Laser Annealing: Revolutionizing Sensor and Semiconductor Manufacturing

Date: December 4th, 2024
Company Name: 3D-Micromac AG
Contact Details: Maurice Clair

Content

3D-Micromac – Micromachining Excellence

We are the leading specialist in laser micromachining.

Our mission:

- **Development and production** of unique process and machine solutions for various high-tech markets
- Customer support **from product development to high-volume production**
- **Enabling** laser micromachining techniques for **new devices**
- Superior production **efficiency** and reliable process **stability**

“Our international customers place great value on future-oriented and user-friendly processes. Our solutions help them increase production efficiency and lower cost”.

Uwe Wagner, CEO

3D-Micromac – The Specialist in Laser Micromachining

Key Facts

- » Founded in **2002**
- » 180 employees
- » Based in **Chemnitz, Germany**
- » Branch offices in US and Taiwan

Services

- » **Feasibility studies & process development** in-house
- » Production of limited lots and ramp-up production
- » **Worldwide** sales & service network

Machine Base

> 600 installations worldwide

> 50 systems in semi industry

> 150 systems in glass/display

> 30 systems in microdiagnostics

> 110 systems in photovoltaics

> 30 systems in roll-to-roll production

Target Markets & Products

» Semiconductor

» Glass & Display

» Microdiagnostic

» Photovoltaic

General Advantages of Laser Annealing

- **Selective** in horizontal and vertical direction
- Very high temperature gradients for **low thermal impact**
- Determined absorption depth by wave length selection
- Excellent **energy homogeneity**
- Spot geometry can be formed as required
- Dynamic spot motion
- **Precise monitoring** of laser and process
- Various options with pulse length, energy and overlap
- **Process adaption** to product by recipe

→ **xMR technology**	laterally limited exposure
→ **OCF technolgy**	vertically limited exposure

xMR Technologies

Magnetic Orientation Sensor Systems

xMR stands for

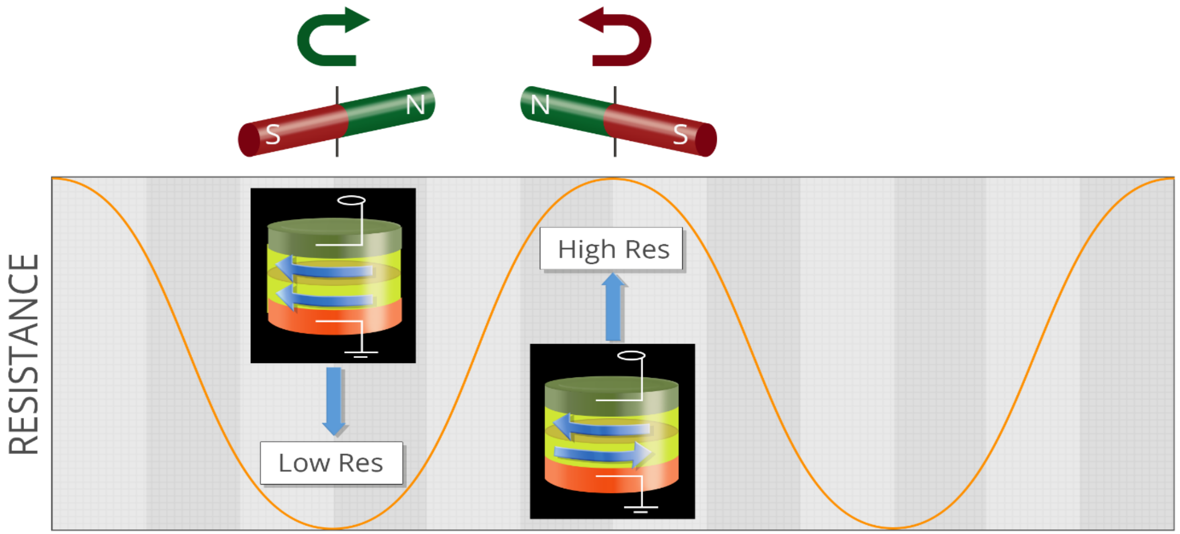
- **G**iant **M**agneto **R**esistance effect
- **T**unneling **M**agneto **R**esistance effect

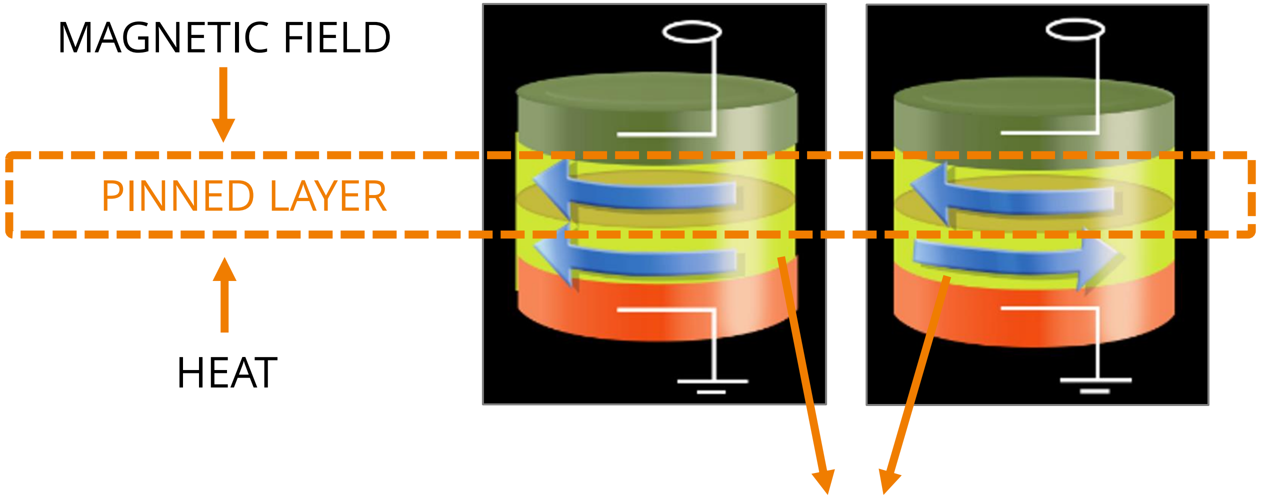
AIM:

Build highly sensitive magnetic orientation sensor chips

→Using GMR or TMR sensors

→Creating a Wheatstone bridge circuit




MAGNETIC FIELD

PINNED LAYER

HEAT

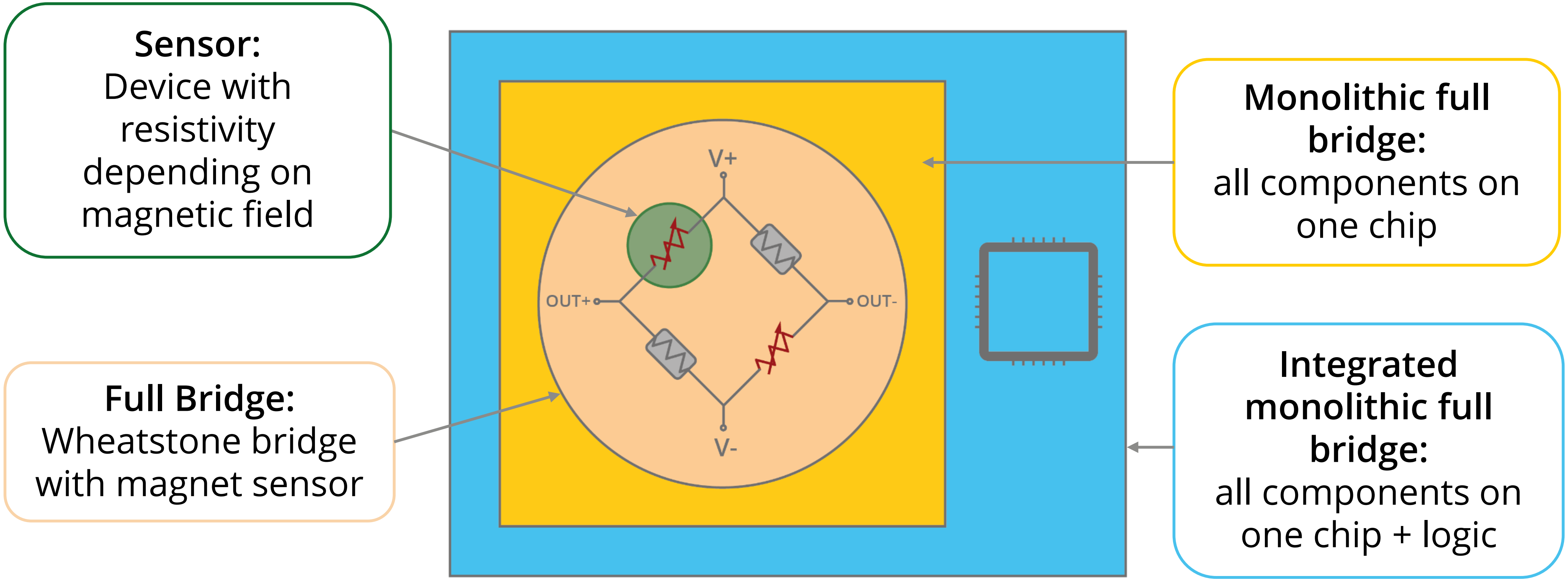
One layer needs to be pinned ➔ magnetic field + heat

Growing Demand for Magnet Sensor Devices

… driven by …

1. Sensors for IoT
   - Integrated rotation sensors
   - e-compass
2. Appliance
   - Brushless DC motor angle sensor
   - Position sensors
3. Automotive
   - Power steering angle control
   - Electronic throttle control
   - Brushless DC motor angle sensor
4. Mobile devices
   - e-compass

Integration Level



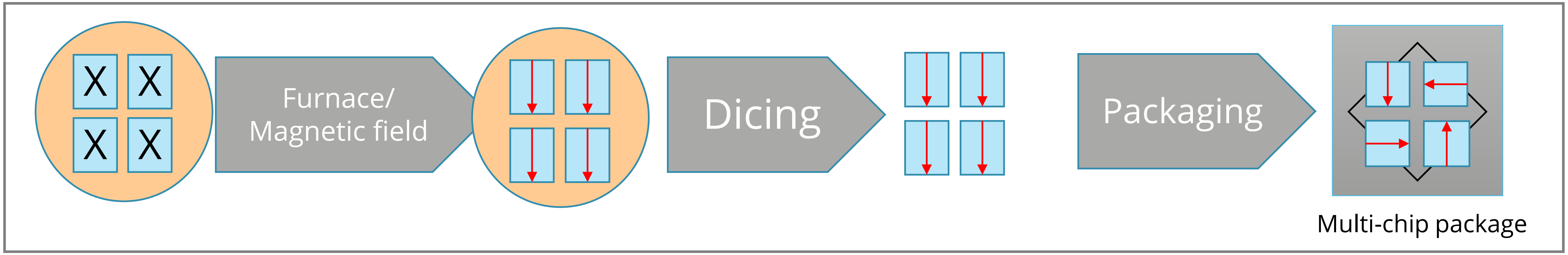
Sensor:
Device with resistivity depending on magnetic field

Full Bridge:
Wheatstone bridge with magnet sensor

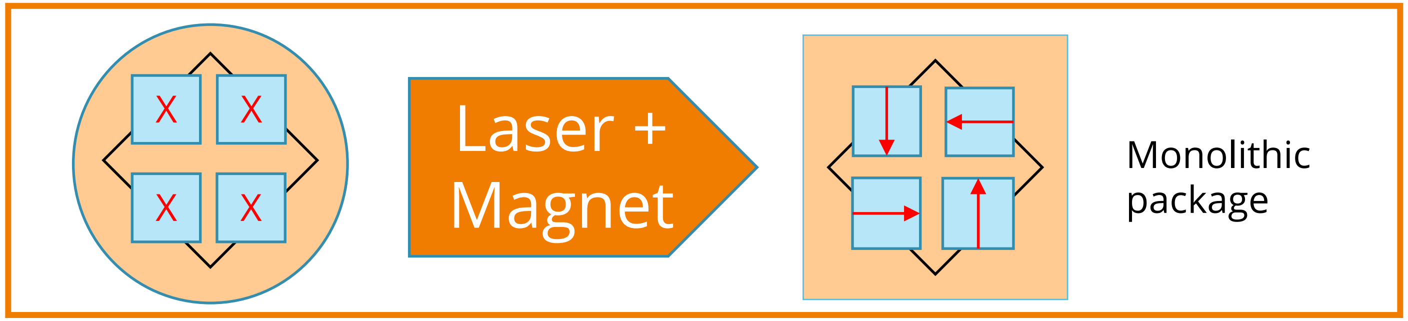
Monolithic full bridge:
all components on one chip

Integrated monolithic full bridge:
all components on one chip + logic

Sophisticated Production Today



NEW solution:
microVEGA™ xMR



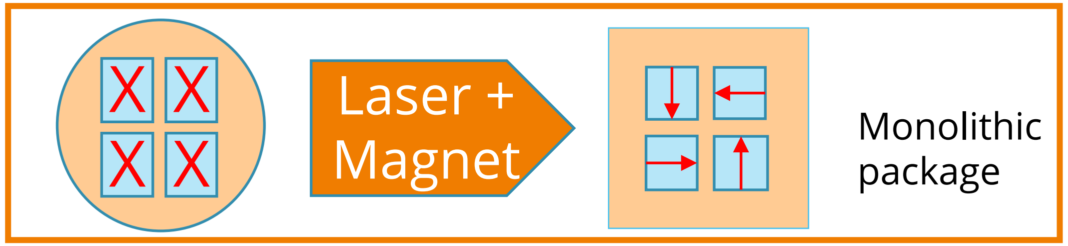
Principle of Laser Pinning

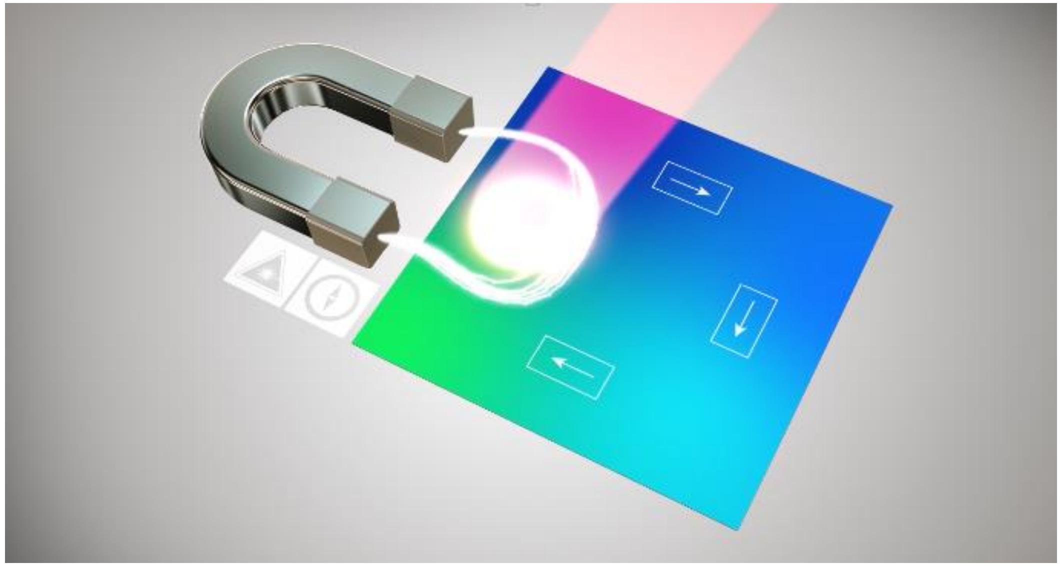
Process description:

- Strong magnet is positioned over the sensor field
- Laser shoots "through" the magnet and heats up the sensor field
- Laser pulse only at sensor field area, using a adjustable laser field dimension → no heating of nearby electronic
- On the fly processing → high throughput possible

Laser parameter:

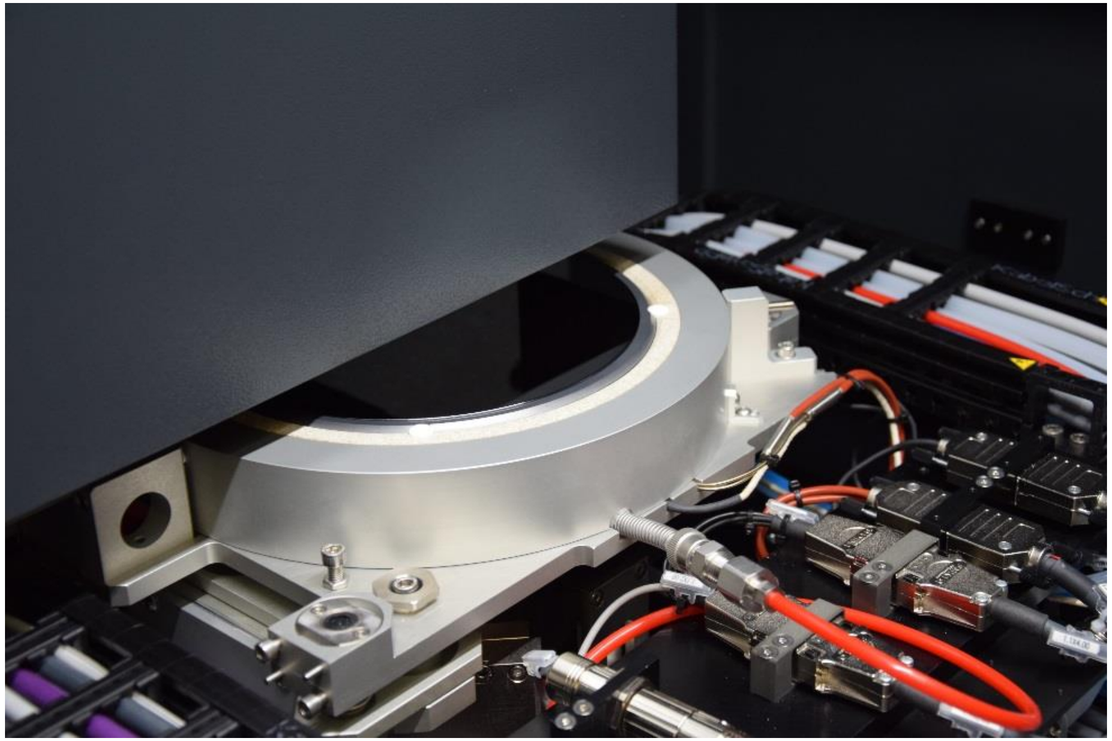
- Wavelength: 1064 nm
- Pulse length: adjustable in ns range





microVEGA™ xMR at a Glance

- High performance laser annealing system
- Standard working area for 300 mm wafer
- Novel solid state laser based process
- Integrated process control
- Automatic wafer handling



Inside microVEGA™ xMR

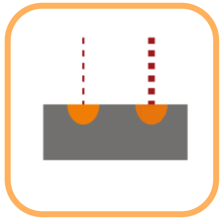
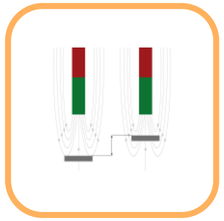
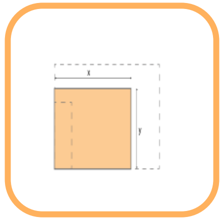
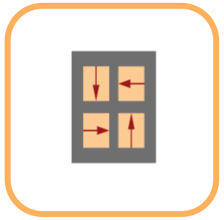
Throughput estimation* (very product specific):

- 520,000 sensors per hour (a customer sample)

* depending on sensor and wafer design

Wafer - Parameter - Fitting

The following parameters can be changed by recipe:

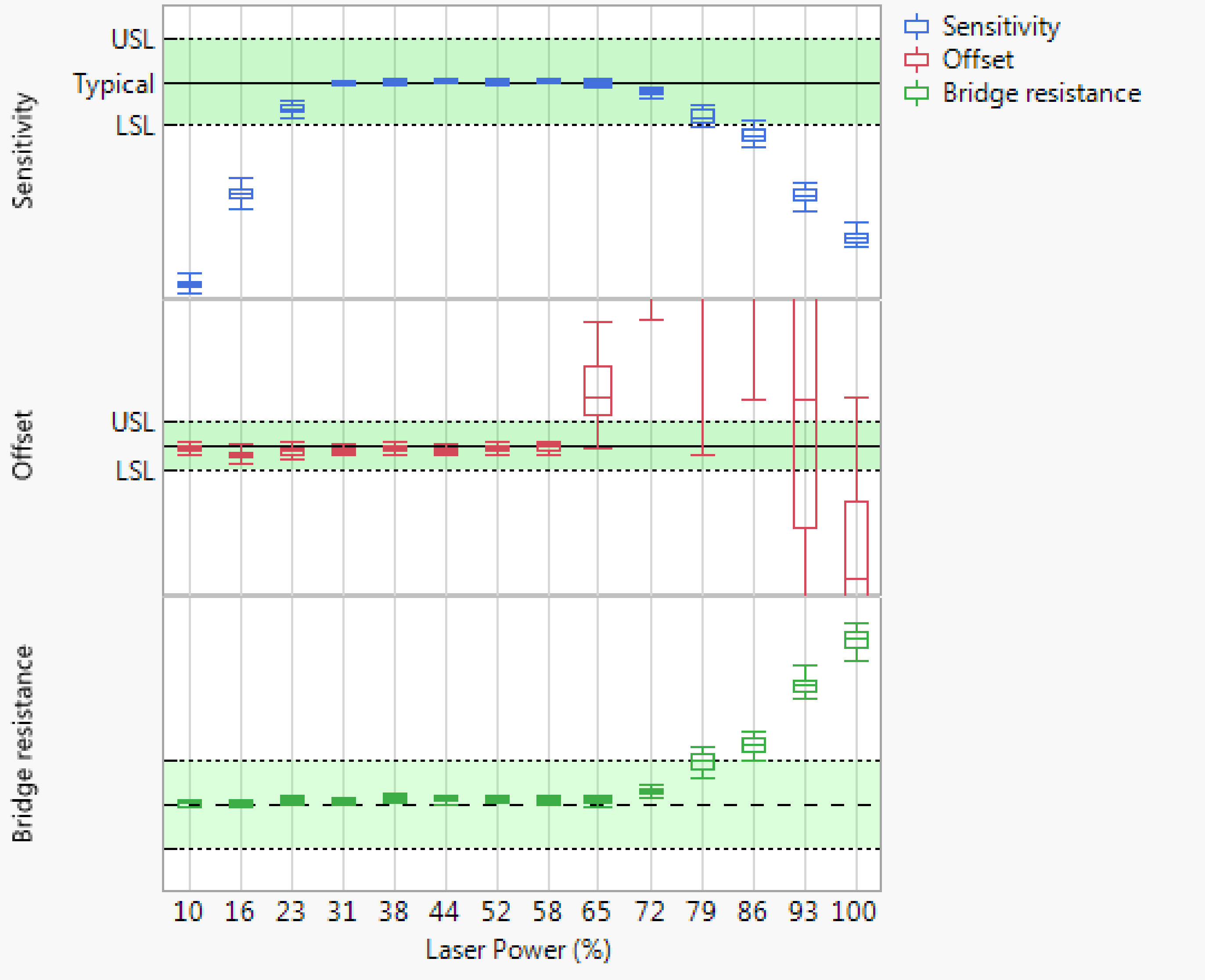
	Laser pulse energy	Variation of laser power
	Magnetic flux	Up to **0.65 Tesla** Variable by height / power of the magnet
	Sensor dimensions	Rectangular shapes changeable by recipe: **10 µm x 10 µm** to **300 µm x 300 µm**
	Orientation	Rotatable by **360°** Accuracy: ± 0.01°

Production Example: Allegro (Crocus) Technology

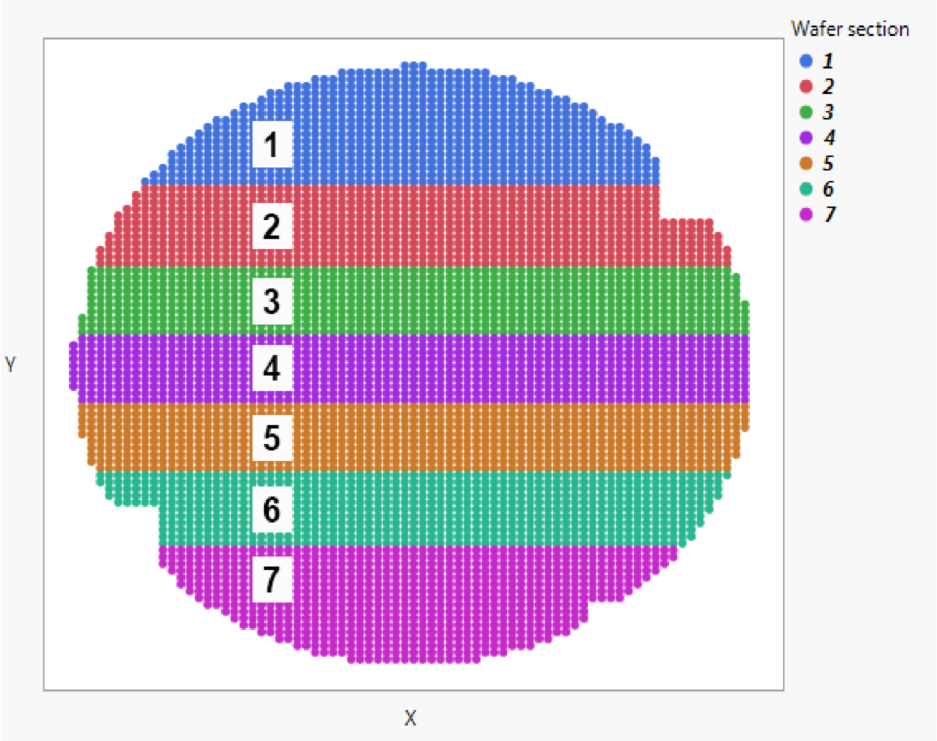
QUALITY ASSESSMENT RESULTS FOR PROGRAMMING OF MONOLITHIC TMR MAGNETIC SENSORS

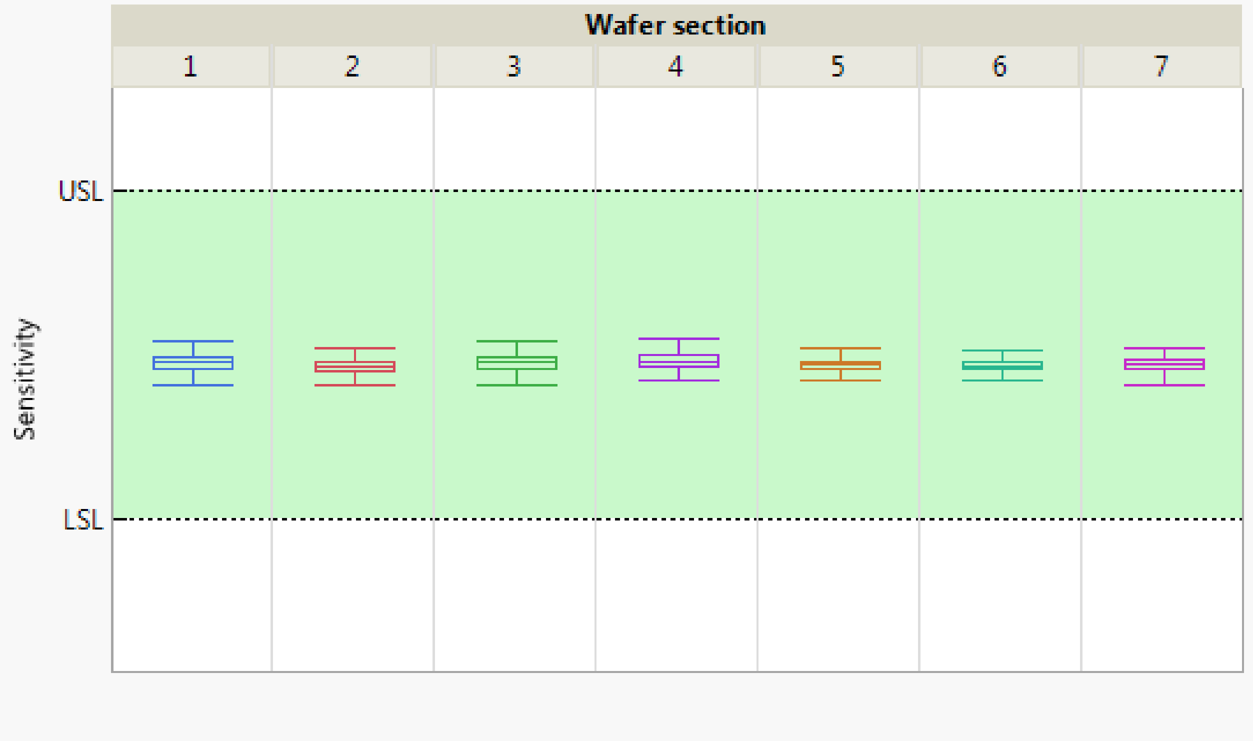
Variation of Laser Power

- Variation of the laser power of each single laser pulse
- Each 100 devices across one wafer
- Analysis of
    - Sensitivity → maximum sensitivity is the quality criteria
    - Offset → mismatches between sensor branches
    - Bridge resistance → overall indicator of sensor structural integrity



Homogeneity over one Wafer



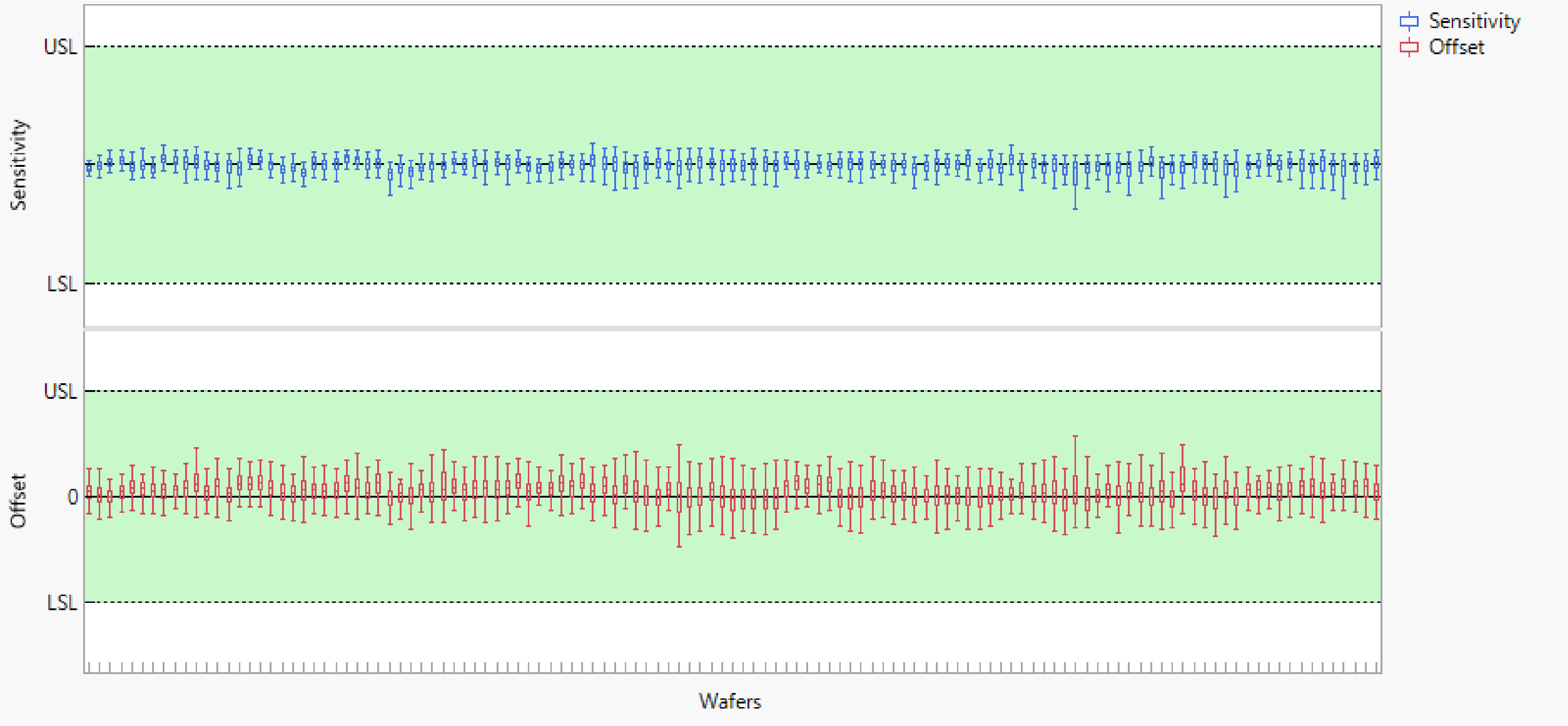


- Sensitivity evaluation over one wafer
- Evaluation of equal number of sensors in 7 lines
- Laser processing horizontal line by line

✓ Highly reproducible median sensitivity
✓ Narrow and reproducible sensitivity distributions

Wafer-to-Wafer Reproducibility

- Sensitivity and offset across wafer
- Sample size: 120 wafers



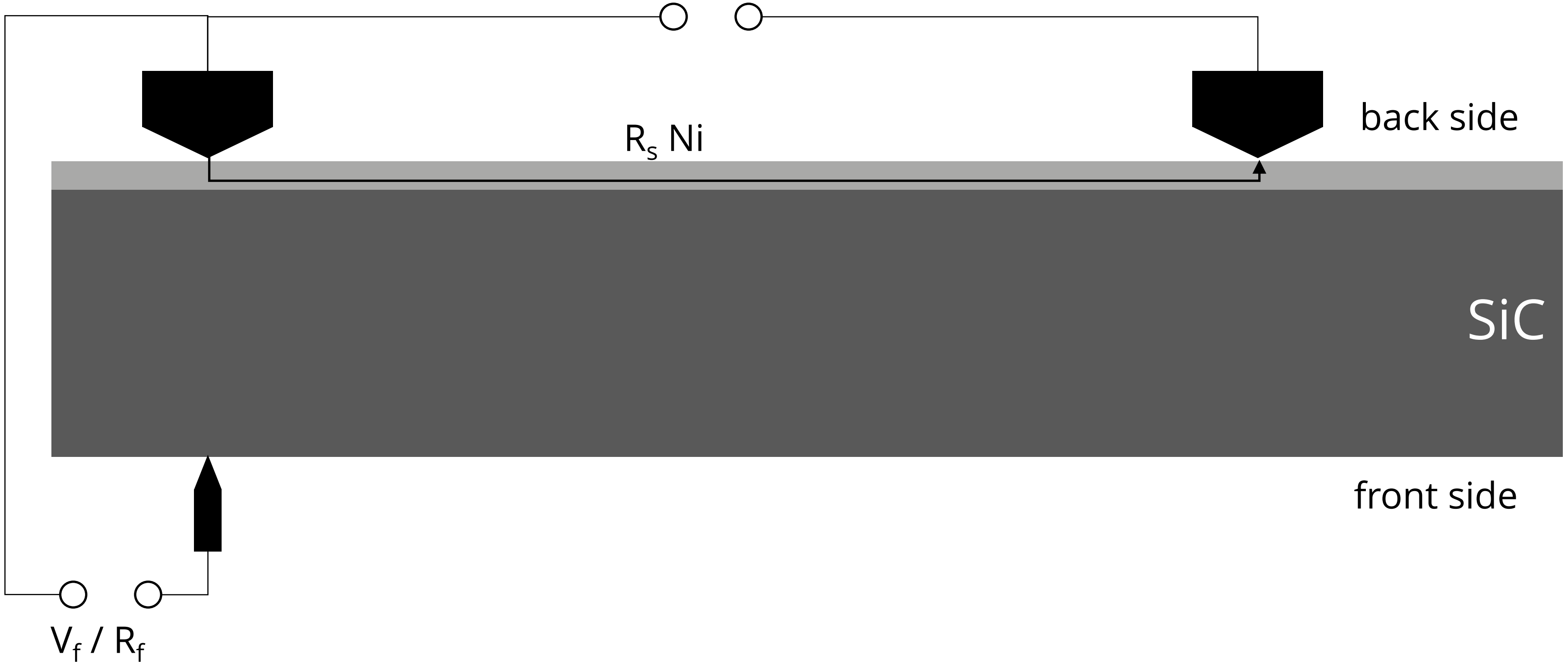
✓ Sensitivity uniformity **below 2%**
✓ Demonstrated for 120 wafers

Ohmic Contact Formation for SiC-Devices

Typical Use Cases for SiC-Devices

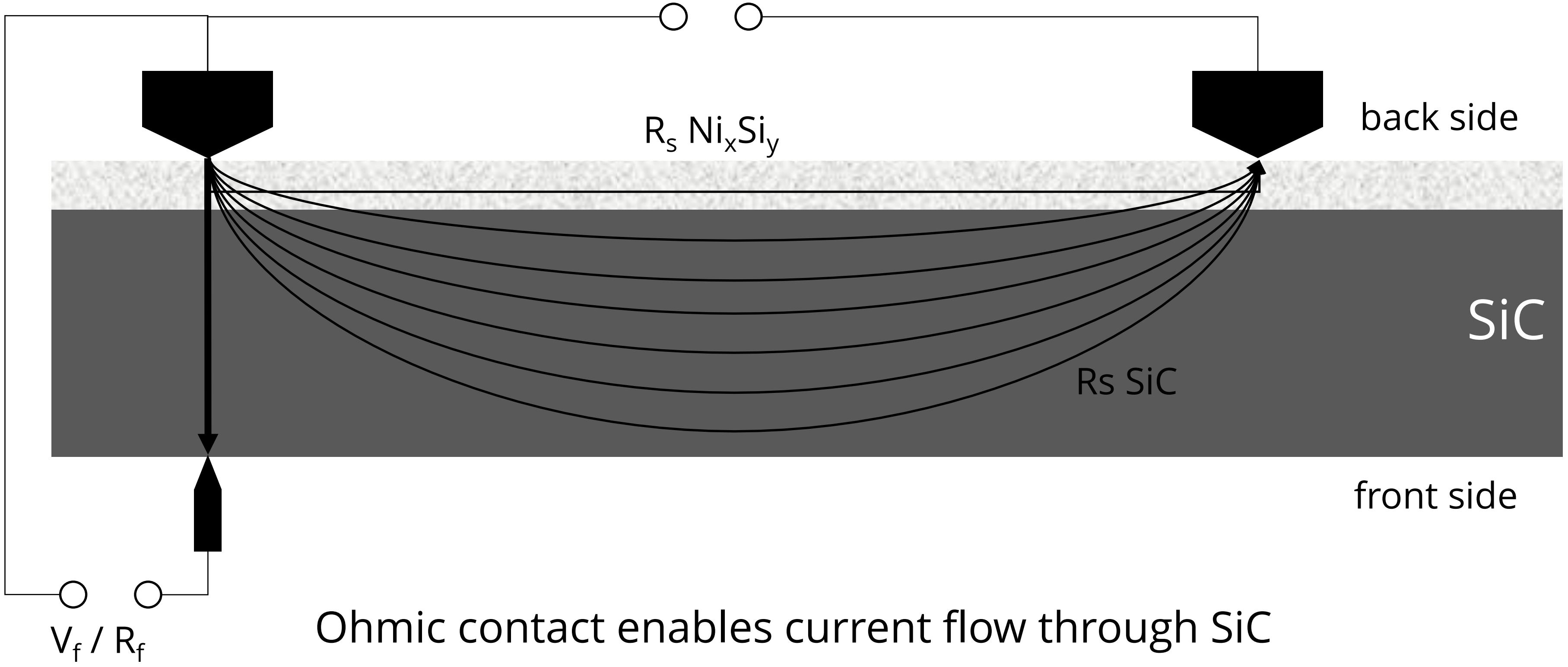
- 4H-SiC as substrate material is mainly used in power electronics
- For sensors the use of SiC as substrate material is best suited for
  - Harsh environemntents
    - High temperatures > 500 °C
    - Strong radiation
    - Chemically agressive media
  - UV Sensors (Photodiodes, UV CMOS)
  - Hall sensors
  - Quantum Magnetometers

Surface Resistance vs. Forward Resistance – Unannealed Condition



Schottky-Contact functions as diode at Metal-SiC interface

Surface Resistance vs. Forward Resistance – Annealed Condition



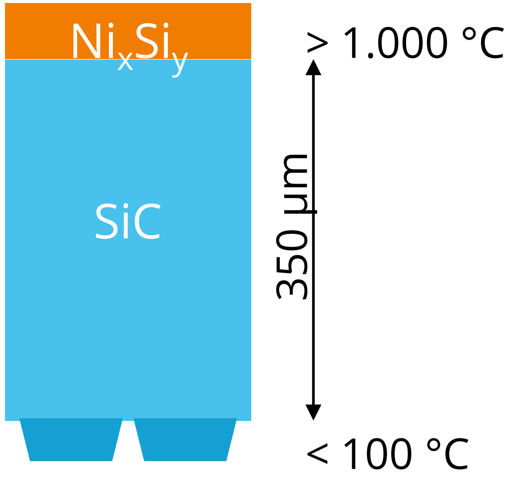
Ohmic contact enables current flow through SiC

Results R_s < 0.6 Ohm/sq @ 350 µm SiC are deemed good.

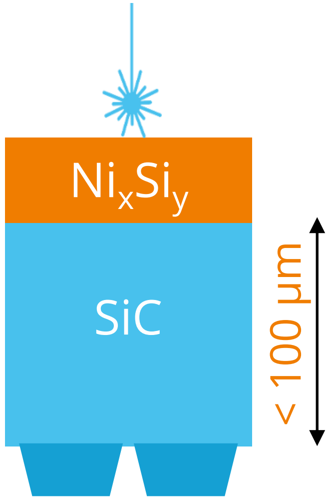
Fluctuations in the actual values below 0.6 are attributed to the material

Main Technologies for Ohmic Contact Formation

- RTP Processes
  - Reference process on frontside
  - Homogenuous layer thickness across wafer
  - Temperature > 900° C
  - No carbon difussion to surface du to low energy
  - Not suited for thin wafers

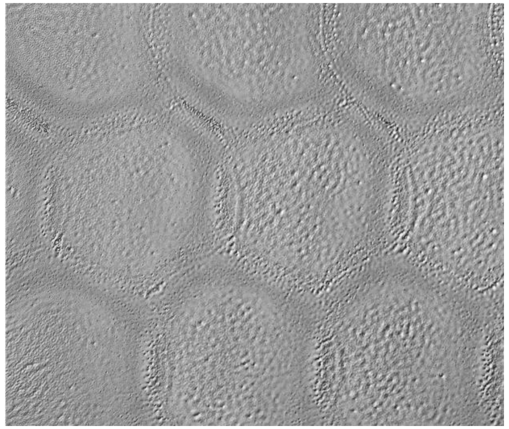


- Laser annealing
  - 355 nm DPSS or 308 nm Excimer Laser
  - Temperature > 1400 °C at backside interface
  - Temperature < 100 °C at backside interface → suitable for thin wafers
  - carbon difussion towards surface → etching step recommended

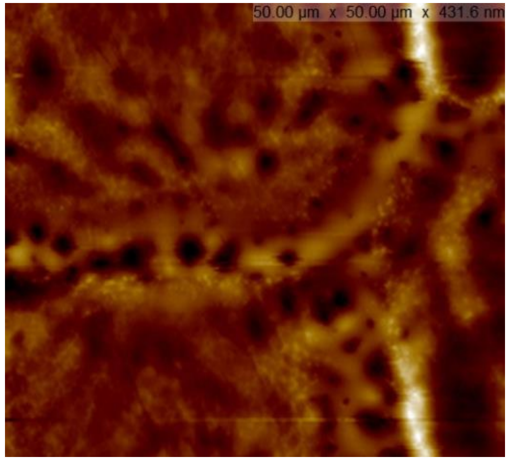


Methods of Material Analysis

Surface morphology

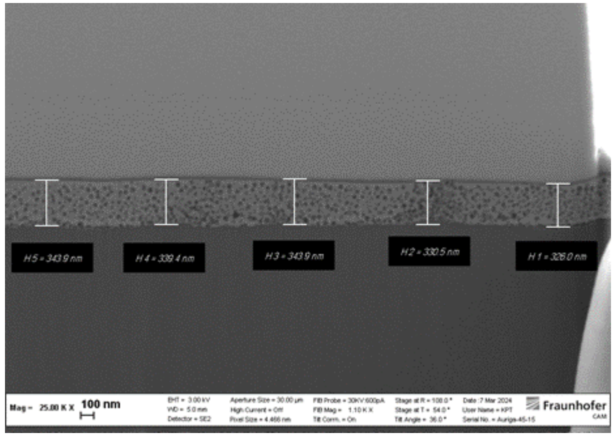


Optical / Laser scanning microscopy

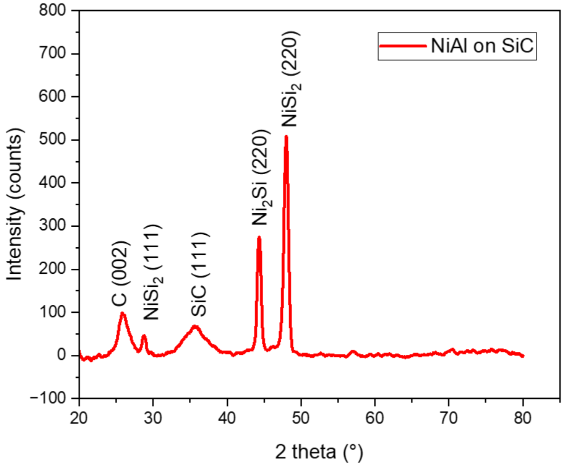


AFM surface roughness

Interface composition

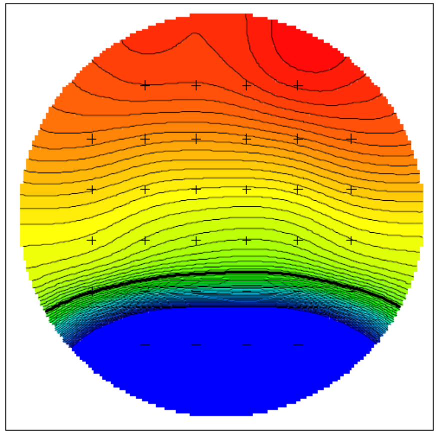


FIB cuts + SEM

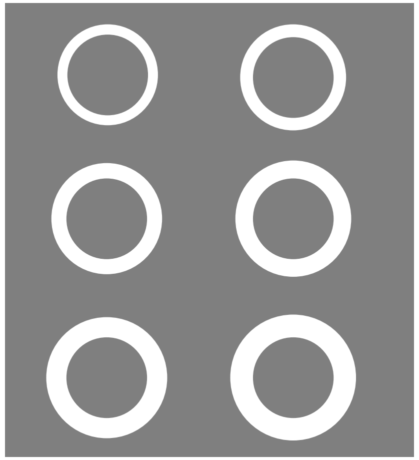


XRD-Spectroscopy

Electrical performance



Sheet resistance



Contact resistance (CTLM)

Application Results

Application results 60nm Ni on 350 µm SiC Wafer

- 355 nm DPSS ns laser
- 100 µm top hat spot
- Adjustable pulse and line overlap (10% … 50%)

→ Significant higher throughput possible

6” up to 21 WPH

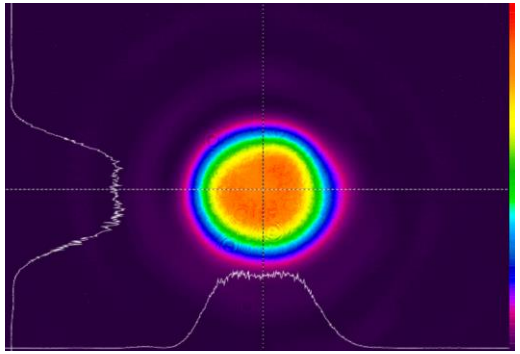
8” up to 11 WPH

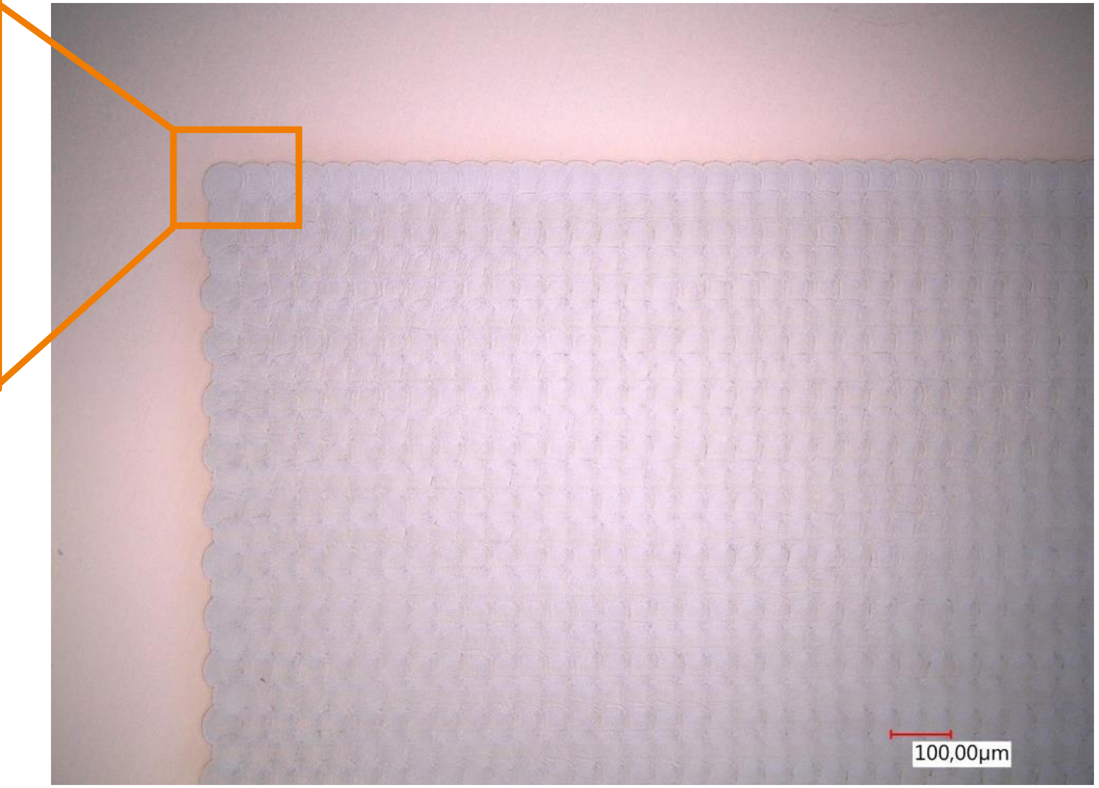
→ Typical surface roughness

$R_a \approx 30$ nm

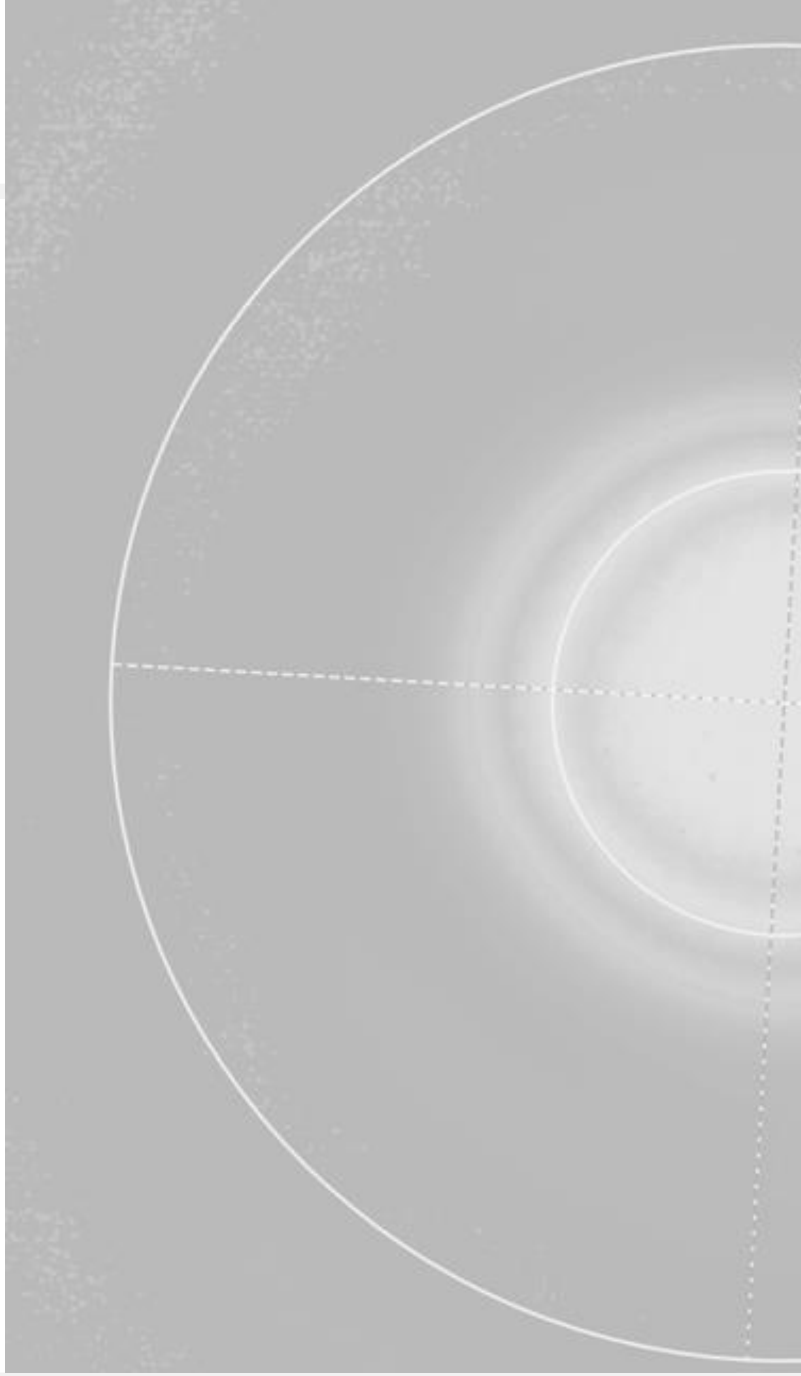
→ Typical uniformity

σ < 1,1 %



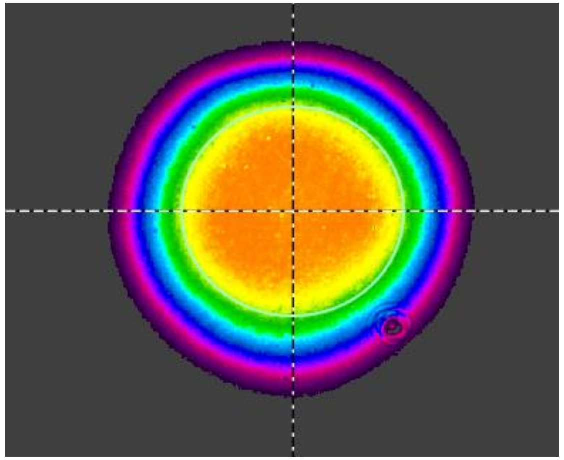


Available Beam Shapes for Process

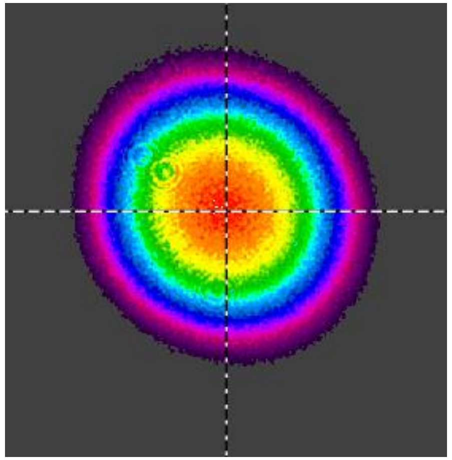


Beamshaping

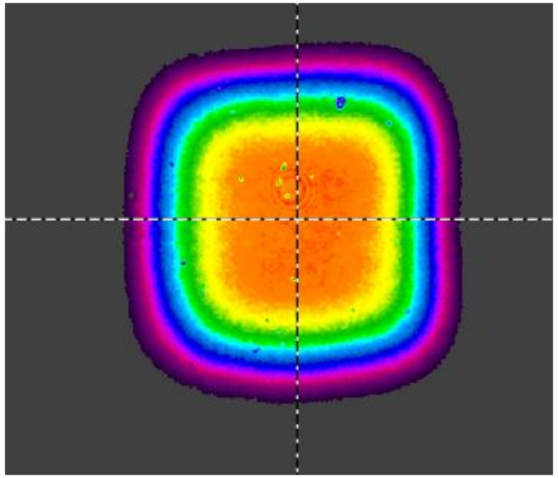
- OCF can be performed with different beamshapes
- Each tool can switch between gaussian and flat-top beam by customer
- Shape of flat-top has to be selected at purchase or requires service after installation



Flat-top - round



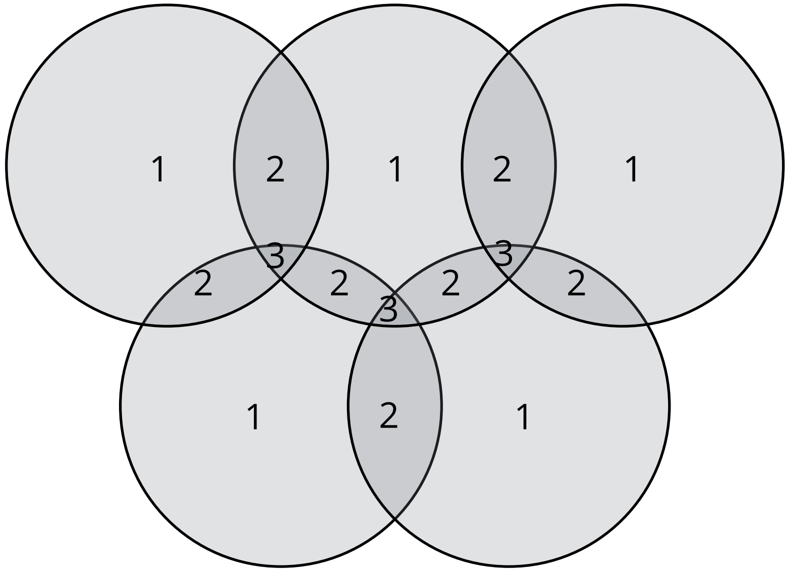
Gaussian



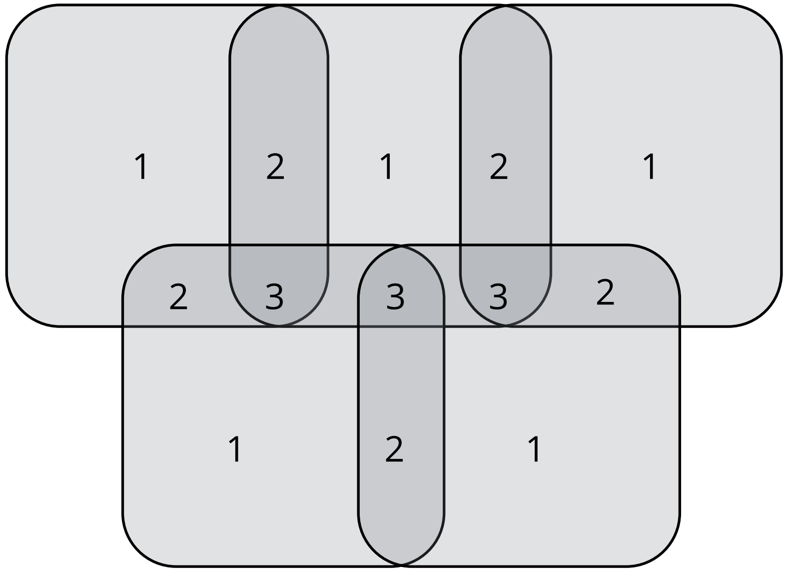
Flat-top - square

Overlap Depending on Beam Shape

- The selection of the beam shape impacts the size and distribution of overlap regions
- Square shape shows larger overlap areas but is more resilient towards positioning tolerances



Round



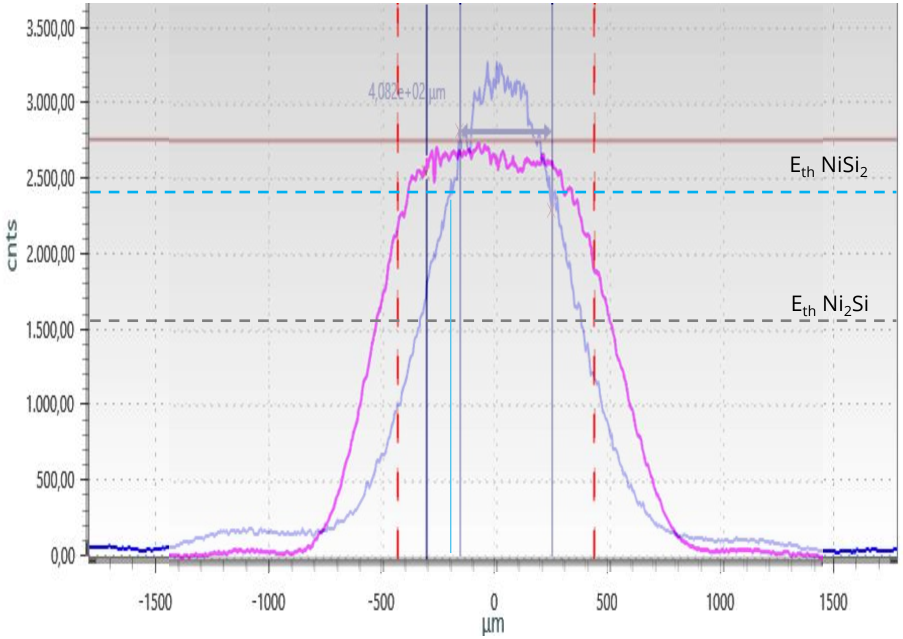
Square

Comparison Energy Level – Gaussian vs. Flat-Top

- Gaussian beam shows higher peak intensity
  - Required energy tresholds exceeded at lower power levels
- Flat-top beam redistributes energy more towards the flanges
  - Beam size at similar energy level is larger
- Various energy thresholds for the formation of Ni_xSi_y-phases are exceed in different positions

Gaussian FWHM pk = 68 μm

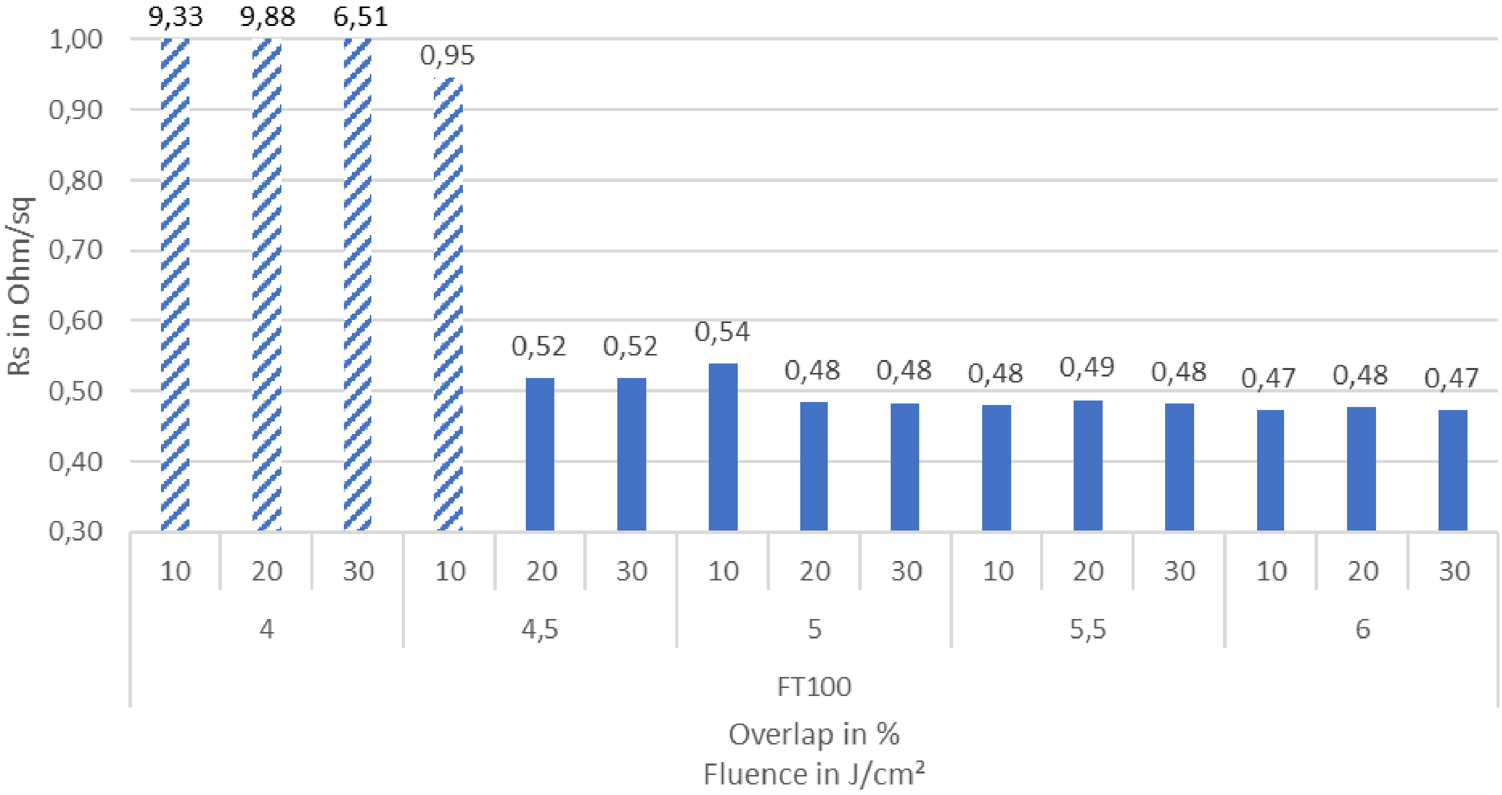
Flat-Top FWHM pk = 103 μm



Beam profiles measured at same power

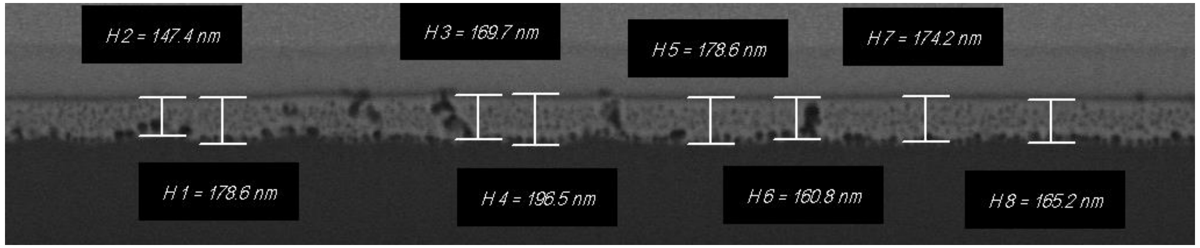
Results with a Flat-Top Beam

Long Pulsed Laser - Overview Sheet Resistances with Flat-Top Beam

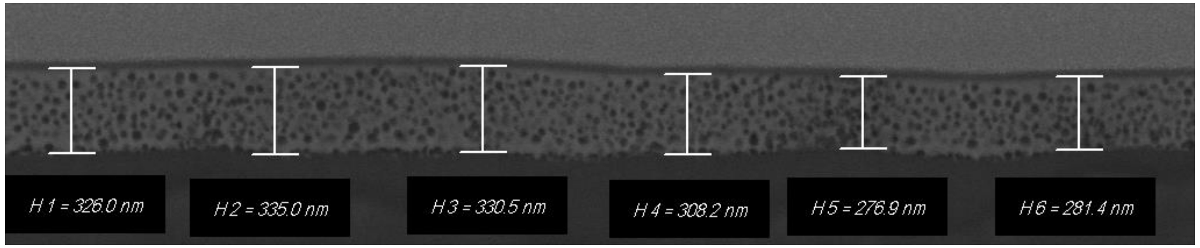


- 4H-Sic 350 µm thick
- 60 nm NiAl (2.6%)

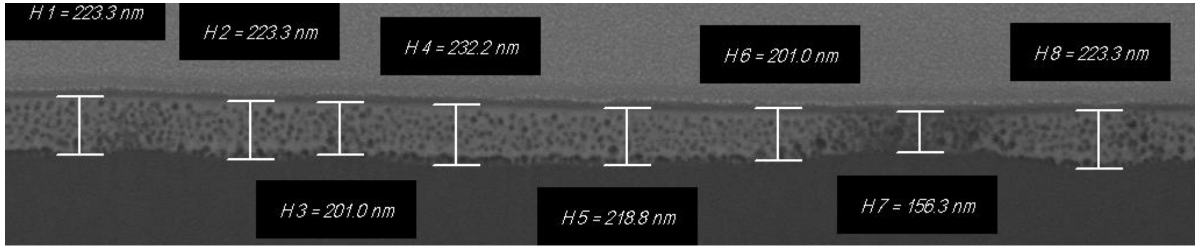
Long Pulsed Laser - Center Area of Laser Spots



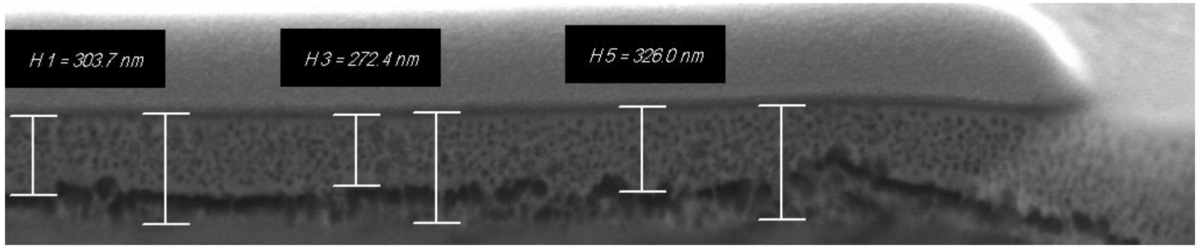
3.8 J/cm^2 20% 11,1 Ohm/sq



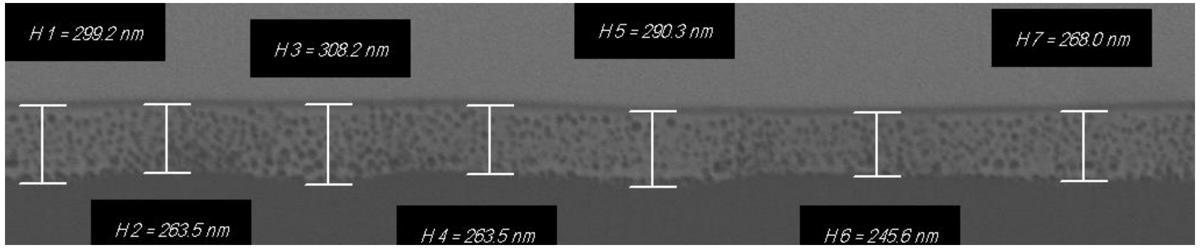
5.5 J/cm^2 20% 0,55 Ohm/sq



4.4 J/cm^2 20% 0,58 Ohm/sq

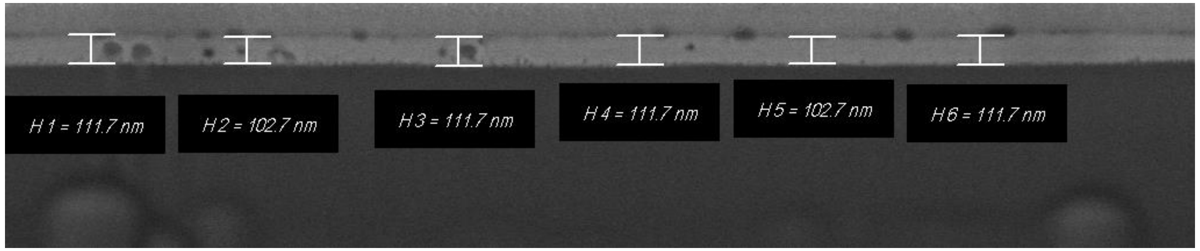


5.5 J/cm^2 50% 0,56 Ohm/sq

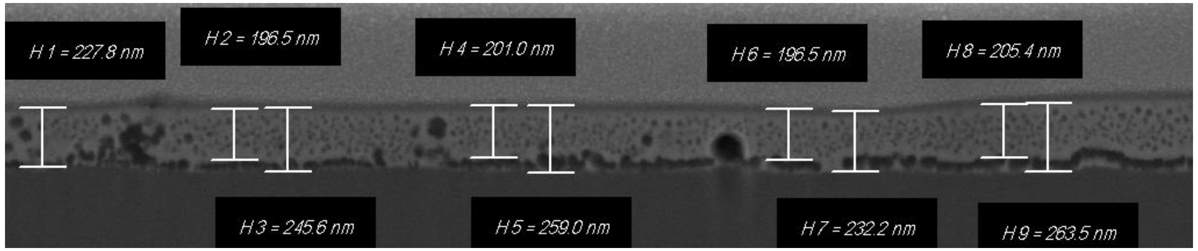


5.0 J/cm^2 20% 0,48 Ohm/sq

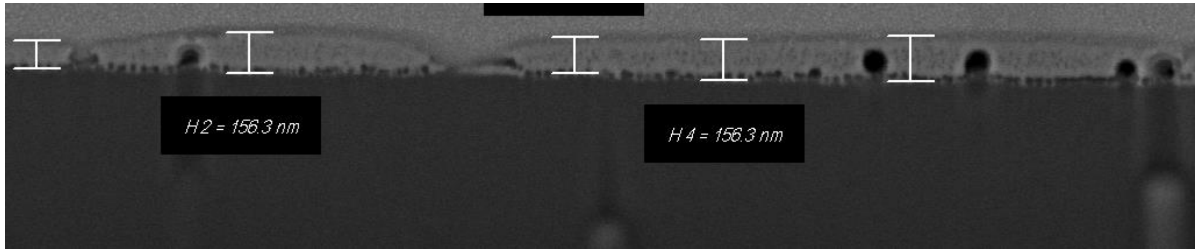
Long Pulsed Laser - Middle of Overlap Region of Laser Spots



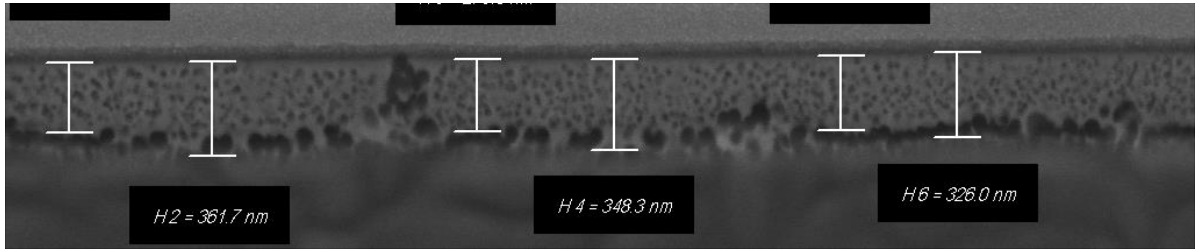
3.8 J/cm^2 20% 11,1 Ohm/sq



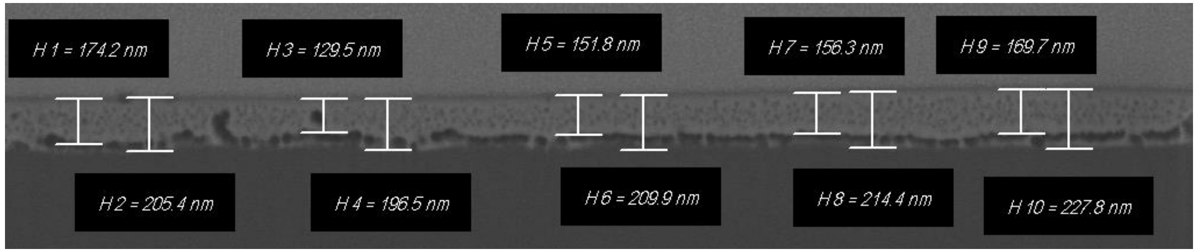
5.5 J/cm^2 20% 0,55 Ohm/sq



4.4 J/cm^2 20% 0,58 Ohm/sq



5.5 J/cm^2 50% 0,56 Ohm/sq



5.0 J/cm^2 20% 0,48 Ohm/sq

Comparison of Ni_xSi_y Interface With Flat-Top Spots – SEM / XRD

5.5 J/cm² /20%

0,55 Ohm/sq

5.0 J/cm² / 20%

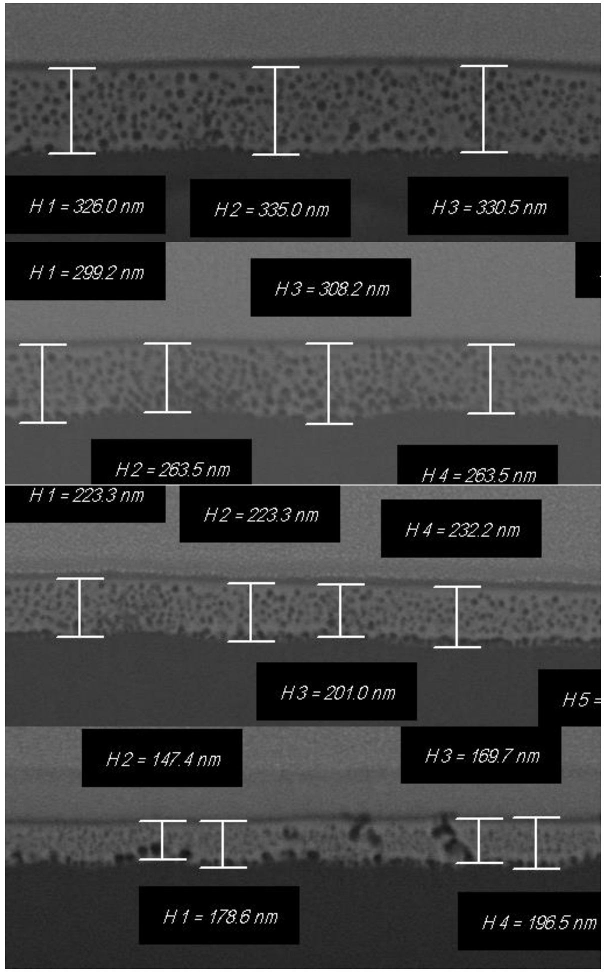
0,48 Ohm/sq

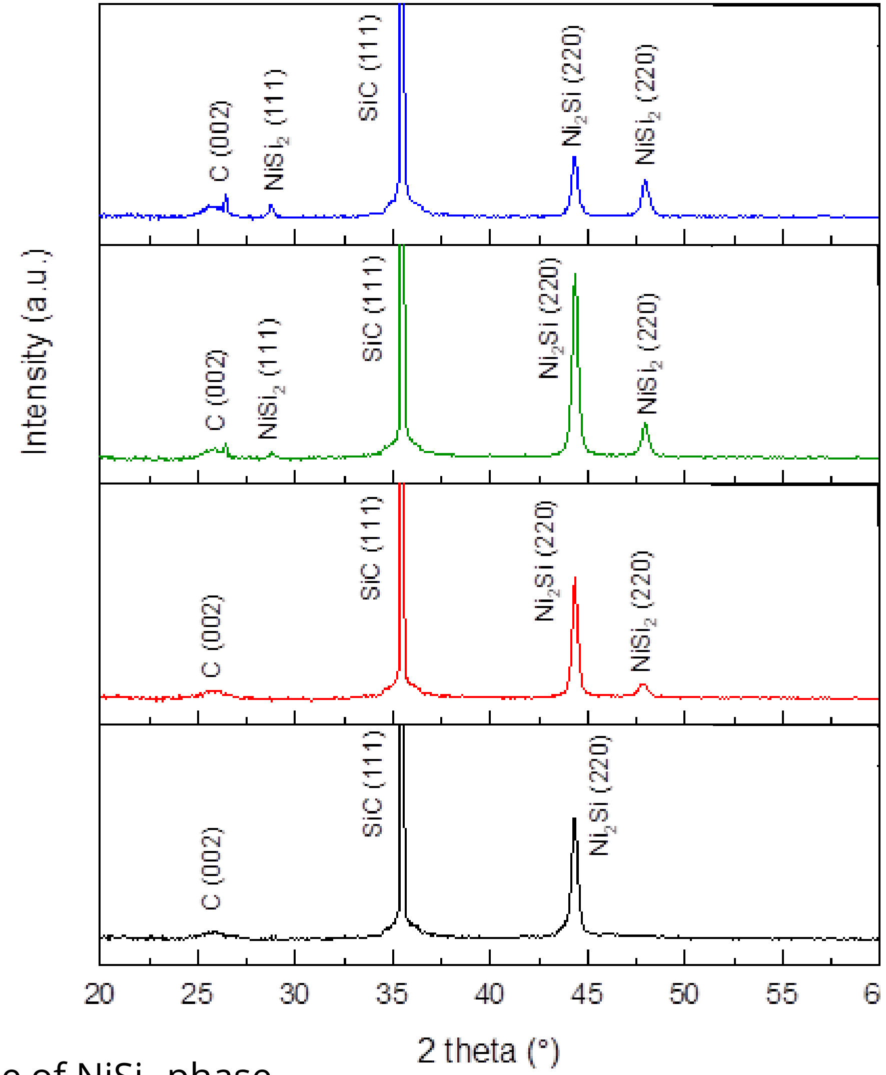
4.4 J/cm² / 20%

0,58 Ohm/sq

3.8 J/cm² / 20%

11,1 Ohm/sq

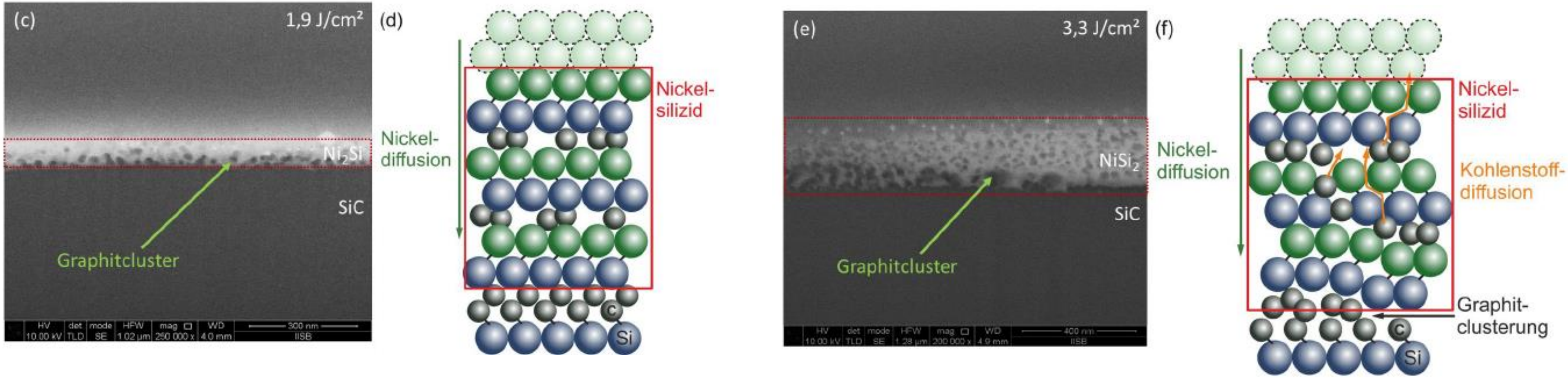




Increase of fluence results in increase of $NiSi_2$ phase

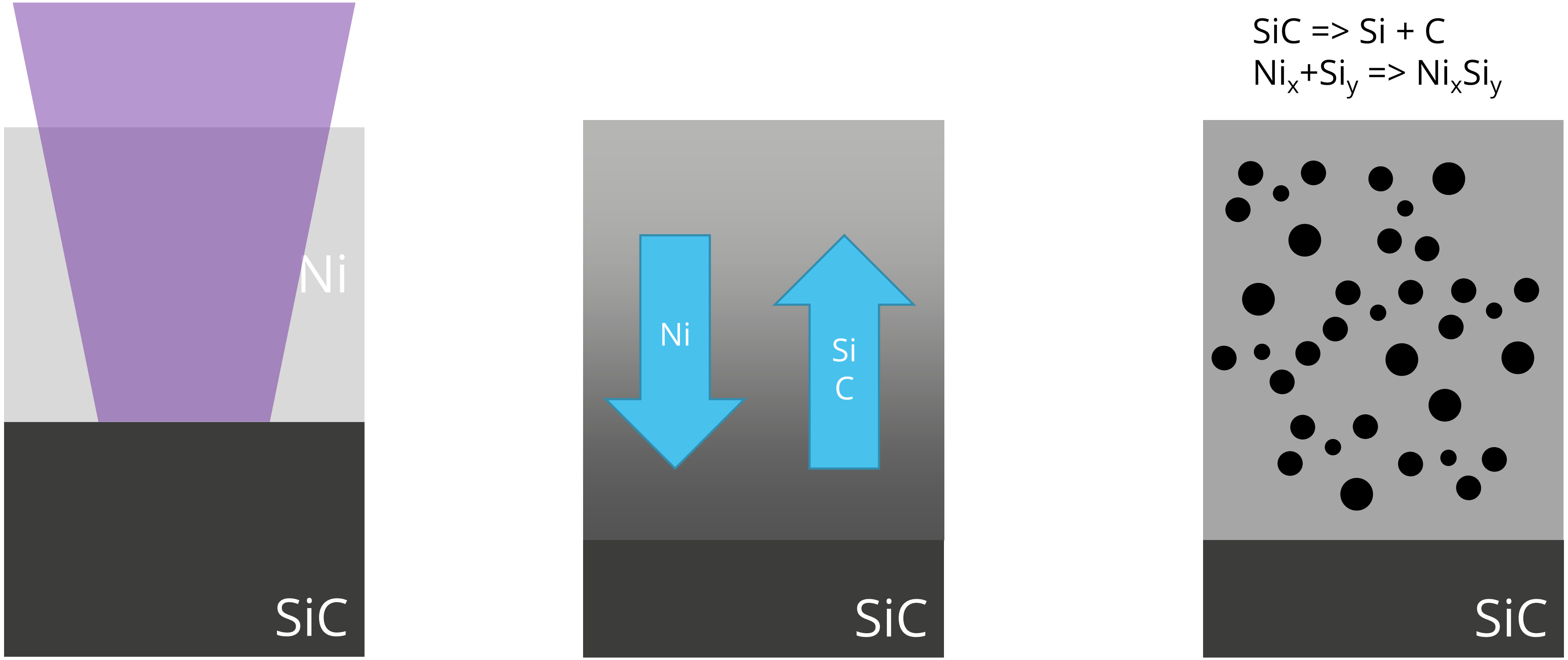
Impact of Overlap

Ni_xSi_y @ IISB – Dissertation Hellinger 2023



- Nickeldiffusion is dominating in the beginning
- Carbon diffusion and clustering starts later

Thesis: Explanation for C-Layer at Overlap – First Pulse

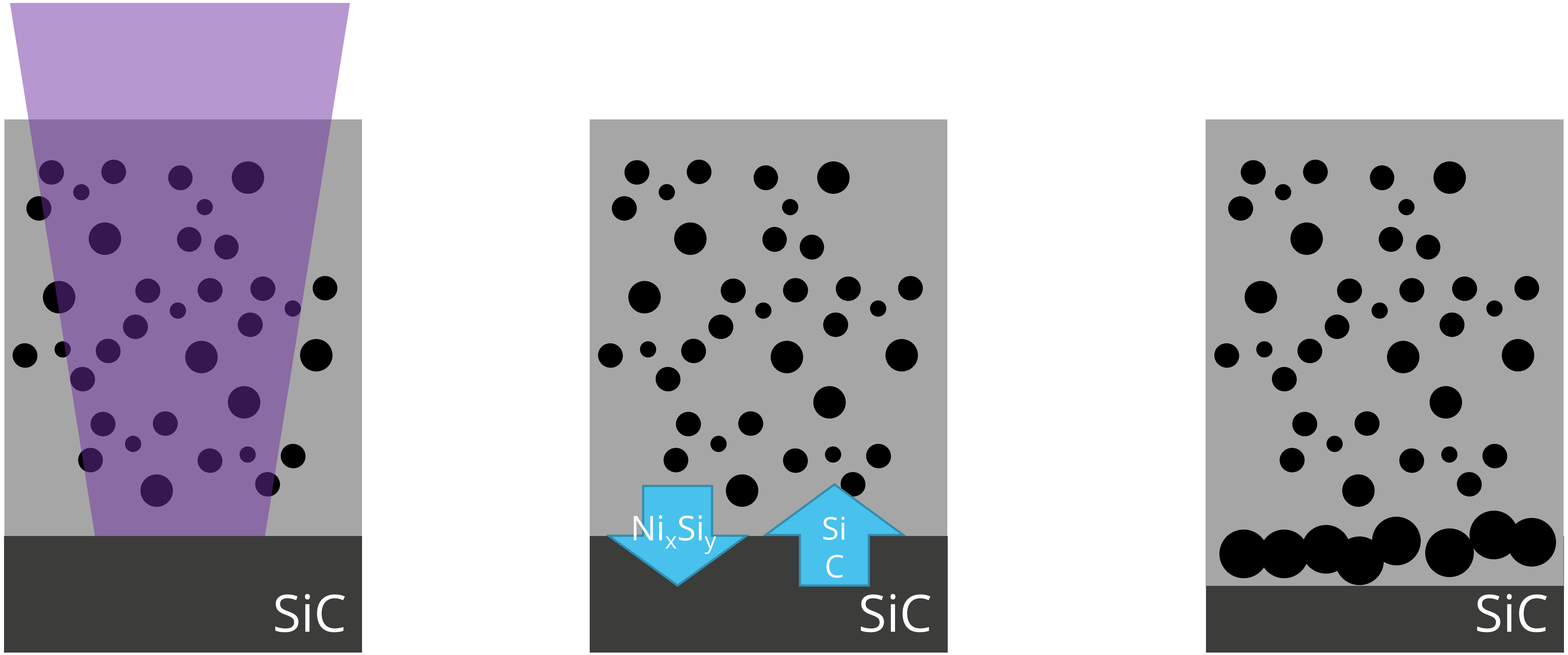


$SiC \Rightarrow Si + C$

$Ni_x + Si_y \Rightarrow Ni_xSi_y$

Ni diffuses into SiC and Si diffuses to the top taking C with it leading to a homogenuous distribution of Carbon clusters.

Thesis: Explanation for C-Layer at Overlap – Second Pulse



No significant material diffusion transporting Carbon beyond interface is observed.
Pre-reacted Ni_xSi_y functions as a diffusion barrier for Carbon.

Synthesis

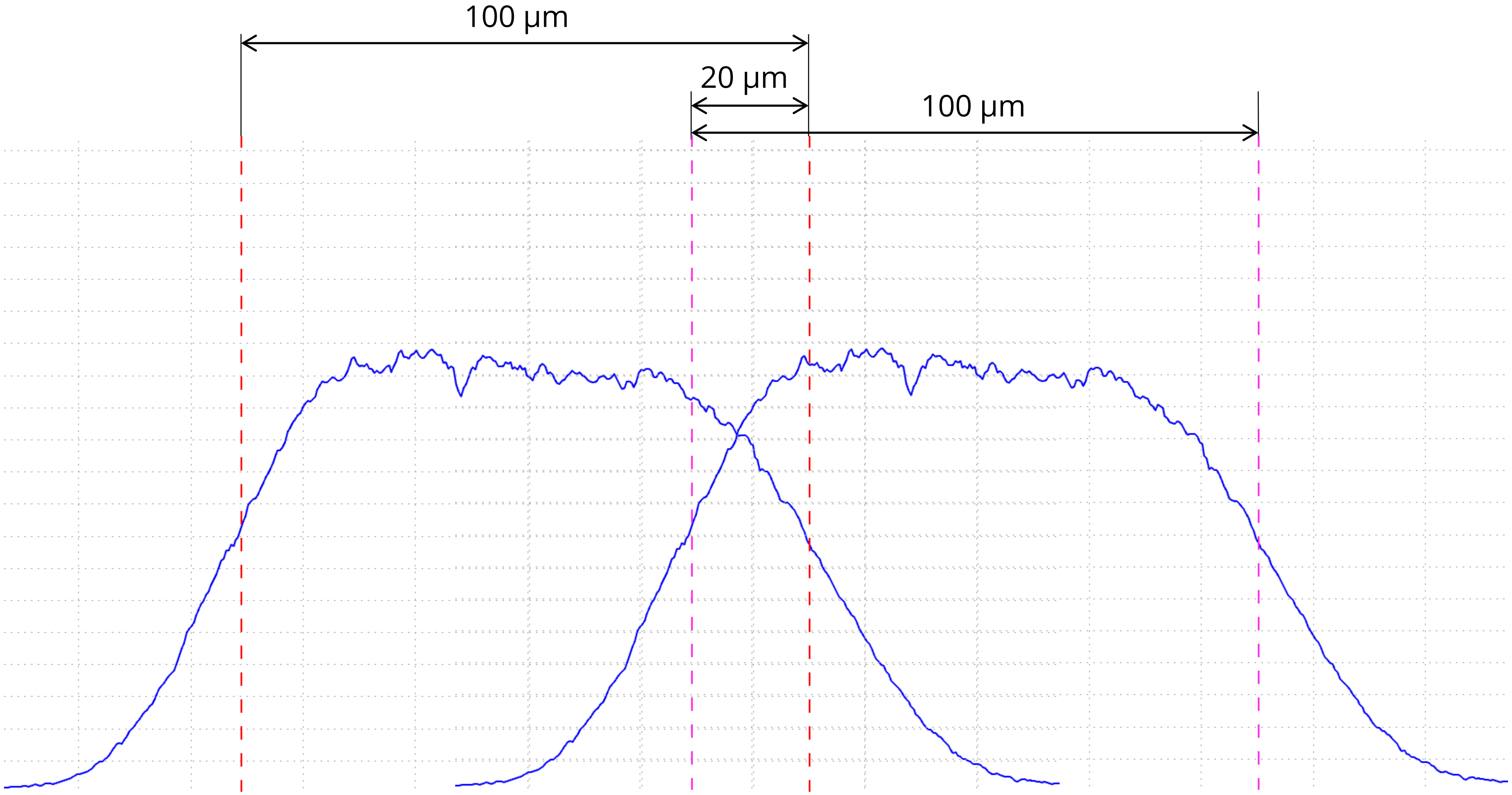
- Type and thickness of Ni_xSi_y-Phase can adjusted by fluence mainly
    - Fluence value should be high enough to compensate for tolerances on the flat-top (10% change in energy distribution is realisitic)
    - Typical process window 5.0 +-0,5 J/cm²

- Overlap leads to the formation of a “new“ Ni_xSi_y underneath the initially formed layer
    - Majority of material has reacted already in first pulse
    - New layer consists likely of $NiSi_2$ and trapped carbon
    - Target overlap < 30%

- Carbon diffusion to the surface is dominated by fluence but also increases in overlap areas

Thesis: Process Explanation
Low Overlap

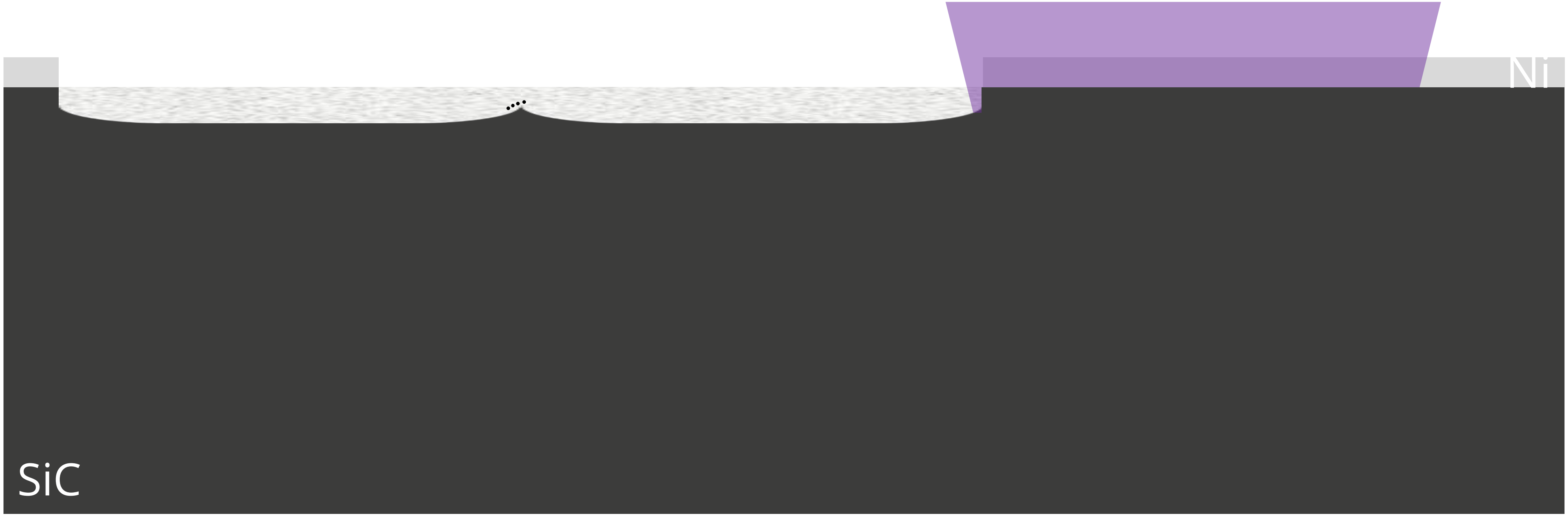
Process Explanation Low Overlap: Overlap 20%



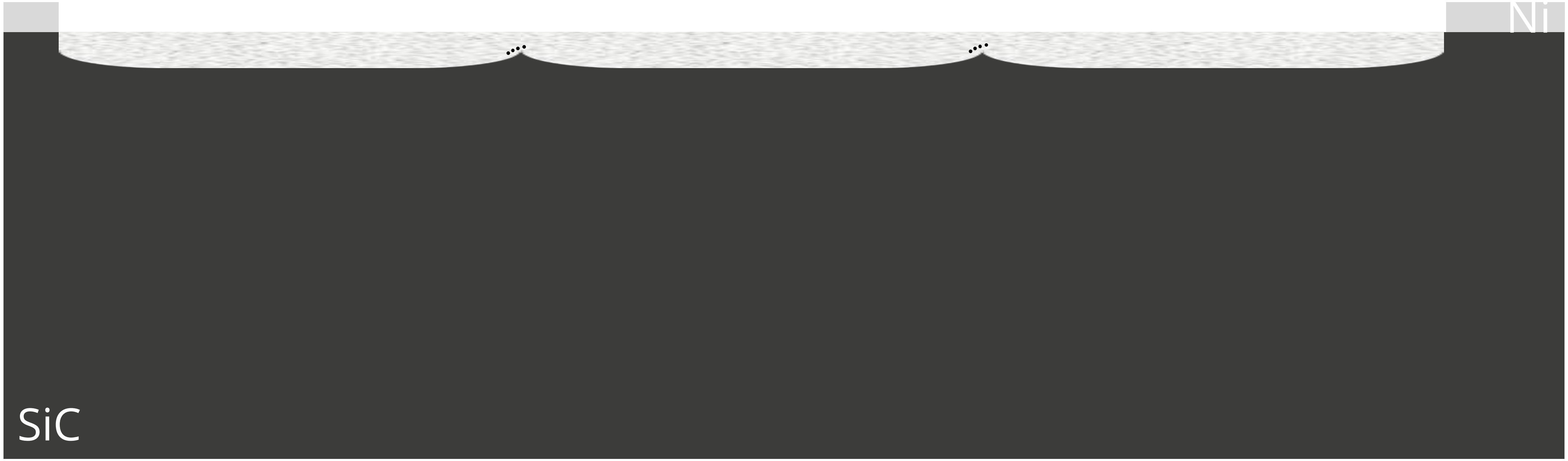
Process Explanation Low Overlap

Process Explanation Low Overlap

Process Explanation Low Overlap

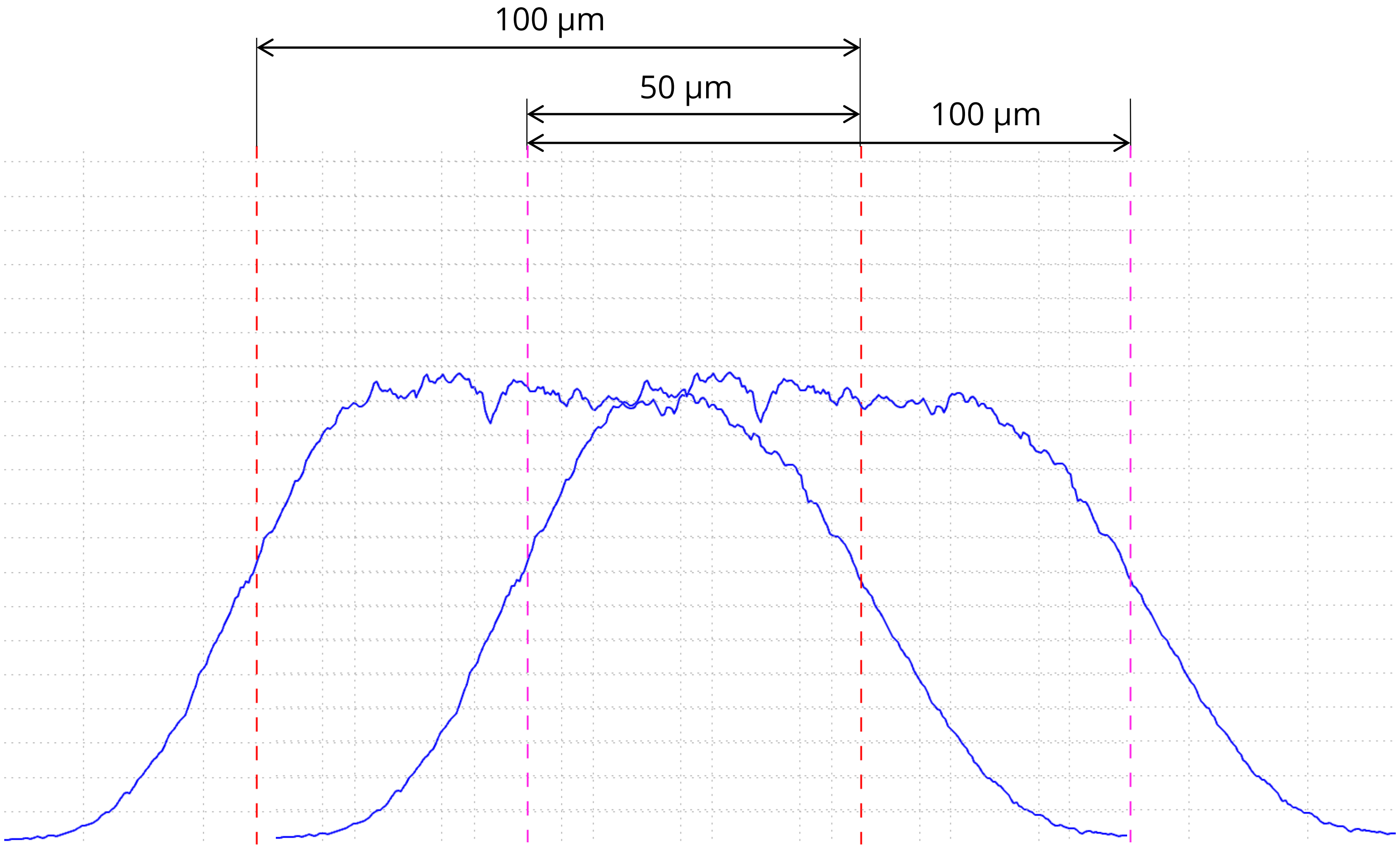


Process Explanation Low Overlap



Thesis: Process Explanation High Overlap

Process Explanation High Overlap: Overlap 50%



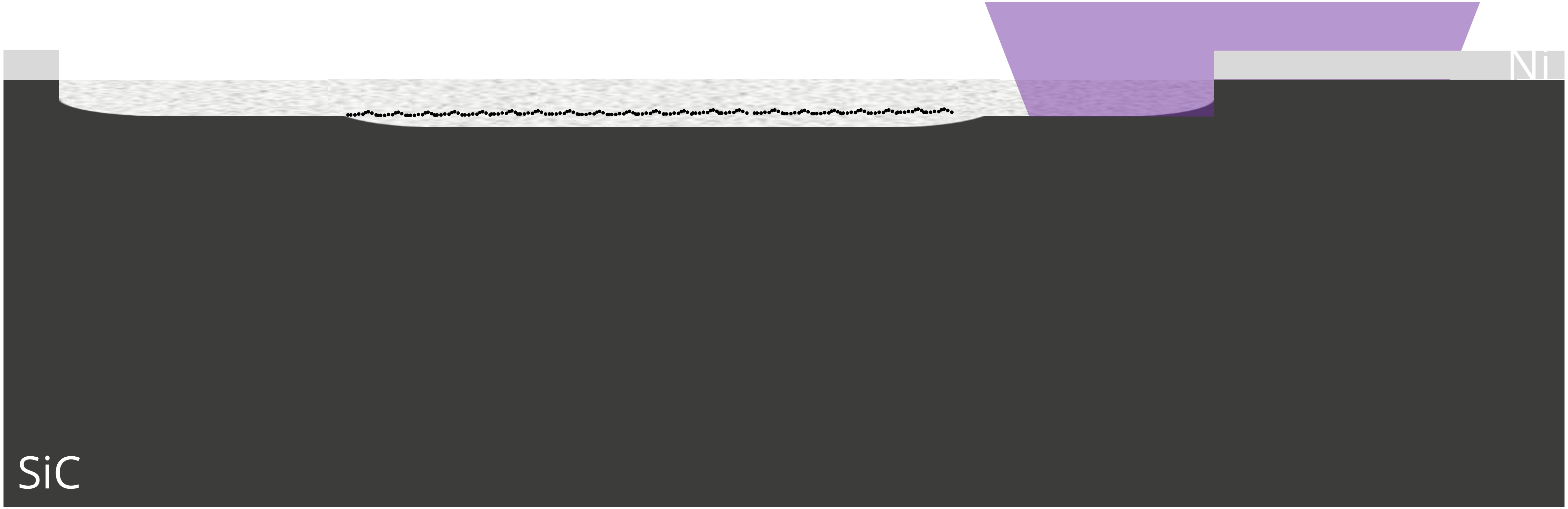
Process Explanation High Overlap

Process Explanation High Overlap

Process Explanation High Overlap

Process Explanation High Overlap

Process Explanation High Overlap



Process Explanation High Overlap

Summary

Laser Annealing – Summary

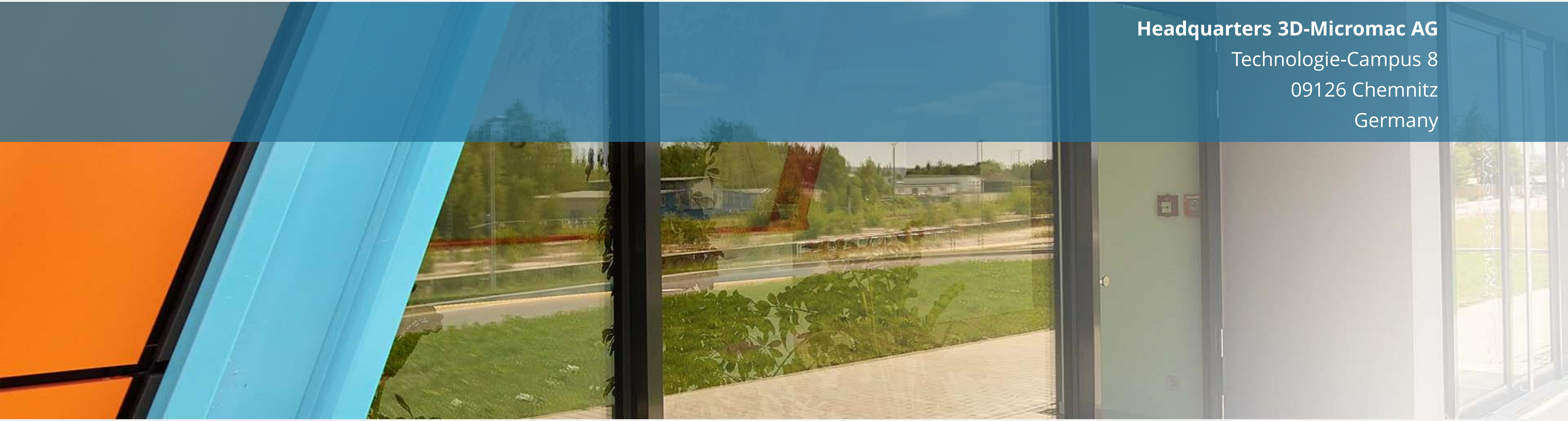
- **Cost-efficient production** of integrated sensor chips/devices in just one production step
- Very high energy homogeneity - resulting in **robust process windows**
- Unique selectivity and maximum precision for **more devices per wafer** or **new device designs**
- High temperature gradient allows annealed areas to be positioned directly **next to active electronic instruments**
- **Easy adjustment** of the annealing properties by recipe parameters
- High precision and high repeatability is **proven in 24/7 production**

microVEGA™ xMR

Thank you for your attention!

Maurice Clair
clair@3d-micromac.com

+49 371 400 43 0 *info@3d-micromac.com* *www.3d-micromac.com*



Headquarters 3D-Micromac AG
Technologie-Campus 8
09126 Chemnitz
Germany