FEM simulation applied to Thermal Laser Separation (TLS) with Deep Scribe for Silicon Wafer Dicing

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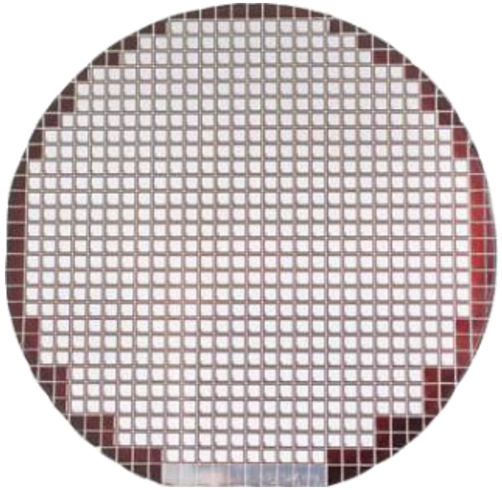
Outline/Agenda

- Motivation
- Principles of
  - Thermal Laser Separation
  - Deep Scribe
- FEM Simulation of Deep Scribe
- Experiments and Results
  - Parameter Study
  - Breaking Strength
- Conclusions

Motivation

How to separate a wafer into single chips?



[Karl O. Dohnke]

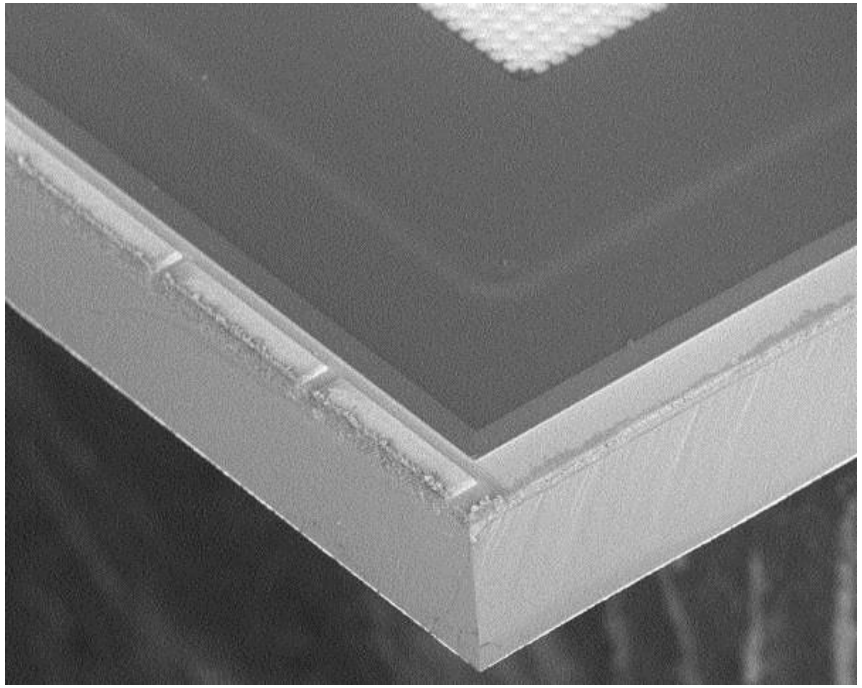
Motivation

- Established methods
  - E.g. Mechanical Blade Dicing, Laser Ablation, …
- Requirements depend on product
- Reduction cost of ownership
- Maximization of throughput and yield

Laser processes become more relevant

Approach TLS-Dicing®

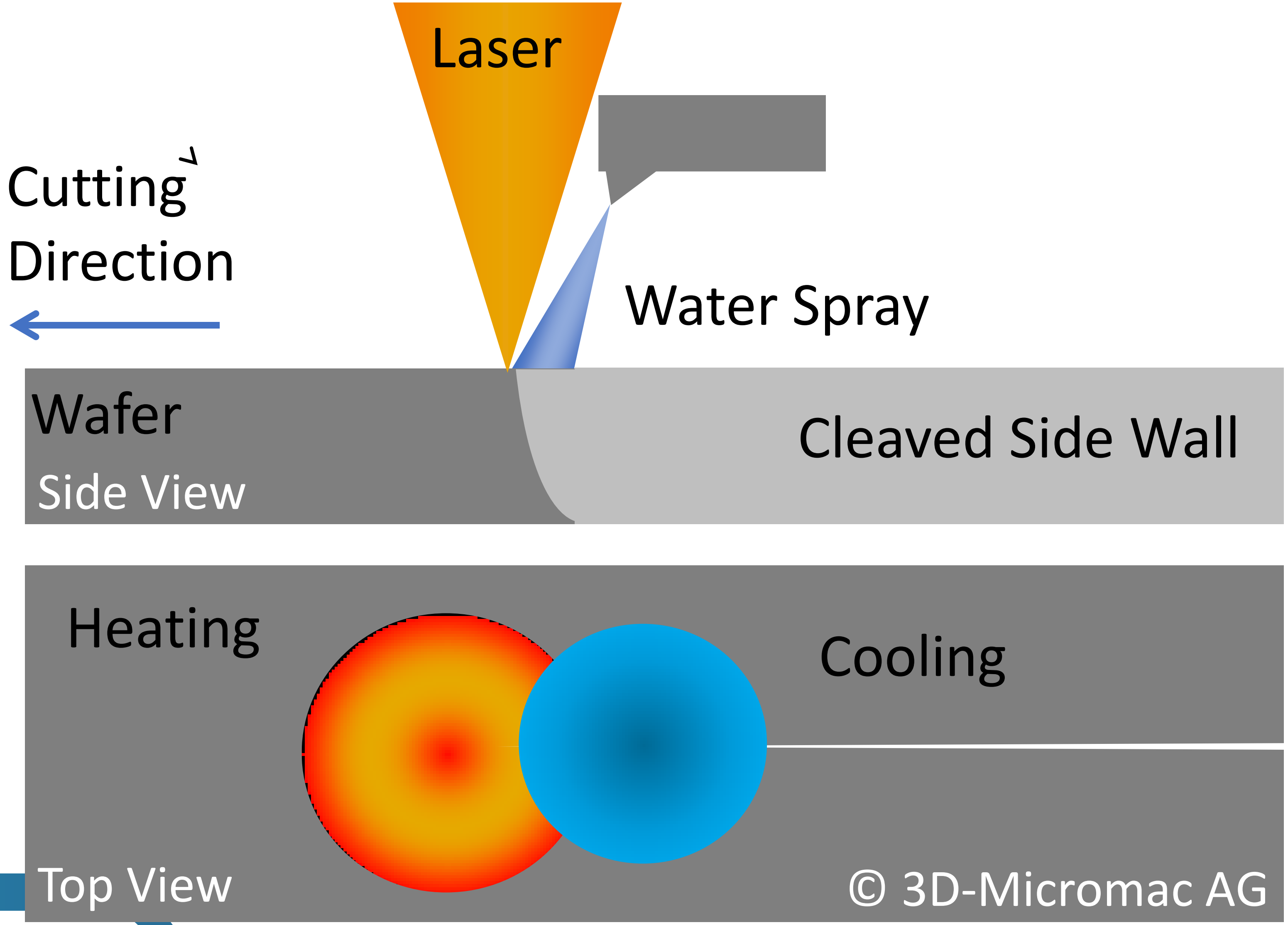
- Two steps (Scribe & Cleave)
- Contact-less & zero kerf
- Feed rates up to 400 mm/s
- High edge quality
- Low cost of ownership



JFET on µ4H-SiC-Wafer,
Thickness 160 m

→ Complex process, absorption depended

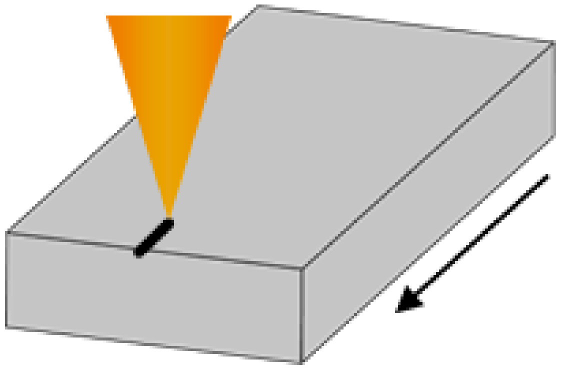
Principle of TLS

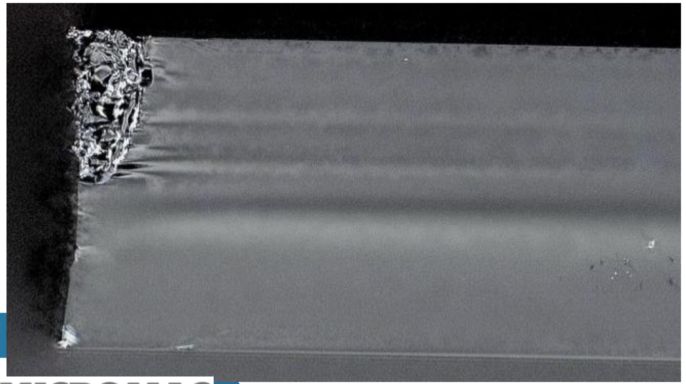


Thermal induced mechanical stresses creating and guiding a crack

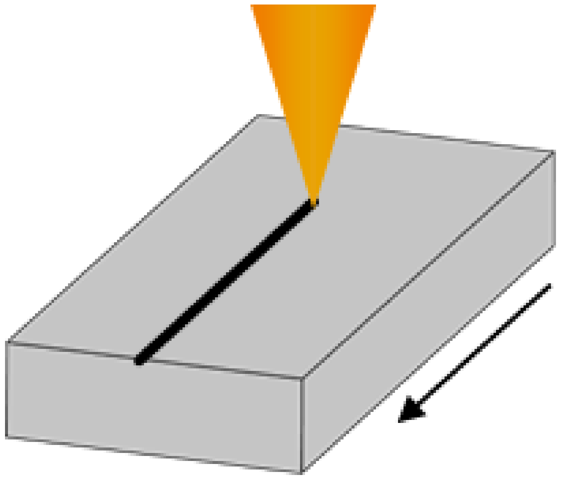
Starting point defined by scribe step

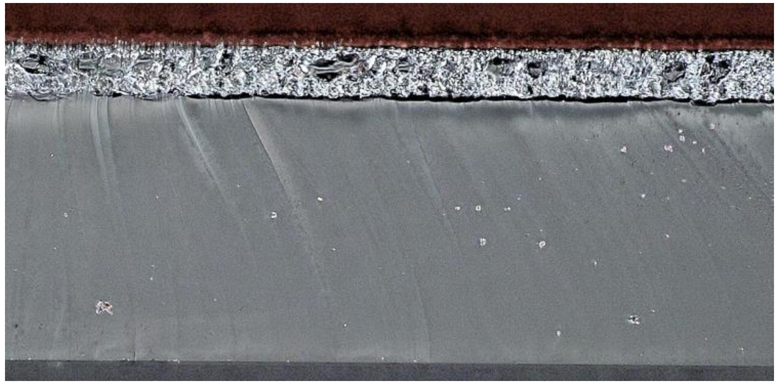
Initial Scribe



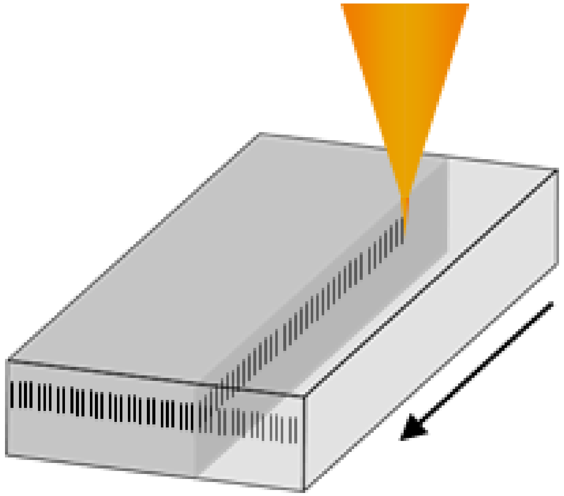


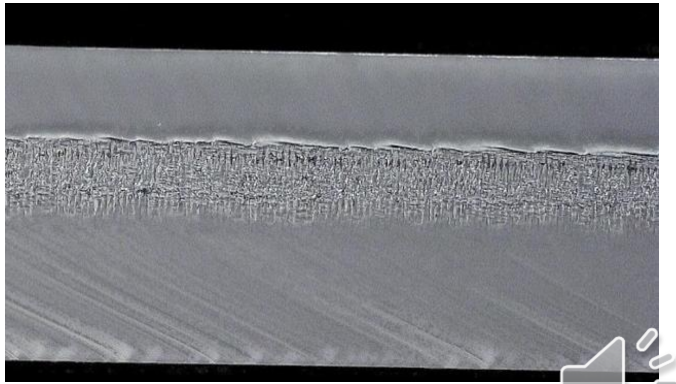
Continuous Scribe





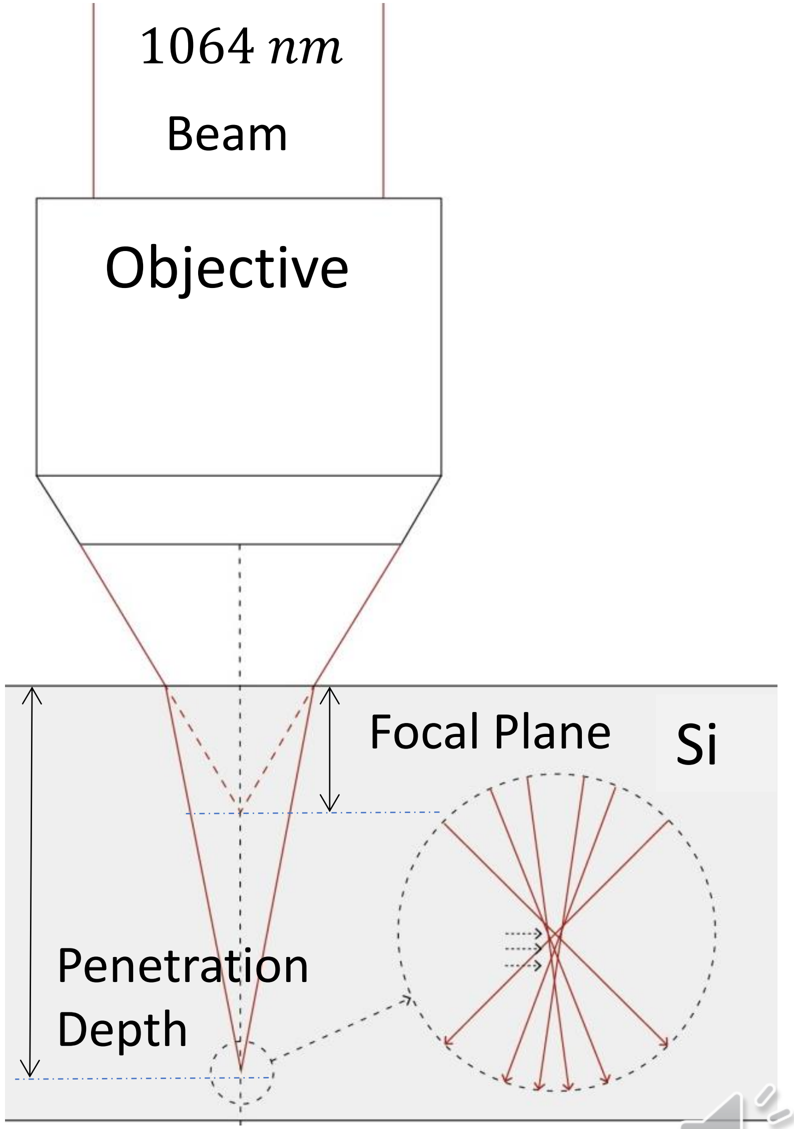
Deep Scribe





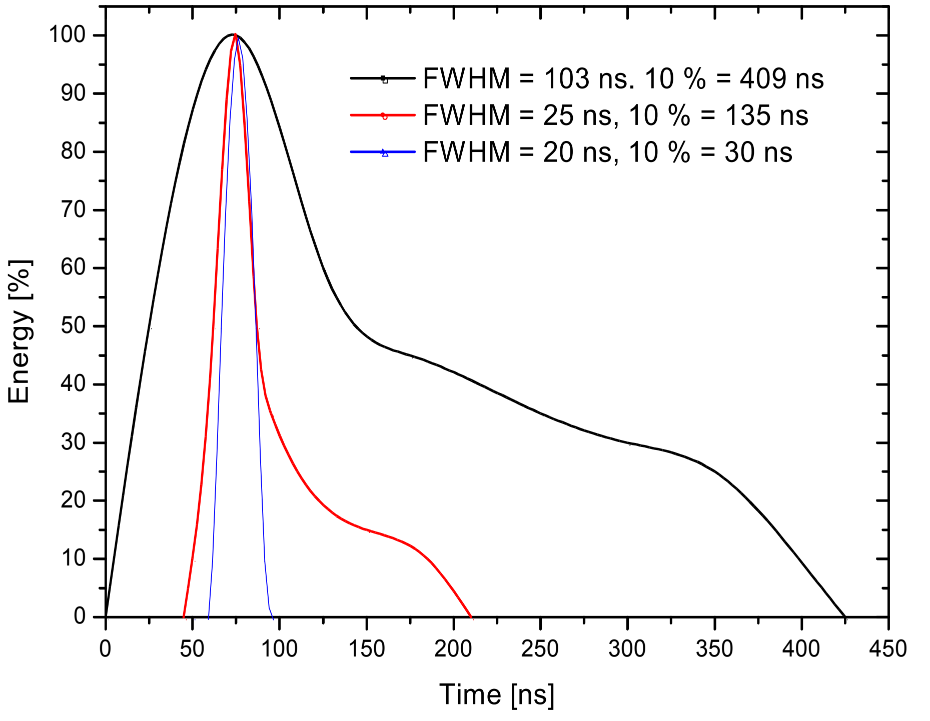
Principle of Deep Scribe

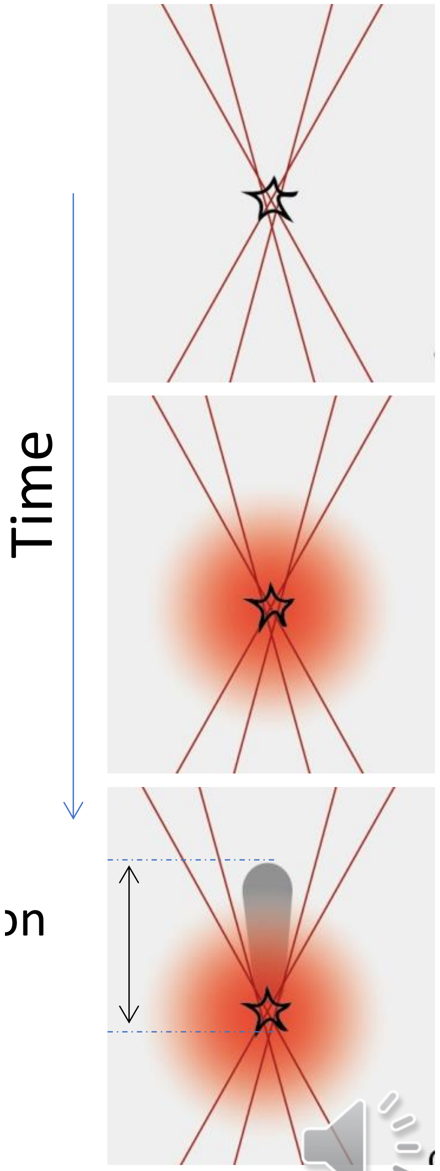
- Conservation: $R+A+T=1$
- Influence of surface
  - Reflection ($R = 0.35$)
  - Refraction ($n_{Si} = 3.56$)
  - Spherical aberration
- Enlargement of focal length and spot size
- Increasing depth - decreasing power
- Fluence at focal plane >> surface



Principle of Deep Scribe

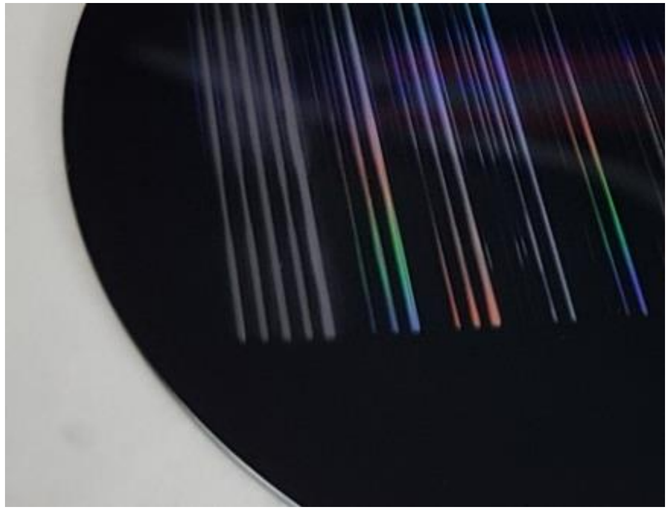
- Reaching threshold fluence
- Spontaneous increase of absorption
- Generating of free charge carriers
- Rising of temperature → lattice absorption
- Heat conduction
- Melting along caustic
- Modification depends on shape & duration of pulses





Requirements for Deep Scribe

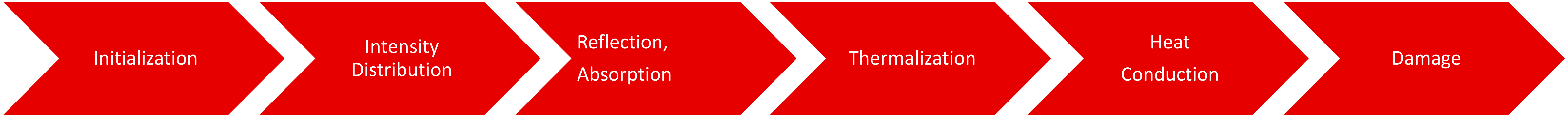
- Material properties
  - Polished surface, doping <$10^{20} cm^{-3}$
- Optical setup
  - $NA = 0.65$, correction of spherical aberrations
- $1064\ nm$ Laser
  - Sufficient shape & duration of pulses
- Correction of focal height
  - Measurement of topography
- Vibration damping of system



Simulation of *Deep Scribe*

- Multiphysical model using Octave
- Simulation of a single pulse
- Two-dimensional model in polar coordinates
- Parameter: E_p, t_p - w_0, z
- Determination of the modification length

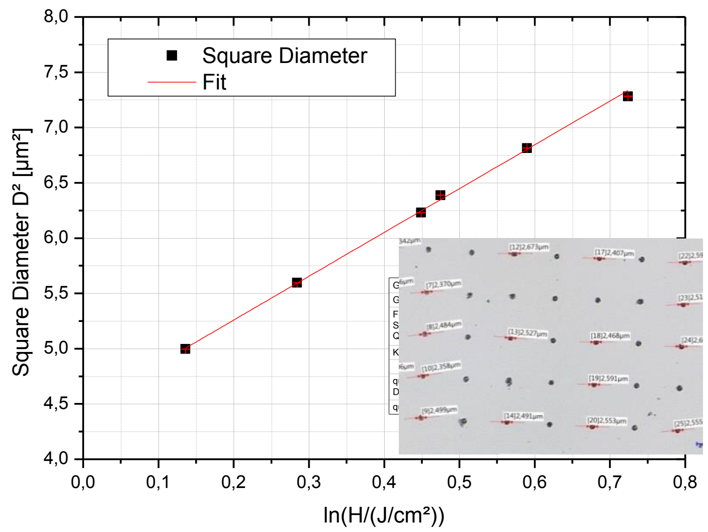
- Program Sequence



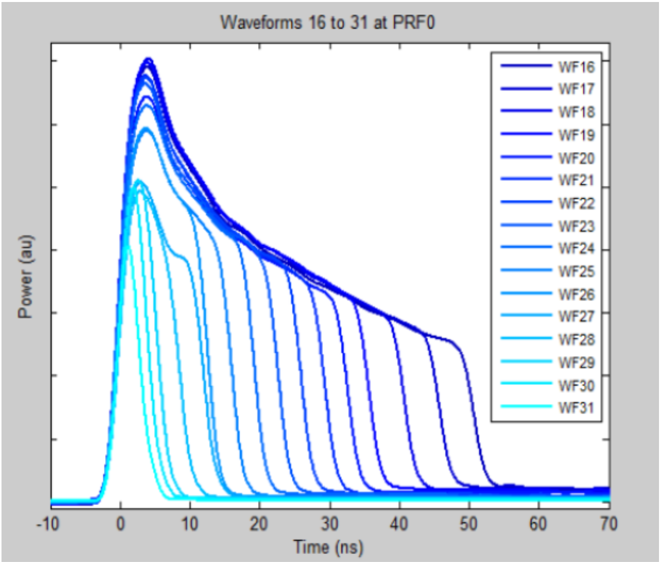
Optical Setup and Laser

- Calculation of beam caustic $w(z) = w_0 \cdot \sqrt{1 + \left(\frac{z \cdot \lambda \cdot M^2}{n_{Si} \cdot \pi \cdot {w_0}^2}\right)^2}$

- Verification spot size via LIU Plot
  - $calc\colon\ 2w_0 = 2.35\ \mu m\ \ vs.\, LIU\colon\ 2w_0 = 2.8\ \mu m \pm 0.3\ \mu m$



- Function fitting for various pulse shapes

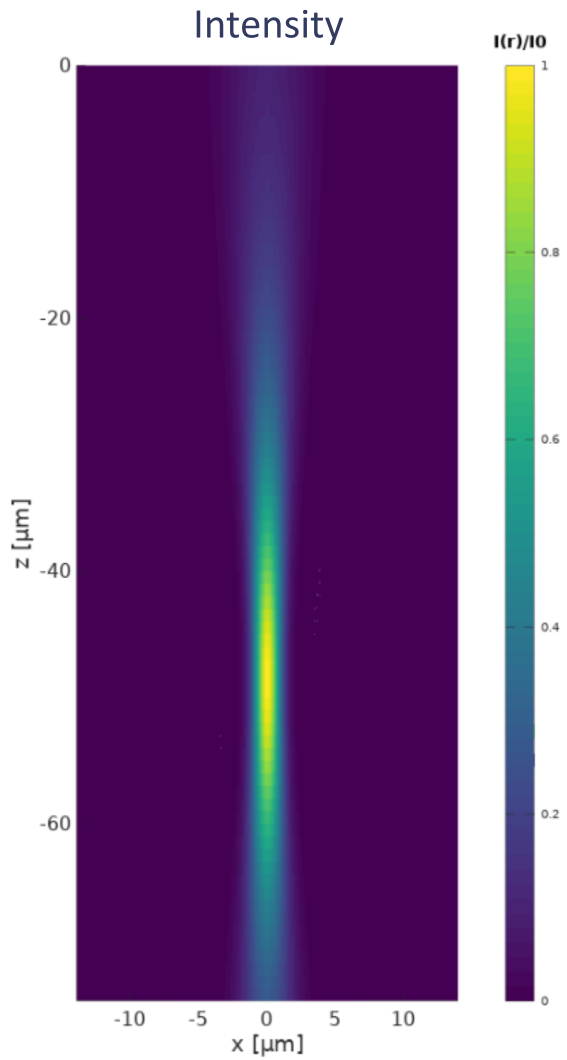


Material Parameter

- Function fitting for temperature dependent material parameters
  - Absorption coefficient α
  - Specific heat capacity C_p
  - Thermal conductivity λ

- Neglecting of variability for
  - Reflection $\mathrm{R} = 0.35$ (nonpolar, <40°)
  - Refraction
  - Density

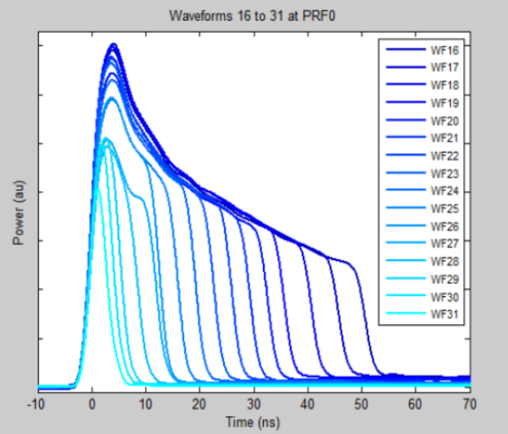
Time Step



- Calculation of laser energy for the step
- Surface reflection $\mathrm{R} = 0.35$ (nonpolar, <40°)
- Maximum of intensity $I_0(z=0)$ $\quad I_0(t) = \frac{2 \cdot E(t)}{\Delta t \cdot \pi \cdot {w_0}^2}$
- Intensity distribution $I(r,z) = \iint I_0 \cdot \left(\frac{w_0}{w(z)}\right)^2 \cdot e^{-\frac{2r^2}{w(z)^2}} drdz$
- Layer absorption $\Delta I(r,z) = I(r,z) \cdot (1 - e^{-\alpha(T) \cdot \Delta z})$
- Intensity loss $I_0(z-1) = I_0(z) - \sum \Delta I(z)$
- Thermalization $\Delta T(r,z) = \frac{\Delta I(r,z) \cdot r^2 \cdot \Delta t}{c(T) \cdot M \cdot \rho}$
- Heat conduction
- Update of temperature dependent parameters

Simulation

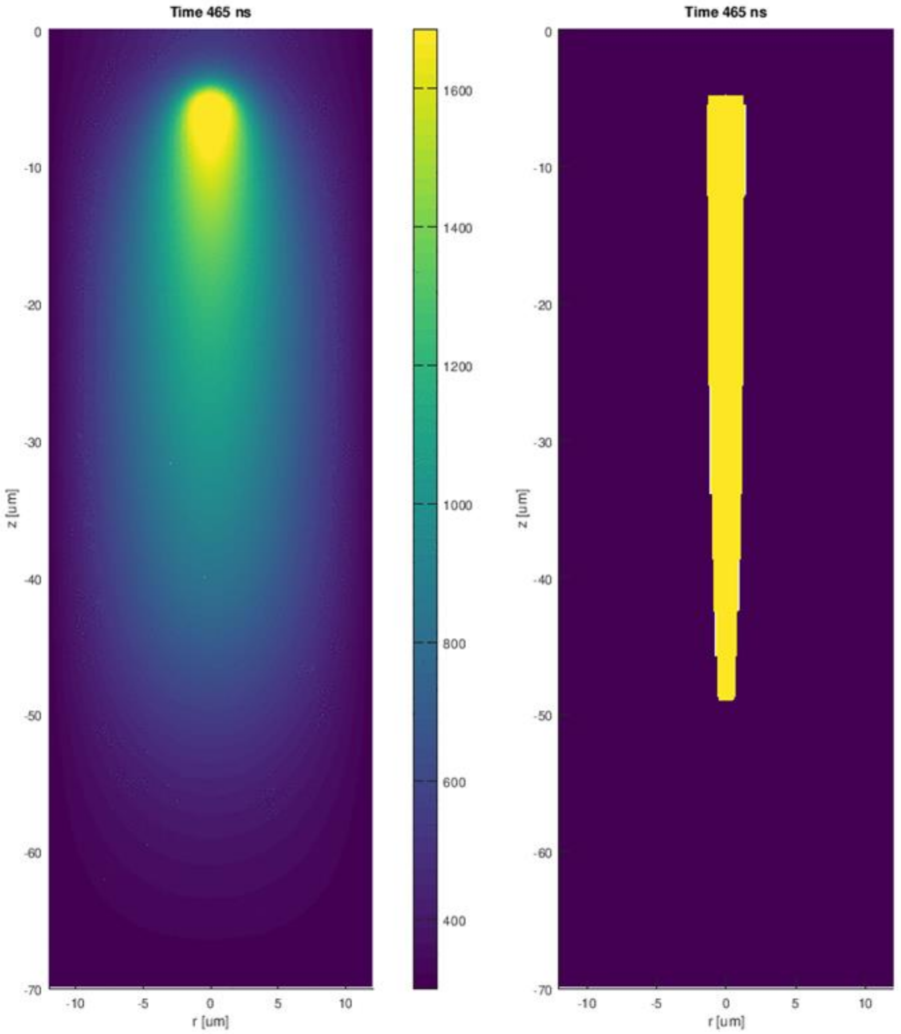
- Pulse duration: $t = 500\,ns$
- Pulse energy: $Ep = 5\,\mu J$
- Focal position: $z = 50\,\mu m$



Results:

- Penetration depth: 49 µm
- Modification length: 45 µm

- Shape of the modification is plausible

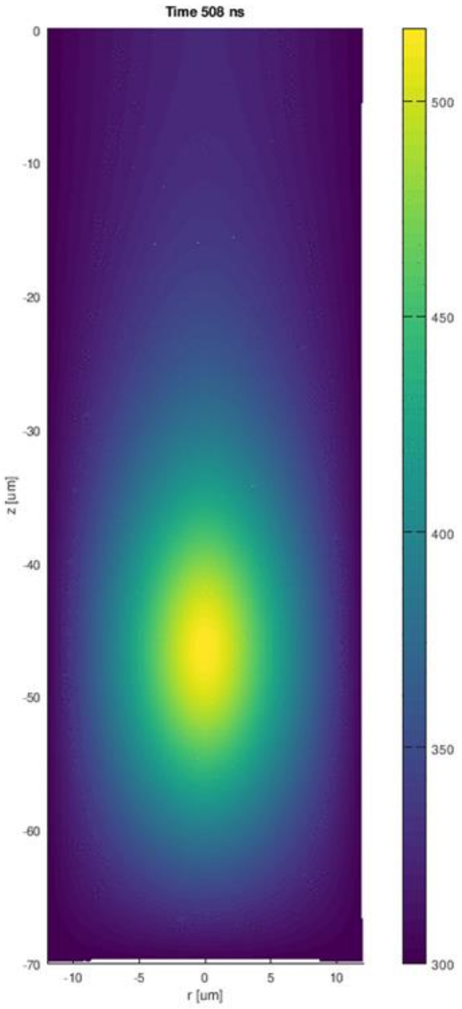


Temperature

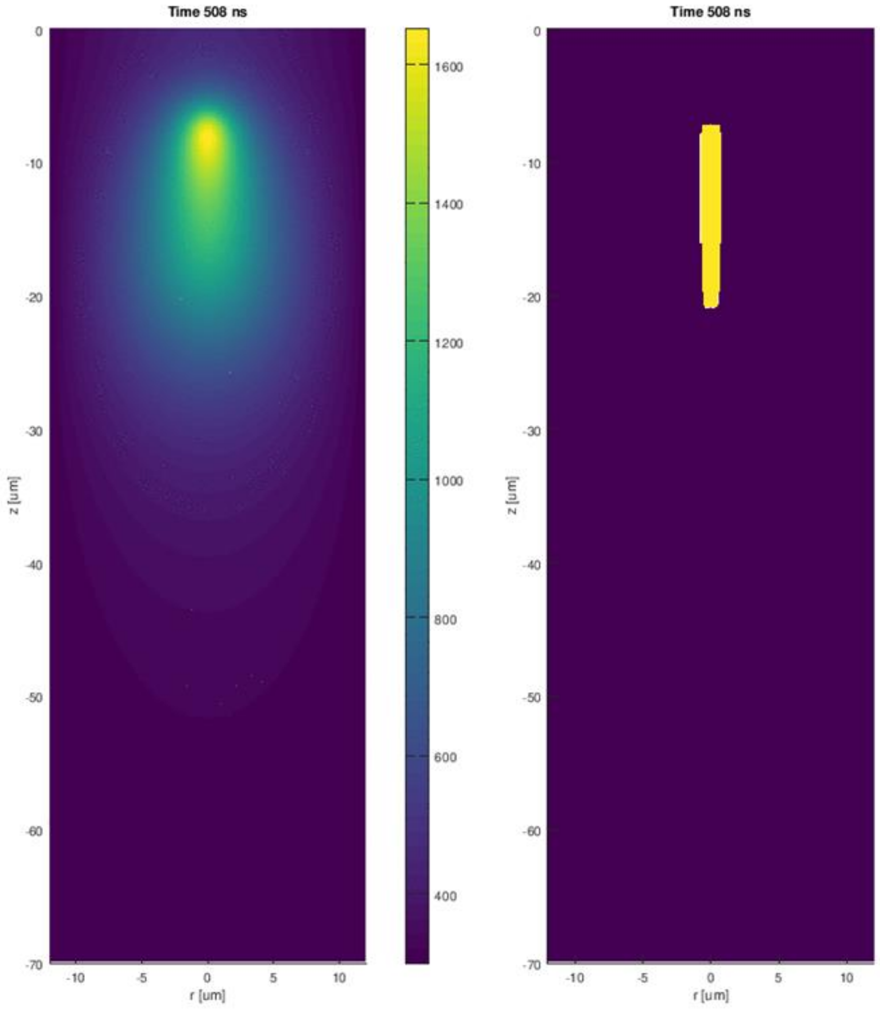
Modification

Influence of Layer Position

- Constant: $Ep \; = 2.5 \; \mu J$
- Variation of focal positon



z = 50 µm



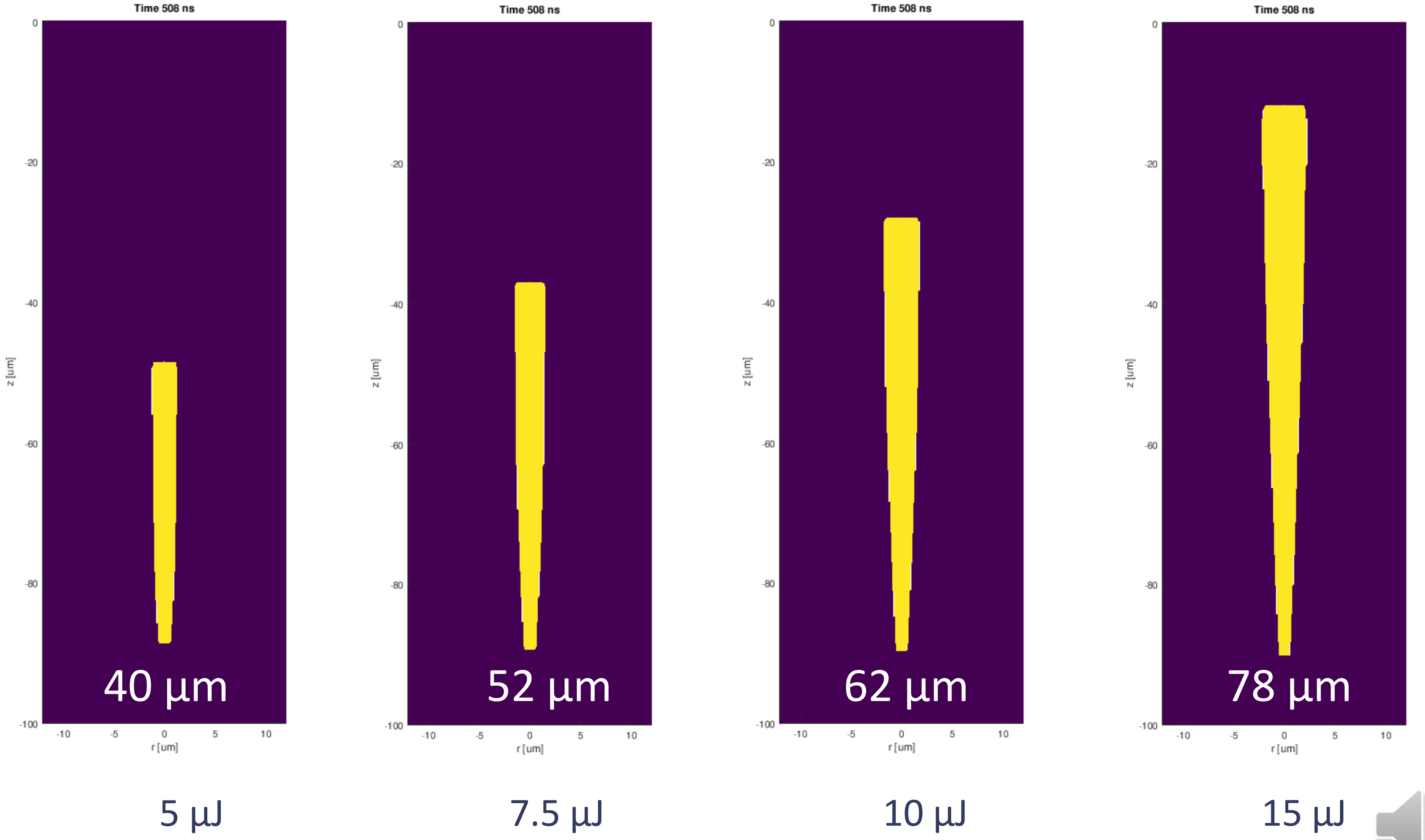
z = 25 µm

Influence of Pulse Energy

- Constant:

  $z = 90\ \mu m$

- Variation of pulse energy

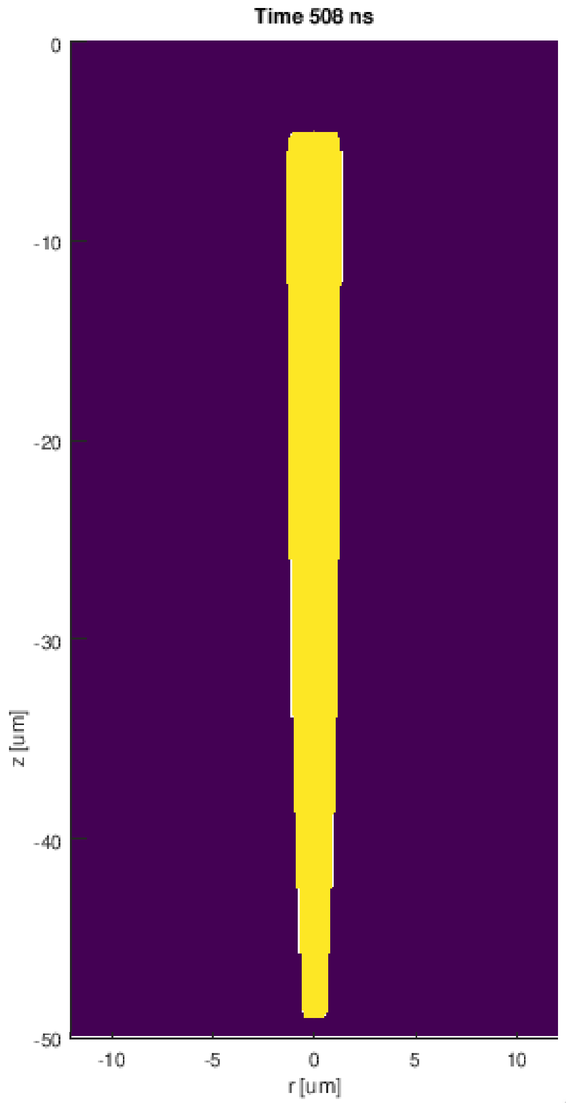


Results of Simulation

- Creation of a FEM model with freeware
- Shape of the modification is plausible
- Correlations between parameters are confirmed
- Difference to experimental results
- Rough estimates of the result are possible

Further work:

- Comparison with additional experiments
- Adjustment of absorption mechanism
- Interaction between multiple laser pulses

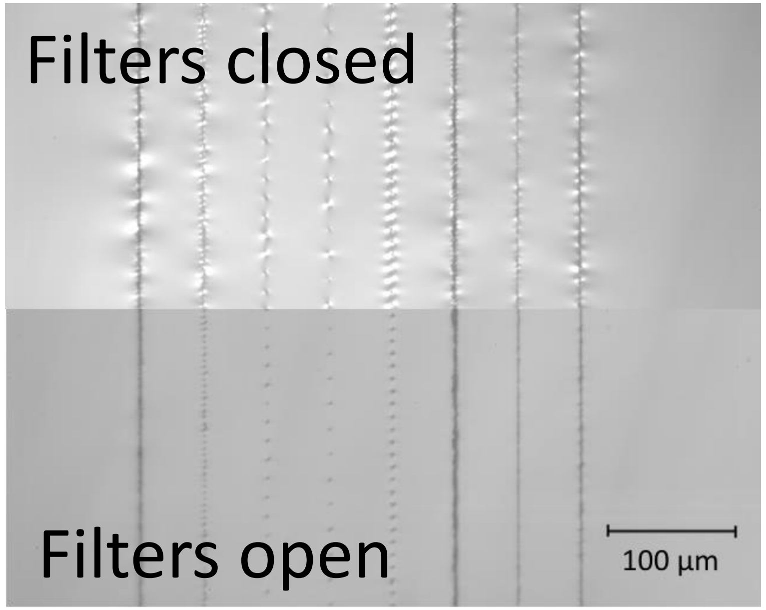


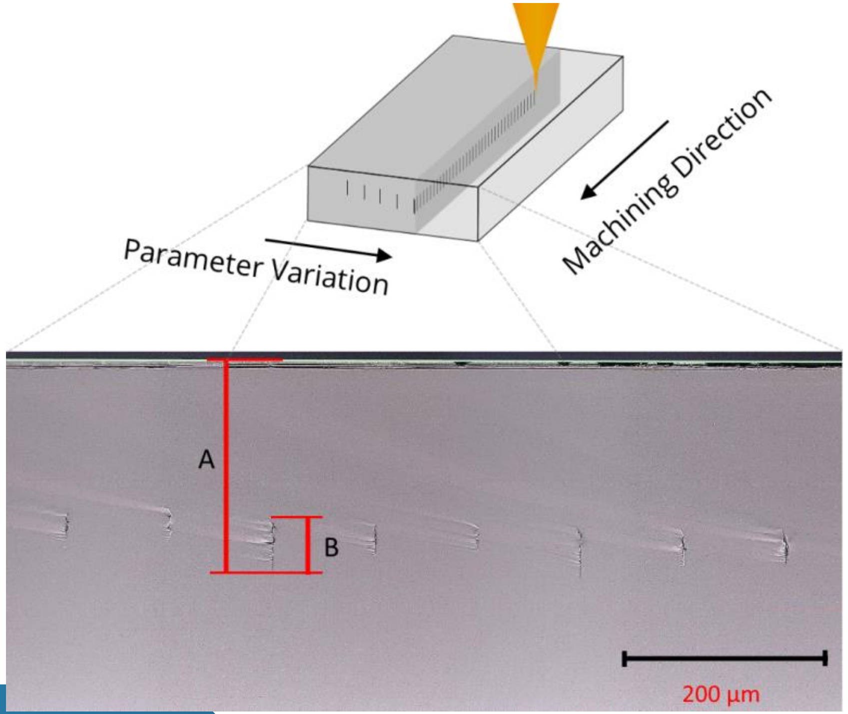
Experiments & Results

- Parameter variation of Deep Scribe
  - Variation of duration, distance, energy and position of pulses
- Combination of Deep Scribe and Cleave
- Investigation of breaking strength
  - 3-point bending test & Weibull analysis

Analysis of Parameter

- In situ camera system
  - Polarizer & analyzer
  - Qualitative feedback deformation

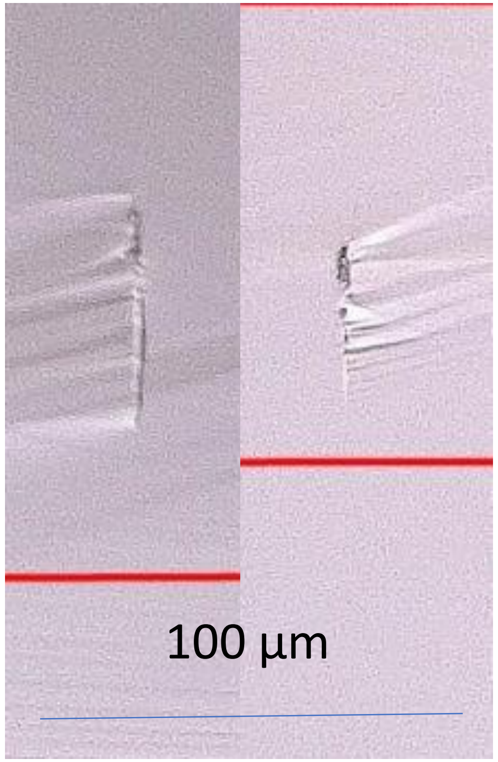




- Microscopic measurement of parameter variation
  - A: penetration depth
  - B: modification length

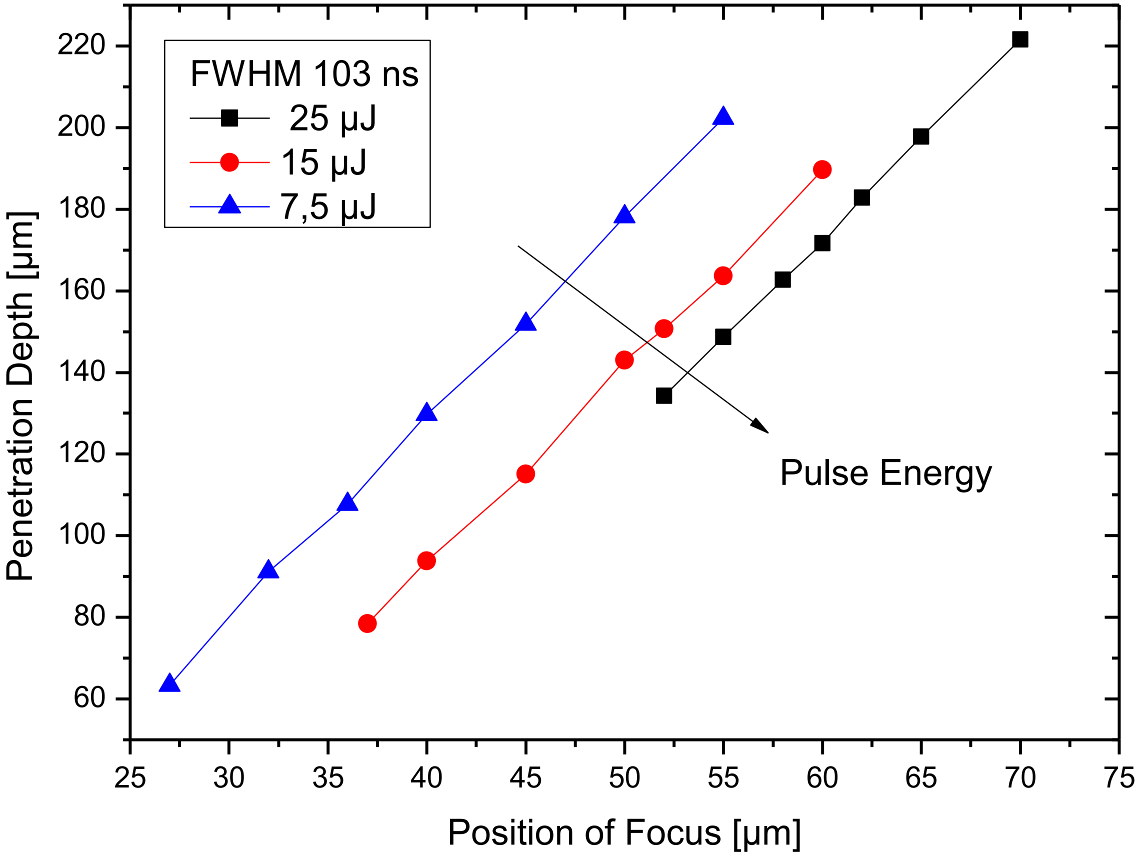
Deep Scribe Parameter

- Process window:
  - Pulse duration: $> 26\ ns$
  - Energy: $5 - 30\ \mu J$
  - Modification length: $15\ -\ 75\ \mu m$
  - Maximal penetration depth: $0.9\ mm$
- Penetration depth = focal plane*refractive index
- Decreasing pulse to pulse distance increasing damage of lattice



Deep Scribe Parameter

- Longer pulse durations Increasing modification length
- Increasing pulse energy
  Decreasing penetration depth
- Higher penetration depth
  Higher pulse energy necessary
- Increasing penetration depth reduction of modification length

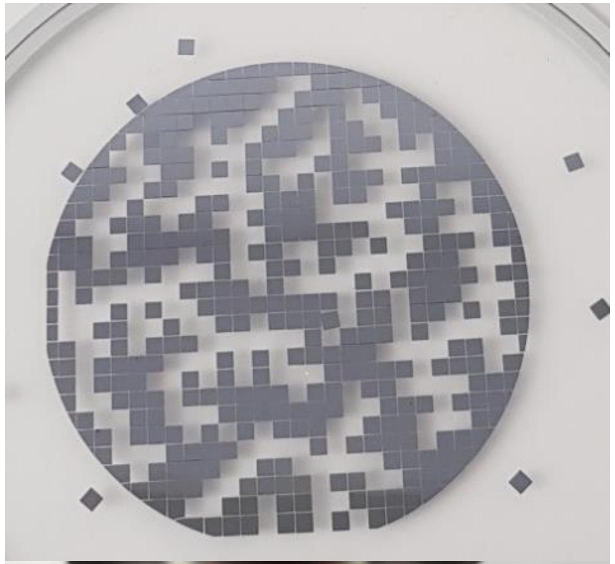


Deep Scribe and Cleave

- Reduction of Cleave laser power
- Improved guiding properties
- Deviations $< \pm 5\ \mu m$
- Layers are stackable
- 1 Layer sufficient for $2\ mm$ Si Wafer

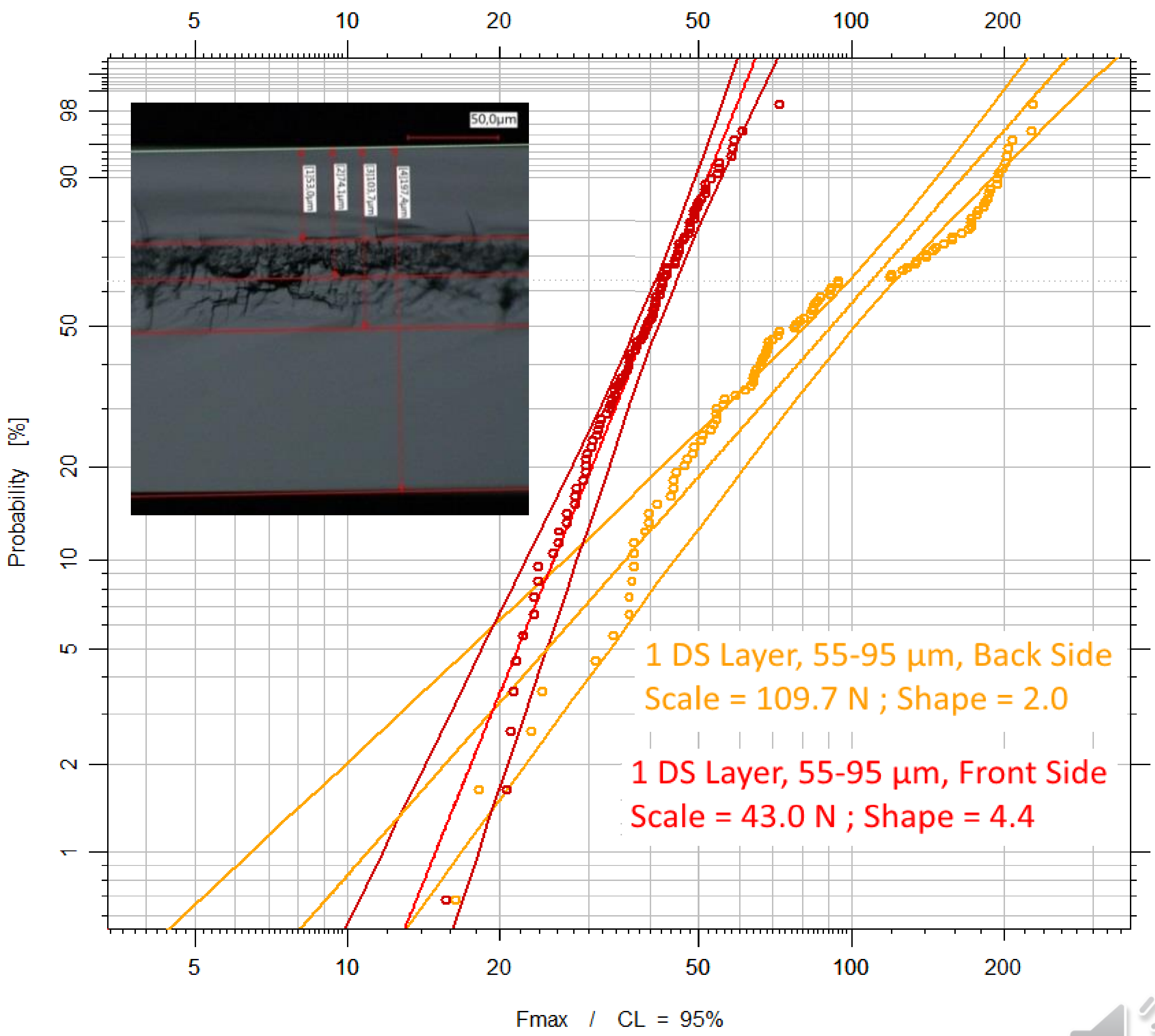
Breaking Strength

- Evidence about process stability
- Material: Si <100>, thickness 200 µm, polished, p-type (Boron), $1 - 10\ \Omega * cm$
- Chip size $3.6x3.6\ mm^2$
- 3-point bending test of 100 chips per site
- Weibull analysis – breakage of $63.21\ \%$
- Optimization of breaking force and compared to mechanical sawing



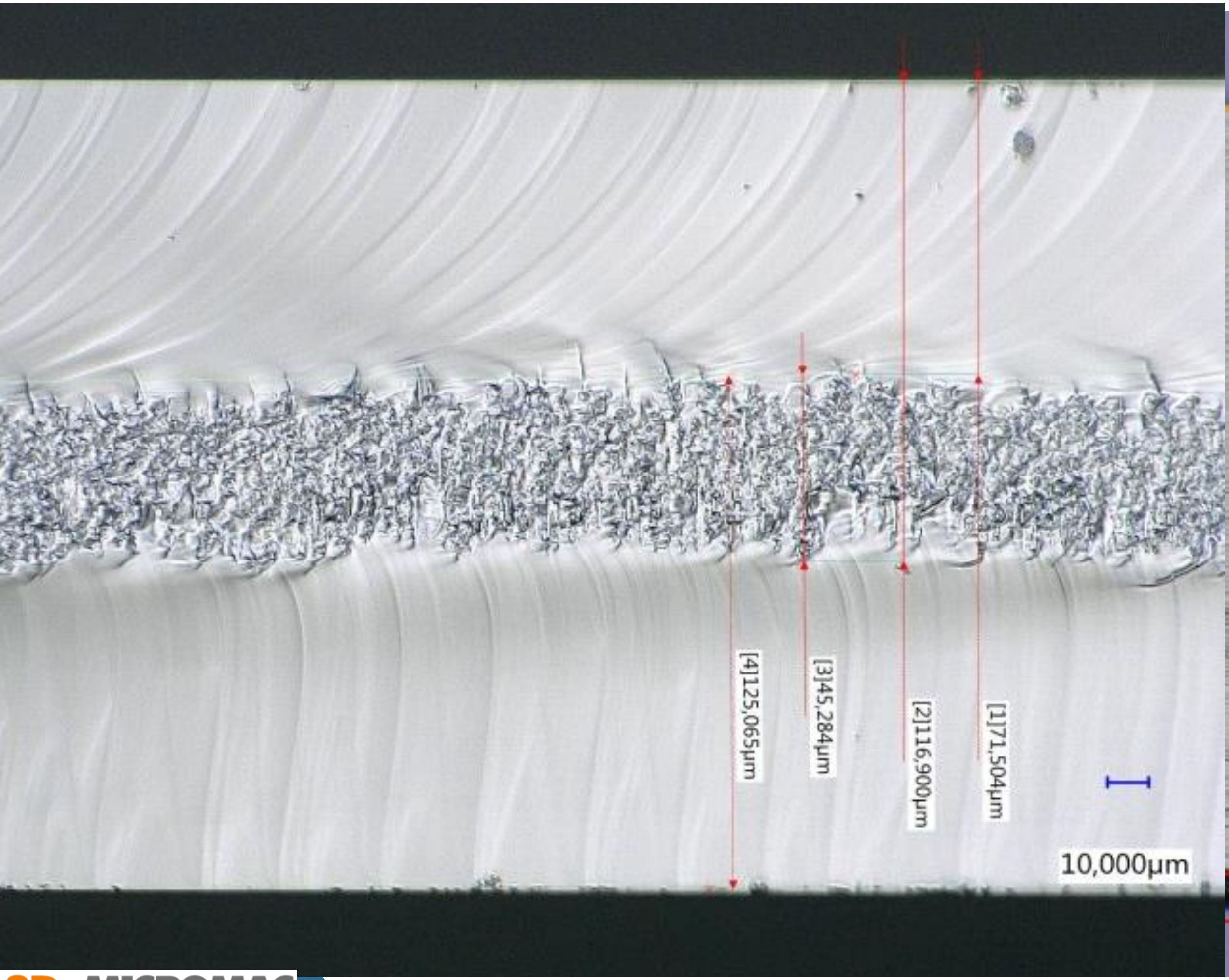
Weibull Analysis

- Single Layer 55 – 95 μm
- 63,21 % value
  - Front: 43 N
  - Back: 109.7 N
- Reduction of front side forces

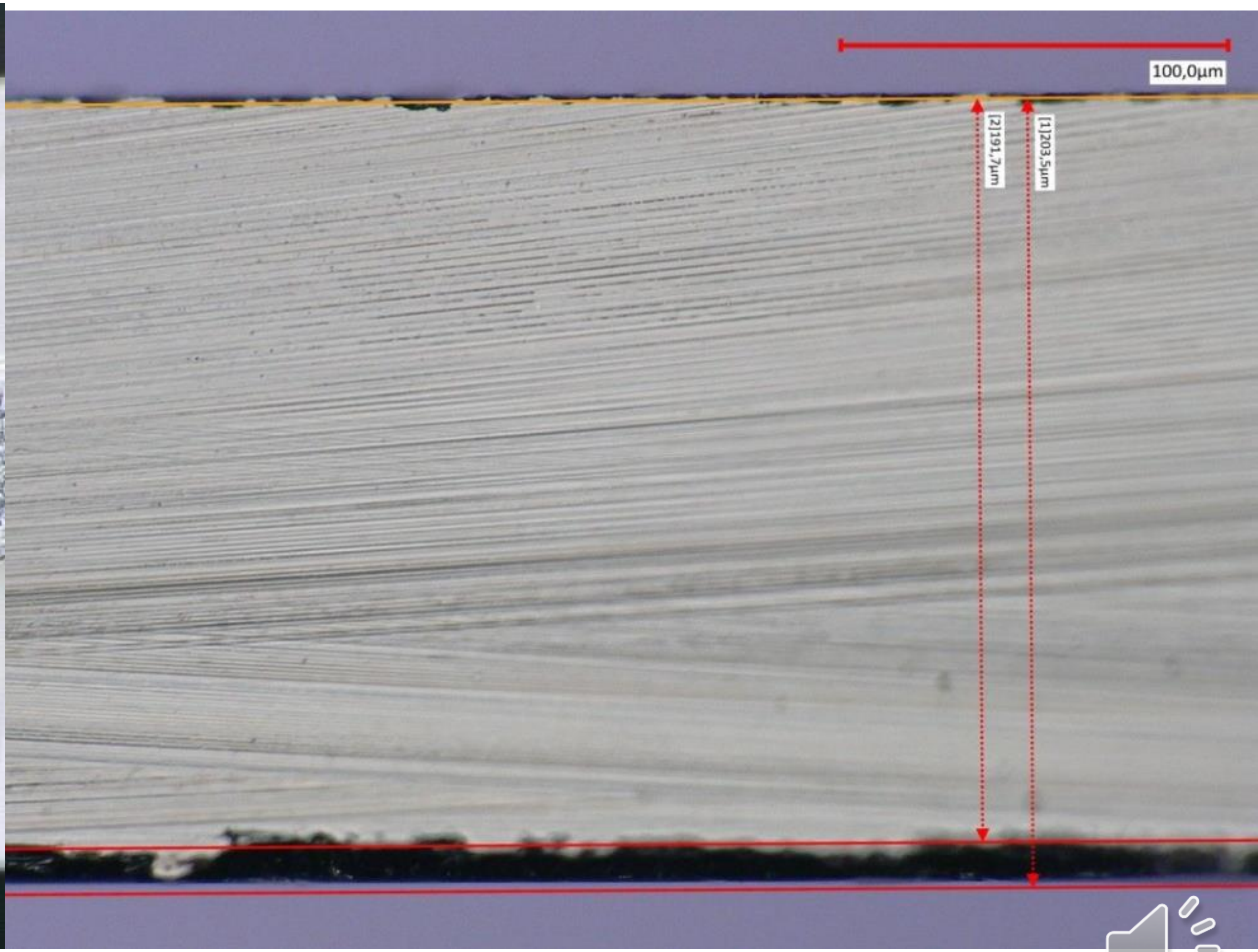


Edge of Separated Die

Deep Scribe

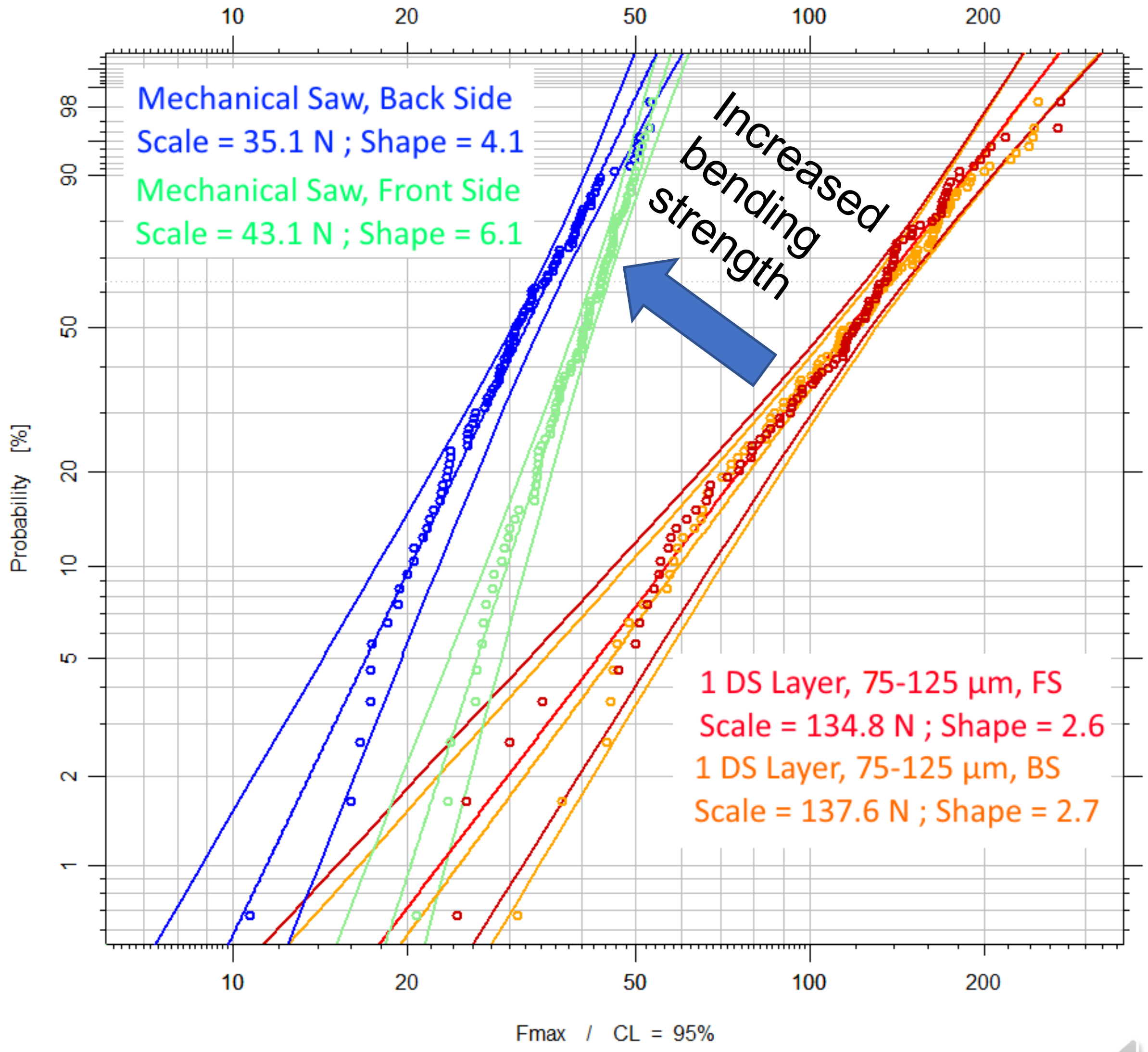


Mechanical Blade Dicing



Optimization & Comparison

- Shifting to neutral fiber
- Single Layer $75 - 125\ \mu m$
  - FS: $134.8\ N$, BS: $137.6\ N$
- Mechanical saw
  - FS: $43.1\ N$, BS: $35.1\ N$
- Higher bending strength for TLS samples

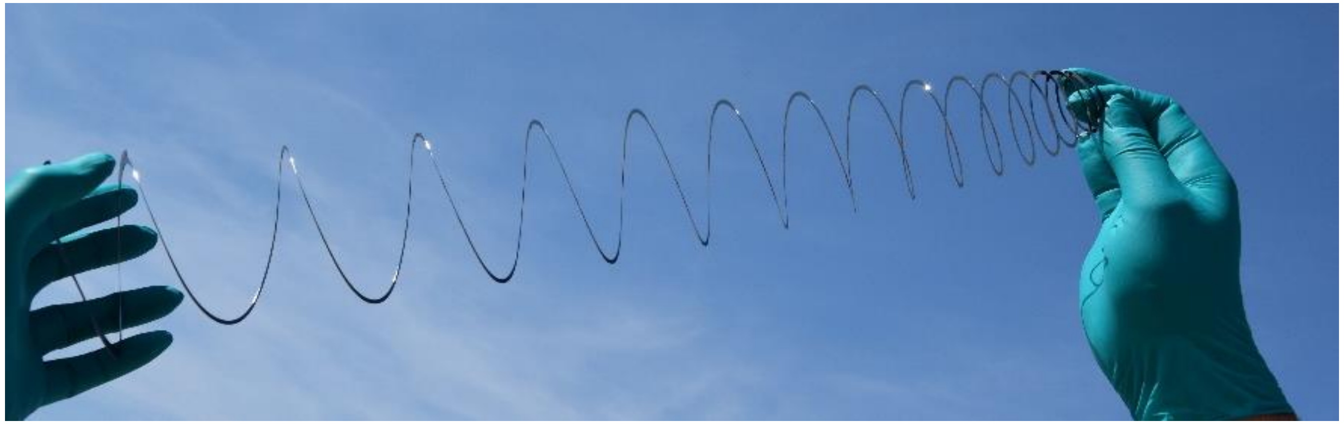


Conclusions

- Development of a Deep Scribe
- Creation of a FEM simulation
- Deep Scribe supported TLS is able to separate silicon
- Free of particles and reduces crack deviation $(< \pm 5\ \mu m)$
- Parameter study shows influences and limits
  - Cleaving up to $2\ mm$ thick Si by a single Deep Scribe layer
  - Layer stacking is possible
- Optimization of breaking forces by shifting layer
  - >3-times higher stability

Acknowledgement

Thank You!



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