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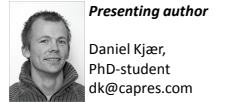
# Improving Dynamic Range and Precision for Current-In-Plane Tunneling Measurements

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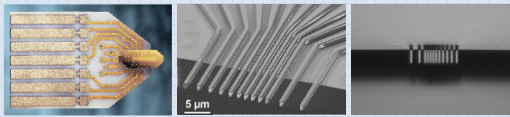
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## Motivation

Improved dynamic range and measurement precision by implementation of position correction algorithms

## Micro 12-Point Probe



Probe info

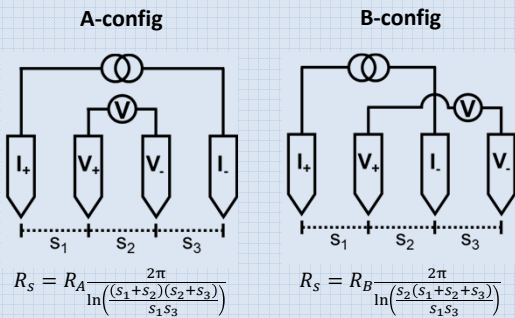
- Length: 10µm
- Width: 0.75µm
- Thickness: 1µm
- 8 subsets of 4 electrodes
  - Mean pitches: 1.5µm – 8.3µm
- Electrode material: Au

## 4-Point Measurements on a Single Sheet

- Apply fixed current
- Measure voltage
- Extract sheet resistance

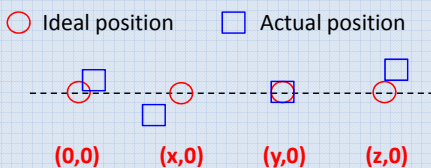
$$R_S = \frac{V}{I} \frac{2\pi}{\ln\left(\frac{bc}{ad}\right)} \quad \begin{array}{l} a = \text{distance between } I_+ \text{ and } V_+ \\ b = \text{distance between } I_+ \text{ and } V_- \\ c = \text{distance between } V_+ \text{ and } I_- \\ d = \text{distance between } V_- \text{ and } I_- \end{array}$$

- Two independent 4-point configurations:



## Positioning Errors

- Influences measured sheet resistance<sup>1</sup>
- Two types of positioning errors:
  - Inline (first order effect)
  - Offline (second order effect)



## Position Correction on a Single Sheet

### Experimental

- A and B-conf measurements
- Current: 200µA and 2000µA
- Frequency: 25Hz
- Integration time: 81ms
- Scan: 10x10 points, step size: 100µm
- Sample: 200mm wafer, 100nm Ru
- $R_S \approx 1.6\Omega/\text{sq}$

### Positioning Error (inline)

- A-config:  $\sigma_{R_S}^{rel} = \frac{\sqrt{5}}{2\ln(2)} \frac{\sigma_x}{s} \approx 1.613 \frac{\sigma_x}{s}$
- B-config:  $\sigma_{R_S}^{rel} = \frac{4\sqrt{5}}{3\ln(3)} \frac{\sigma_x}{s} \approx 2.714 \frac{\sigma_x}{s}$
- $\sigma_x \approx 5\text{nm}$

### Two Position Correction Strategies

- Modified van der Pauw<sup>2</sup>

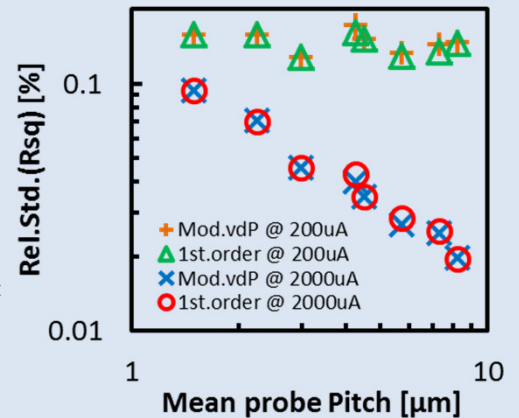
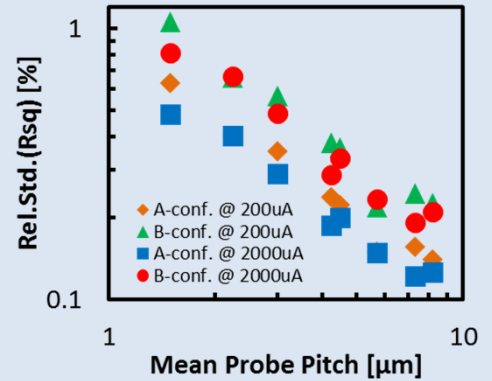
$$\exp\left(\frac{2\pi R_A}{R_S}\right) - \exp\left(\frac{2\pi R_B}{R_S}\right) = 1$$

- 1st. order approximation<sup>3</sup>

$$R_S = \frac{2\pi(R_A - \alpha R_B)}{\ln\left[\frac{y(z-x)}{x(z-y)}\right] - \alpha \ln\left[\frac{z(y-x)}{x(z-y)}\right]}$$

$$\text{where } \alpha = \frac{z(y-x)}{y(z-x)}$$

- Equal performance on a single sheet sample



## Position Correction for CIPT Measurements on MTJs

CIPT model<sup>4</sup>:  $R = \frac{V_- R_t R_b}{I_- R_t + R_b} \frac{1}{2\pi(R_b)} \left\{ K_0\left(\frac{a}{\lambda}\right) + K_0\left(\frac{d}{\lambda}\right) - K_0\left(\frac{b}{\lambda}\right) - K_0\left(\frac{c}{\lambda}\right) + \ln\left(\frac{bc}{ad}\right) \right\}$ , where  $\lambda = \sqrt{\frac{RA}{R_t + R_b}}$

MC-simulations

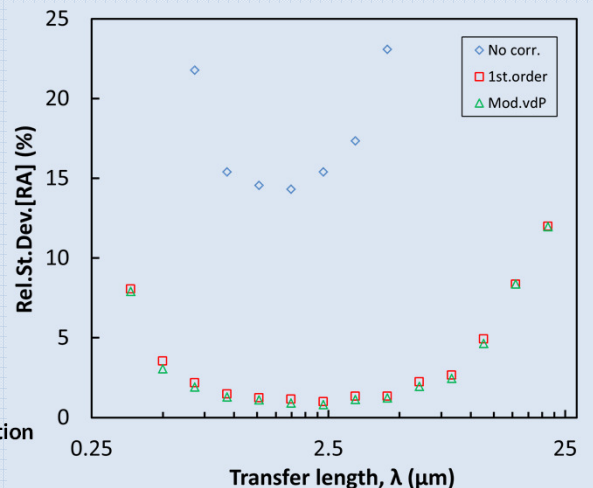
- $\sigma_x = 20\text{nm}$
- Electrical noise = 1%

Strategy (for each probe pitch):

- 1) Measure A-B-A-B
- 2) Calculate pseudo  $R_S$ 
  - Mod.vdP
  - 1st. order approx.
- 3) Theoretical pseudo  $R_S$ 
  - Based on  $R_t$ ,  $R_b$  and  $R_A$
- 4) Minimize error by fitting  $R_t$ ,  $R_b$  and  $R_A$

Conclusion:

**Modified van der Pauw correction gives the best measurement precision and dynamic range**



## References

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