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A Comparative Study Of Size Dependent Four-Point Probe Sheet Resistance Measurement On Laser Annealed Ultra Shallow Junctions

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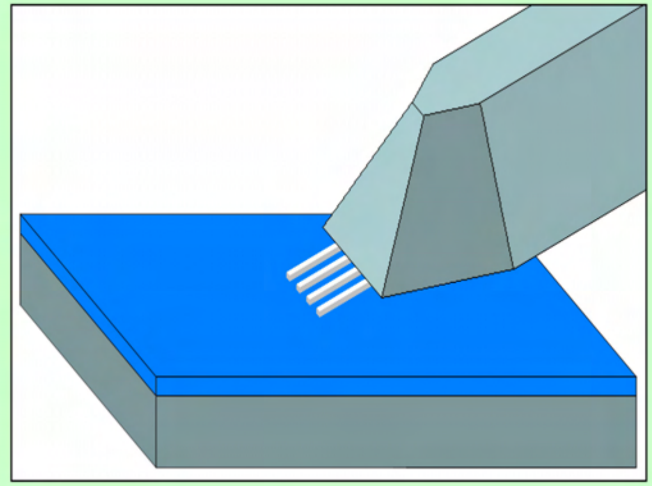
Introduction



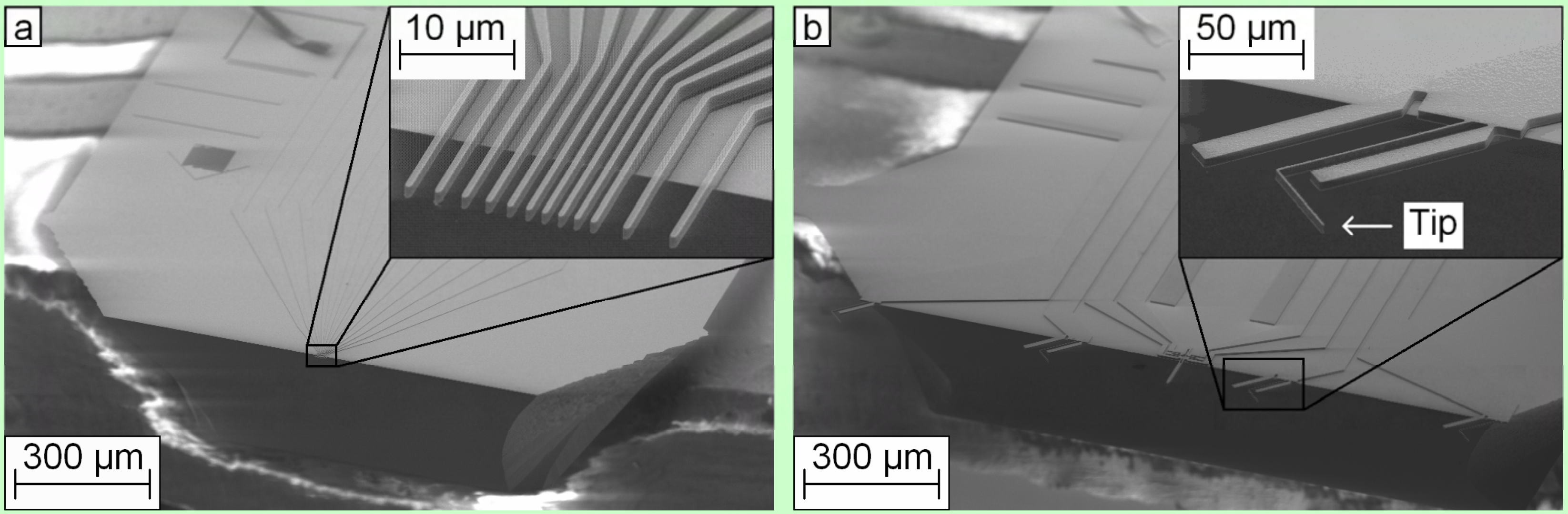
In this work we investigate the relationship between macroscopic and microscopic four-point sheet resistance measurements on laser annealed ultra shallow junctions (USJ) both experimentally and theoretically. Micro-fabricated cantilever four-point probes (M4PP) with probe pitch ranging from 1.5 µm to 500 µm were utilized to characterize sheet resistance uniformity.

An ultra shallow junction was formed by low energy ^{11}B implantation (0.5 keV, 1e15 cm^{-2}) into a lowly doped 300 mm n-type Si wafer and subsequent laser anneal at a nominal anneal temperature of 1300°C.

The laser beam was scanned in straight lines across the sample surface with a step size of 3.65 mm whereas its spot size is significantly larger (~ 11 mm) such that the scanned lines overlap and each region gets irradiated several times.

Four-Point Probes

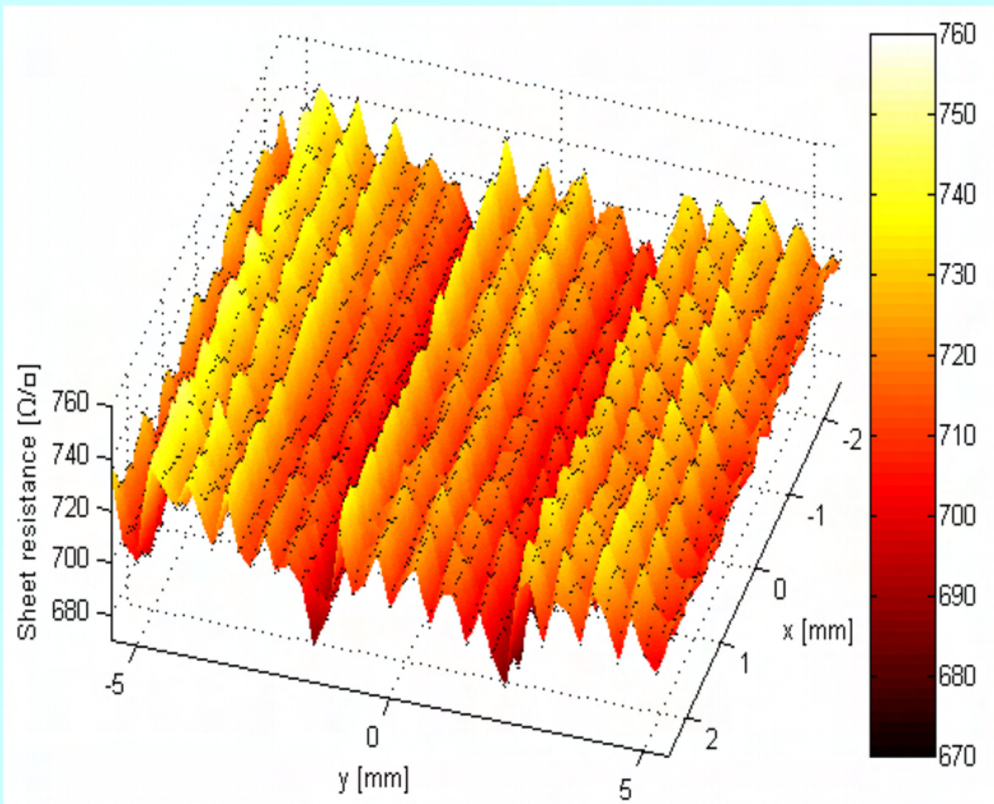
Four-point probes used in this study consist of silicon oxide or silicon cantilevers coated with a metal thin film (either Au or Ni) and provide extremely low contact forces (~ 10^{-5} N).



SEM micrographs of (a) a multi-cantilever probe with minimum electrode pitch of 1.5 µm and (b) a 500 µm pitch four-point probe with L-shaped static contact cantilevers.

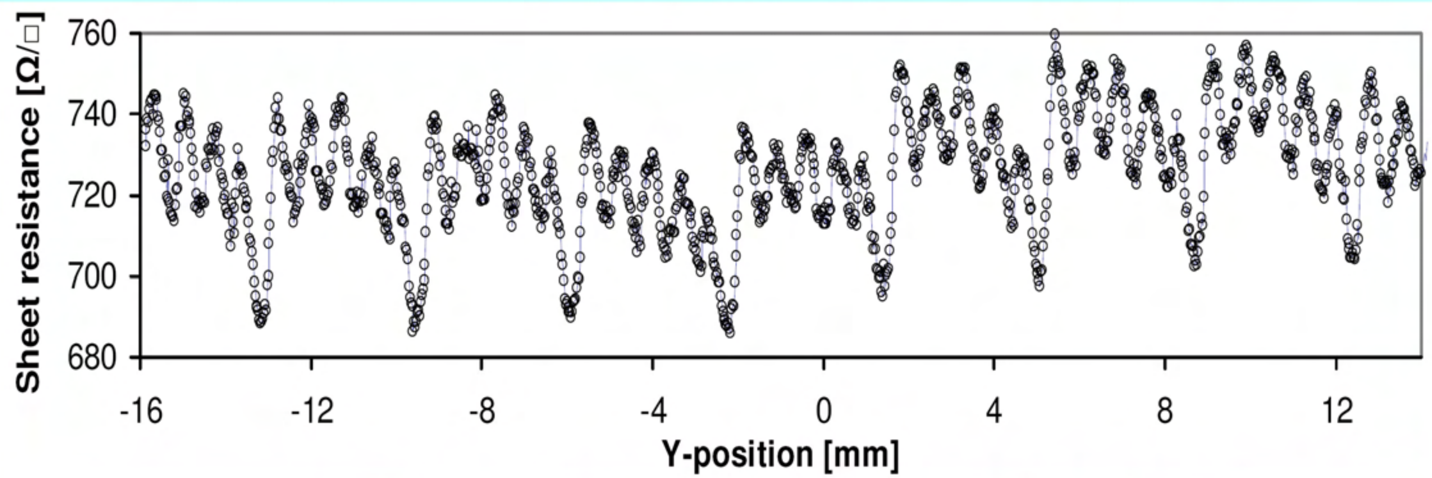
Uniformity of Laser Annealing

High resolution area scan



A 45×101 point area scan measured with a 10 µm pitch M4PP. The scan step size is 50 µm and 250 µm in the x- and y-direction respectively. The laser was scanned in the x-direction. Raw data are represented by dots.

30 mm line scan



Line scan performed with a 10 μm pitch M4PP and a step size of 25 μm.
Two periodical features with a period of 3.65 mm and 750 μm are resolved.

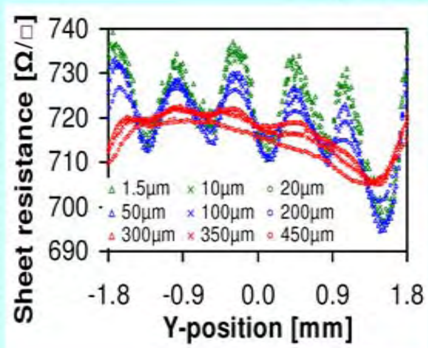
Size Dependent Sheet Resistance

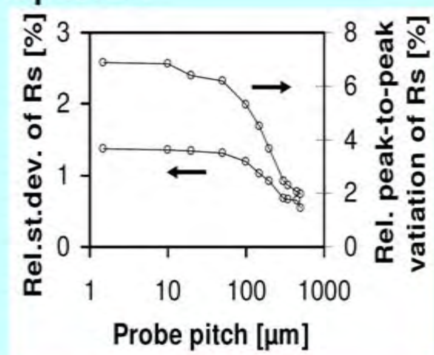
Comparison of measured micro- and macro sheet resistance for the two periods of 3.65 mm and 750 µm. A line scan was repeatedly measured at the same location with various pitched four-point probes. The larger probe pitch smoothens out the variation.

The smoothing effect of larger pitch probes has been quantified by calculating the relative standard deviation and peak-to-peak variation.

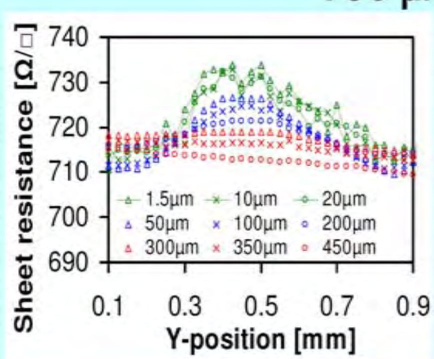
The difference between small (<20 µm) and large (>300 µm) pitched probes in measured sheet resistance variation is up to a factor of 3.5 for the 3.65 mm period and up to a factor of 14 for the 750 µm period.

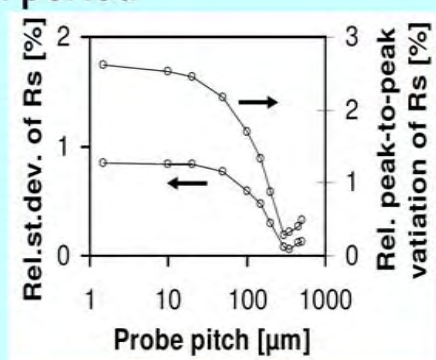
3.65 mm period





750 µm period



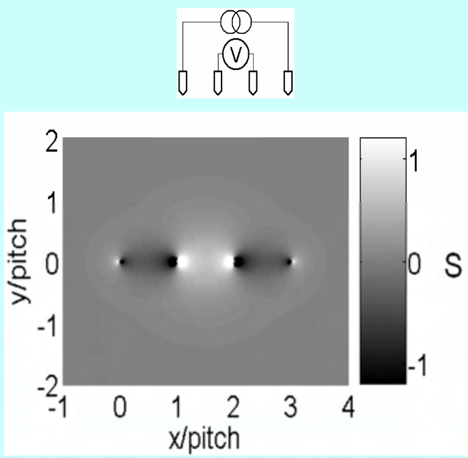


”Spot Size” / Sensitivity

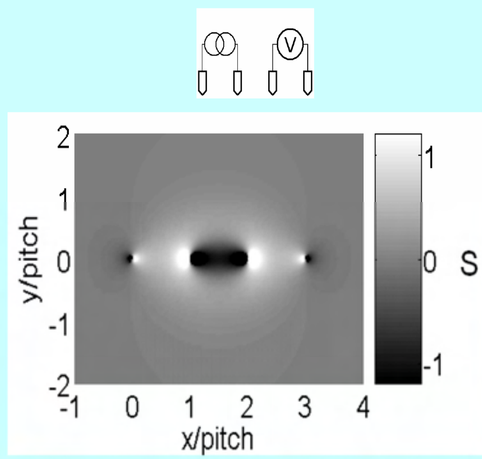
The sensitivity to local sheet resistance variations, $R_{S,L}$, has been calculated. With R_S as the sheet resistance, p as the probe pitch and A as the area, the sensitivity is defined as:

$$S = \frac{\partial^2 R_S}{\partial R_{S,L} \partial A} p^2$$

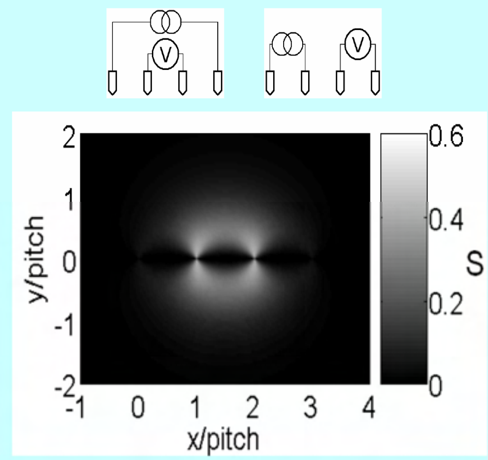
A configuration



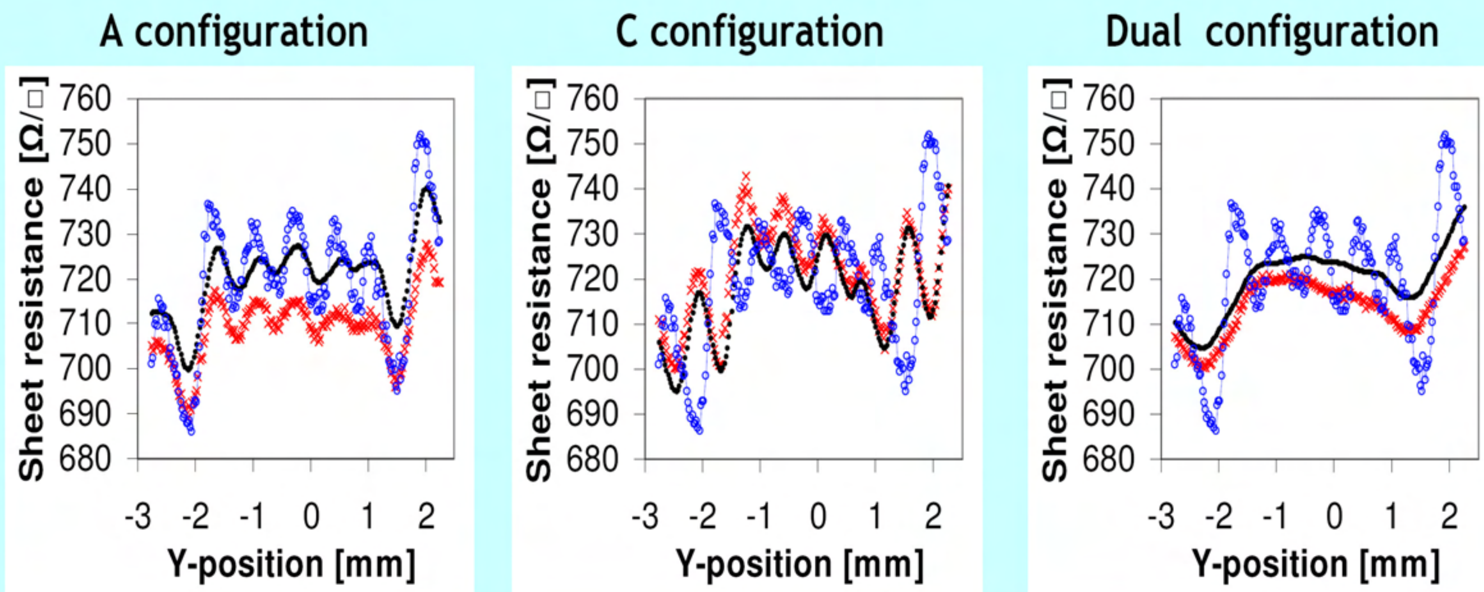
C configuration



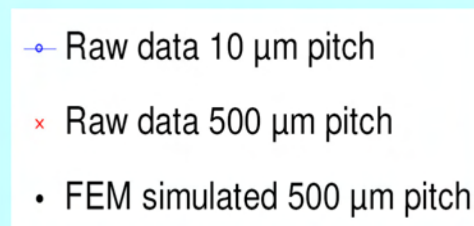
Dual configuration



A and C configuration have both positive and negative sensitivity and the sensitivity at the contacts is ±infinite. The dual configuration has purely positive sensitivity and the sensitivity at the contact points is zero. Note the sensitivity for A and C configuration is “out-of-phase”.



The C configuration gives completely out-of-phase results whereas the apparent good result of the A-configuration is due to an interference-like behaviour. The dual configuration smoothens the variation significantly.



Conclusion

It has been observed experimentally that conventionally sized four-point probes significantly underestimates the sheet resistance variations of non-homogeneous USJ. In general we conclude that four-point sheet resistance measurements are only correct when the probe pitch is much smaller than the length scale of the sample variations.

A clear correlation between the theoretical sensitivity, FEM simulations and measurement results has been established. The sensitivity of the different configuration modes strongly affects the measured resistance. The sensitivity shows how the measured variations may be completely out-of-phase with the actual sheet resistance variation.

Acknowledgements

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