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Non-contact metrology for Advanced Emitter Structures

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Semilab today

Main activity: Development, manufacturing and marketing of metrology equipment for the semiconductor and photovoltaic industries.

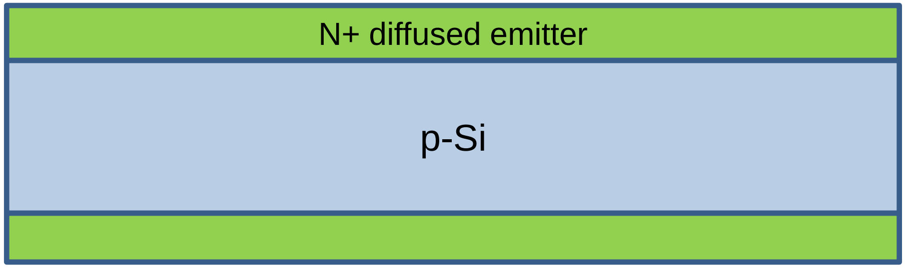
- Employees: ~450 worldwide
- Laboratory, office and manufacturing space: 11,000 m^2, 3,000 m^2 in the US
- 80 physicists, 29 employees holding a Ph. D. in physics
- Installed base: more than 3,000 units
- Patents: wholly owned – 90, applications – 8, lincensed – 41
- 4th biggest 'pure-play' metrology company in the industry

Outline

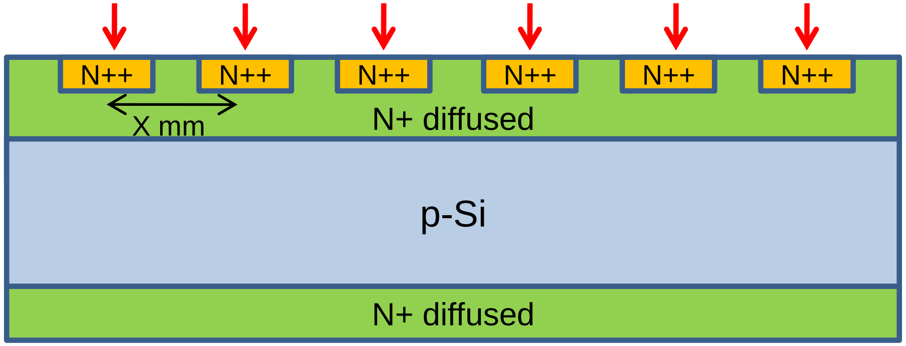
Non-contact sheet resistance (SHR) measurements

1. Principle of Junction Photovoltage (JPV) method, and correlation to 4PP
2. High resolution SHR probe: resolution and mapping capability
3. Model Based Infra-Red reflectometry

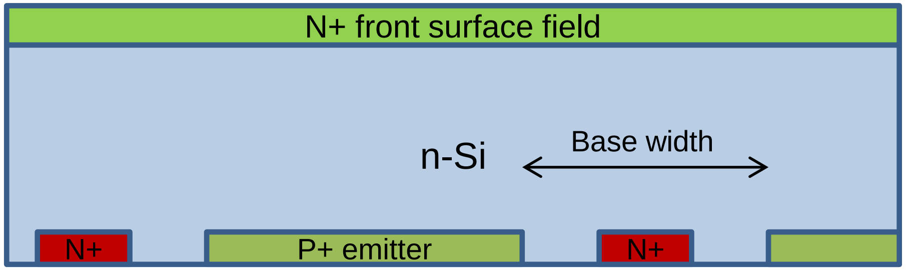
1. Traditional PV wafer after emitter diffusion



2. Selective emitter structure



3. Example of a back contact cell structure

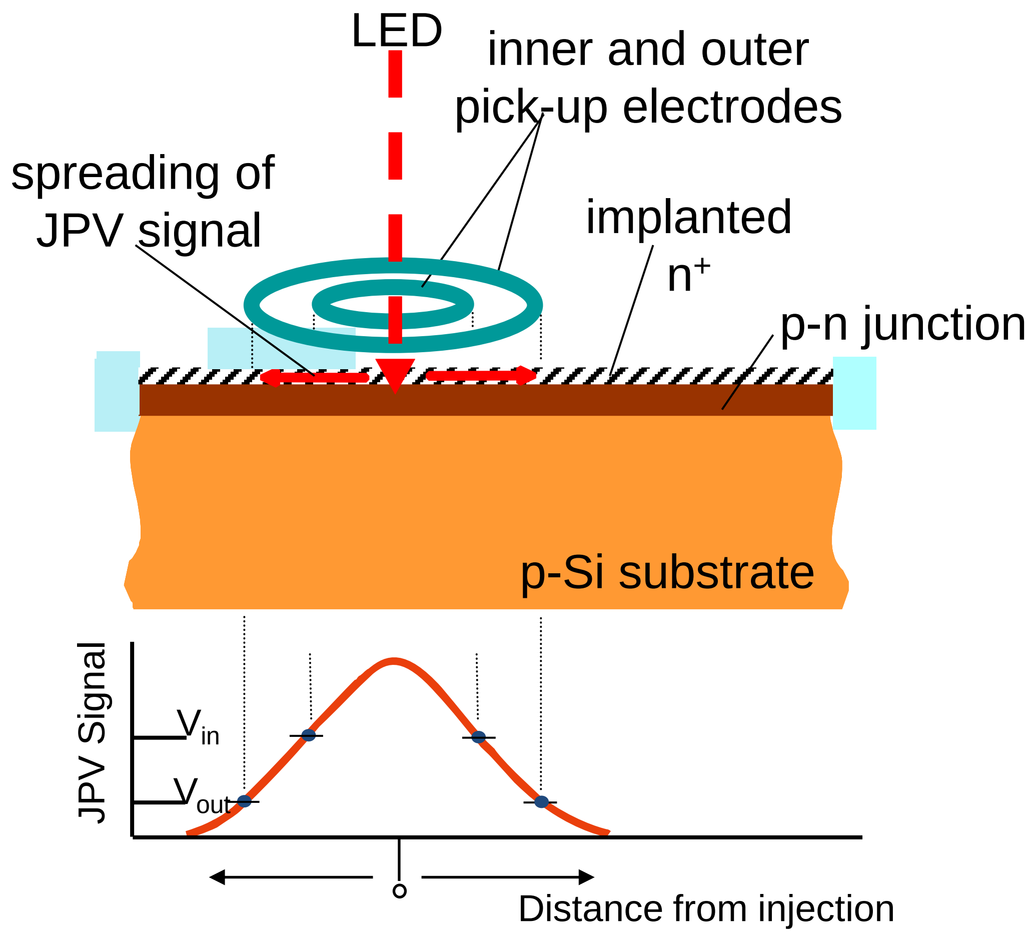


I. Non-contact Sheet Resistance (SHR) measurements

Using the Junction Photovoltage (JPV) method

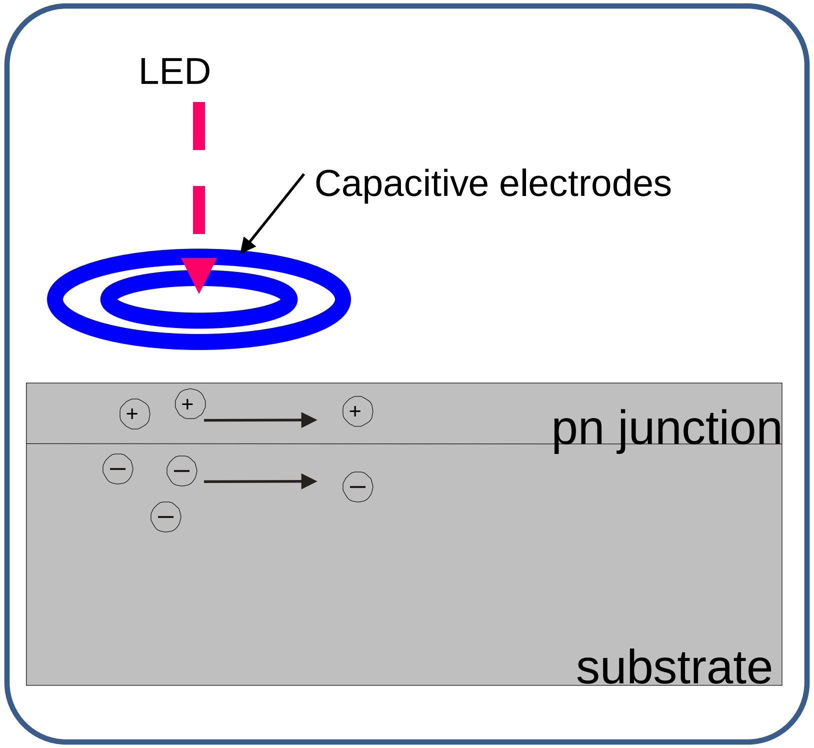
Noncontact Junction Photo-Voltage, JPV, Measurement of Sheet Resistance

- Chopped LED light (a.c) generates carriers that are separated by the junction and create a.c photo-voltage signal
- Voltage spreads laterally from excitation spot and spreading distance increases with decreasing the sheet resistance
- Spreading JPV signals V_{in} and V_{out} are measured with two capacitive electrodes
- Sheet resistance R_S is calculated from the signal ratio V_{in}/V_{out} at elevated light chopping frequency



Frequency dependence of JPV:
determination of leakage and capacitance

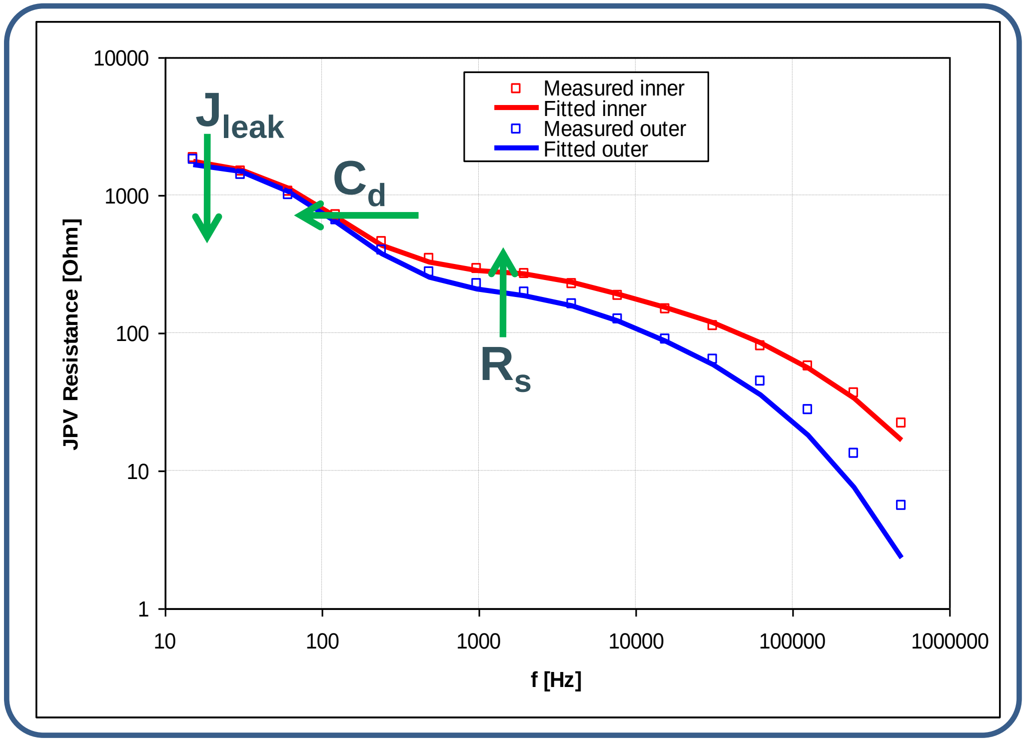
- JPV signal is measured as a function of modulation frequency
- JPV frequency dependance is function of Rs, leakage and capacitance. Each of them has dominant influence in different frequency range.
- **Leakage** influences low frequency JPV
- **Rs** mostly influences high frequency JPV



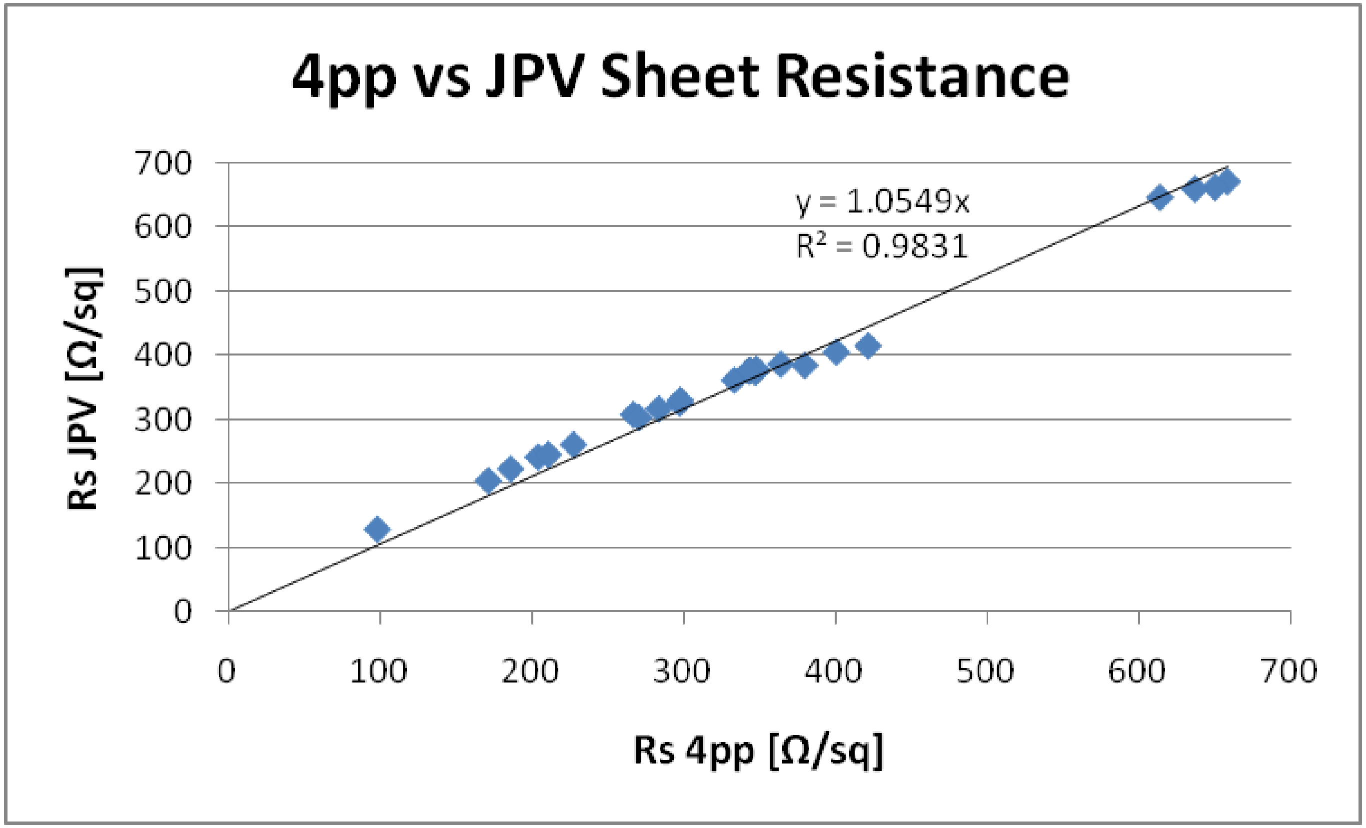
JPV ; Rs and leakage determination

- Determination of $\mathbf{R_s}$, $\mathbf{C_d}$, $\mathbf{J_{leak}}$ by fitting the theoretical solution (Bessel functions) into measured JPV curves at inner electrode
- Full wafer mapping at a frequency where signal is influenced only by $\mathbf{R_s}$, or leakage.
- For PV application JPV method is applicable just at higher frequencies (from125 kHz), where the spreading of signal is small compared to the sample size. In this region J_{leak} is not measureable.

Frequency dependence of JPV signal



4pp and JPV Sheet Resistance Correlation

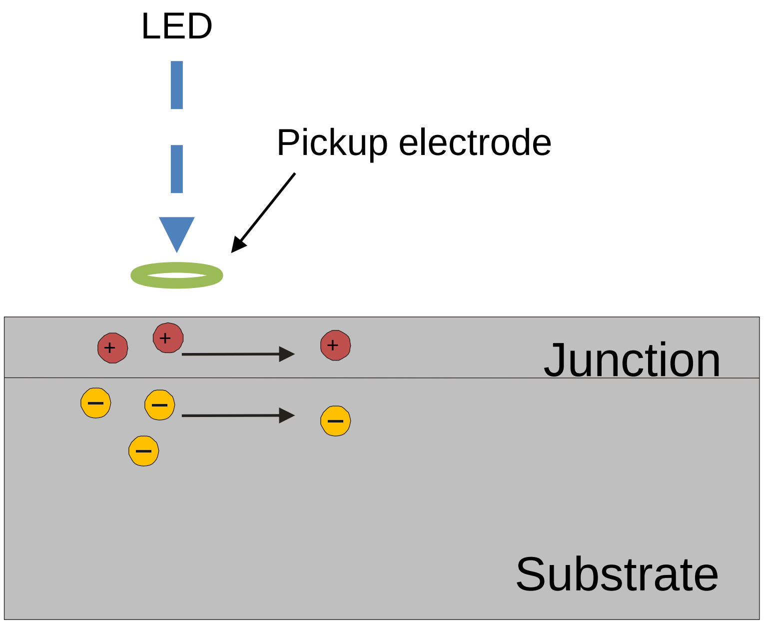


This non-contact method is widely used in production for monitoring of blanket diffused emitters.

II. High Resolution Sheet Resistance measurements

for selective emitters and back contact cells

Theory of operation of HR-SHR

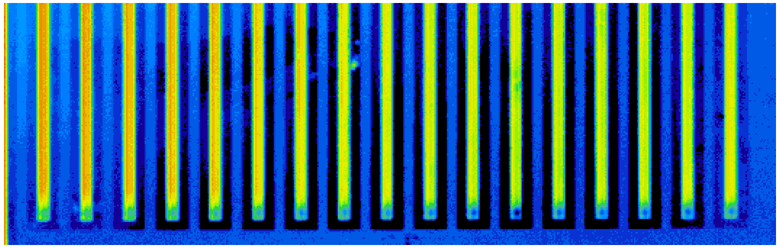


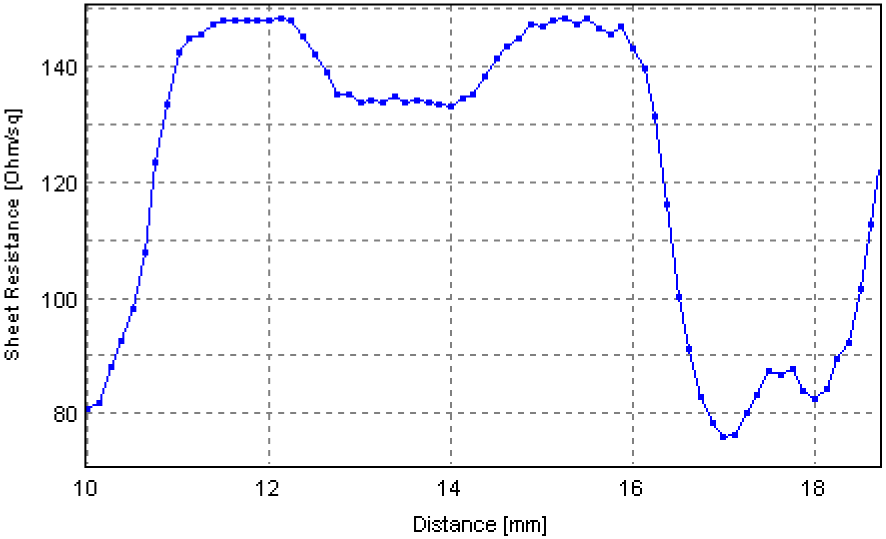
- A single smaller pickup electrode is used, with sensor for height control.
- The HR-SHR head consists of an excitation LED light source illuminating the wafer under test in a spot, and a ring-like capacitive electrode to give non-contact measurement of the photovoltage signal.
- By measuring the photovoltage signal at a given distance from the light spot we can get information on the sheet resistance.
- The sheet resistance of the material is proportional to measured photovoltage signal but calibration is required. HR-SHR can be calibrated by a standard SHR head or by four-point-probe.

Physics of JPV signal spreading

- Planar junction; signal spreading 2 dimensional (junction plane; x,y)
- Selective emitter: signal spreading mostly one dimensional along selective emitter length which gives high conductivity path (few times lower resistance than in perpendicular direction)
- Rate of signal spreading depends on:
  - 1) doping (Rs) and
  - 2) geometry; mostly emitter width and to some extend pitch
- Separate calibration is required for each geometry

Resolution test:





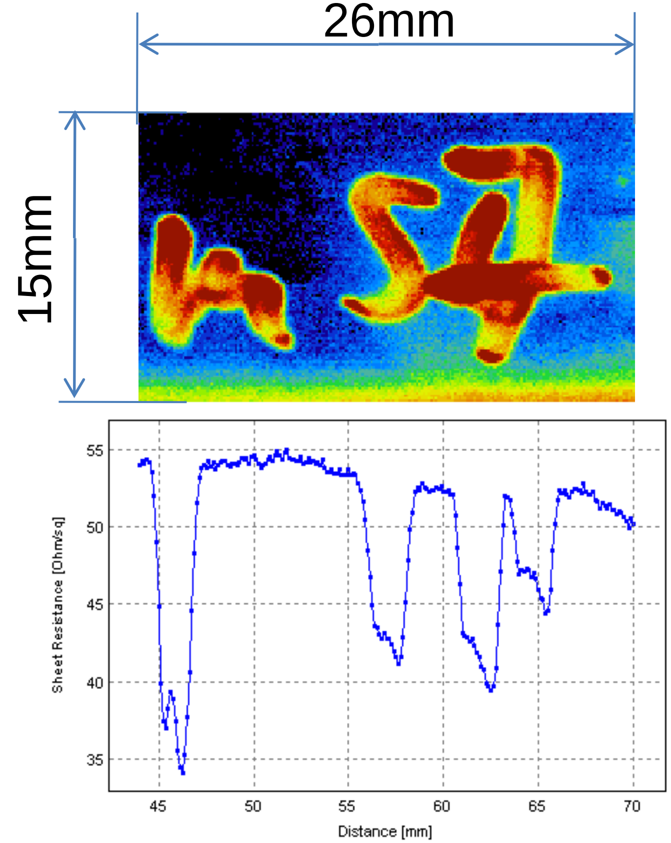
Signal change from 10% to 90%:

Resolution 600um

Applications

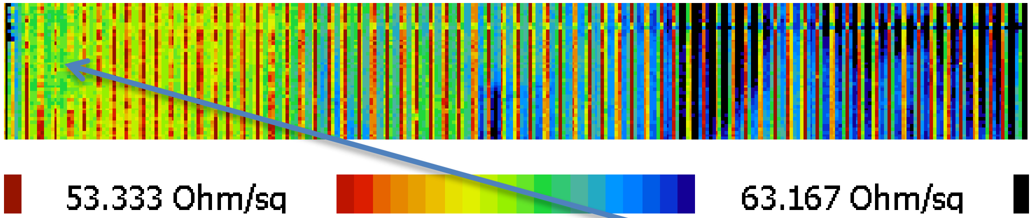
Advanced Photovoltaic samples

- without pattern
- with selective emitter
  - min. 500 µm; working on higher resolution.
- Back contact cell structures

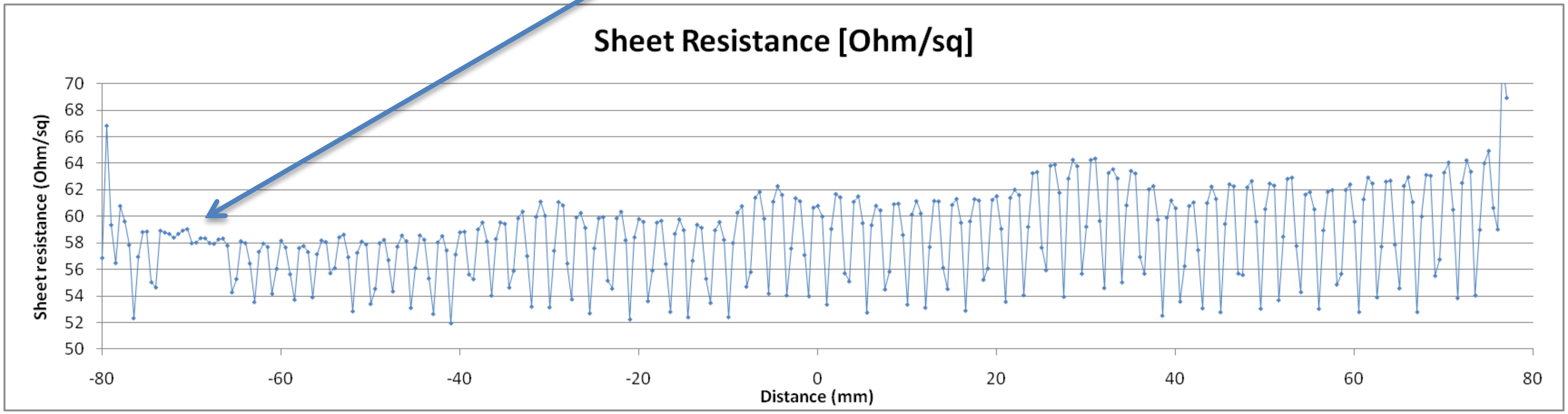


High resolution Sheet Resistance Map and linescan on diffused solar wafer

Effect of emitter width (same calibration regardless of geometry)



The discontinuity of selective emitter lines are clearly visible in the map



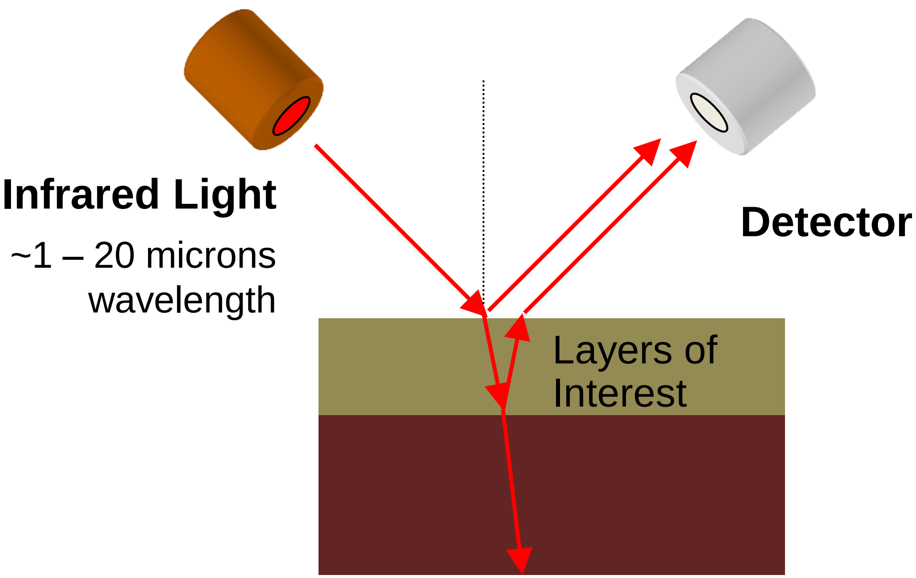
Product specification

- Light source: LED with 470 nm wavelength (depends on junction depth)
- Probe diameters: 0.5 mm
- Lateral resolution: 0.5 mm
- Samples: np or pn structure (Diffused or implanted-USJ)
- Raster in X-Y mapping: 0.125, 0,25, 0.5, 1, 2, 4, 8 and 16 mm, or single point measurements at pre-defined points (up to 50)
- Measurement speed: 50ms/data point
- Measurement time: <1h for 6” wafer 0.5mm lateral resolution
- Resolution in ohm/sq: 0.1%
- Measuring range: 10 ohm/sq to 1000 ohm/sq
- Min. junction depth: down to 5nm
- Repeatability: <1%

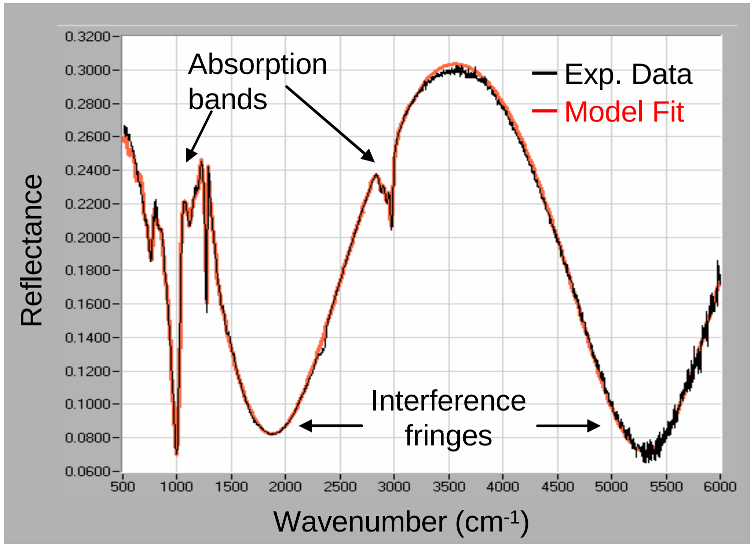
III. Model Based Infrared Reflectometry (MBIR)

Overview

MBIR Measurement Principle - 1



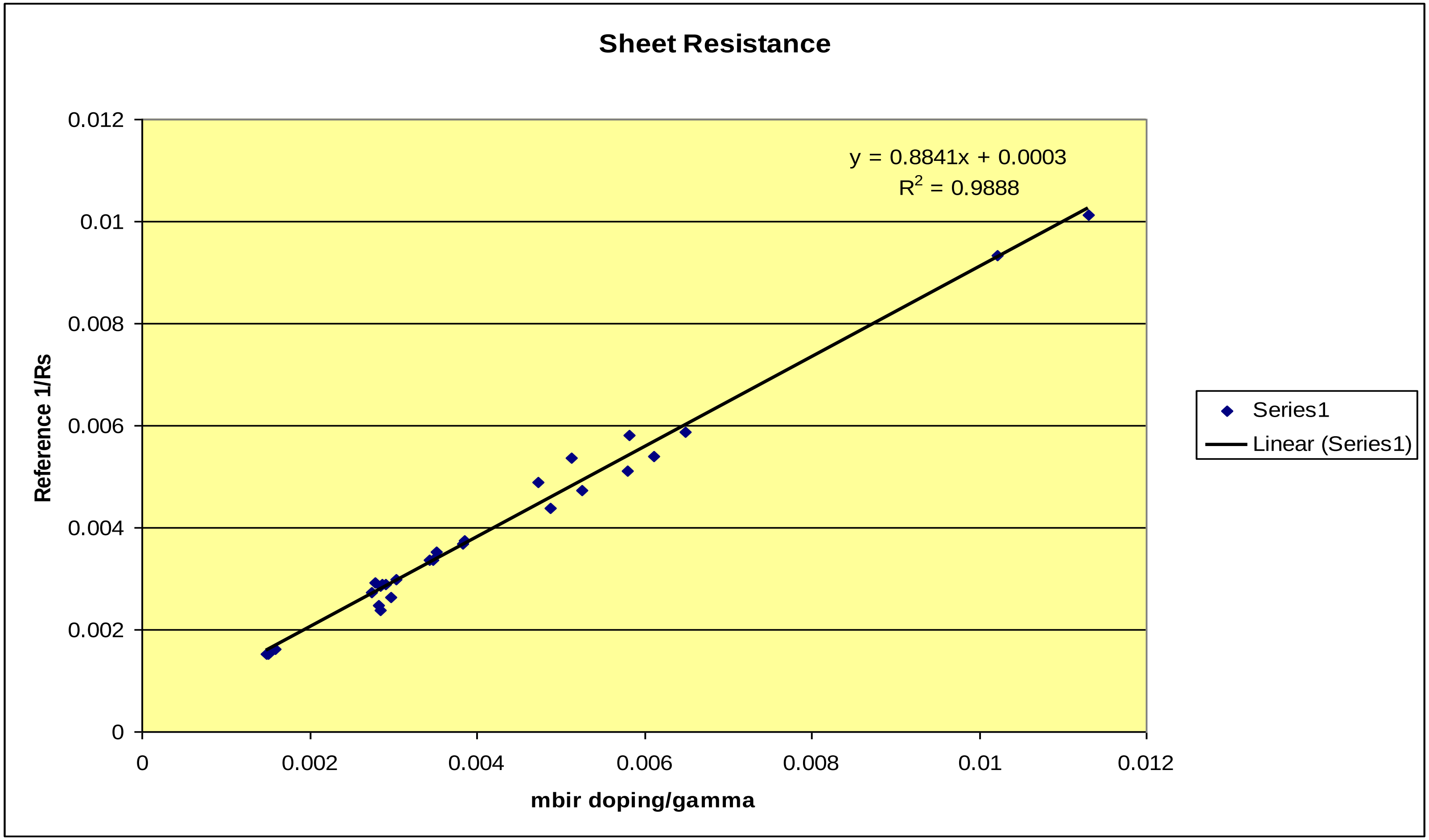
Reflectance Spectrum



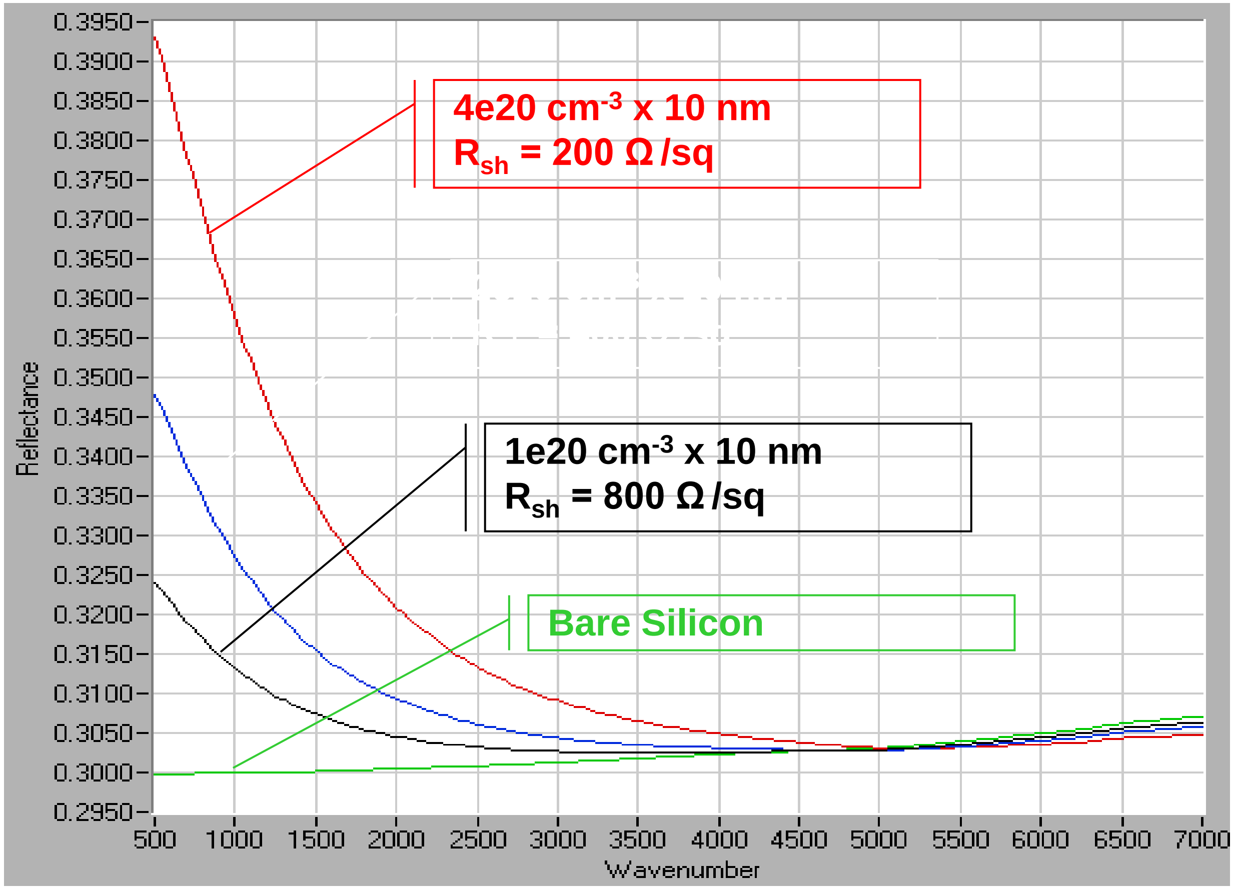
- Reflections from layer interfaces create interference patterns in reflectance spectra.
- Modeling the reflectance spectrum allows determination of trench/via or thickness parameters.

MBIR correlation to sheet resistance

IR reflectivity is a function of free carriers in the surface layer



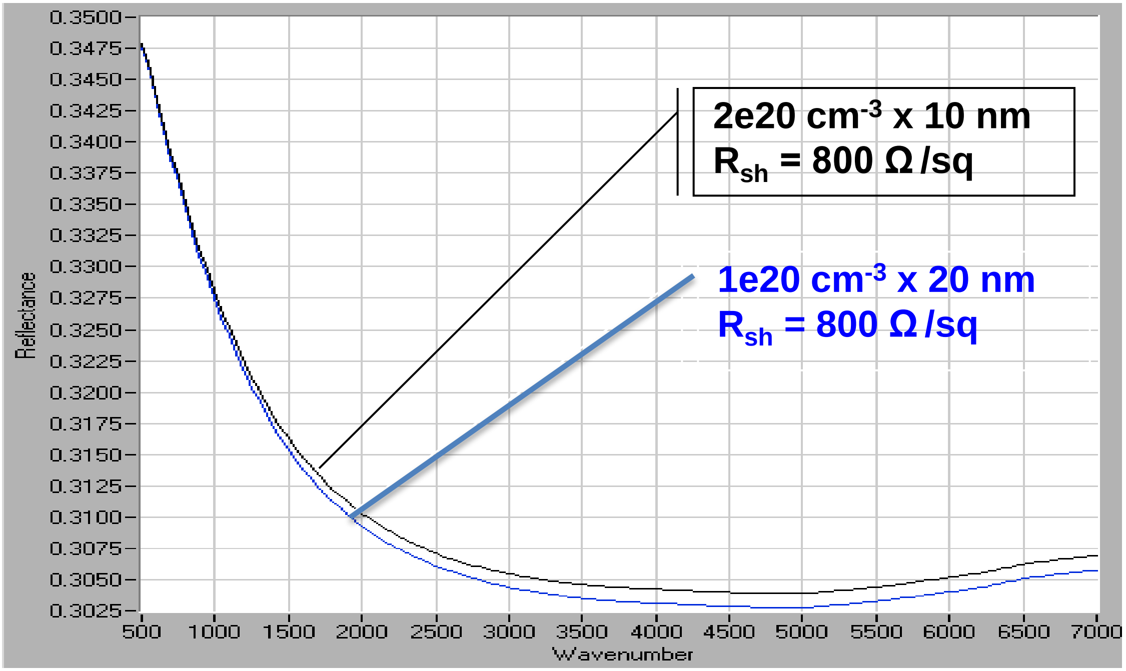
Simulated reflectance spectra for various activated implant dose at the typical junction depth (X_j = 10 nm)



* The relaxation time τ = 13×10^{-15} sec is assumed for the modeling. This is a typical value for medium doped silicon, τ for USJ may be different.

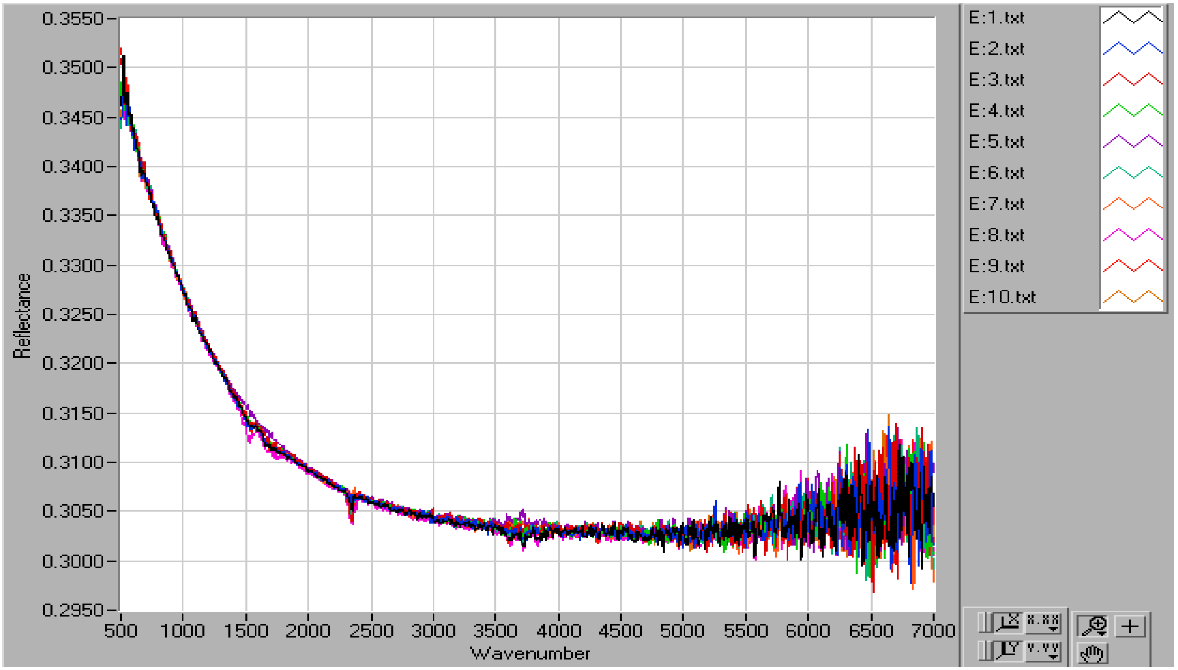
Signals have very weak sensitivity junction depth; making this ideal sheet resistance measurement

- Nearly identical reflectance curves for two implant profiles with the same “dose times depth” product. The probing wavelength is too long compared to the junction depth.
- Essentially the sheet resistance measurement.

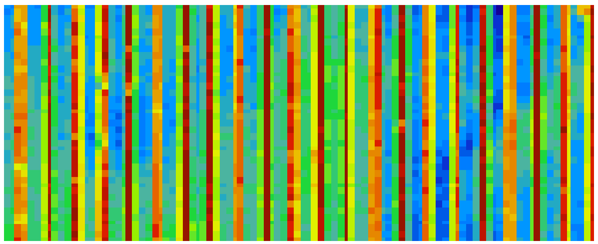


Repeatability: 1 sigma < 1%

- The experimental IR3000 system noise (taken from a bare Si measurement) was added to the predicted reflectance for the $2x10^{20}$ cm^{-3} x 10 nm implant (see the chart).
- The spectra were then fitted for the implant dose. The "1σ" repeatability is ~0.9%.
- This repeatability will likely stay roughly the same as ITRS predicts nearly constant sheet resistance spec for 2006-2012 (and no data beyond 2012).

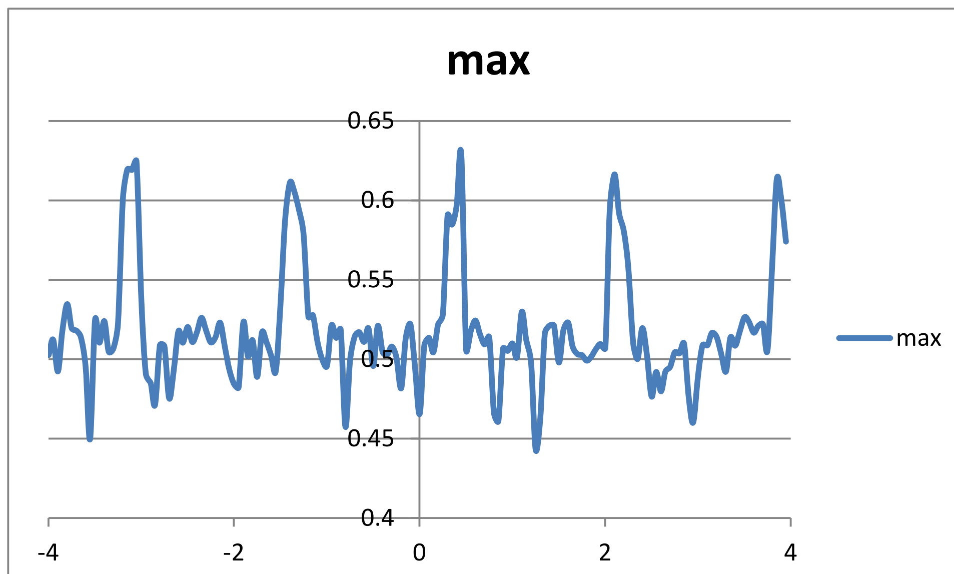


Line scan across selective emitter structures:



MBIR signal

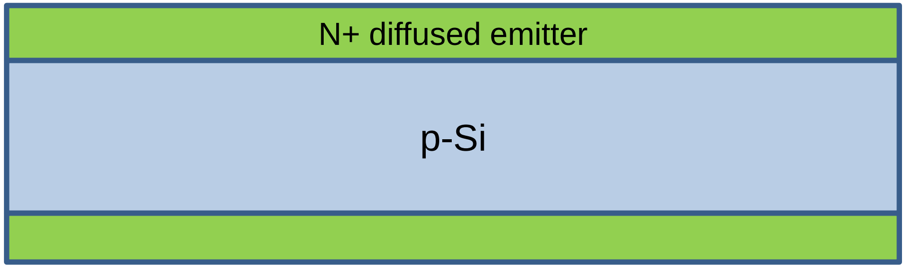
Spot size: 50um



Semilab provides 3 solutions for non-contact emitter sheet resistance measurements, all with mapping capability:

1. SHR: non-contact sheet resistance using the JPV method, for blanket diffused / implanted wafers
2. High resolution SHR: for selective emitters – with resolution of ~500um (to 300um)
3. Model Based Infra-Red reflectometry (MBIR): under development for PV;

1. Traditional PV wafer after emitter diffusion



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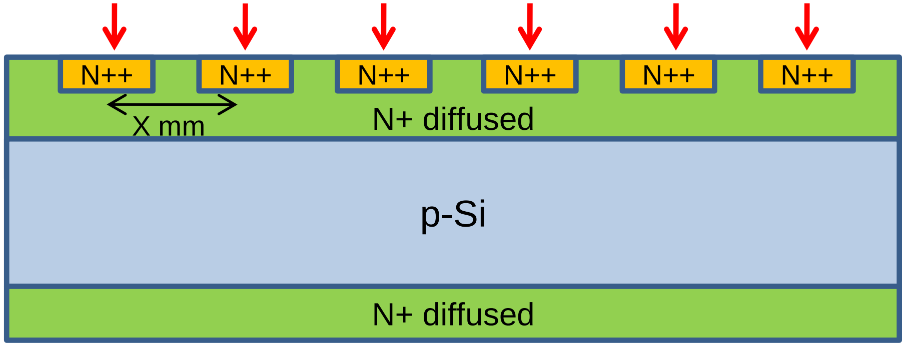

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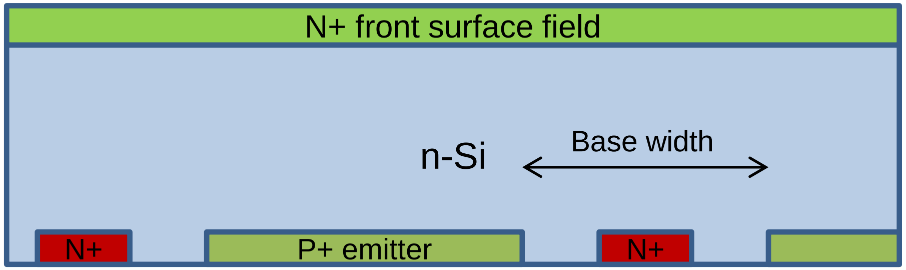

Acknowledgments

I would like to acknowledge my colleagues for their contributions to this presentation:

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Dr Lubek Jastrzebski

Miklos Tallian