Tues 2:45-3:15pm

NEAR-LINE TEM FLOW : WHAT DOES IT BRING TO THE TABLE

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PUBLIC

NEEDS OF THE INDUSTRY

TEM/STEM & CHEMICAL IMAGING

AUTOMATED TEM WORK FLOW

HVM LANDSCAPE

- Manufacturing
  - -Over 1 month of processing
  - -1000+ processing steps
  - -Dimensions approaching atomic scale
  - -More complex materials and structures (3D)

By 2020, current cost trends will lead to an average cost of between $15 billion and $20 billion for a leading-edge fab, according to the report. According to Gartner,

Worldwide semiconductor **revenue is forecast to total** $451 billion in 2018, an increase of 7.5% from $419 billion in 2017, according to **Gartner**.

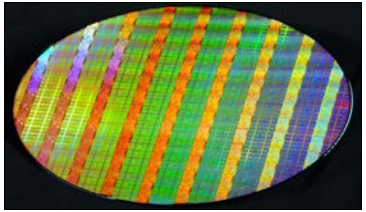
In High Volume Manufacturing (HVM) :

1 cycle of learning ~100M (USD)

1 fab down event costs >1M (USD)/day

PROPERTIES-ANALYTICAL TOOLBOX

Incoming chemicals



Processed wafer

Wafer processing

- Dimensions
- Composition
- Dopants
- Strain
- Electrical

- OM/SEM
- TEM/STEM
- SPM
- XPS
- XRD
- SIMS
- APT
- C-V etc.

SPM includes: AFM, SSRM, STM, nanoprobe, etc
C-V includes: Hg-Probe, Faast, Thermowave, 4pt probe, etc

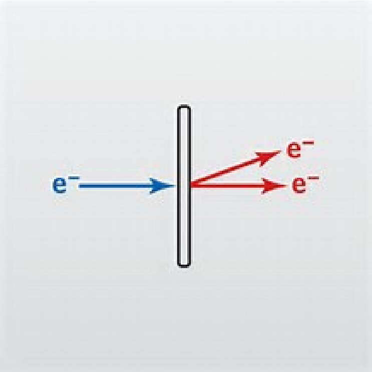
*And there are other techniques for supporting R&D+HVM

NEEDS OF THE INDUSTRY

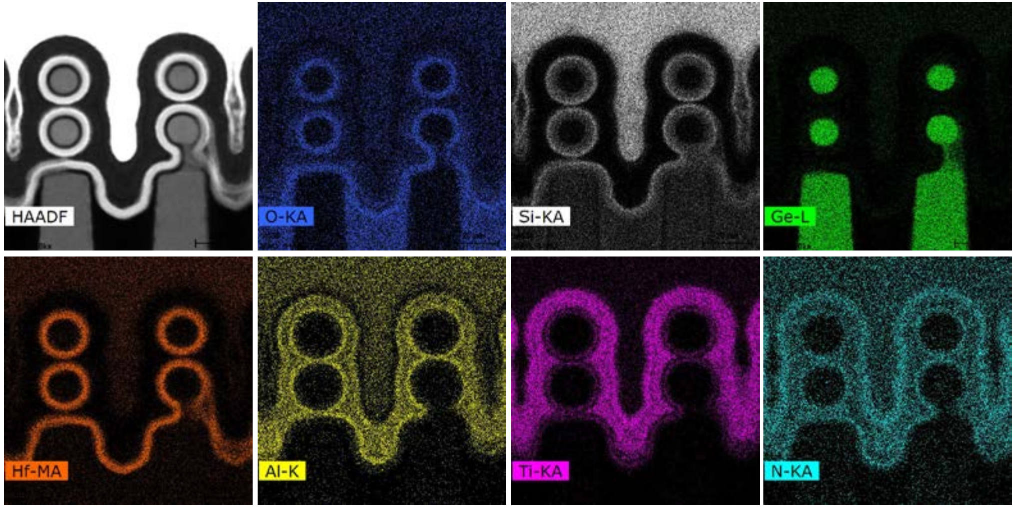
TEM/STEM & CHEMICAL IMAGING

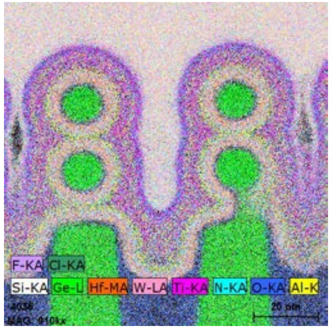
AUTOMATED TEM WORK FLOW

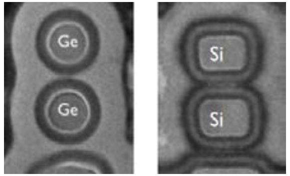
TEM/STEM AND CHEMICAL IMAGING

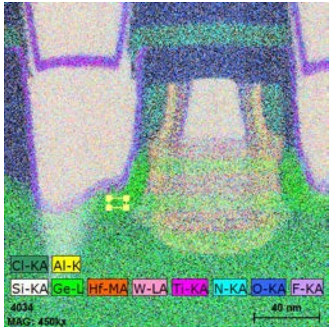


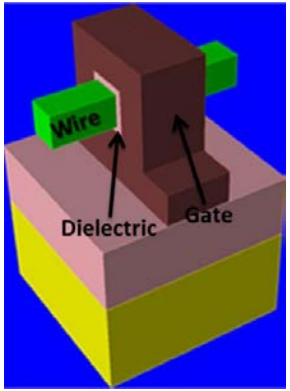
- Traditionally TEM/STEM has been a highly manual process











- $Si_{1-x}Ge_x$ composition maps derived via EDS

0.39 ANGSTROM RESOLUTION AT 80 KEV

https://doi.org/10.1038/s41586-018-0298-5

Electron ptychography of 2D materials to deep sub-ångström resolution

Yi Jiang[1,6], Zhen Chen[2,6], Yimo Han[2], Pratiti Deb[1,2], Hui Gao[3,4], Saien Xie[2,3], Prafull Purohit[1], Mark W. Tate[1], Jiwoong Park[3], Sol M. Gruner[1,5], Veit Elser[1] & David A. Muller[2,5]*

Aberration-corrected optics have made electron microscopy at atomic resolution a widespread and often essential tool for characterizing nanoscale structures. Image resolution has traditionally been improved by increasing the numerical aperture of the lens (α) and the beam energy, with the state-of-the-art at 300 kiloelectronvolts just entering the deep sub-ångström (that is, less than 0.5 ångström) regime. Two-dimensional (2D) materials are imaged at lower beam energies to avoid displacement damage from large momenta transfers, limiting spatial resolution to about 1 ångström. Here, by combining an electron microscope pixel-array detector with the dynamic range necessary to record the complete distribution of transmitted electrons and full-field ptychography to recover phase information from the full phase space, we increase the spatial resolution well beyond the traditional numerical-aperture-limited resolution. At a beam energy of 80 kiloelectronvolts, our ptychographic reconstruction improves the image contrast of single-atom defects in MoS_2 substantially, reaching an information limit close to 5α, which corresponds to an Abbe diffraction-limited resolution of 0.39 ångström, at the electron dose and imaging conditions for which conventional imaging methods reach only 0.98 ångström.

NEEDS OF THE INDUSTRY

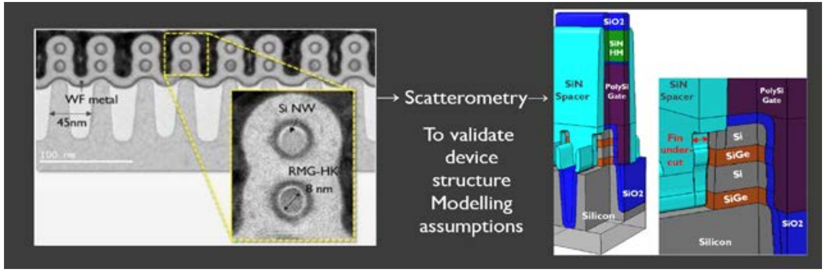
TEM/STEM & CHEMICAL IMAGING

AUTOMATED TEM WORK FLOW

WHY

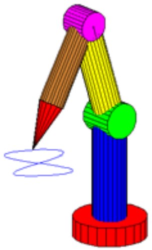
- 1) Escalating industry costs → Faster ROI

  2) Reduced dimensions and going to 3D → More difficult analysis needed faster



Method	Internal ref	Resolu-tion	Speed	Damage	Statistics
OCD					
CD-SEM				† 	
TEM/ STEM			* 		* 

† Resist shrinkage
* Manual based flow



Automated TEM/STEM

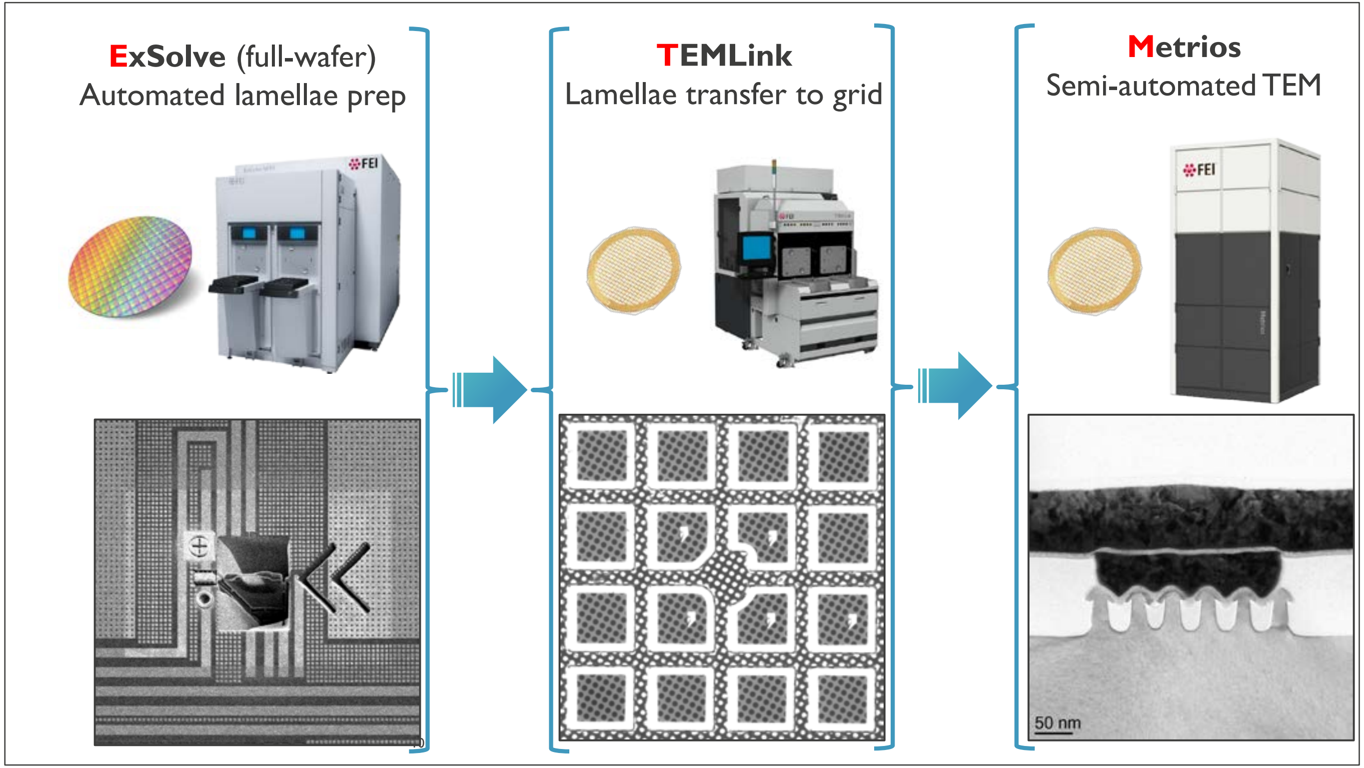
AUTOMATED WORKFLOW VIA ETM SUITE

ETM=ExSolve(dual beam FIB)-TEMLink(sample transfer)-Metrios(TEM)

- The ETM suite provides an automated TEM work flow

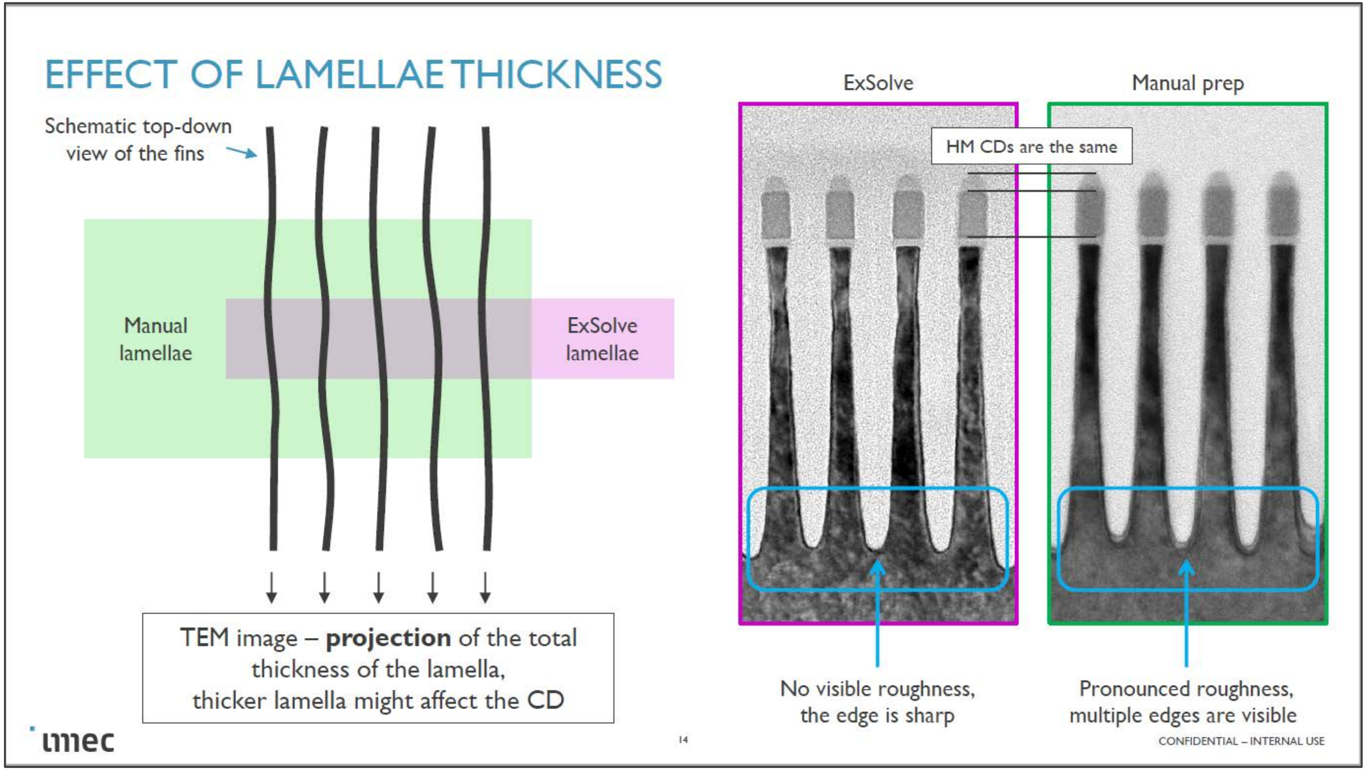
- Process=

  1) Sample (lamella) milling



AUTOMATION → IMPROVED PRECISION

- Automated TEM workflow



- Automation=

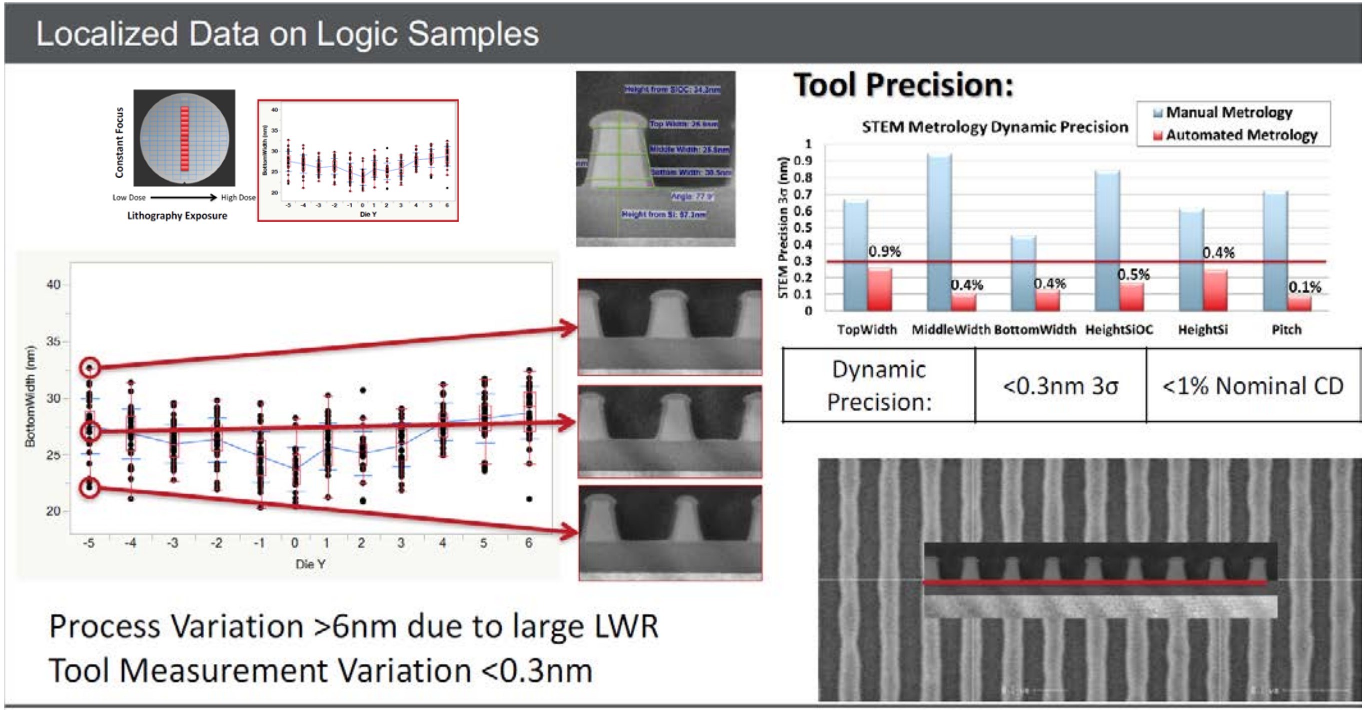
  1) More precise thin lamella
  2) Faster through-put
  3) Improved CD precision

** Full auto mode on straight forward structures assuming recipes exist

AUTOMATION → PRECISION → STATISTICS

- Throughput: Up to 21 lamella/day with numerous sites per lamella available**

- Statistical=
  1) More precise thin lamella
  2) Faster through-put
  3) Improved CD precision



Slide from presentation of Ozan Ugurlu (from FEI now Thermo-Fisher-Scientific)

DOWNSIDES

Opportunities

More vendors = More competition

Can ML/AI support recipe development?

Can device emulation inputs add value?

- Costly & only one vendor
- Automated=

1) Recipe driven

   Need onsite expert/s that know specific process flows

2) Recipe development times are long

   Weeks for 1st recipe down to hours for recipe modification

3) Recipes are highly specific & these run blindly

   No on-the-fly changes to experiment & no visibility to device abnormalities

- Downtime at any step impacts entire workflow (multiple flows needed)

WHAT DOES IT BRING: NEW CAPABILITIES & MORE CAPACITY

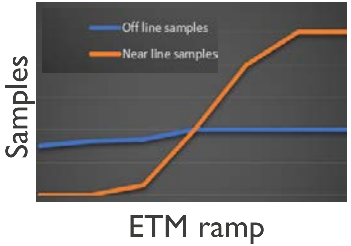
- Automated TEM

  1) Faster time to data (>>2x)

  2) Improved CD precision
     a) Recipe driven sample prep (faster, more precise)
     b) More precise thin Lamella (less projection effects)
     c) Recipe driven data collection (removes human factor)

New capability (→CD-TEM)

Both are of high value to the industry



- Manual TEM (traditional)

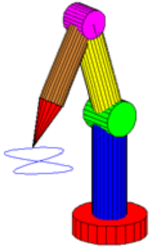
  1) Single site one-off analysis
     a) R&D
     b) FA

  2) Advanced capabilities
     a) Strain analysis (NBD, PED, ...)
     b) Tomography
     c) Holography
     d) Ptychography

More technically diverse R&D and FA requirements

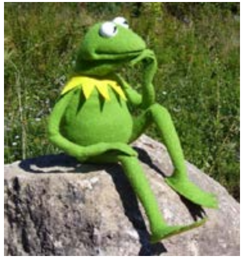
SUMMARY

- Escalating industry costs → Faster ROI
- Manual TEM flow (best for one-off "characterization" approaches) → Accurate
- Automated TEM flows (best for "metrology" approaches) → Accurate & precise combined with faster speed



Automated TEM

Manual TEM



TEM/STEM semiconductor workflows

Near-line (high volume)
-Dimensions (CDs)
→CD-TEM
"Metrology"

Mix

Off-line (low volume)
-FA
-R&D
"Characterization"

Statistics

Advanced capabilities

embracing a better life