Measuring of doping profiles with Spreading Resistance Profiling

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1. Background: Motivation

**Silicon Sensors in Collider Experiments:**

- The Vertex detector systems of modern particle detector experiments are exposed to high radiation.
- Due to high Energies and Intensities in future experiments (e.g. LHC upgrade) the radiation exposure will further increase.
- The radiation hardness of silicon sensors is crucial determined by the material choice and specific production process.
- Detailed investigation of material properties and their influence on the sensor performance are necessary.
- In that context a simple and easily realizable method of measuring doping profiles has been developed and used.

*Left: Expected number of Particles at the CMS Experiment (LHC) integrated over 10 years, relative to the beam line position (z) and for different distances (colours). See: CERN/LHCC 98-6, CMS TDR 5, 20 April 1998*
1. Background: Measuring of doping profiles

Methods to measure doping profiles:

• Secondary Ion Mass Spectroscopy (SIMS): Mass Spectroscopy of Sputtered Ions

• Rutherford Backscattering Spectroscopy (RBS): Spectroscopy of high energetic elastic scattered light ions

• CV Profiling methods make use of the dependence of capacitance on doping concentration by depleting a pn junction (low dynamic range and quality)

→ Difficult and expensive to realize or low quality

Spreading Resistance Profiling (SRP):

• Two tungsten carbide or osmium probes are stepped along a beveled surface and measure the resistance at each point

• Probe Spaces in the order of 30-100µm and probe tips of 5-10µm enable the measurement of spreading resistance [2]

• The spreading resistance of Semiconductor material is strongly correlated to the material resistivity and hence doping concentration

\[
R_{SP} = \frac{\rho}{2a}
\]

\[
N = \frac{1}{(\mu_n n + \mu_p p)q}
\]

→ Easy to realize with standard equipment of high energy institutes
Background

1. Background: The Principle of SRP

**Spreading Resistance:**
- Spreading resistance is caused by current spreading due to small contact areas.
- The smaller the contact area becomes, the stronger becomes the resistance dependence.
- At probe spacing of about five times the contact radius, 80% of the potential drop occurs due to current spreading [1].

**Characteristics of SRP:**
- The total measured resistance by contacting semiconductor surfaces is composed by four components:
  \[ R_{\text{tot}} = R_{\text{SP}} + R_{\text{C}} + R_{\text{S}} + R_{\text{P}} \]

- SRP measurements deliver relative data and require calibration methods.
- Only the concentration of activated dopants is measured.

**Calculation of doping concentration:**
- The value of the contact radius (a) has to be calibrated on samples or parts of samples with known resistivity (\( R_{\text{SP}} = \rho/2a \)) [4].
- The minority charge carrier are neglected by calculating the concentration. (\( N = 1/(\mu_n n q), \mu_p p \approx 0 \))
2. Performance: Preparation (At the USTEM of TU Vienna)

Preparation of the samples:

• Separating parts of interest in adequate size (by scratching or the using diamond saws).

• If needed the topmost layer can be removed by etching methods.

• The samples are mounted on the top of a calibrated bevel block by the use of synthetic resign (samples are heated up to 100°C)

• The samples are grinded in the desired angle and lifted of the bevel block by the use of chemical solutions (acetone, ethanol,...)

The grinding sequence:

• Small scratches cause fluctuations of the measured resistance

• In order to reduce scratches grinding wheels with iterative reduced grain sizes are used

• The abrasion of each grinding wheel should equal the grain size of the previous used one

• By preparing the samples grain size up to 0.01µm has been used

Etching Solutions:

• Aluminum layer have been removed with phosphoric acid (good selectivity) to reduce probe contamination

• Silicon Oxide layer can be removed with hydrofluoric acid but can also be used to mark the bevel edge
2. Performance: Preparation

Calibrating the Angle:

• In order to calculate the depth of the profile accurate, the angle has to be measured
• By the use of a commercial coordinate measurement machine the angle has been verified
• The result fits well the preparation settings

Determining the Angle:

• Scratches and surface defects strongly influence the result
• The resistivity is sensitive to changes in temperature and humidity
• To reduce measuring time and the measured surface angles are chosen, which enable to measure the expected profile in around 100 points
2. Performance: The Facility

Elements of the Facility:

• Digital weighing Scale (accuracy of 0.01g)
• XYZ Table (moves in three directions accuracy of 0.5µm)
• Microscope
• Tungsten carbide Probes and Positioner placed on the xyz table

Tungsten Carbide Probes:

• Probes of special Hardness and Elasticity are necessary to contact silicon bulk material
• By contacting the sample on areas of some 10µm² the pressure is in the order of GPa
• A phase transformation of Silicon to the beta thin phase takes place → probe marks
2. Performance: The Measurement

Performance:

• Aligning the probes before the bevel edge

• Lowering the table with 1µm and after a threshold weight 0,5µm steps per 500ms

• Measuring the weight at each step especially at the first and last contact

• After a desired weight is reached the average weight is taken in 1s and the resistance is measured

• The probes are lifted and start to low again several µm before the position of first contact

Effects of loaded weight:

• The contact resistance strongly depends on the loaded weight

• Changing the position of the xyz table of 0,5µm corresponds to a change in weight of approximately 0,15g

• Measurements are reproducible
2. Performance: The Measurement

Typical Profiles:

- Common produced doping profiles start with a high surface concentration (low resistance) and end with low concentrations (high resistance).
- Each probe mark can be assigned to one measured point by the use of optical microscopes.
- Characteristic peaks in the profile can be explained by scratches between the points.

The probe marks of one measurement, assigned to the corresponding positions in the profile.

![Image of probe marks and measured resistance profile](image_url)
3. Results: Strip Implants

Measurement of different Strip Implants

- **P+ Implant in N Bulk Material**
  - The Influence of the space charge region could be observed
  - Characterized by an abrupt change over

- **N+ Implant in N Bulk Material (double sided)**
  - There is no space charge region and a smooth change over to the bulk concentration
3. Results: Strip Implants

Comparison with Scanning Electron Images

• Chemical preparation with hydrofluoric and nitric acid changes the topographic contrast at doped areas
  • The contrast changes scale continuously with the concentration
  • Penetration depth fits the scanning microscopy results

The SRP doping concentration in comparison to the contrast change of SEM images.
3. Results: Backside diffusion

Backside Diffusion

• In order to build radiation hard structures the active zone is narrowed down by backside implants.

• A new diffusion methods allows to produce controlled implants in the range of 100-200µm penetration depth.

• Samples of p+ type implant in p bulk material and n+ type implant in n bulk material have been measured [3]

Three samples with measured back side diffusion in P bulk Floating Zone (FZ) material, produced by Vendor I.
3. Results: Backside diffusion

Comparison with Capacitance Voltage measurements

• Capacitance Voltage Profiling is based on the derivation of the CV curve and hence sensitive to fluctuations

• Only depleted regions and hence low concentrations can be measured by the use of CV profiling

• At deep penetration a smooth crossover could be verified, although CV measurements are mainly adequate to measure penetration depths
Thank you for the attention

Bibliography:


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