# Spreading Resistance of Thin Film Contacts

**Peng Zhang, Y. Y. Lau, and R. M. Gilgenbach**

Department of Nuclear Engineering and Radiological Sciences
University of Michigan
Ann Arbor, MI, USA, 48109-2104

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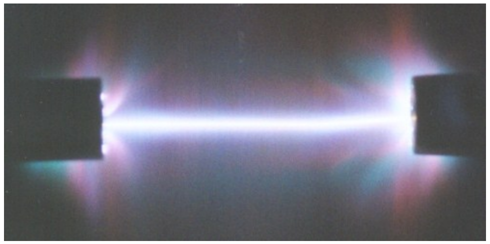
# Introduction

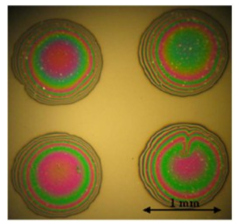
- Electrical contact is important to

**Wire-array Z pinches**



Z-pinch @ UM & Sandia

**Metal-insulator-vacuum junctions**

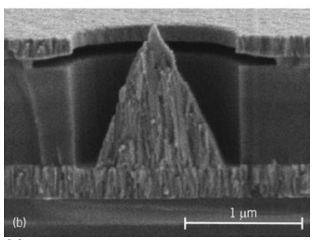



Metal-oxide-junction cathodes [Jordan *et al.* Rev. Sci. Instrum. 79, 064705 (2008)]

**High power microwave (HPM) sources**

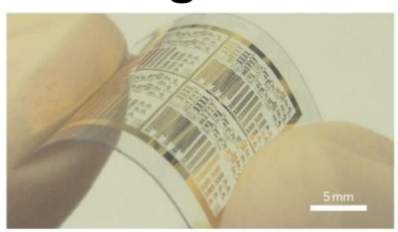
UM/ L-3-Titan relativistic magnetron

**Field emitters**



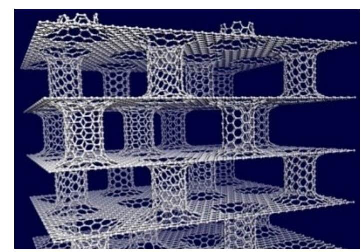

http://accessscience.com

**Thin film devices & integrated circuits**



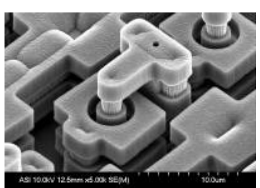

Sun et al, Nature Nanotechnol. 6, 156 (2011)

**Carbon nanotubes based cathodes and interconnects**



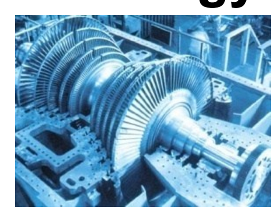
CREDIT: SPIE

**Micro-electromechanical System (MEMS)**



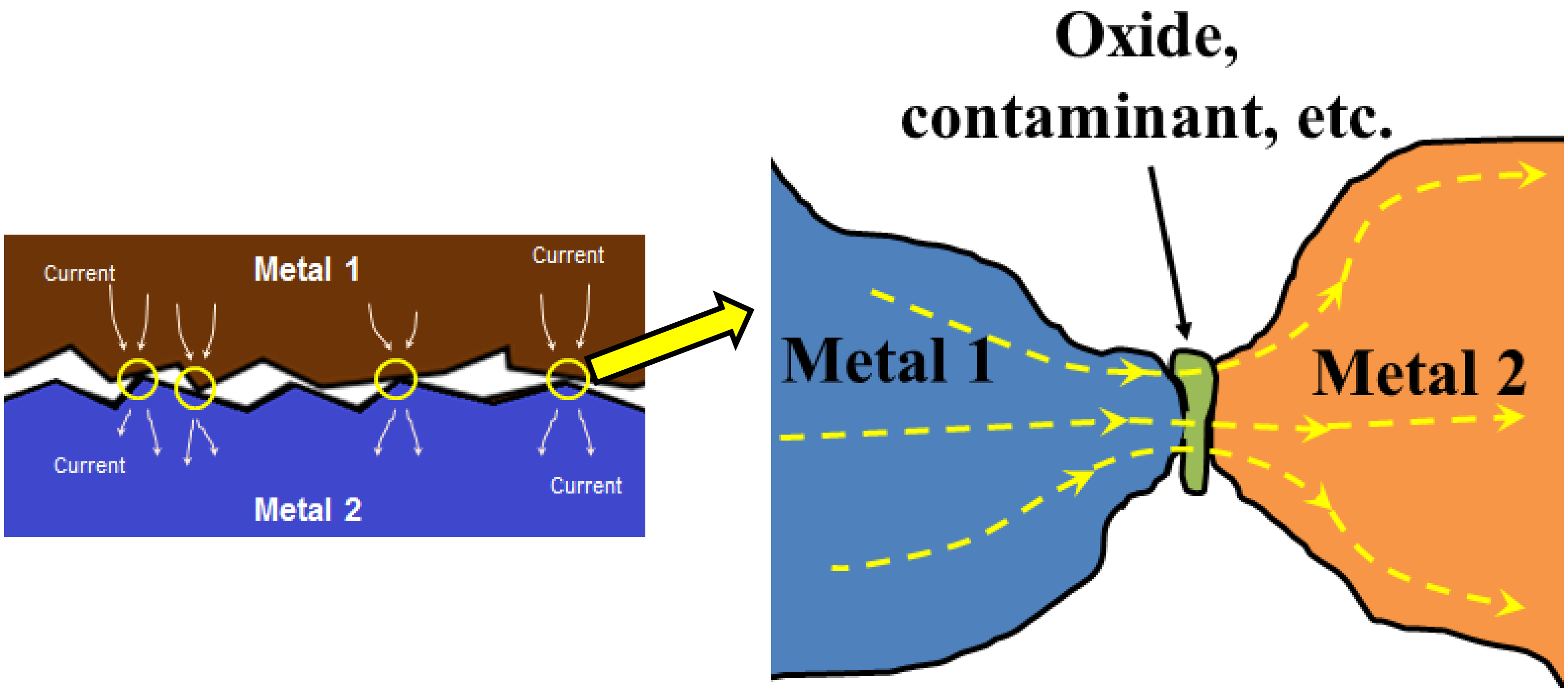
http://www.memx.com/products.htm

**Tribology**

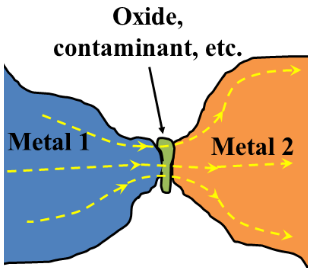


http://machinedesign.com

# Bulk Contact Model




- Contact resistance is highly random, affected by surface roughness, pressure, hardness, residing oxides and contaminates, etc.



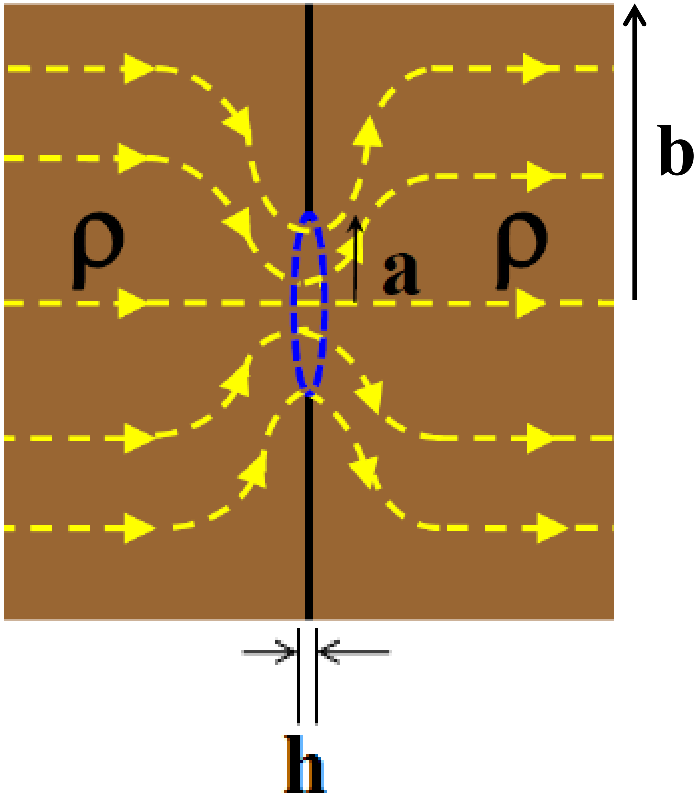

# Holm's *a*-spot model (1967)

Contact Resistance $\boxed{R_c = \dfrac{\rho}{2a}}$

$$h = 0$$

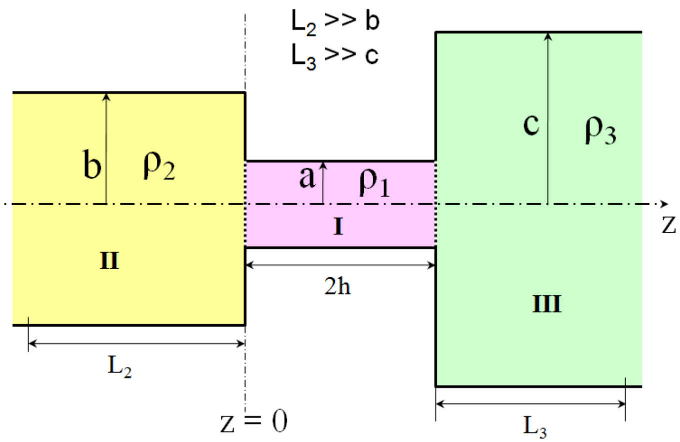
$$b \to \infty$$

Same material

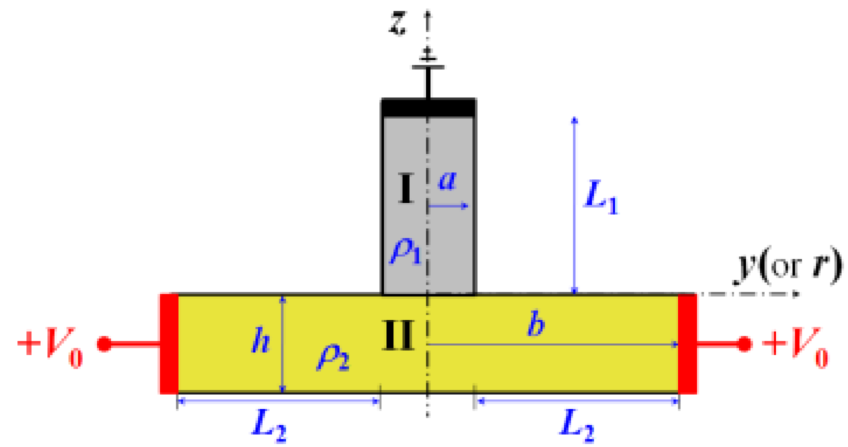



*Holm, *Electric Contacts: Theory and Application*, Springer-Verlag, NY (1967).

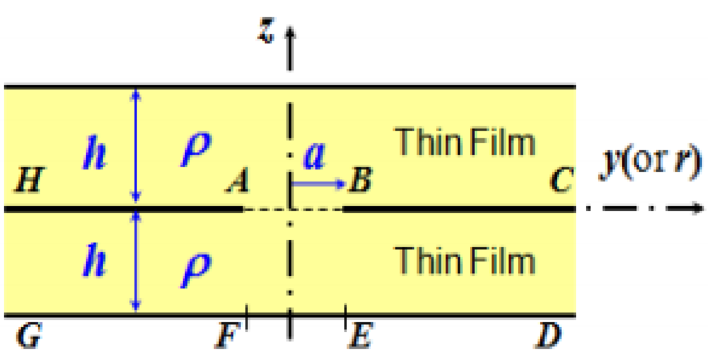
## Bulk Contact [1]




## Thin-film Contact [2]

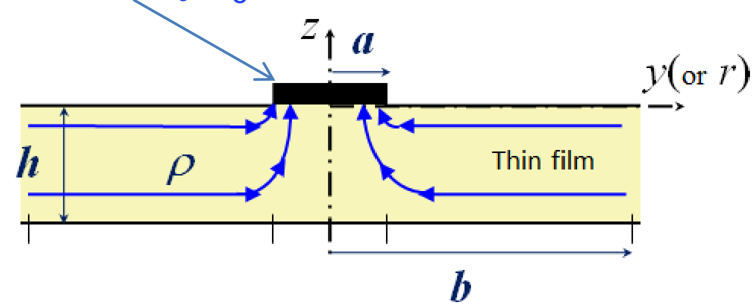



## Thin-film Contact – MEMS [3]




## Metal-Metal Contact [3]

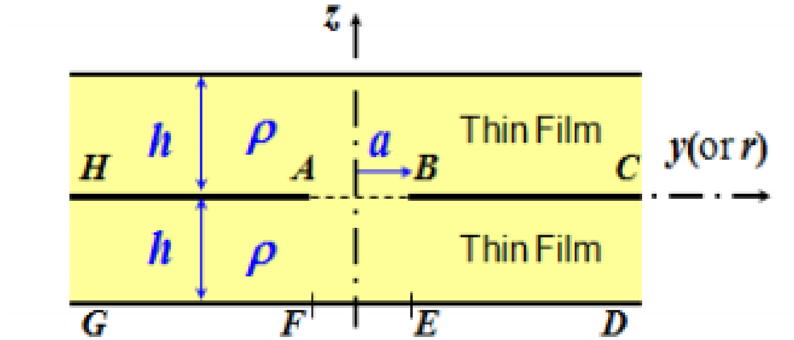
Contact resistivity $r_c$=0





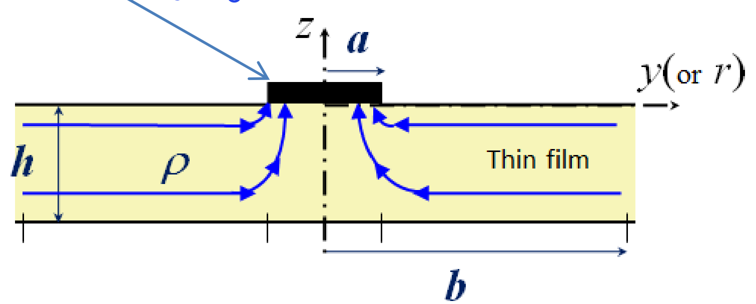
[1] P. Zhang and Y. Y. Lau, J. Appl. Phys. **108**, 044914 (2010).
[2] P. Zhang, Y. Y. Lau, R. M. Gilgenbach, Appl. Phys. Lett. **97**, 204103 (2010); J. Appl. Phys. **109**, 124910 (2011).
[3] P. Zhang, Y. Y. Lau, and R. S. Timsit, IEEE Trans. Electron Devices, **59**, 1936 (2012).

# Thin-film Contact – MEMS



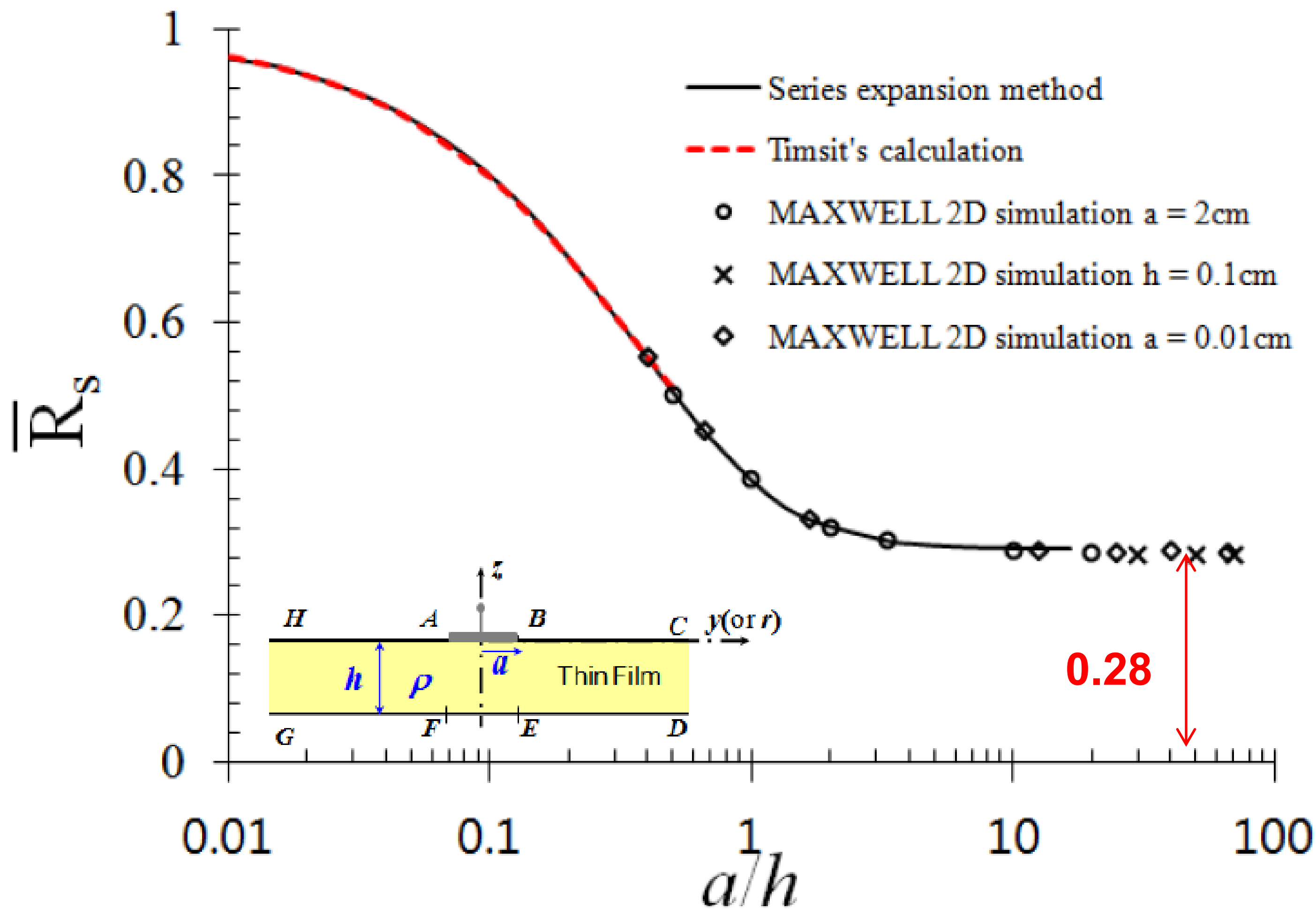

## Same as Metal-Metal Contact, by Symmetry

Contact resistivity $r_c$=0



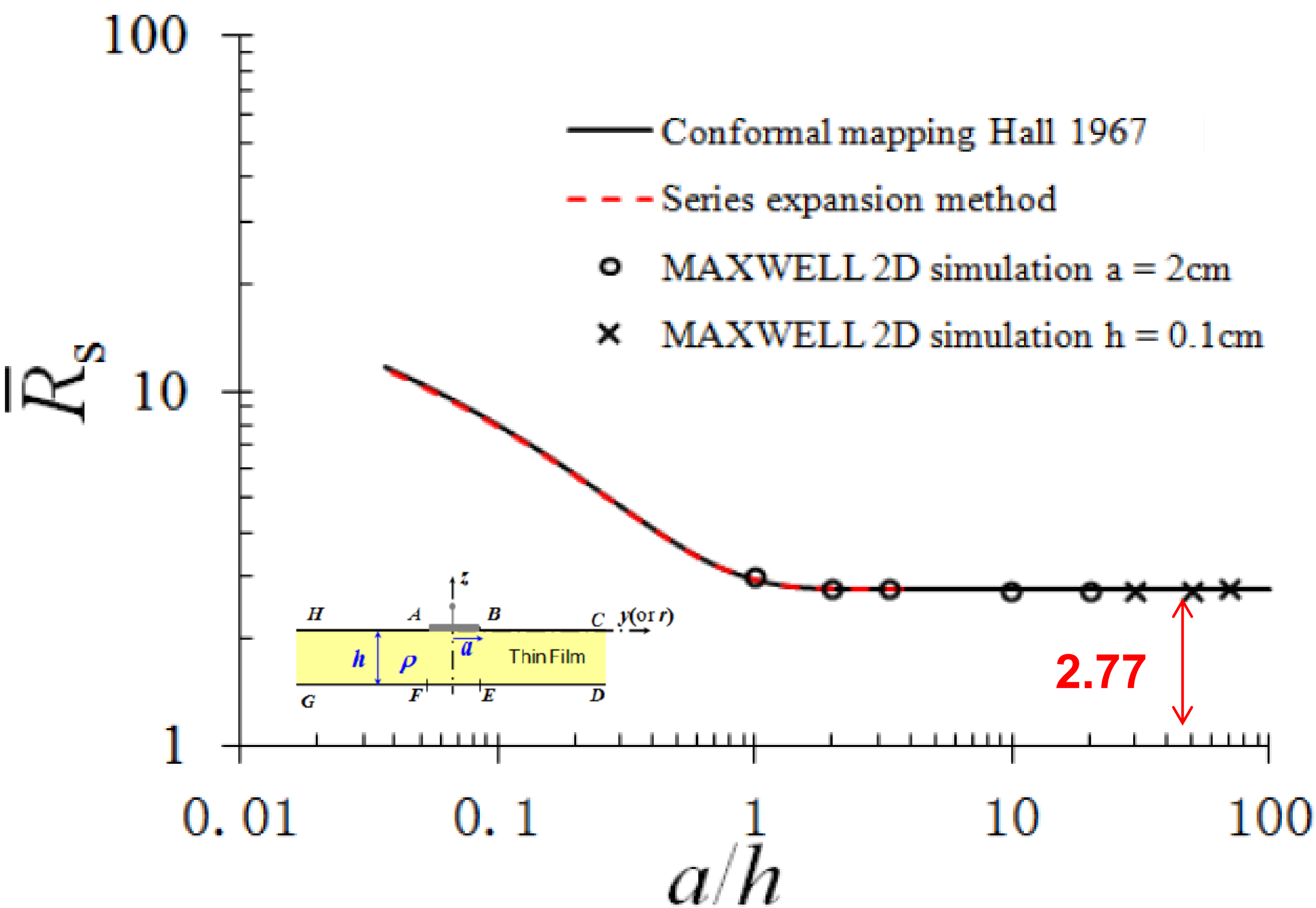

Peng Zhang, Y. Y. Lau, and R. S. Timsit, "*On the spreading resistance of thin-film contacts*", IEEE Trans. Electron Devices **59**, 1936 (2012).

# Cylindrical Thin Film Contact (Spreading) Resistance, $R_s$




$$R_s = R_{Total} - R_{bulk} \equiv \frac{\rho}{4a}\overline{R}_s$$

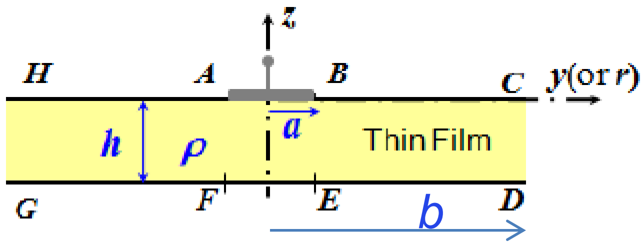
# Cartesian Thin Film Contact (Spreading) Resistance, $R_s$




$$R_s = R_{Total} - R_{bulk} \equiv \frac{\rho}{4\pi W}\bar{R}_s$$

# Current Crowding and Enhanced Heating

As h→0,




$$R_{\text{Total}} = R_S + R_{bulk} = 2.77 \times (\rho / 4\pi W) + \rho(b-a)/2Wh$$
$$\equiv \rho(b-a')/2Wh$$

**Cartesian**

$$a' = a\left(1 - \frac{2\ln 2}{\pi} h/a\right) \cong a - 0.44h$$

$$R_{\text{Total}} = R_S + R_{bulk} = 0.28 \times (\rho / 4a) + (\rho / 2\pi h)\ln(b/a)$$
$$\equiv (\rho / 2\pi h)\ln(b/a')$$

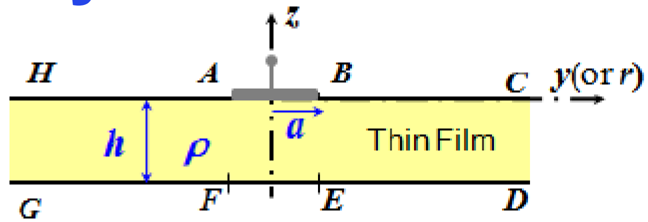
**Cylindrical**

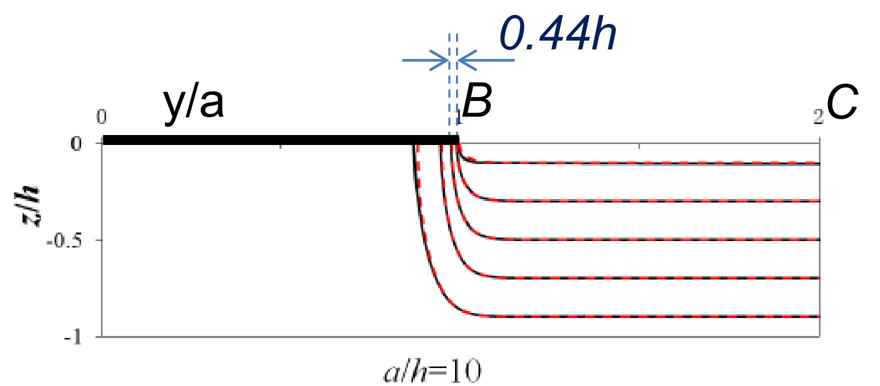
$$a' = ae^{-0.28 \times \frac{\pi h}{2a}} = ae^{-0.44h/a} \cong a - 0.44h$$

In general, current-crowding region ~ 0.44 h

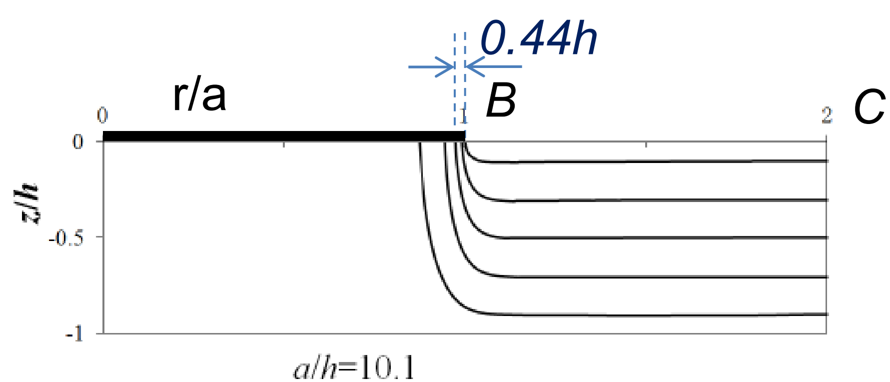
# Identical Field Line Patterns for Both Cartesian and Cylindrical Thin Film Contacts

As h→0,



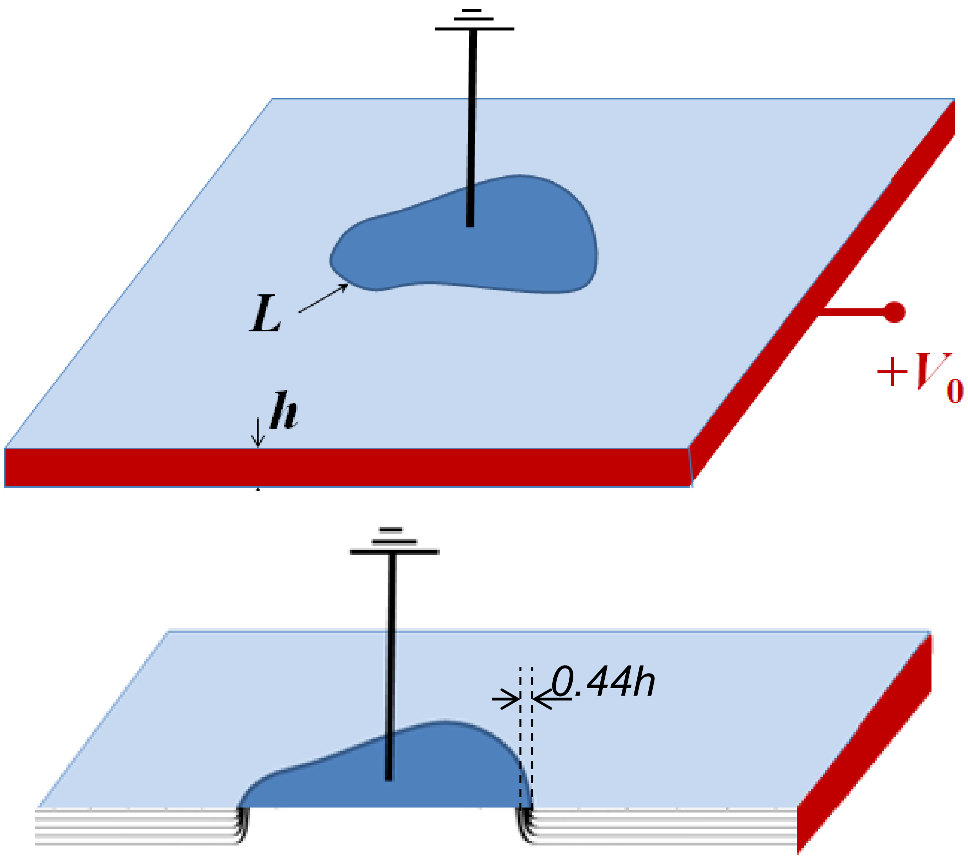

Cartesian




Cylindrical

Note: Enhanced heating at Edge "B" (& "A").

# Contact Resistance in an Electrode of Arbitrary Shape*



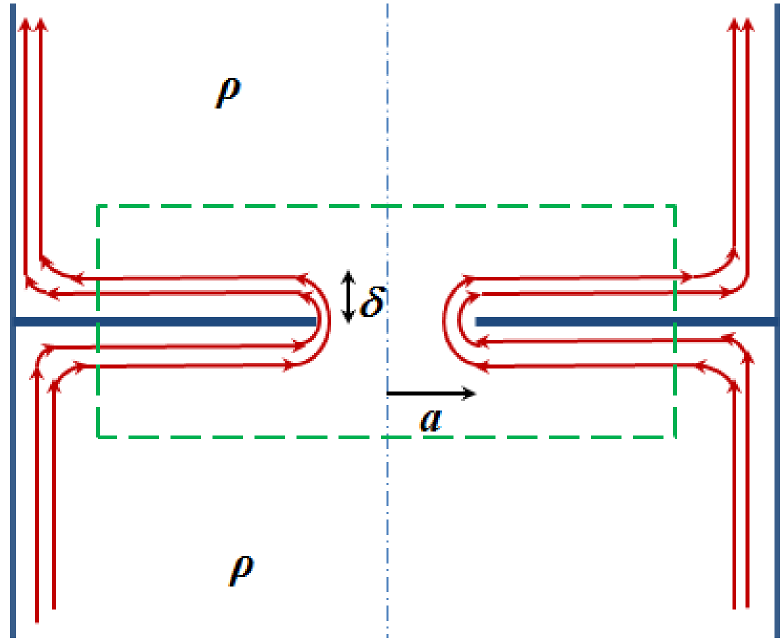

$$R_s = \left(\frac{\rho}{L}\right)\frac{2\ell}{\pi} \quad , \quad .. \to 0$$

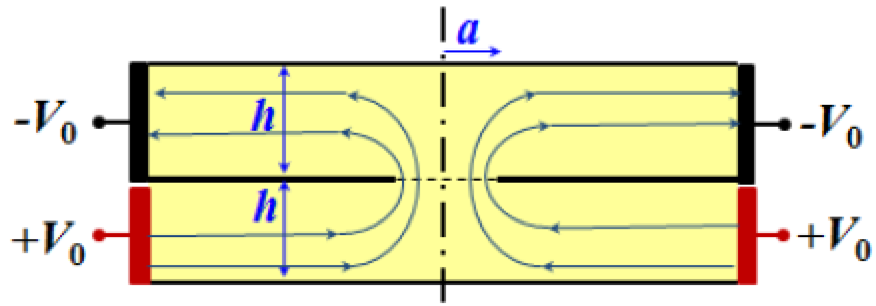
*L*: circumference of electrode

*Note:* Intense local heating on electrode rim because of crowding of field lines there.

Peng Zhang, Y. Y. Lau, and R. S. Timsit, "*On the spreading resistance of thin-film contacts*", IEEE Trans. Electron Devices **59**, 1936 (2012).

# Relation of high frequency AC bulk contact and DC thin-film contact




## AC Case (Bulk Contact)

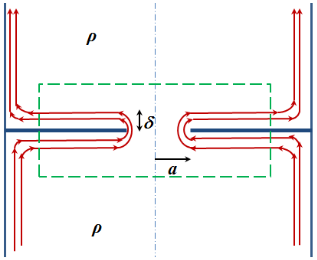
Lavers and Timsit, *IEEE Trans. Compon. Packag. Technol.*, **25**, 446–452, 2002.

## DC Case (Thin Film)

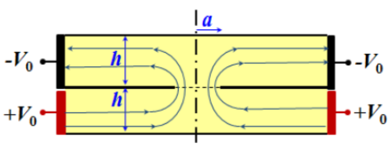
P. Zhang, Y. Y. Lau, and R. S. Timsit, *IEEE Trans. Electron Devices* **59**, 1936 (2012).

Rule: Identify skin depth ($\delta$) with thin-film thickness ($h$).

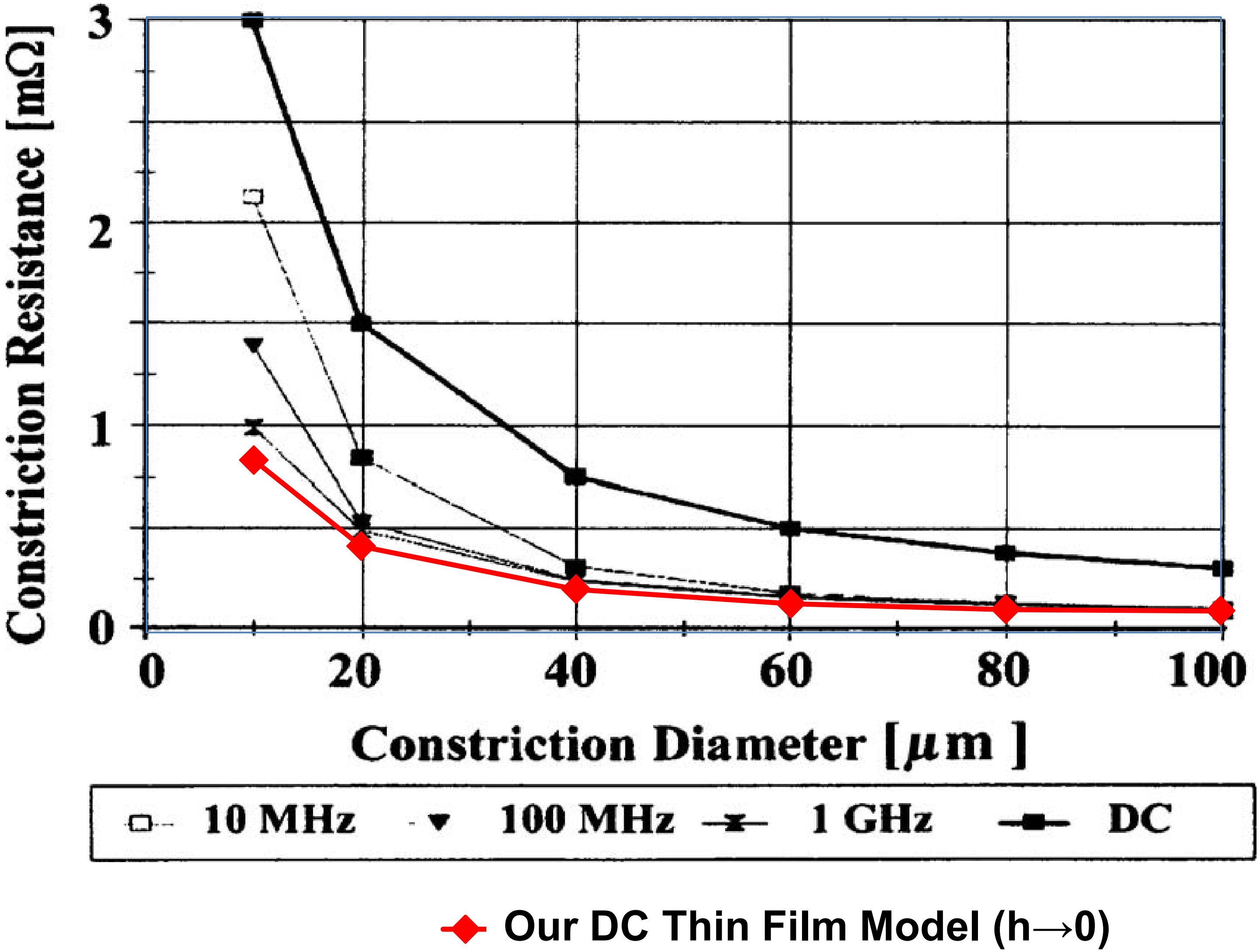
# AC bulk constriction resistance for frequencies ranging from dc to 1 GHz*




AC case




Our DC model




*Lavers and Timsit, *IEEE Trans. Compon. Packag. Technol.*, 25, 446–452, 2002.

*Peng Zhang, Y. Y. Lau, and R. S. Timsit, IEEE Trans. Electron Devices **59**, 1936 (2012).

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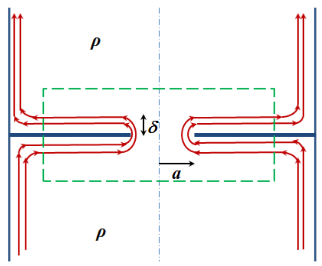
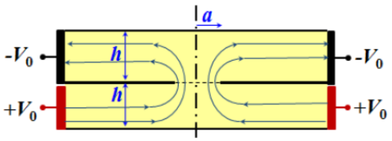
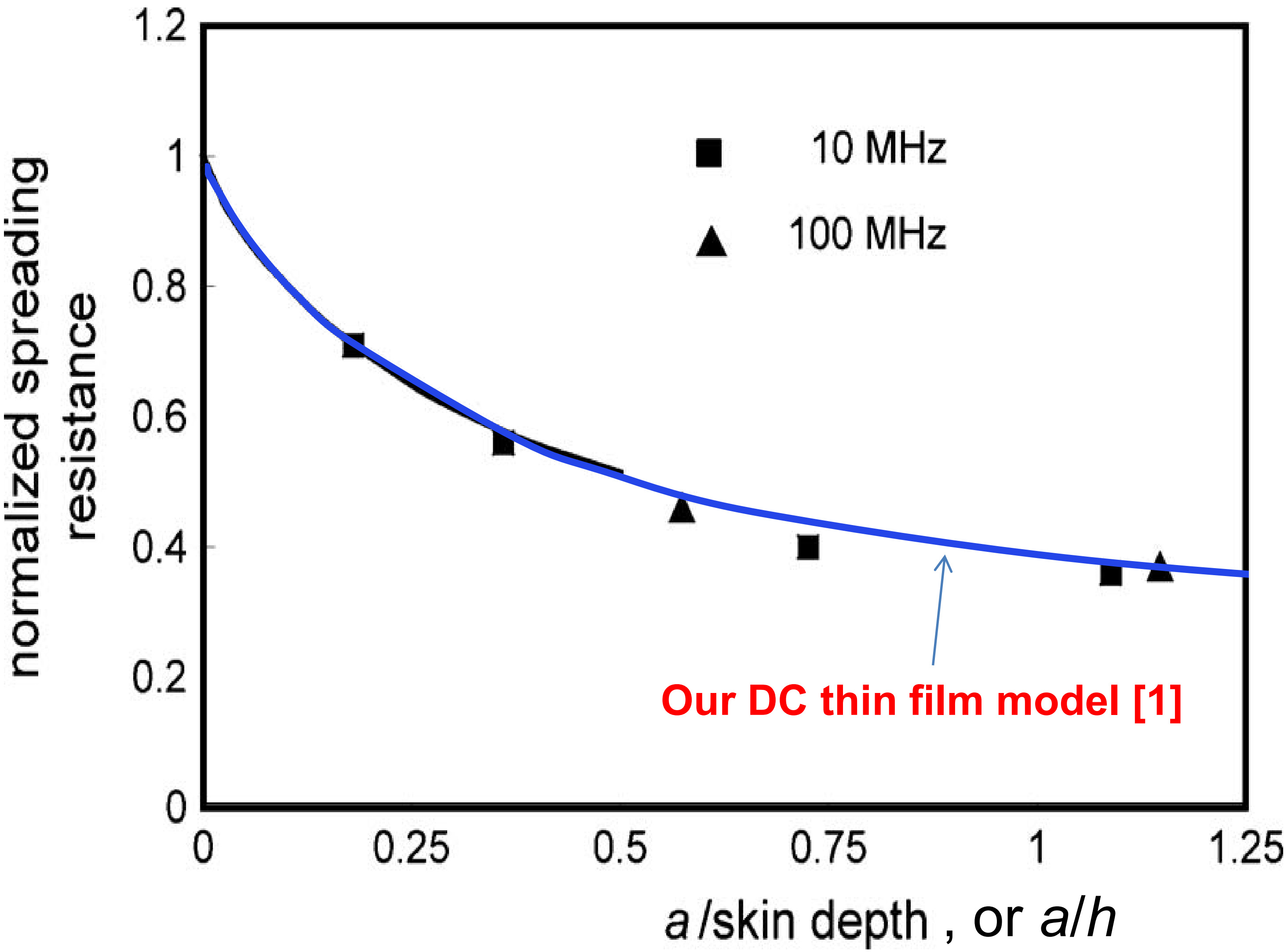



AC case




Our DC model



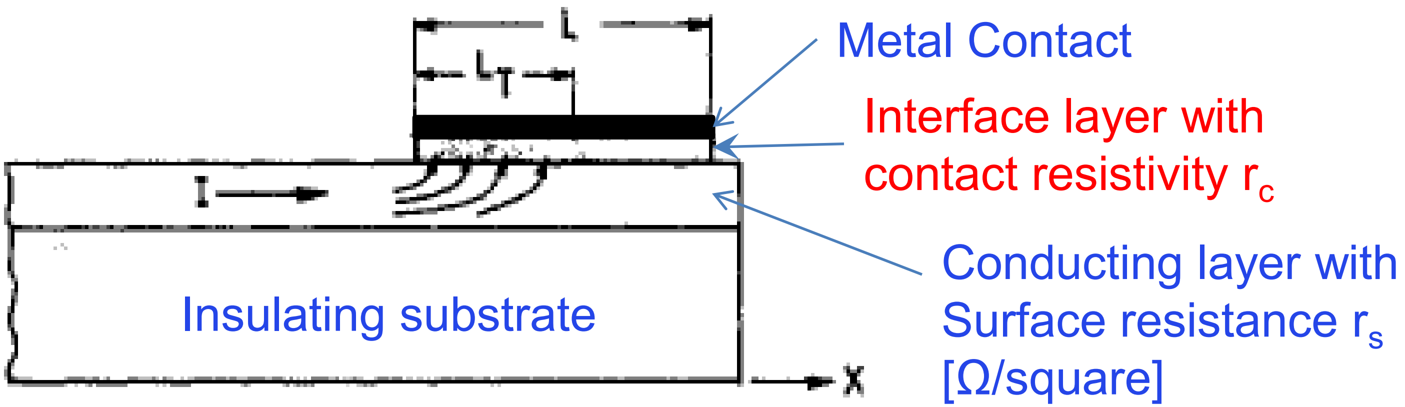

*Lavers and Timsit, *IEEE Trans. Compon. Packag. Technol.*, 25, 446–452, 2002.

[1]Peng Zhang, Y. Y. Lau, and R. S. Timsit, IEEE Trans. Electron Devices **59**, 1936 (2012).

# Metal-Metal vs Metal-Semiconductor Contacts

Transfer Length, $L_T$: The length scale over which most of the current from a contact into a semiconductor layer flows

## Metal-Semiconductor Contact*

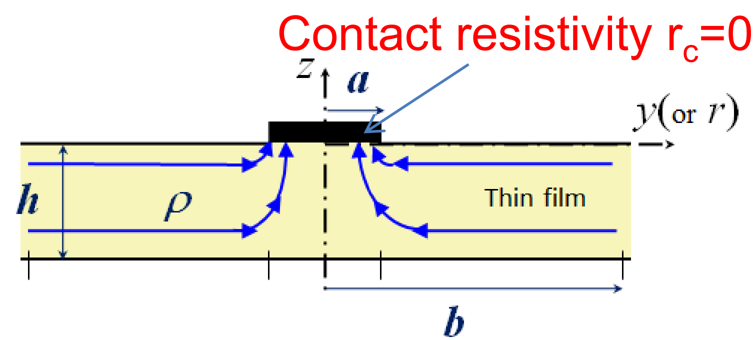



## Transmission Line Model*


$L_T = (r_c/r_s)^{1/2}$,

due ONLY to the semiconductor resistive loss

## Metal-Metal Contact model




$L_T \sim 0.44h$, due ONLY to fringe fields



* D. K. Schroder, *Semiconductor Material and Device Characterization*, Wiley & Sons, NY, 1998.

# Conclusion

- Made vast generalization in theory of electrical contact, for both bulk and thin-film contacts (applicable to HPM, field emitters, thin-film devices, MEMS, interconnects, etc).
- Thin film contact model is extended to an *a*-spot of arbitrary geometry.
- The DC thin film contact model turns out to be applicable to the bulk contact resistance, from DC to high frequency (!)
- Transfer length is estimated and compared with Transmission Line Model.

# Future Works

- Evaluate ohmic heating at thin-film and bulk contacts based on the newly calculated current flow profile, electro-thermal instability, migration of atoms
- Study RF heating of contacts, with the capacitive and inductive effects of the asperities
- General theory of metal-metal and metal-semiconductor contacts