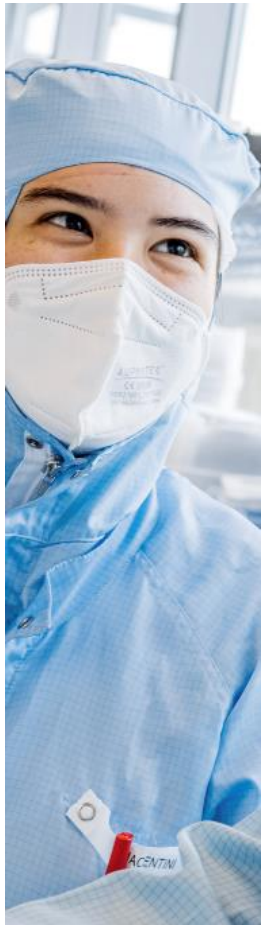
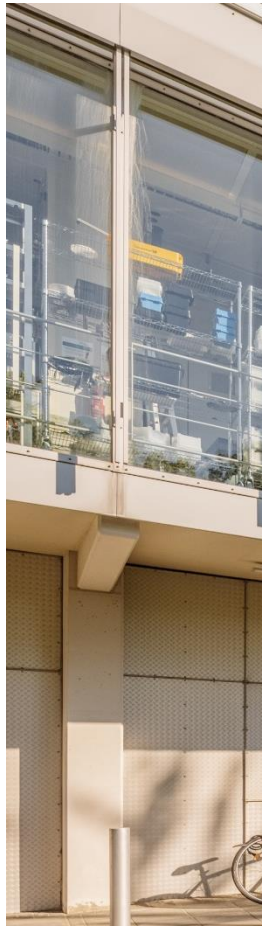
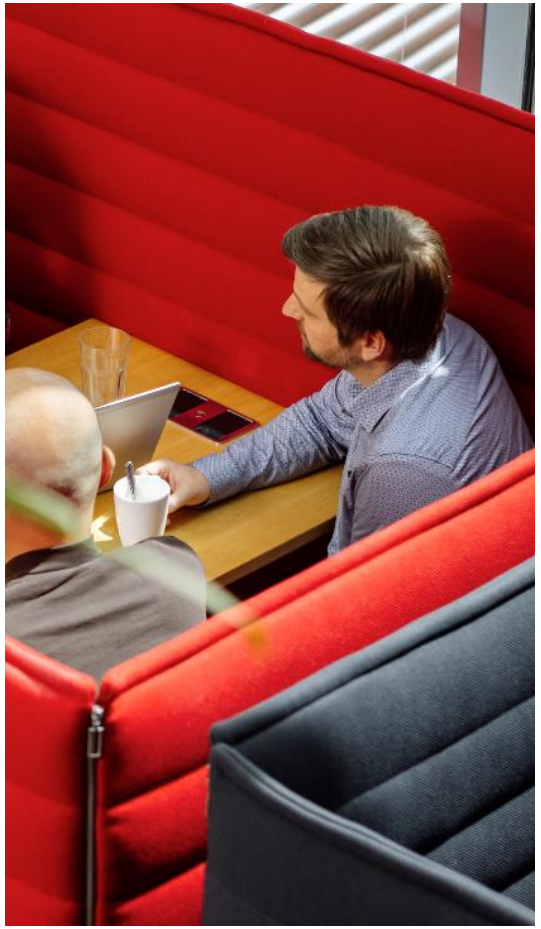
Enhanced SEM metrology for R&D at the nanometer scale

Jens Bolten, Giovanna Capraro, Sebastian Lukas







AMO

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Company Profile

RWTH Aachen Univercity

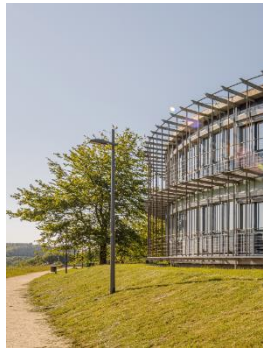
- Large European Technical Univ.
- 45.000 students
- Triangle:
  Germany / Belgium / Netherlands
- Chair of Electronic Devices

Managing Directors

- Prof. Dr.-Ing. Max Lemme
- Dr. Michael Hornung

AMO GmbH

- Founded 1993
- High-Tech SME / Institute (non-profit)
- Research Foundry
- 400 m^2 clean room
- ~ 80 staff members
- Johannes Rau Research Institute
- Key technologies
  - Silicon Technology Base
  - Nanofabrication (NIL, E-Beam, IL)
  - New Materials Integration (high-k, graphene, 2D, perovskites, phase change)
  - Applications (Nanoelectronics, Nanophotonics, Integrated Sensors)

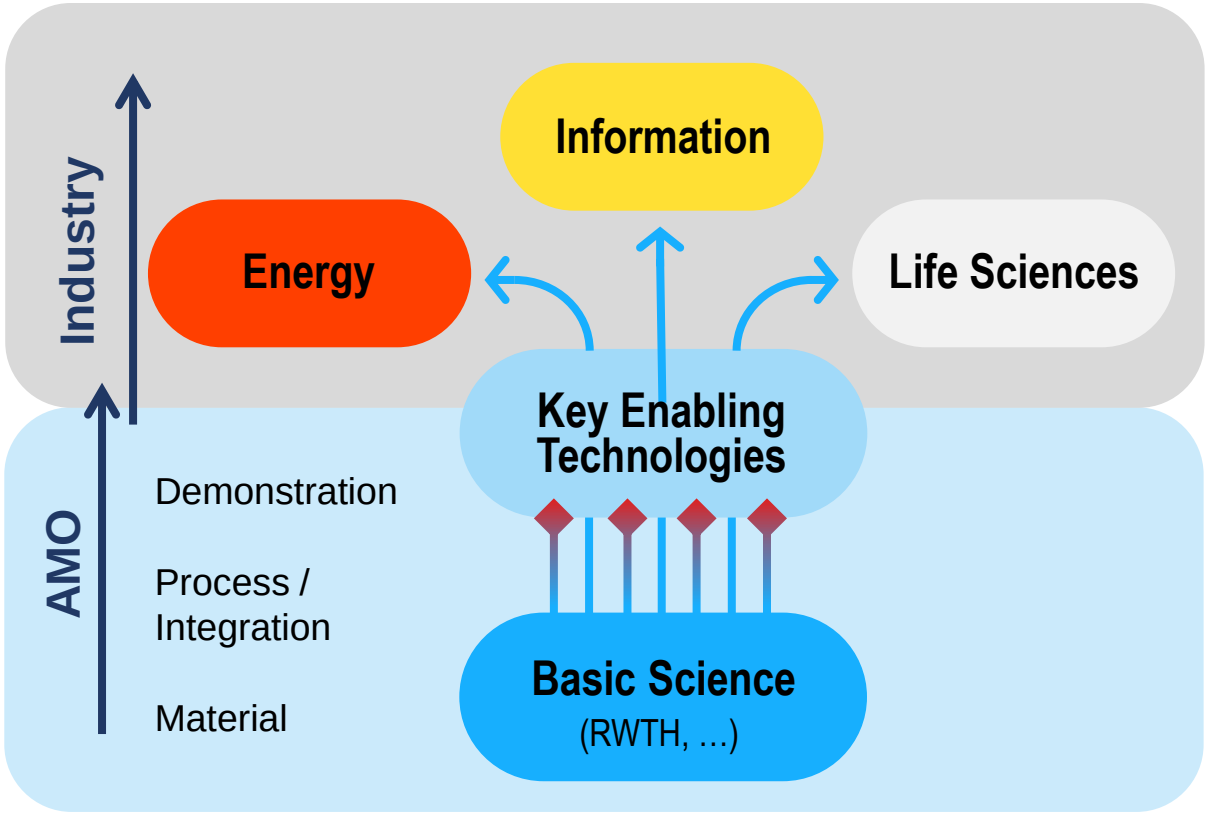



Mission

Global societal challenges
- Climate change
- Aging societies / sustainable health care
- Mobility
- Data Security

Emerging Technologies
- Neuromorphic Computing
- Quantum Technologies
- Bio-/Nanotechnology
- Computational Sciences

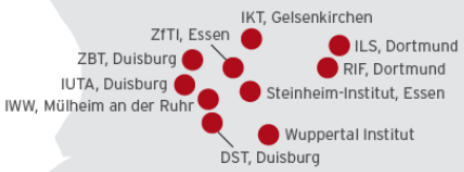
AMO Mission
- Identify Key Enabling Technologies
- Demonstrate applications
- Bridge the innovation gap



Network

Johannes Rau Forschungsgemeinschaft

15 Interdisciplinary Research Institutes of NRW



AMO works professionally, collaboratively, interdisciplinary

- 150 R&D partners from 25 countries
- > 40 funded research projects
- Regional (NRW)
- German (DFG, BMBF, BMWi)
- European Union (H2020)
- Bilateral (Spin-Outs)
- Research Associations
  - Johannes Rau Institutes
  - ZUSE Institutes
- Industrial Associations
  - EPIC (Photonics)
  - IVAM (Microsystems)
  - NMWP (Nano, Micro, Materials, Photonics)
  - AMA (Sensors)
  - VDE (Electronics, Photonics)

Aachen Graphene & 2D Materials Center
From material science to new device applications

Members (06/2021)

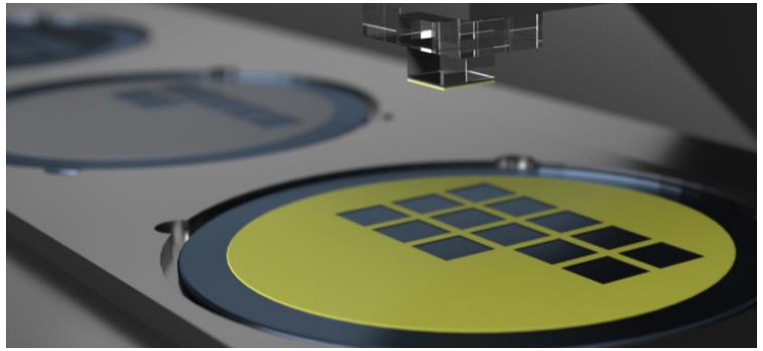
Prof. Dante Kennes (RWTH)
Prof. Joachim Knoch (RWTH)
Dr. Annika Kurzmann (RWTH)
Prof. Max Lemme* (RWTH / AMO)
Prof. Markus Morgenstern (RWTH)
Prof. Renato Negra (RWTH)
Prof. Daniel Neumaier (AMO / Wuppertal)
Prof. Christoph Stampfer (RWTH)
Prof. Andrei Vescan (RWTH)
Dr. Zhenxing Wang (AMO)

Benefits

- Collaboration in R&D projects
- International visibility
- Interdisciplinary education of PhD / Master students
- Use synergies (existing infrastructure)

Goals

- Establish further industry collaborations
- Cover the innovation value chain from basic research to technology demonstration



* Sprecher

Content

- About AMO
- History of automated SEM image analysis @AMO
- Use cases
- Conclusion

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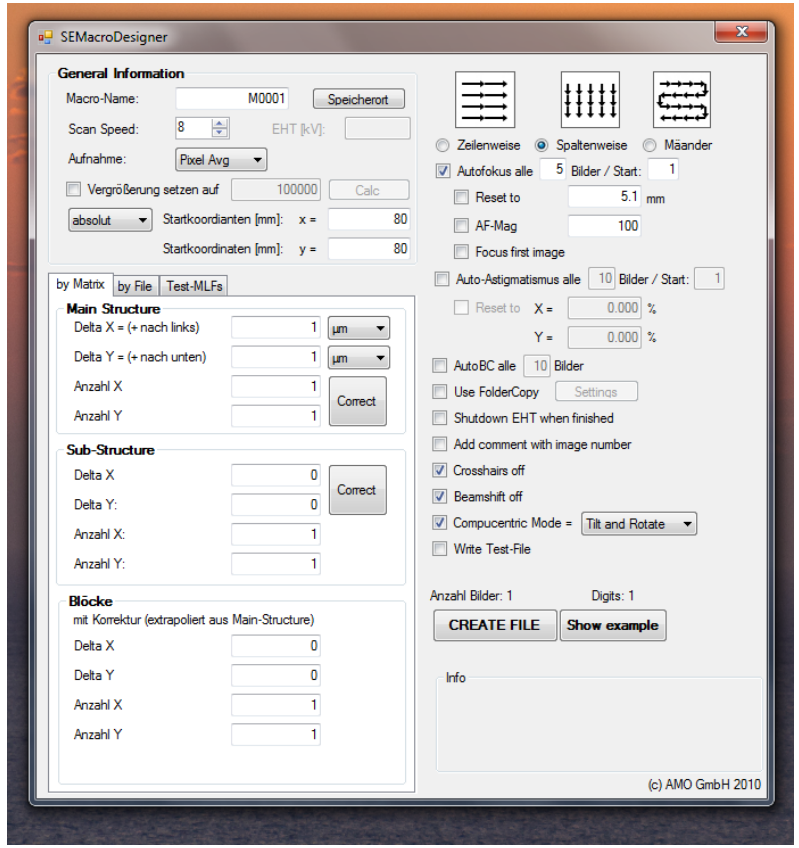
History of automated SEM image analysis @AMO

- Why?
  - Because taking just a few images and measuring just a few features or just one position per feature is often not good enough when it comes to nanoscale features and demanding applications such as optics
  - And because taking “enough” images and analysing them by hand can *a lot* of time
  - The “big boys” in industry have dedicated CD-SEMs for this, but we don´t



- Solution
  - In 2009 a student @AMO started programming two tools
    - *SEM Macro Designer* to create macros for our SEM, enabling semi-automated image acquisition
    - *SEMAlyzer* to automatically analyse SEM images

History of automated SEM image analysis @AMO

AMO

Applications of ProSEM at AMO GmbH

Giovanna Capraro

History of automated SEM image analysis @AMO

- With ProSEM, the image analysis part has been covered better and better during the last couple of years

- Right now the automated image acquisition is still lacking behind
  - Our in-house macro creation approach works
  - *But:* Hard to use, not well integrated with ProSEM, not “design aware”, ...

- Future ProSEM versions will offer much better options for automated image acquisition

- Hence, in future we may have a fully integrated, easy to use and design aware toolset for automated SEM image acquisition and image analysis

Things developed quite a bit since the times of SEM Macro Designer and SEMAlyzer, but there is still some work to do until our SEMs can do things fully automatically

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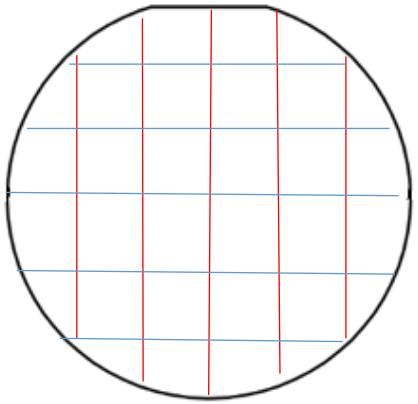
Use case I: SEM analysis of an entire wafer

- Analysis of an entire 6” wafer filled with a nanoscale grating structure
- Goal: Observe both period and duty cycle variations over full 6” wafer area

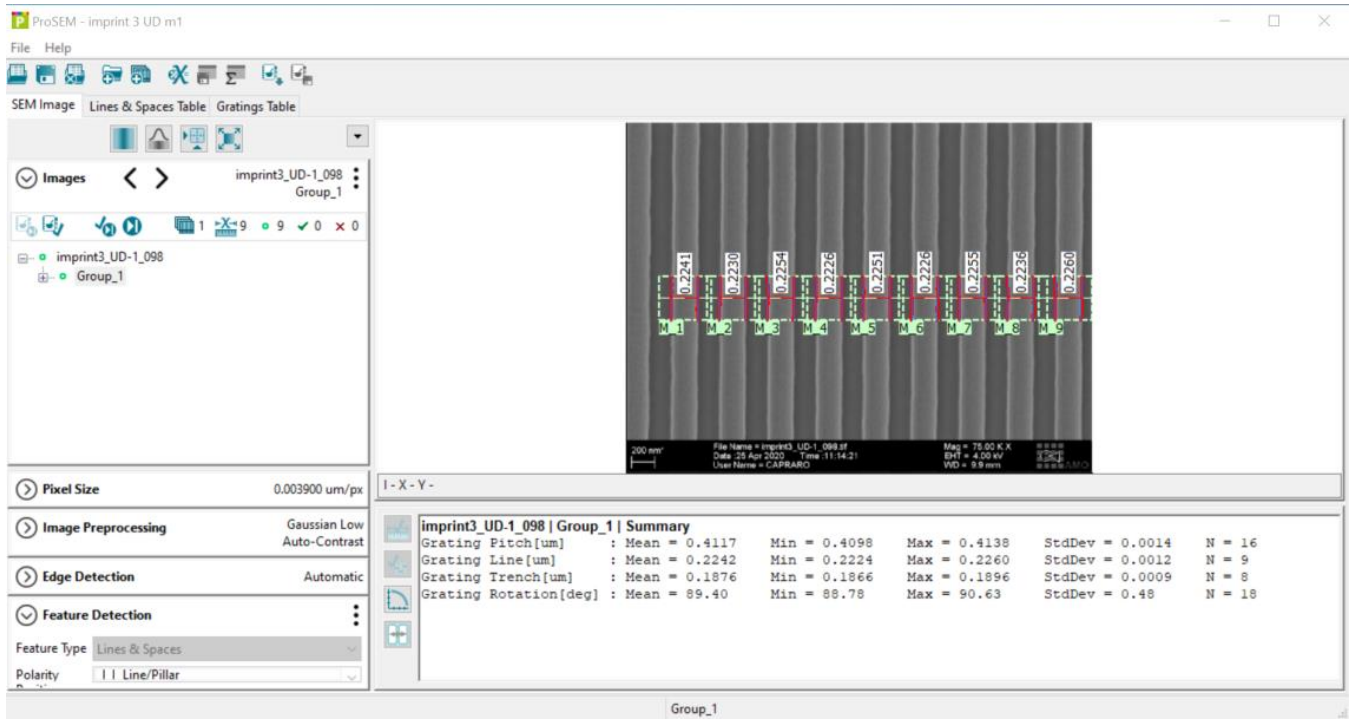
- Without automation for both image acquisition and image analysis
  - No more than a few dozen images can be taken in a realistic time
  - Only few measurement values can be extracted per image

Use case I: SEM analysis of an entire wafer

- Giovanna's approach:
  - Use automation for both image acquisition and image analysis
    - Automated image acquisition using software-created scripts
    - Batch analysis of images using GenISys ProSEM

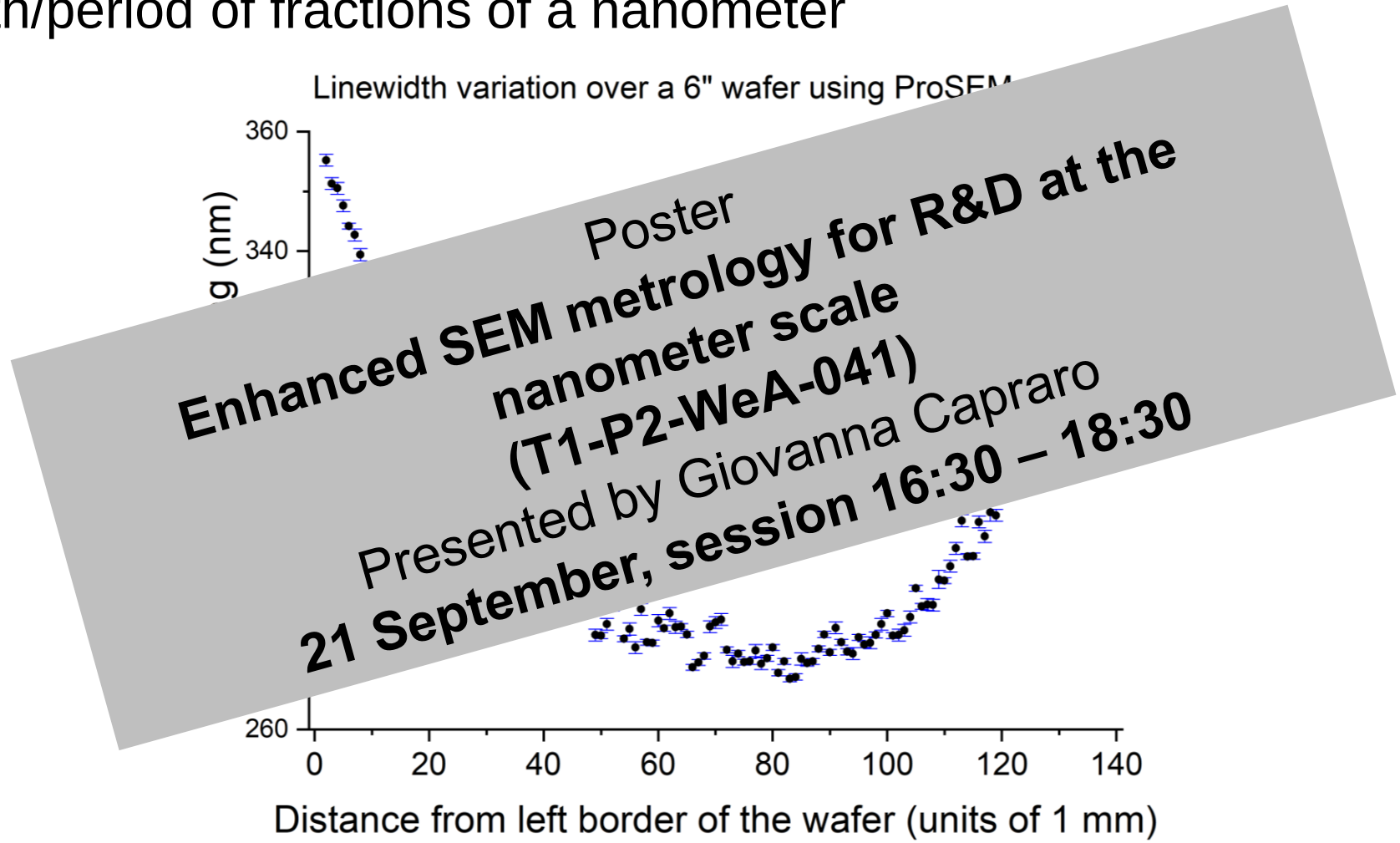


6" wafer
~ 10 lines in total
~ 1300 images



Use case I: SEM analysis of an entire wafer

- By using a large number of images and all available data in the image with ProSEM, the absolute error is low enough to observe differences in linewidth/period of fractions of a nanometer



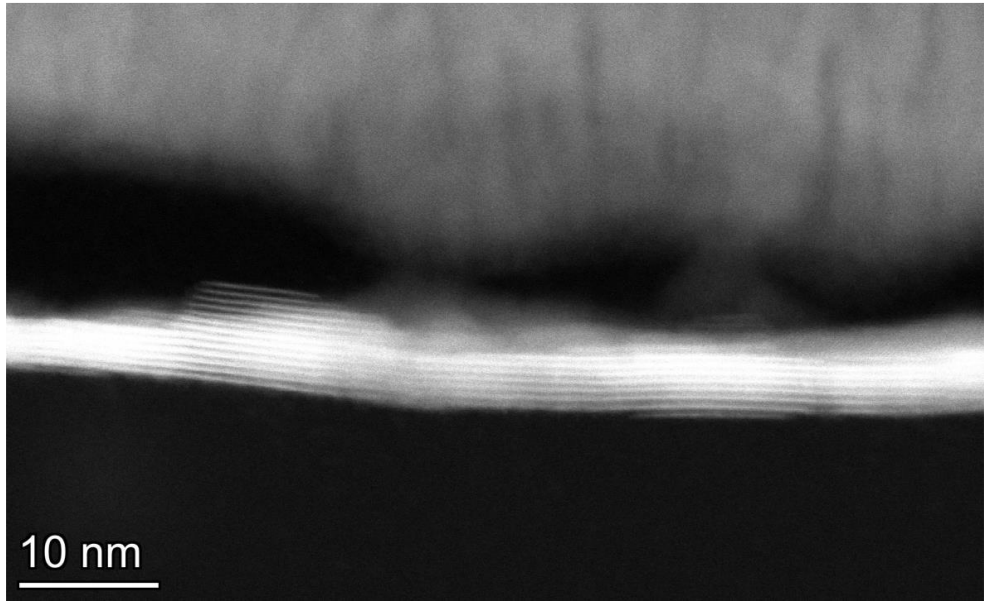
Poster
Enhanced SEM metrology for R&D at the nanometer scale
(T1-P2-WeA-041)
Presented by Giovanna Capraro
21 September, session 16:30 – 18:30

Use case II: An unconventional use of ProSEM…

- TEM image analysis

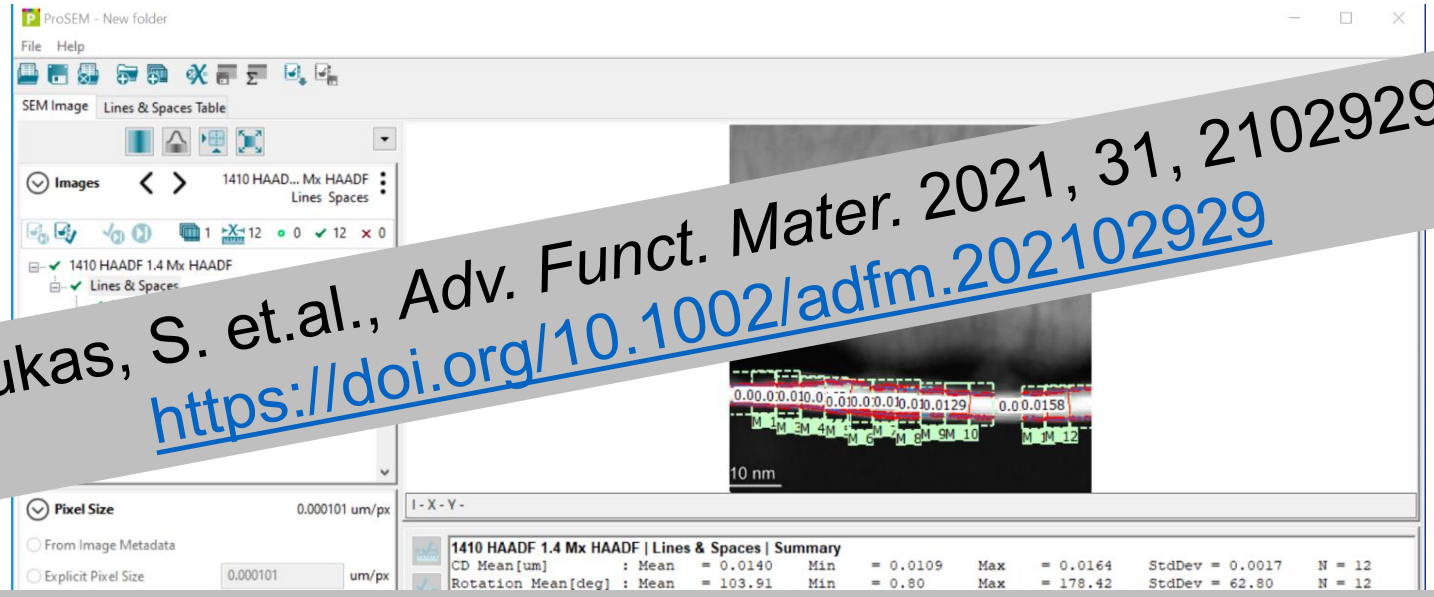
- Goal: Analysis of the growth process of a new 2D material $PtSe_2$

- Image a stack of layers using TEM
- Measure the orientation of 2D material crystallites
- Relate that to the growth process



Use case II: An unconventional use of ProSEM…

- ProSEM can not only measure feature sizes, but also their orientation
  - Measurement of top and bottom layer orientation (angle)
- With this method it was possible to measure angles of fractions of degree, with standard deviations of units of degree.



Lukas, S. et.al., Adv. Funct. Mater. 2021, 31, 2102929
https://doi.org/10.1002/adfm.202102929

Think "out of the box" and use tools such as ProSEM also in ways they may not have been designed for but still work just fine

Use case III: Classic stuff …

- “Classic” inspection tasks
  - Dose variations
    - Right now, often just detailed enough to find the correct dose for a given exposure
    - With automated SEM inspection one can check every feature of every dose to not only find the right dose, but also get a better understanding of certain effects (Do I hear someone say “Mid-range effects with HSQ”?)
    - Also, this route would offer insight into things such as etch biases more or less for free
  - Take an image of every device on a sample or wafer
    - Right now, often a full inspection follows the characterization
    - Full inspections before the characterization can be done now
    - *And:* We can do full inspections after each fabrication step

We can automate a lot of things we did by hand for decades!

Use case IV: … and novel ideas

- Combine SEM data with AI image analysis
  - Have an AI calculate your yield by automatically checking for bad devices
    - How much time can a PhD save if an AI tells her/him that a certain device will not work before it is characterized?
  - Have an AI correlate “more expensive” data, gathered by Raman spectroscopy, EDX or other techniques with “cheap” SEM data
    - How much time can we save by extracting material-related data from SEM data?

- Such approaches require lots and lots of SEM data
- And they often require “design awareness”
- Hence, automation is key and an integrated, design aware software suite is needed

Combination of large SEM data sets and freely available AI tools offer significant potential in R&D settings

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Conclusion

- In-house solutions to automate SEM inspection tasks have been developed by AMO & others for more than a decade now
- With ProSEM, the image analysis part of that is now covered by a commercially available software tool
- Future ProSEM versions will most likely also provide more options for automated image acquisition
- With that CD-SEM-like functionality becomes available in R&D settings

“If you have to do it more than twice, automate it!”

Thank you for your attention!

AMO

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