

Modeling of Random Nanostructures Based on SEM Images and Analysis of Resulting RF Performance

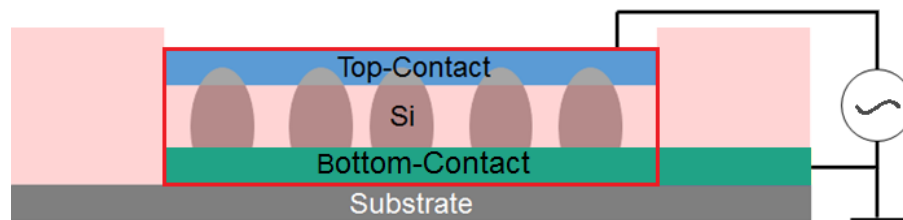
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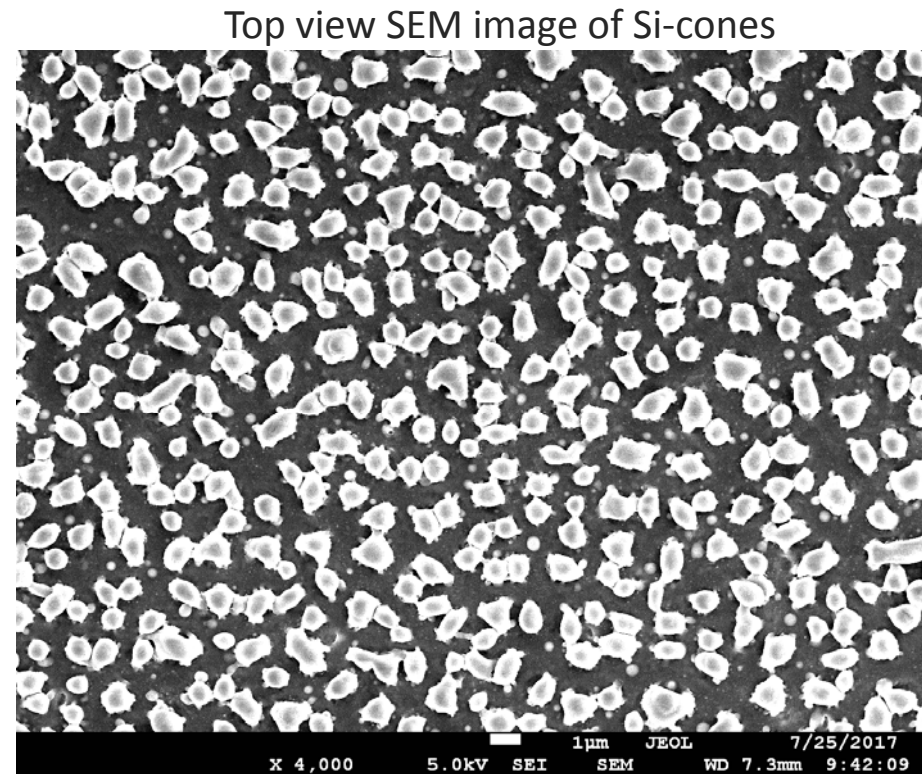
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Duisburg, Germany

- Goal: Printable radio frequency rectifier
- Silicon nanoparticles → laser sintered → cone like structures
- Potential Schottky diodes



- Geometry →
Parasitic capacitances →
Limit cut-off frequency

Is this approach suitable for RF applications?

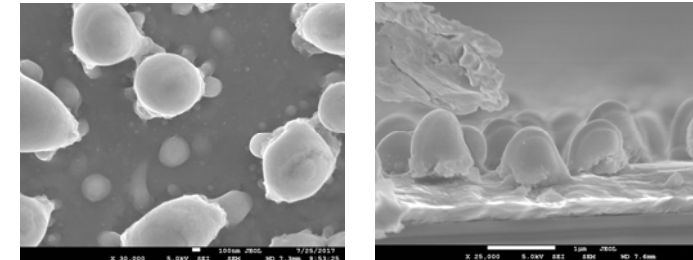


Workflow

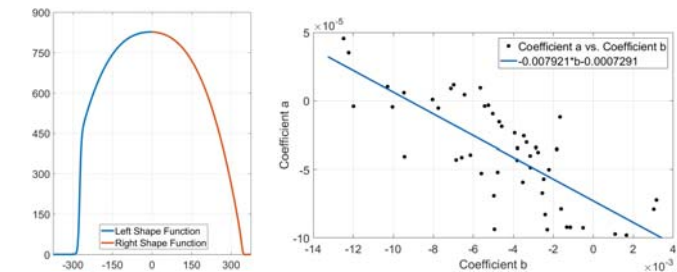
SEM Image Analysis

Top view → footprints

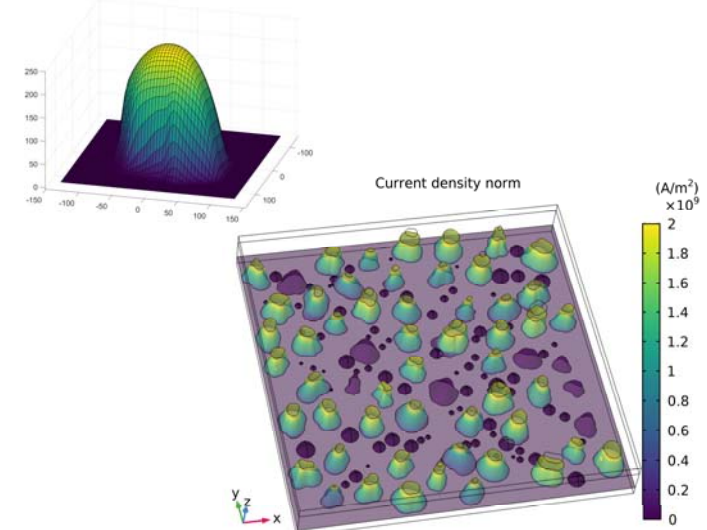
Cross cut → shape functions



Mathematical representation
Stochastic formulation



Random 3D surface generation in MATLAB®

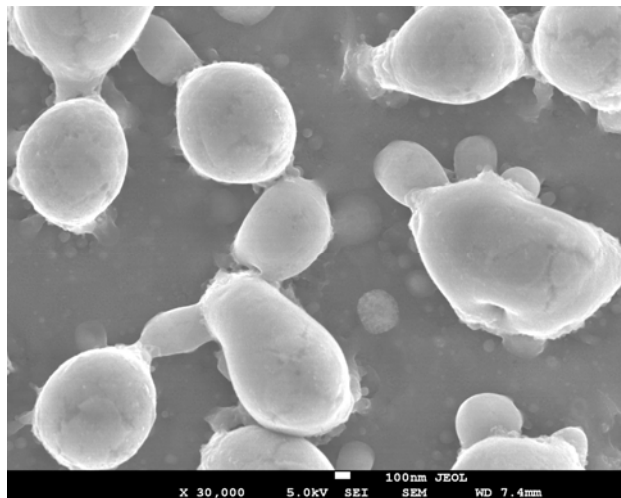


LiveLink™ for MATLAB®

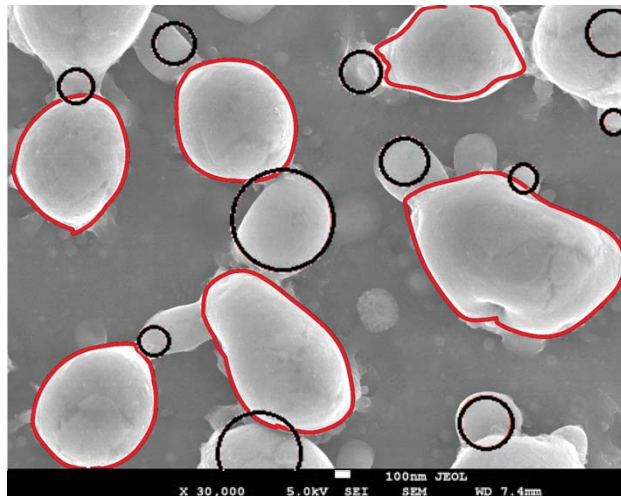
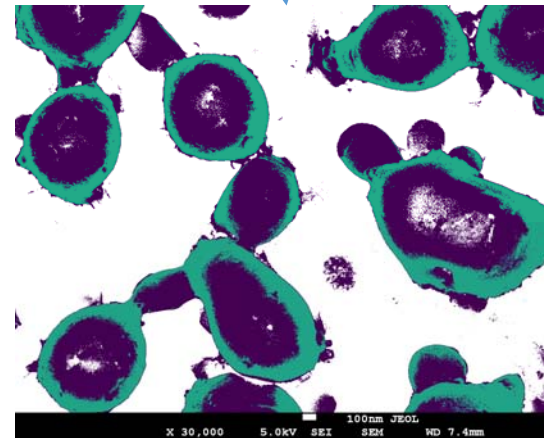
One cone model

Multi cone model

Image Analysis – Top View



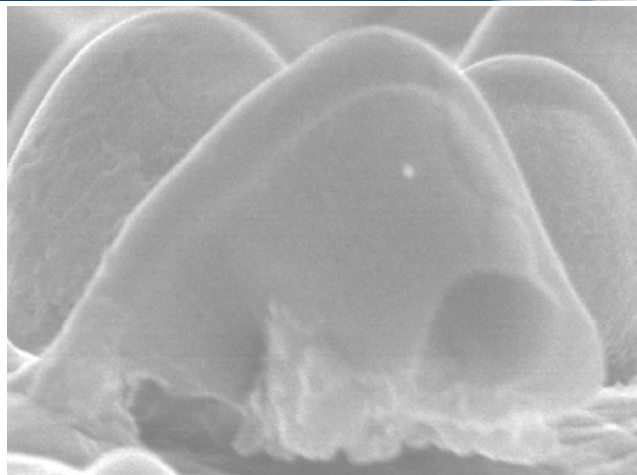
Multilevel thresholding



Edge detection and Morphological opening/closing operations

1. Footprint = function of angle and distance from center (polar coordinates)
2. Extraction of droplets (tiny structures that do not form cones)

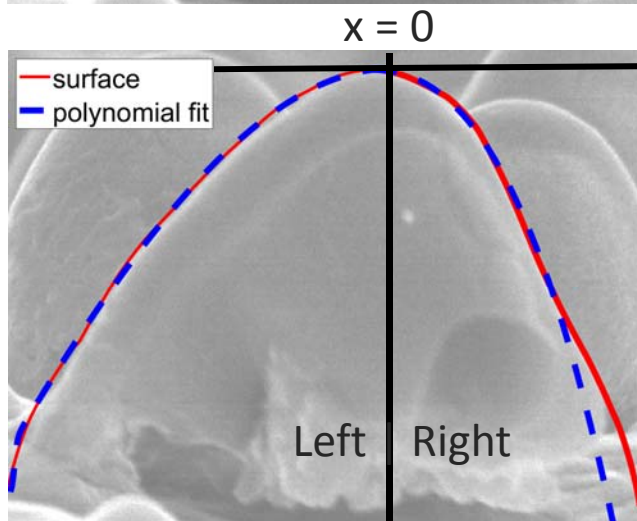
Image Analysis – Cross Cut



Thresholding +
Edge detection



Morphological
operations +
edge detection



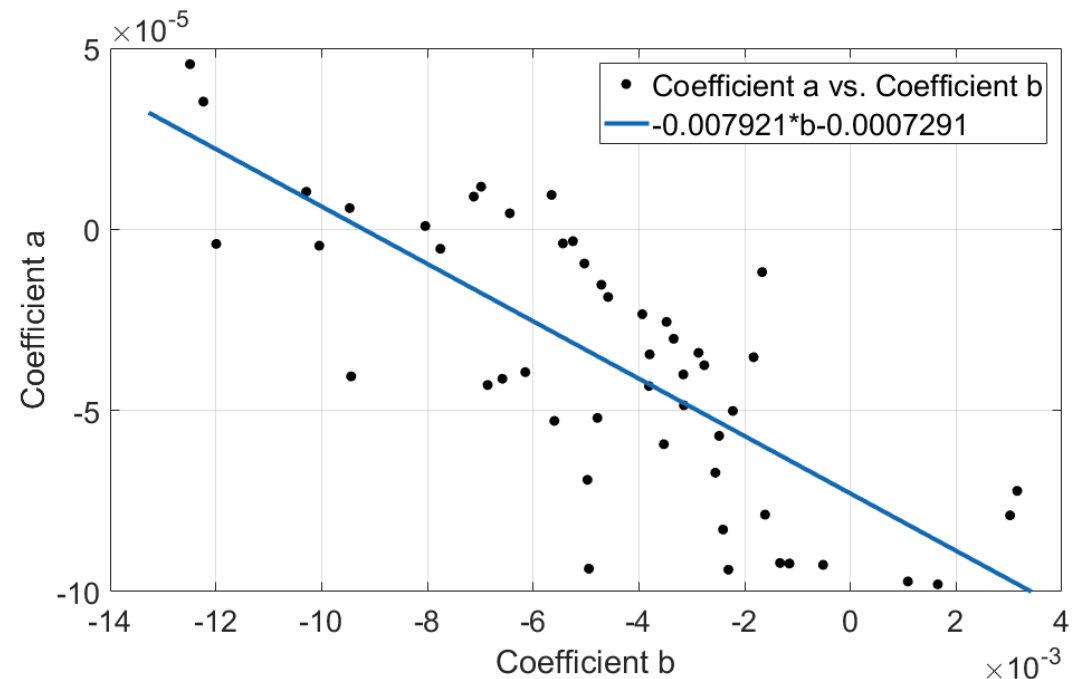
$$y(x) = (a \cdot x^3 + b \cdot x^2 + c \cdot x + d) \cdot \frac{1}{1 + e^{x+w}}$$

Coefficient d = height of the cone

→ 4 coefficients to fit (a, b, c, w)

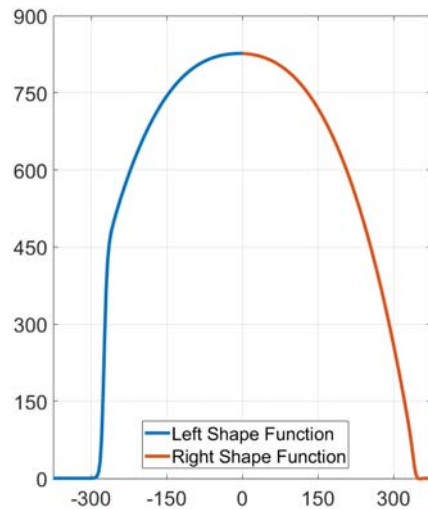
- Shape extraction of front cone
- Fit both halves with a combination of polynomial and sigmoid function

- 50 extracted shape functions with different coefficients
- normal distributions
- Every structure is different but all follow a conical shape
- Correlation between coefficients?
- Coefficient *b* exhibits the strongest correlation to the other coefficients

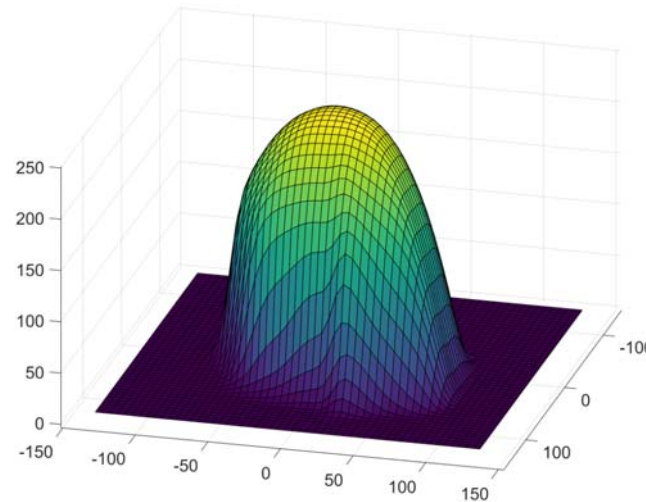


For random shape generation: correlation function $f(b)$ has to be incorporated!

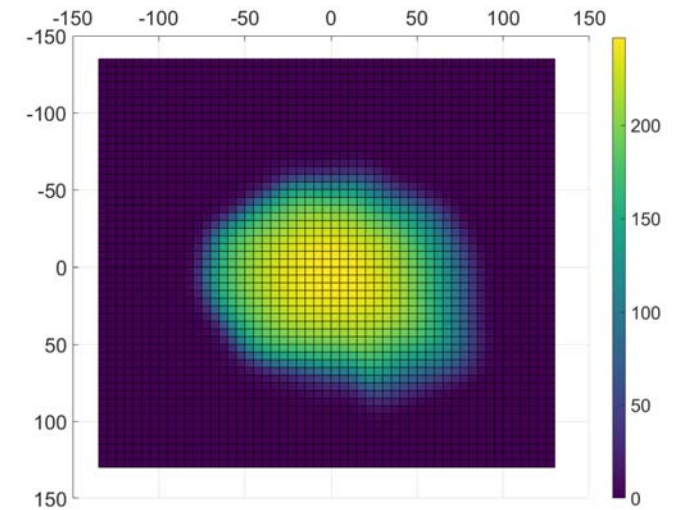
Random 3D Model Generation



shape functions



3D view



top view

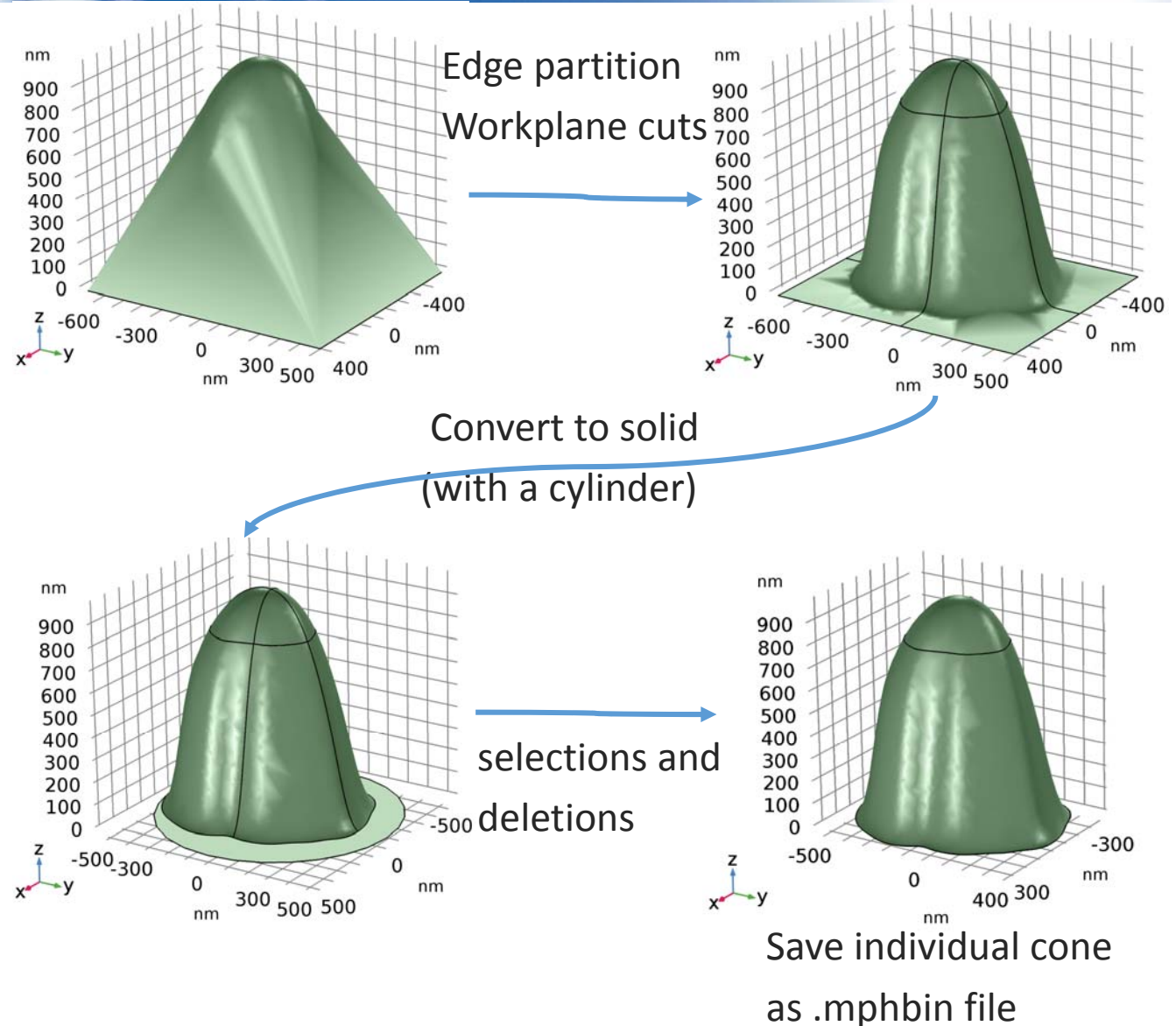
- Randomly generated shape functions
- Rotation by 180 degrees
- Use morph function $\mu(\alpha)$ to avoid discontinuities
- z: insert r' – footprint function
- Export .txt file for usage in COMSOL Multiphysics®

$$\mu(\alpha) = \frac{1}{1 + 3 \cdot e^{\alpha + \frac{\pi}{2}}}$$

$$z(r', \alpha) = \mu(\alpha) \cdot y_{left}(r') + \dots \\ (1 - \mu(\alpha)) \cdot y_{right}(r')$$

One Cone Model

- Import as interpolation from file
- Parametric surface using this function



Top workplane cut
→ separate dielectric
and top metal contact

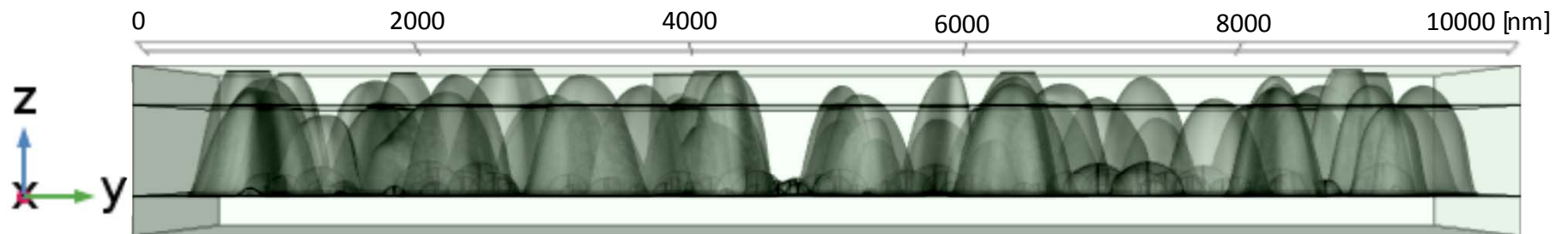
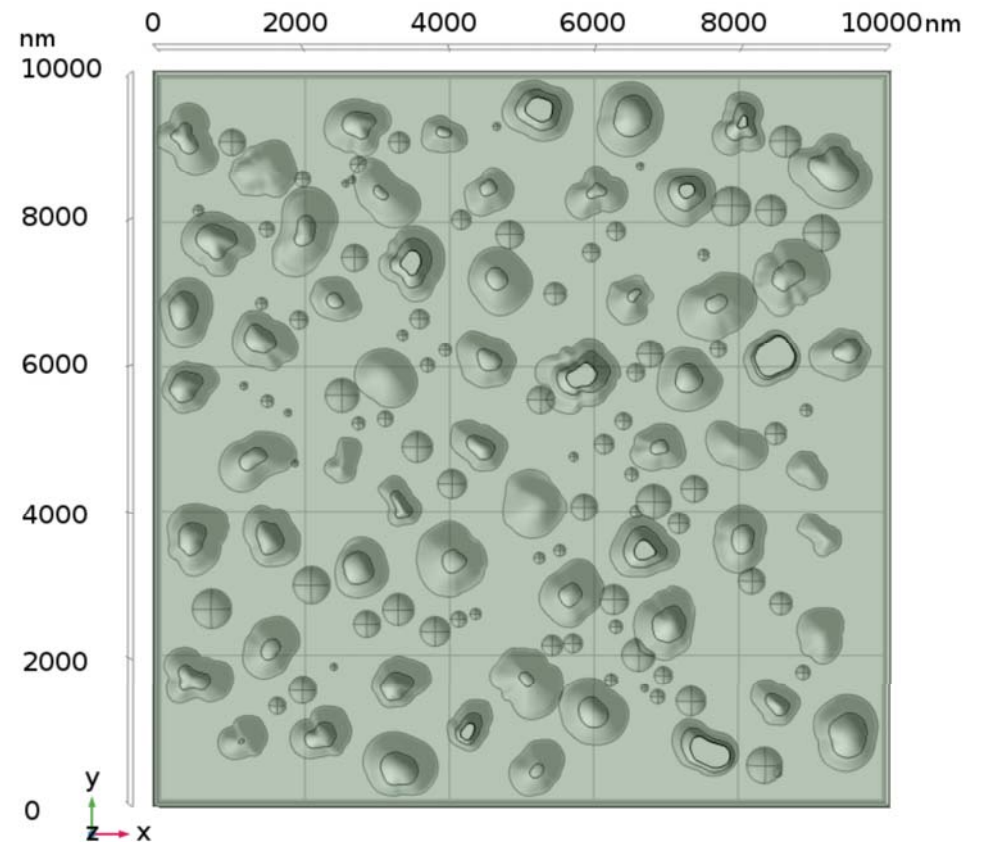
Multi Cone Model

Purpose:

- Viable for RF-rectifier?
- Only parasitic capacitances

LiveLink™ for MATLAB®:

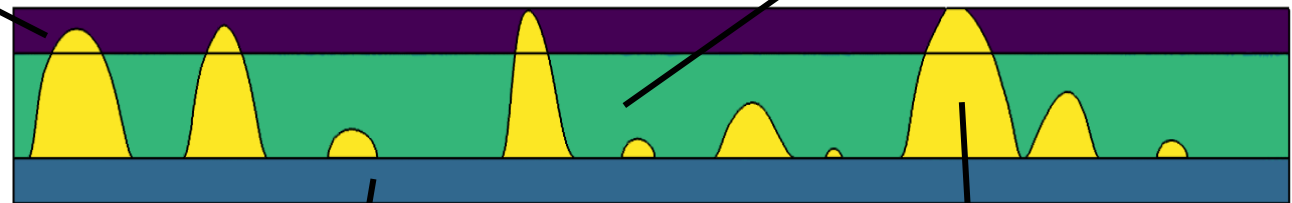
- Import of cone models
- Random distribution
across the simulation area
according to cone density
from SEM images



Simulation Setup

Top metal contact
(Terminal)
Terminated (50Ω)

Dielectric medium $\epsilon_r \approx 3.25$



Bottom metal contact
(Ground)

N-doped Silicon
 $N_d = 5 \cdot 10^{16} \text{ cm}^{-3}$
 $\sigma = 710 \frac{\text{S}}{\text{m}}$

- AC/DC Module
- Electric Currents
- Scattering parameters \rightarrow Y parameters
- Frequency sweep to estimate cut-off frequency f_c :
Frequency where the displacement currents predominate.
 $\text{Im} \{Y\} = \text{Re} \{Y\}$
- Vary geometric parameters to maximize f_c

Simulation Results

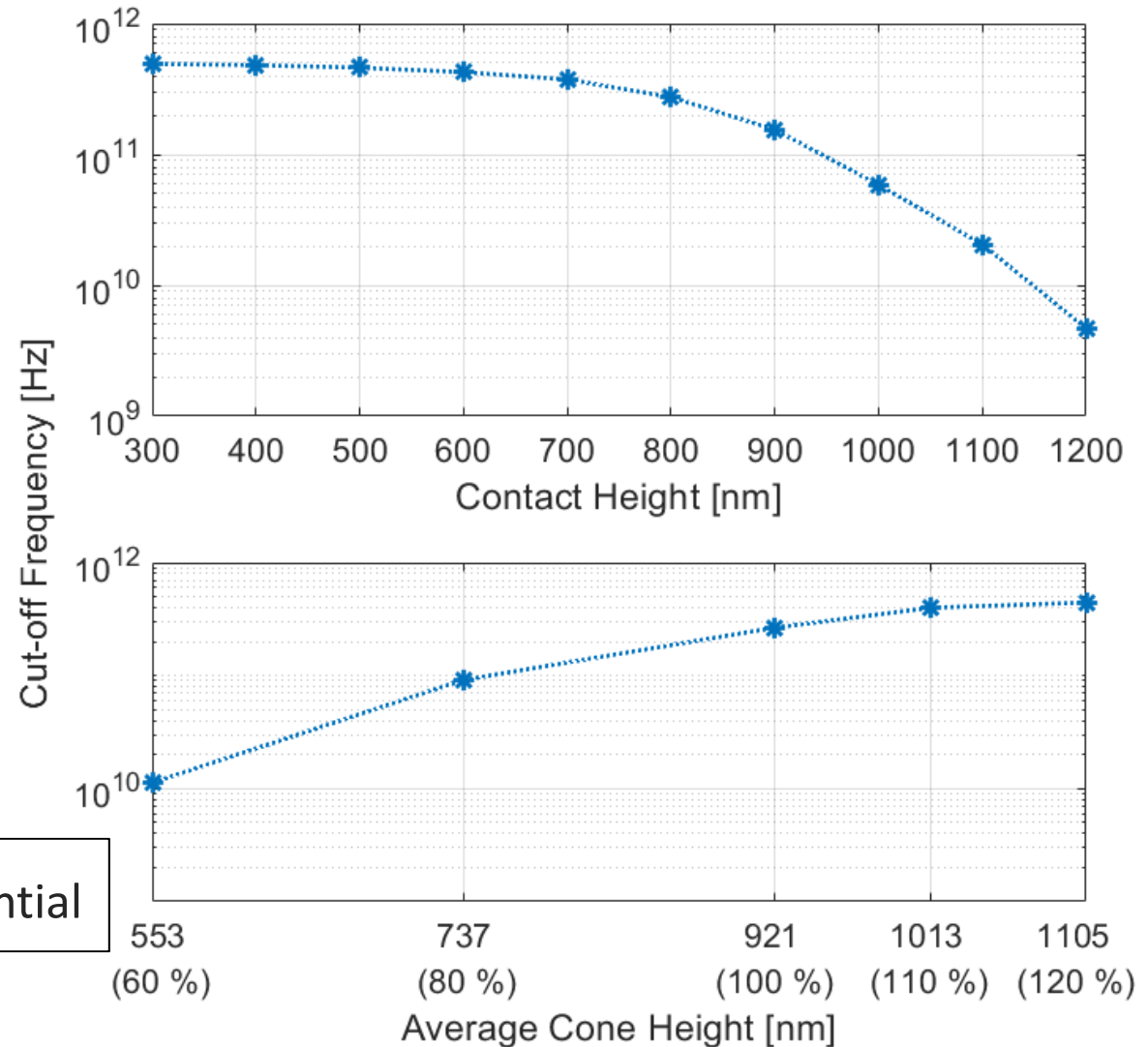
- Contact height $H_{contact}$ = distance between top and bottom contact

$$H_{contact} \downarrow \Rightarrow f_c \uparrow$$

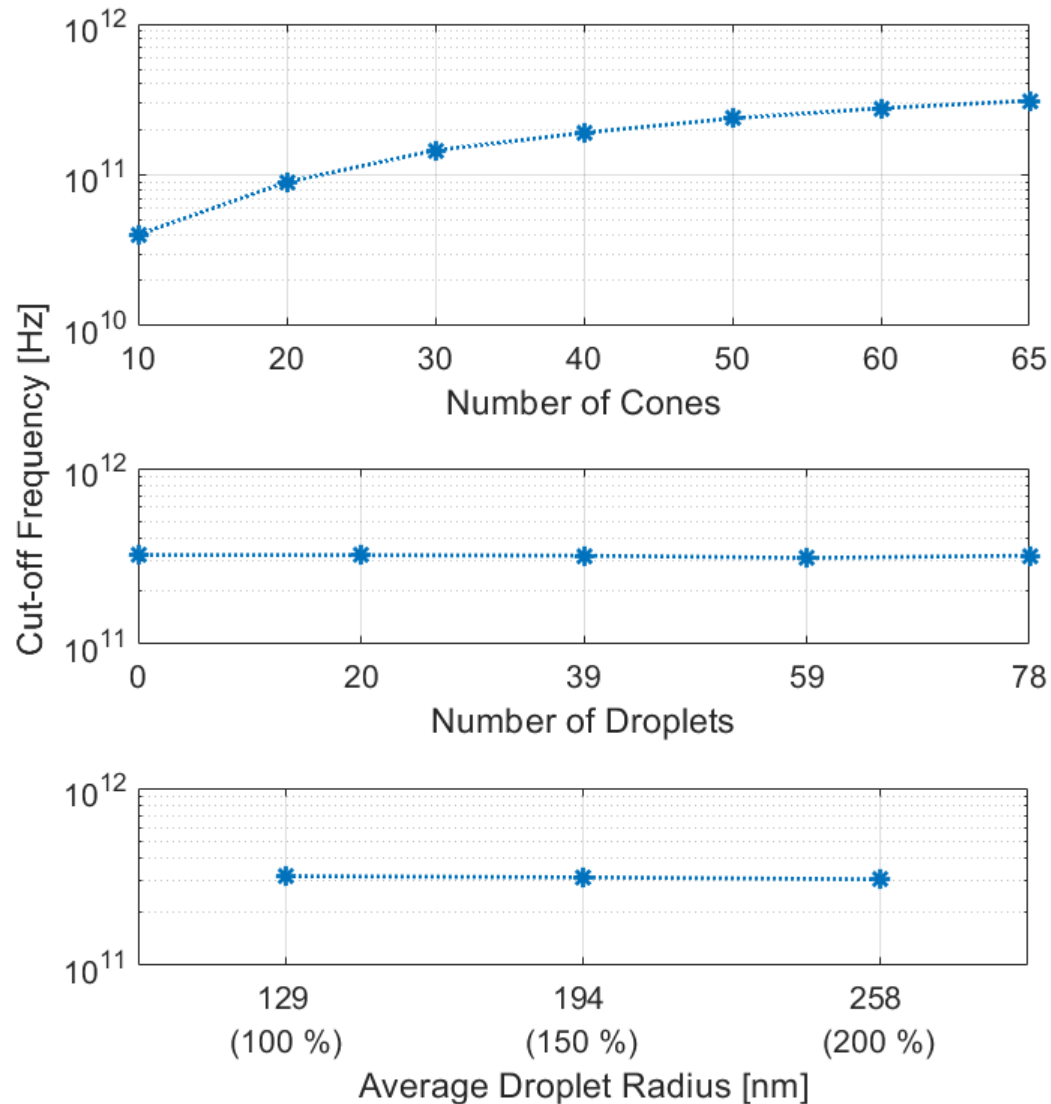
- Average cone height $\overline{H_{cone}}$

$$\overline{H_{cone}} \uparrow \Rightarrow f_c \uparrow$$

High (parasitic) f_c shows RF potential



Simulation Results



- Number of cones N_c

$$N_c \uparrow \Rightarrow f_c \uparrow$$

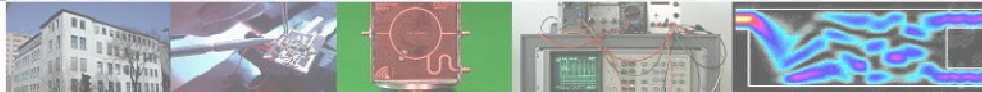
- Number of droplets N_d

$$N_d \updownarrow \Rightarrow f_c = \text{const}$$

- Radius of droplets \overline{R}_d

$$\overline{R}_d \updownarrow \Rightarrow f_c = \text{const}$$

- Proposed idea suitable for realising a printable RF rectifier
- Extraction of geometry by SEM image processing
- Mathematical formulation
- Generation of random 3D models with same statistic properties
- Model helps to optimize device:
 - Main focus should lie on contacting every cone
 - Effects of droplets do not need to be considered



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ATE in a Nutshell [pdf_\(464_kB\)](#)

Aktuelles

Neue forschungsnahen **Bachelor-/Masterarbeiten** auf dem Gebiet Radarsensorik mittels Vortex-Wellen. [pdf_\(61_kB\)](#)

Neue forschungsnahen **Masterarbeit** auf dem Gebiet der Ausbreitung von Oberflächen-Radiowellen. [pdf_\(310_kB\)](#)

Neue forschungsnahen **Masterarbeit** auf dem Gebiet der computerorientierten Feldtheorie. [pdf_\(530_kB\)](#)

Ringvorlesung "**Ausgewählte Kapitel der Medizintechnik**" (WS 2018/19)-Flyer: [pdf_\(2,7_MB\)](#)

Aktueller **Themenkatalog** für Abschluss- und Projektarbeiten. [pdf_\(6,0_MB\)](#)

Zu den **aktuellen Anmeldungen** im WS 2018/19:

Projektumsetzung GE 11 zur Anmeldung ab 1.10.2018 möglich

Electronic Workshop for Students, Soldering - Basic Course.

Gruppenstärke bis zu 8 Personen. Termine nach Absprache. zur Anmeldung (ab 01.10.2018 möglich)

Advanced Electronic Workshop for Students: zur Anmeldung (ab 01.10.2018 möglich)

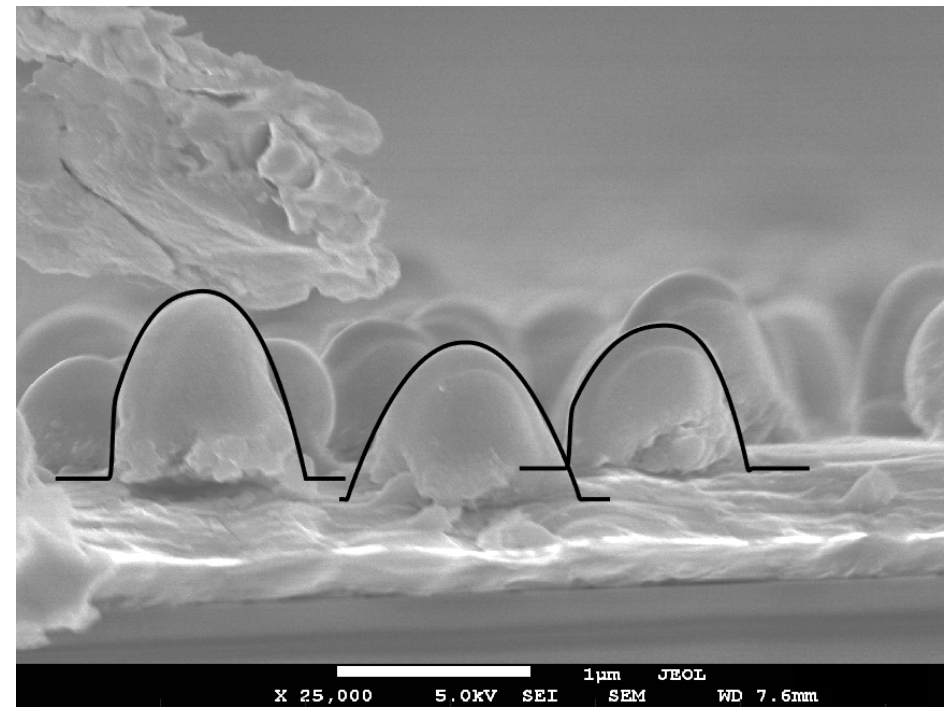
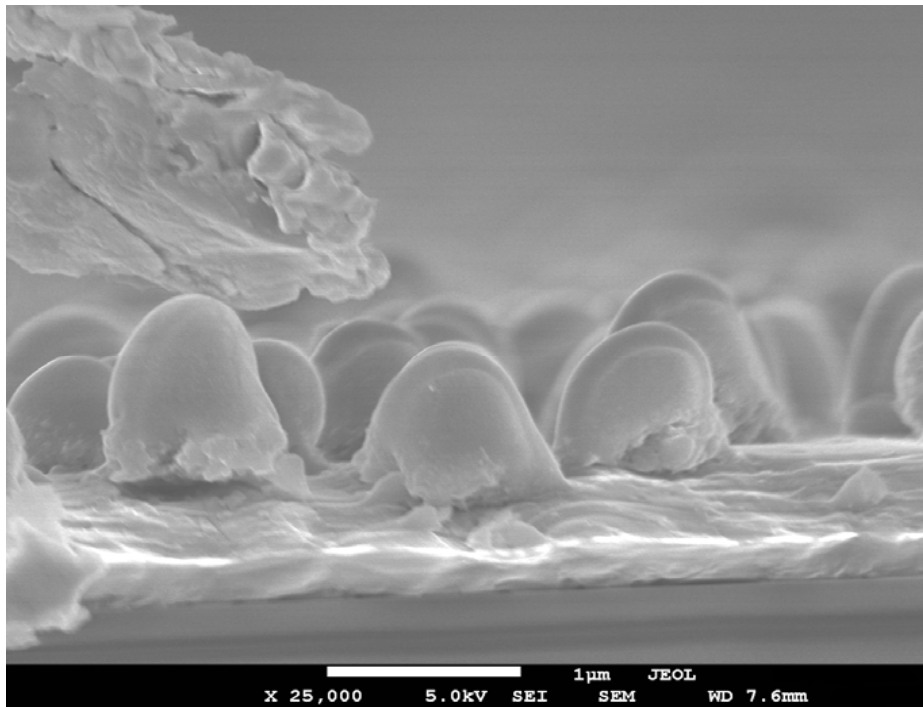
Vorlesungsankündigung: Vorlesungsverzeichnis für das WS 2018/19. [pdf_\(190_kB\)](#)

22.05.2018: Dr.-Ing. Fedor Schreiber, Sortieralgorithmen und -architekturen für Elektrowetting-basierte Mikro-fluidik-Zellsorter-Chips und deren elektrofluidynamische Untersuchung. Dissertation University of Duisburg-Essen. Wir gratulieren herzlich! [pdf_\(27375_kB\)](#)

08.05.2018: Dr.-Ing. Christoph Prall hat die im Rahmen seiner Kooperation Promotion (Hochschule Ruhr West) erarbeitete Dissertation zum Thema "Photolumineszenz bei hohen Temperaturen aus epitaktisch wachsenden Nitrid-Halbleiterschichten zur In-situ-Materialcharakterisierung" mit Auszeichnung verteidigt. Wir gratulieren herzlich! [pdf_\(6135_kB\)](#)

Thank you for your attention!

Image Analysis – Cross Cut



- Some cones are not in contact to the top terminal
→ can't carry any current

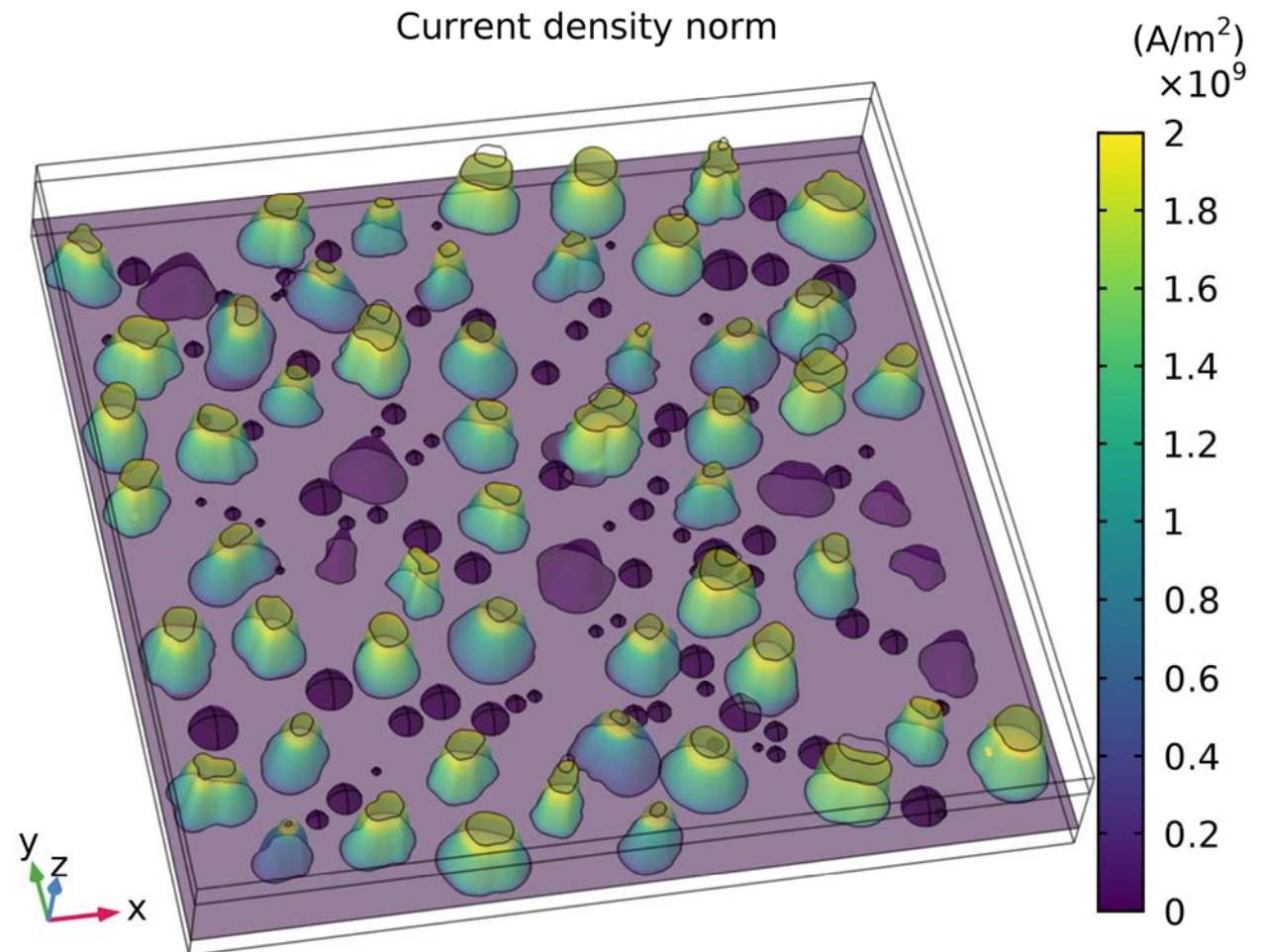


Fig. A1: Current density norm @ 1 GHz between the two terminals calculated by the Electric Currents module