of the effect of roughness.
- Measurement in temperature (→ 200°C / 473,15K).

Acknowledgments *:*

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[1] H. Boutry, J. Brun, R. Franiatte, A. Nowodzinski, N. Sillon, B. Dubois- Bonvalot, F. Depoutot, O. Brunet, A. Peytavy, Reliability characterization of Ni-based microinsert interconnections for flip chip die on wafer attachment and their evaluation in multichip simcard prototype, in: Proc. 10th IEEE EPTC, Singapore, 2008, 1334–1339.
[2] R. Holm, "Electric contacts: theory and applications." (Springer, 1999).
[3] T. Chudoba, N. Schwarzer, F. Richter and U. Beck, " Determination of mechanical film properties of a bilayer system due to elastic indentation measurements with a spherical indenter." Thin Solid Films, 2000, 377, 366-372.
[4] A. C. Fischer-Cripps, "Nanoindentation – 2nd Edition." (Springer, 2004).
[5] R. S. Timsit, "Electrical contact resistance: fundamental principles", in Electrical Contacts: Principle and Applications (ed. By P. G. Slade - Marcel Dekker, pp. 45-51, 1999).
[6] [J. G. Simmons, "Generalized Formula for the Electric Tunnel Effect between Similar Electrodes Separated by a Thin Insulating Film." Journal of Applied Physics, 1963, 34(6), 1793-1803.
[7] Y. V. Sharvin, Zh. Exp. Teor. Fiz., 1965, 48.
[8] K. L. Johnson, "Contact mechanics." (Cambridge University Press, 1987).
[9] R. S. Timsit, "Some fundamental properties of aluminum-aluminum electrical contacts." Ieee Transactions on Components Hybrids and Manufacturing Technology, 1980, 3(1), 71-79.
[10] J. C. Grosskreutz, "Mechanical properties of metal oxide films." Journal of the Electrochemical Society, 1969, 116(9), 1232-1237.
[11] J. Pethica et D. Tabor, "Contact of characterised metal surfaces at very low loads: Deformation and adhesion," Surface Science, vol. 89, n°. 1, p. 182-190, 1979.