Improved geometrical correction in micro four-point probe technique with three omega correction

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1. Joule heating in M4PP

- The accuracy of a micro four-point probe (M4PP) measurement depends on sample resistivity and geometry, electrode separation [1] and second order effects such as Joule heating.

- Joule heating ($\propto RI^2$) can change the sample resistance, consequently introducing measurement errors in sheet resistance [2].
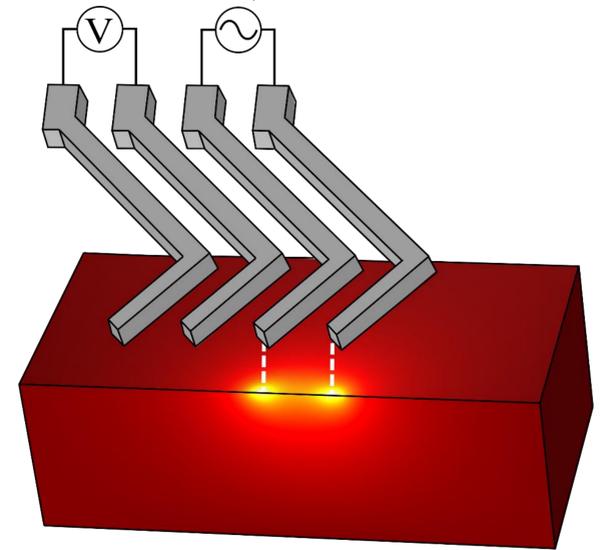

20 µm

L8PP probe
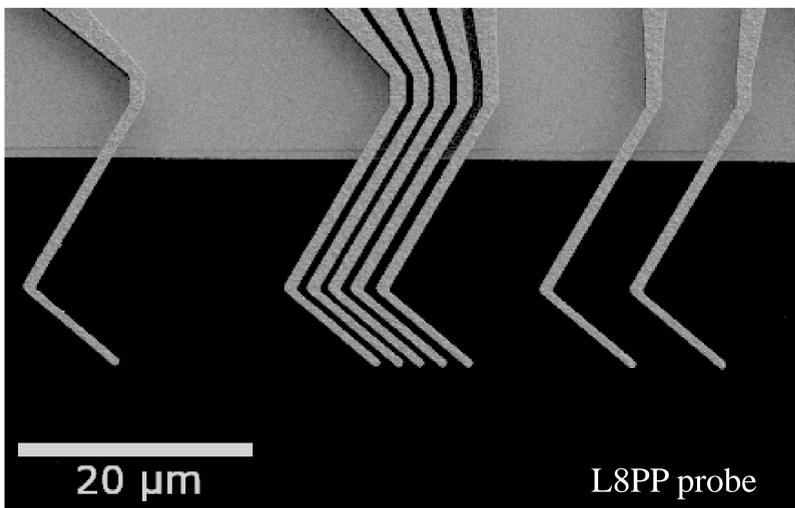
3. Investigation of Joule heating effects using finite element method (FEM)
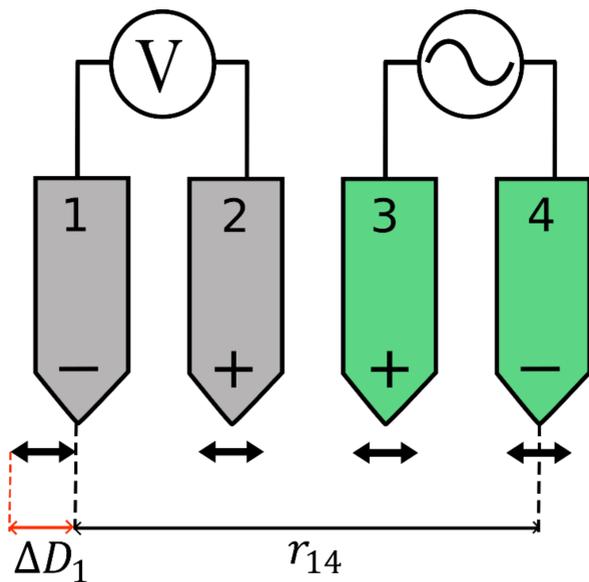
CAPRES microRSP-A301

COMSOL (electrical + heat transfer)

Bulk silicon parameters

Dopant	Resistivity (Ω cm)	Seebeck coefficient (µV K^{-1})	Thermal conductivity (W m^{-1} K^{-1})	TCR (‰ K^{-1})
Boron	0.0132	632	128.3	0.18

2. Geometrical error are crucial for accurate M4PP results

$$V_{model} = \frac{I(t)\rho}{2\pi}\left(\frac{1}{r_{13}} - \frac{1}{r_{14}} + \frac{1}{r_{23}} - \frac{1}{r_{24}}\right)$$

ΔD_1 r_{14}

4. Improved accuracy of geometry via 3ω correction

- **3ω correction**: removal of the current dependency from the measured first harmonic voltage using the third harmonic voltage [2].

$$\chi^2 = \sum_{i=1}^{N}\left(\frac{V_{i,mod}(X,\beta_i)}{V_{1,mod}} - \frac{V_{i,meas}}{V_{1,meas}}\right)^2$$
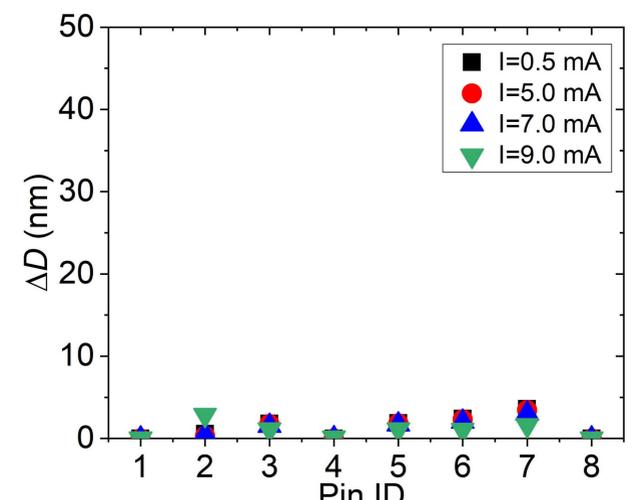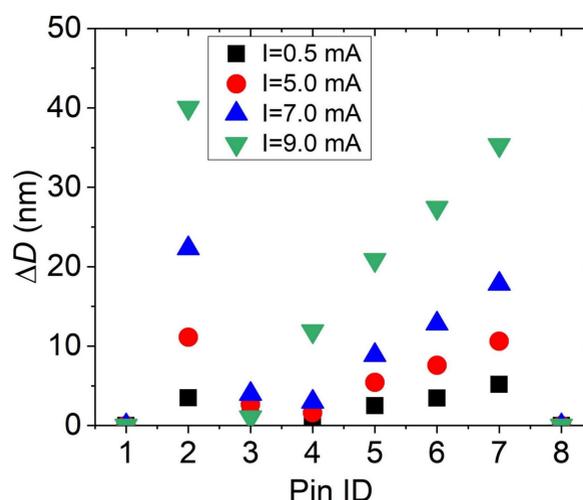
$$\Delta D = \text{abs}(X_{regress} - X_{nominal}).$$

$$V_{corr} = V_{1\omega} - 3V_{3\omega}$$

- ➢ Relative error in resistivity up to 0.6% at highest current value
- ➢ Position error up to 42 nm

- ➢ Relative error in resistivity up to 2 ppm

Uncorrected

3ω corrected

5. Conclusion

- Effect of Joule heating on position-correction analysis with and without 3ω correction of data, the former leads to tenfold improvement of pin position.
- Joule heating can also be utilized to characterize thermal properties of the materials.

References:- [1] A. Cagliani *et al.*, Rev. Sci. Instrum. **88**, 095005 (2017).
[2] B. Guralnik *et al.*, Rev. Sci. Instrum. **92**, 094711 (2021).
[3] T.A. Marangoni *et al.*, J. Appl. Phys. **129**, 165105 (2021).

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