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Cross-plane electrical conductivity measurement using finite element model

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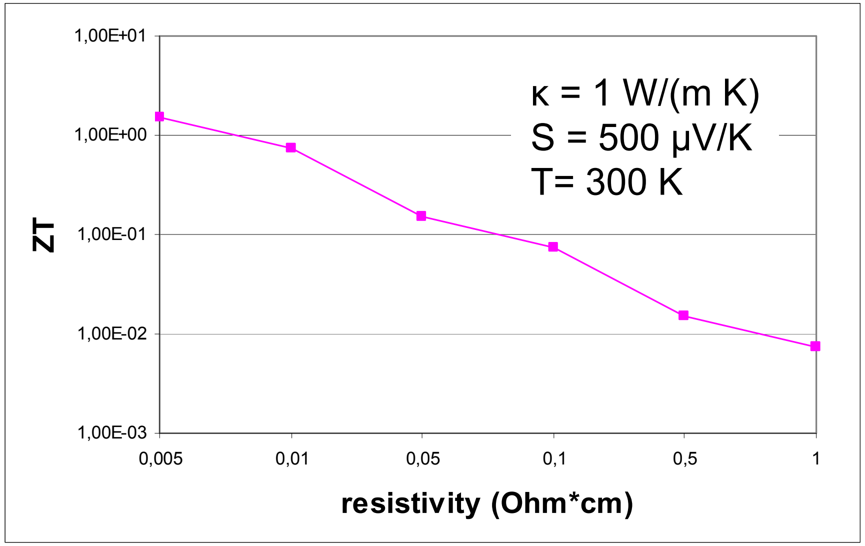
Motivation

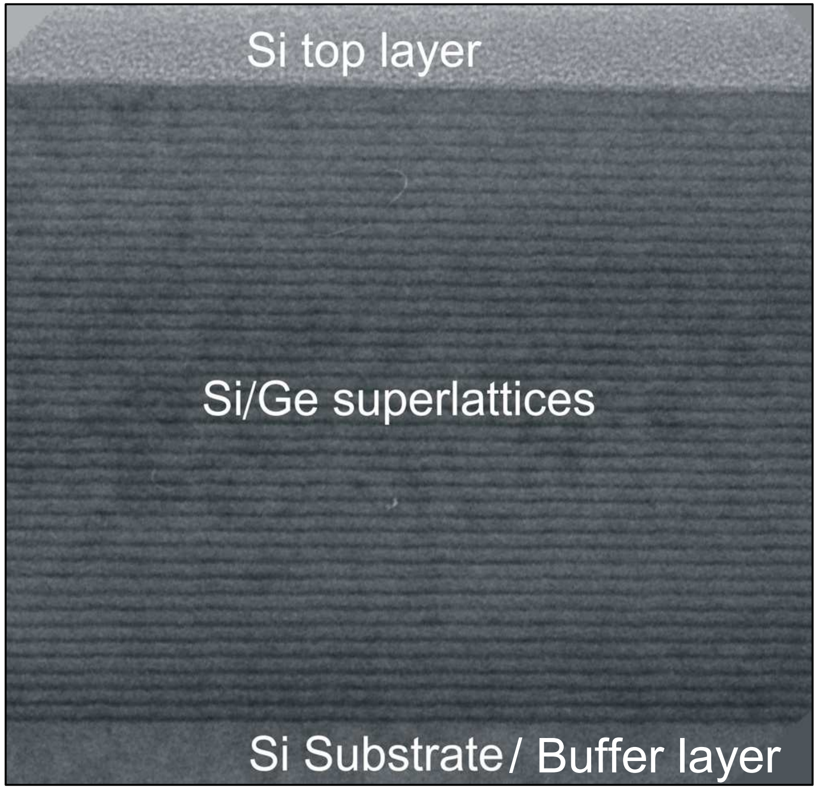
Si/Ge SL:

reduced thermal conductivity

anisotropic thermoelectric parameters

Growth method: MBE





high electrical conductivity

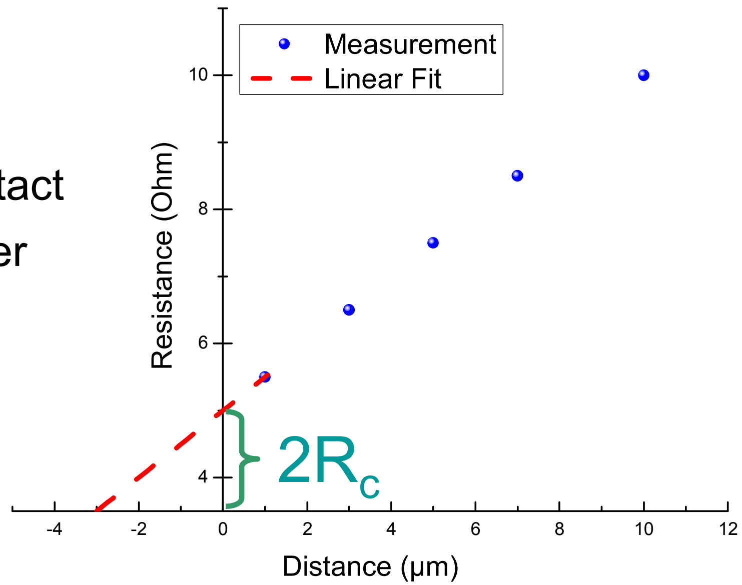
Transmission-line-model

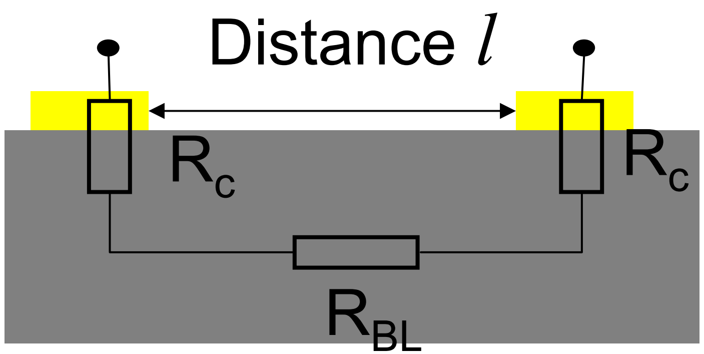
$$R_{tot} = 2 \cdot R_c + 2 \cdot R_{metall} + R_{BL}$$

R_c contact resistance

R_{metall} resistance of the metall contact

$R_{BL} = \rho_{BL} \cdot l / (h_{buffer} \cdot w)$ resistance of the buffer layer





R_c depends on the contact resistivity ρ_c between metal contact and buffer layer

Transmission-line-model

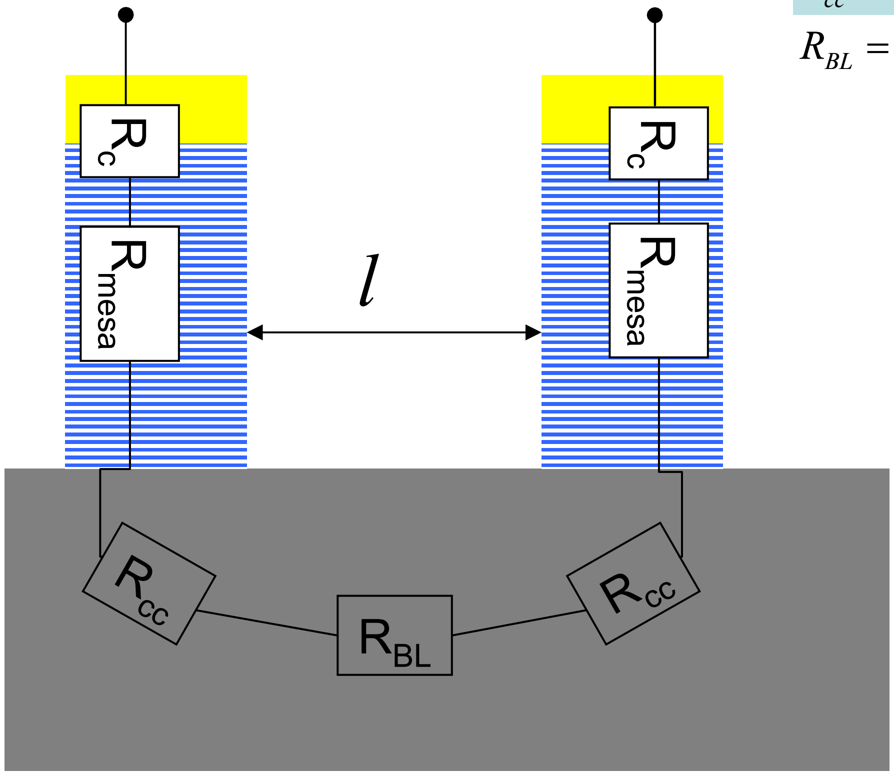
$R_{tot} = 2 \cdot R_c + 2 \cdot R_{mesa} + 2 \cdot R_{cc} + R_{BL}$

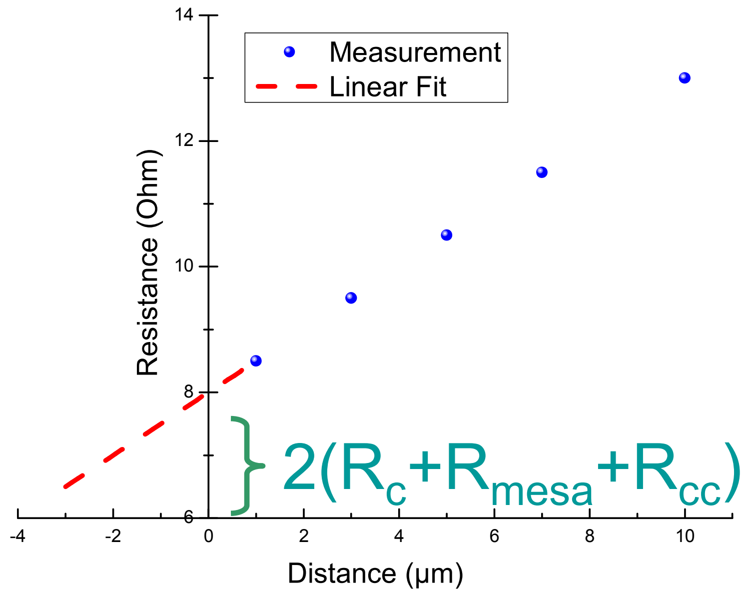
R_c contact resistance

$R_{mesa} = \rho_{SL} \cdot h_{mesa} / (d \cdot w)$ resistance of the mesa structure

$R_{cc} = ???$ resistance due to current crowding

$R_{BL} = \rho_{BL} \cdot l / (h_{buffer} \cdot w)$ resistance of the buffer layer



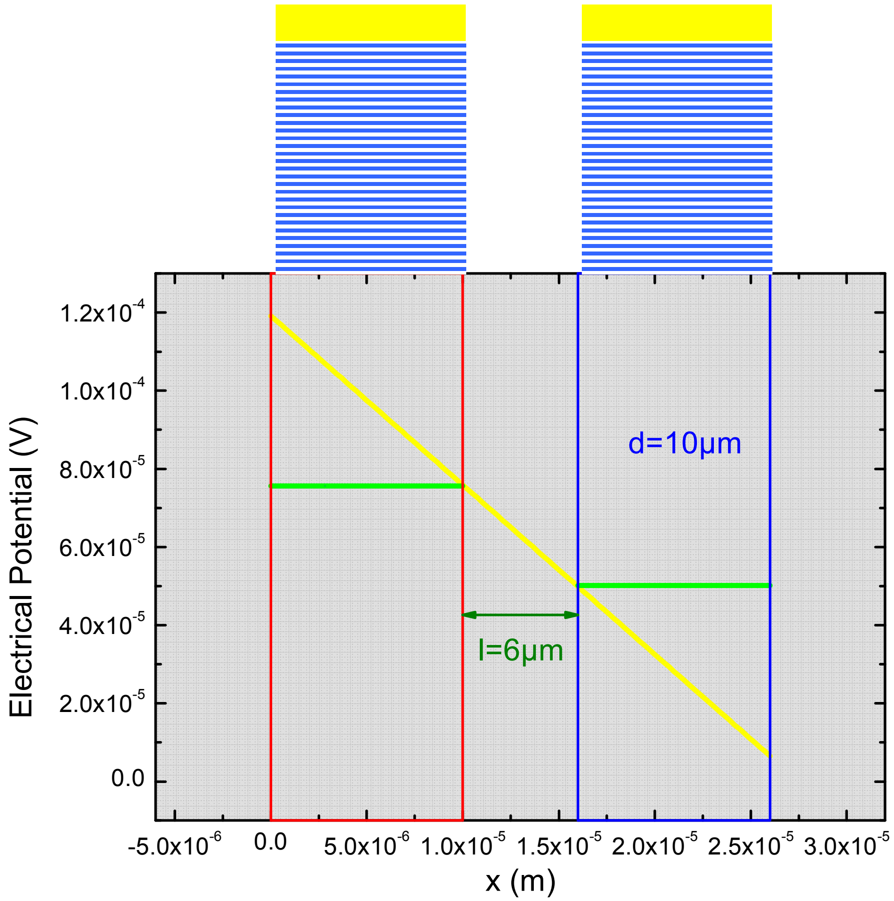


Calculation of R_{cc}

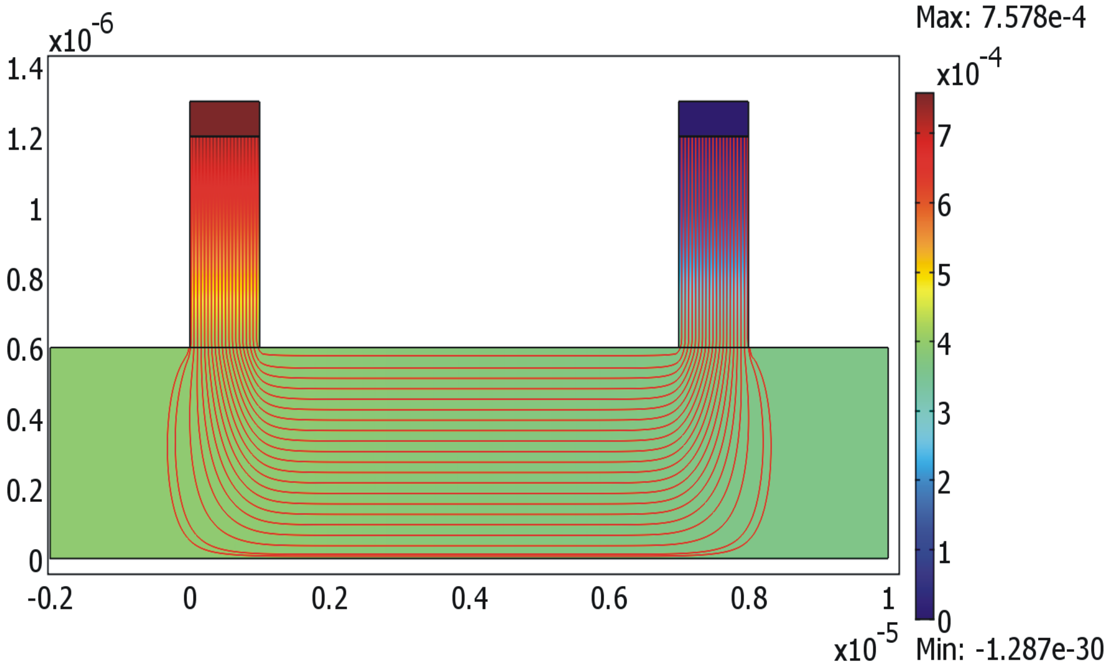
2 approaches:

no/ neglectable voltage drop under the mesa

linear voltage drop under the mesa



FEM-Simulation



d = 1 µm, l = 6 µm

ρ_{BL} = 0.026 Ohm*cm

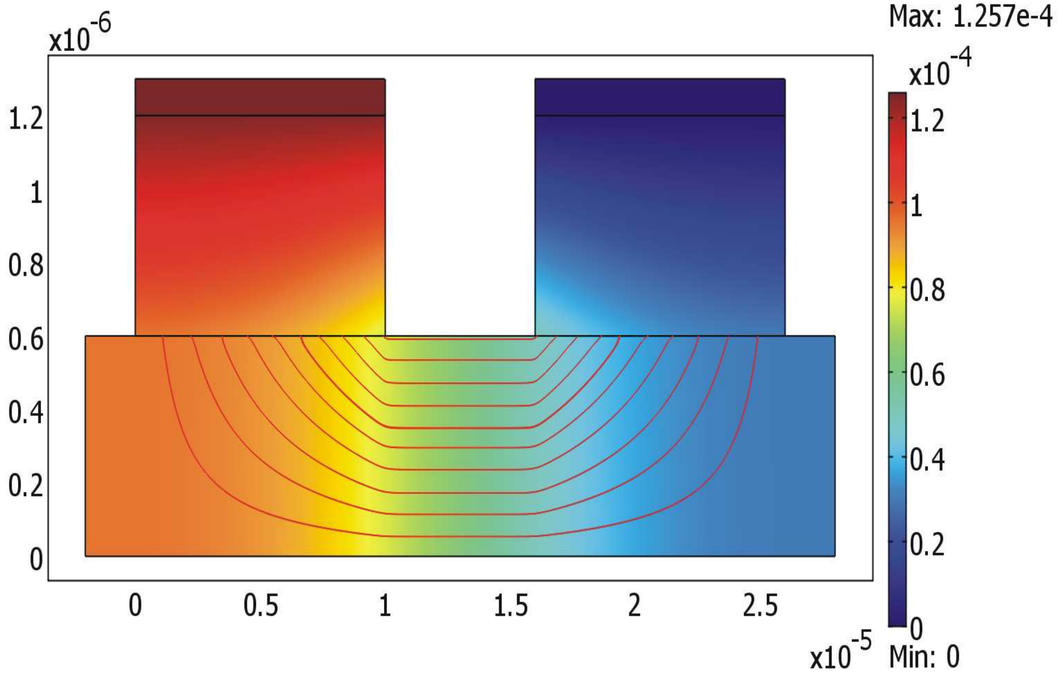
ρ_{SL} = 5.90 Ohm*cm

d_{BL} = 600 nm

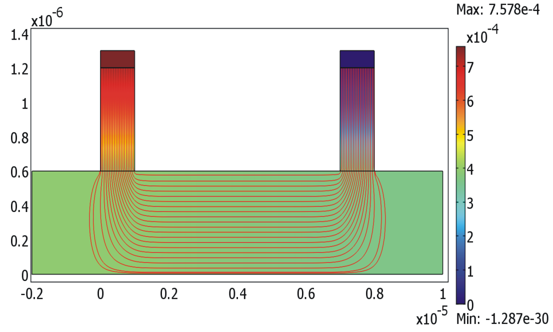
d_{SL} = 600 nm

main voltage drop in the mesa structures

FEM-Simulation



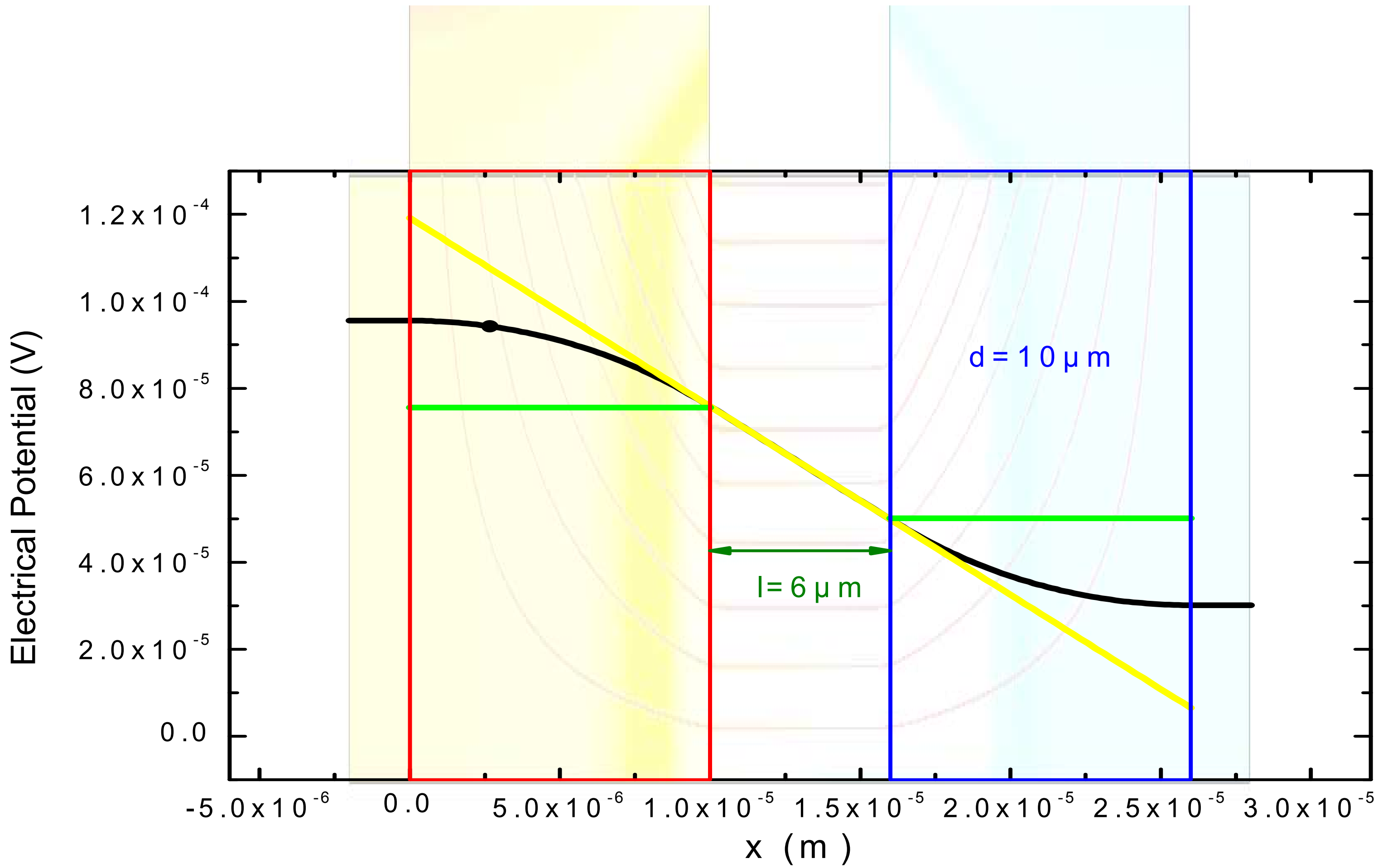
d = 10 µm, l = 6 µm



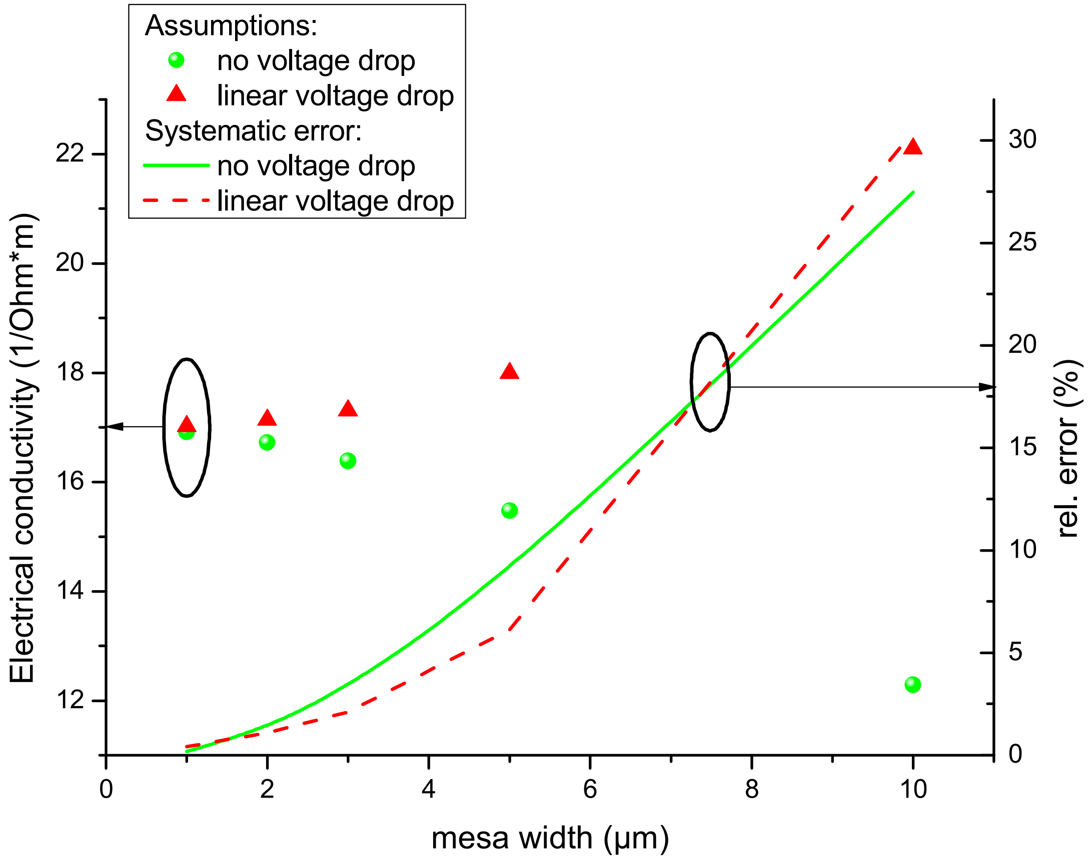
d = 1 µm, l = 6 µm

voltage drop in the buffer layer

FEM-Simulation



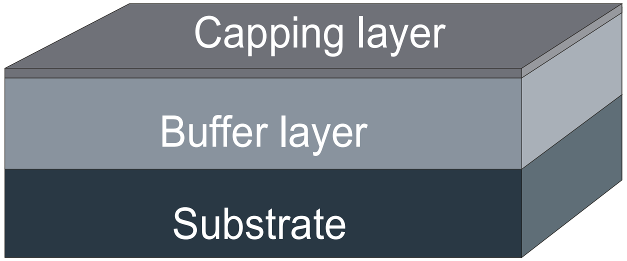
FEM-Simulation



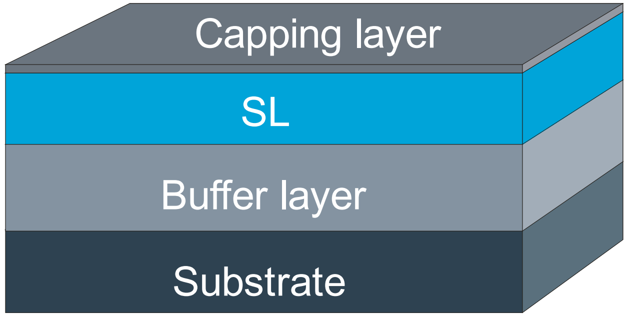
real value of the electrical conductivity is 17 1/(Ohm*m)

Systematic error, if the voltage drop under the mesa is supposed to be linear or if it is neglected.

Comparison
Simulation -Experiment



Thin film sample



Superlattice sample

Substrate

Si n-type (111)

Buffer layer

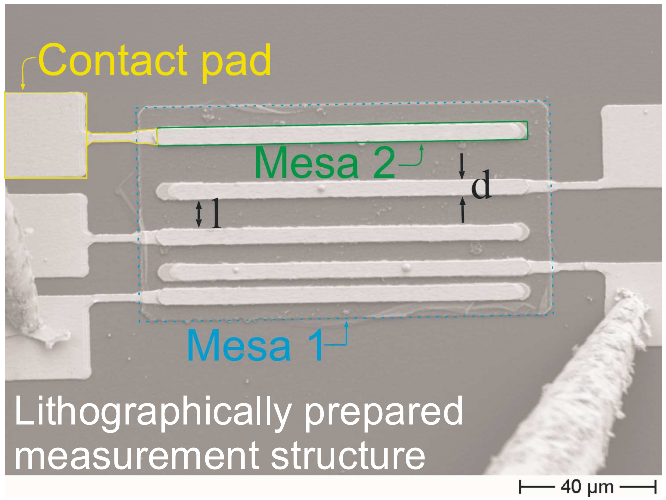
Si p-type 10^{19} cm^{-3}, 600 nm

Capping layer

Si p-type 10^{19} cm^{-3}, 10 nm

Superlattice

Si/ Ge (1.5 nm/ 2.0 nm), 600 nm, p-type, 10^{17} cm^{-3}



Comparison
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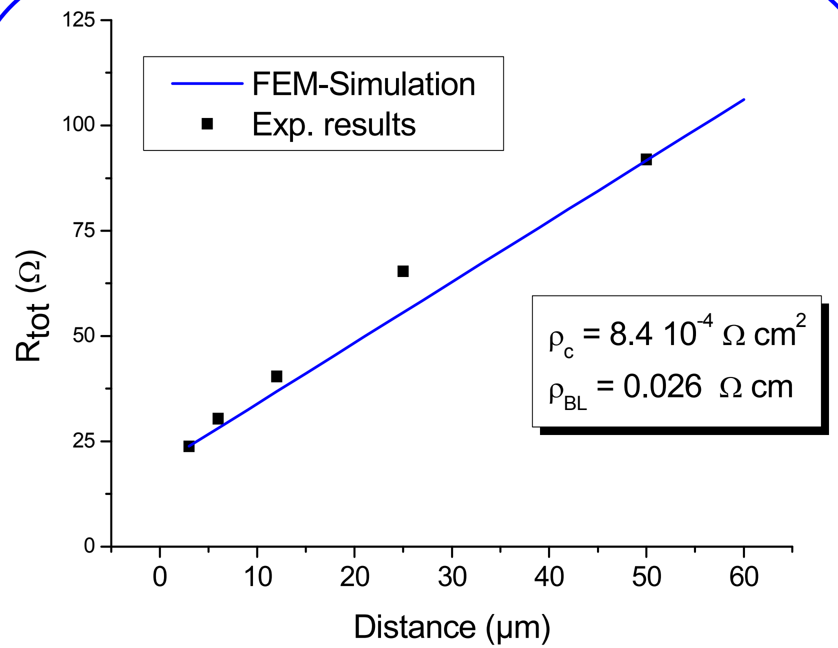
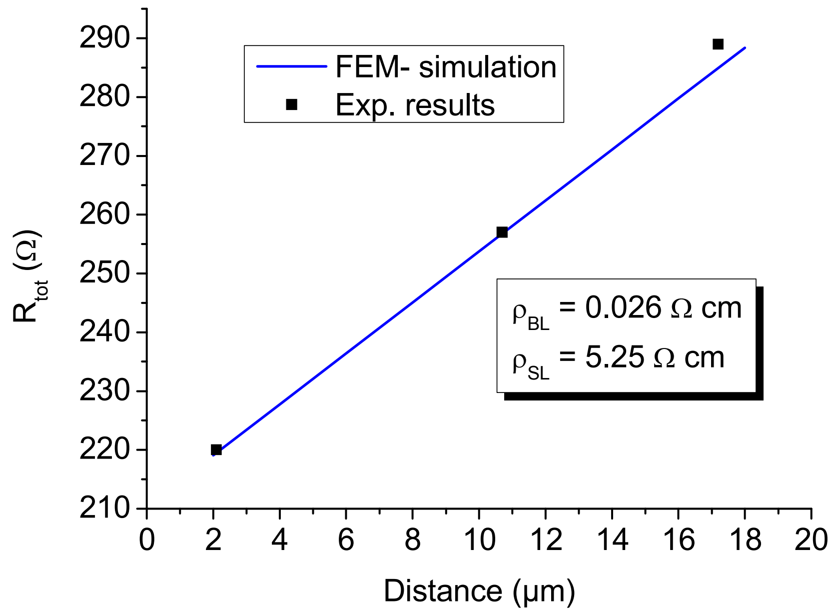


Thin film sample



SL sample

Summary

measurement of the cross plane electrical conductivity of very thin films is very complicated

the geometric properties of the measurement structures can cause very huge systematic errors on the results depending on the assumption which is made:

linear behaviour of voltage drop
-> calculated electric conductivity is to high

neglected voltage drop
-> calculated electrical conductivity is to low