VELION

FIB-SEM where FIB truly comes first

FIB and SEM for Nanofabrication, Nanoengineering and Inspection

FIB-SEM NANOFABRICATION

RAITH
NANOFABRICATION

New state of the art in FIB-SEM nanofabrication

- FIB-centric with high-resolution gallium or multi-species IONselect technology
- Nanofabrication-dedicated system architecture for FIB and SEM
- Different system configurations and stage setups including sample tilt

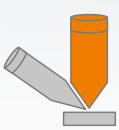
Four modes. Two Beams. One System.

VELION is a novel FIB-SEM instrument dedicated to advanced nanofabrication, in which FIB is the true priority technique. An evolution of Raith's ionLINE, the ion column at the vertical position features a unique design to meet the most demanding nanofabrication requirements. It is supported by a field emission SEM solution as well as a highest-precision laser interferometer-controlled sample stage.

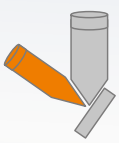
With its FIB-prioritized nanofabrication setup, including SEM and a high-accuracy stage, VELION allows for versatile use in four different operation modes that offer

- direct and versatile FIB patterning for simplified, flexible, 3D, and automated processing
- highest-precision nanofabrication over extended areas and periods of time with both FIB and SEM
- SEM imaging for *in-situ* process control, inspection and sample preparation.

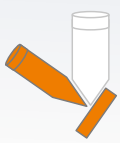
FIB Nanofabrication



Sample Preparation



Process Control



E-Beam Lithography

FIB versatility

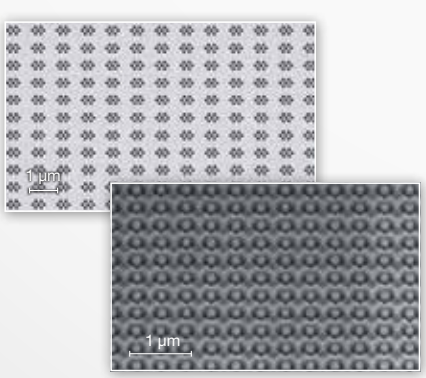
FIB provides various direct patterning techniques, enabling the best suited and simplest process for each purpose to be selected. This helps reducing the number of process steps and development efforts. Most FIB techniques create 3D structures directly and can be applied to highly topographic 3D samples. Raith's unique FIB technology is optimized for nanofabrication, and its benefits are enlarged by multiple ion species beyond gallium.

Advanced nanofabrication

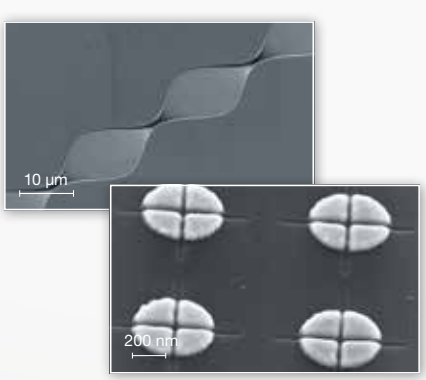
The lithography system architecture ensures unrivaled stability, accuracy, and automation. Raith offers matured column and platform technologies for nanofabrication processes. Besides the laser interferometer stage, electronics and software are designed for sophisticated processes, offering features for beam and stage controlled patterning. New applications can be explored, making the most out of FIB and SEM for nanofabrication.

SEM and more

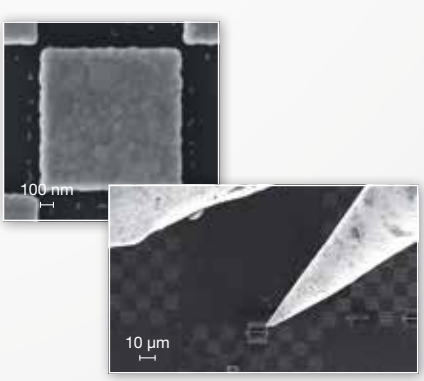
A SEM column, gas injection systems, nano probers, EDX, and other options support the FIB processes and massively increase the application range. SEM inspection for *in-situ* process control, live imaging during TEM sample preparation, gas assisted processes, and manipulation or probing are possible. More upgrade paths are available, and the SEM can be employed for resist lithography applications.



Direct FIB milling for high resolution (1) or 3-dimensional structures (2).



1-mm fluidic channel (1, FIB) and array of plasmonic gold cakes (2, EBL plus FIB).



Expanded capabilities due to SEM high resolution inspection (1), gas injection and nano manipulation (2).

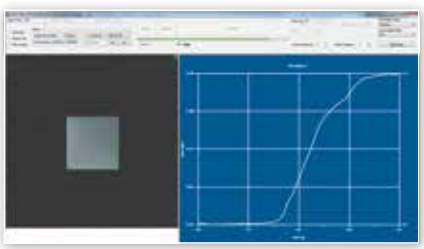
Excellence in FIB Nanofabrication

FIB centric lithography architecture and laser interferometer stage

VELION breaks new ground for your nanofabrication challenges by realizing the synergy of a focused ion beam and a lithography platform. Direct FIB processing techniques are complemented by the highest-accuracy laser interferometer stage and the unique capabilities and advanced beam control of Raith's powerful pattern generator and software.

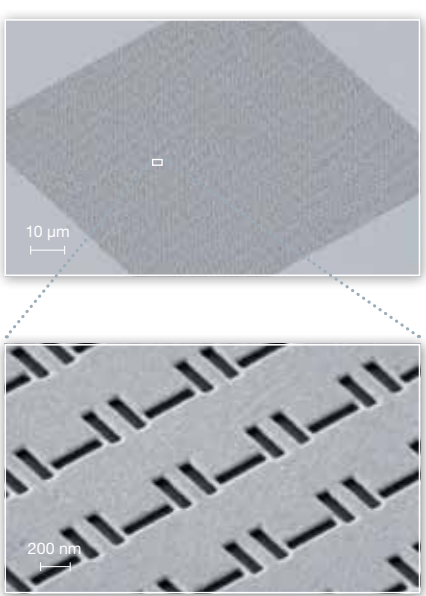
Choose and optimize versatile techniques

Choose from various FIB patterning techniques to find the approach that is best suited for each application. Instantaneous process control for fast *in-situ* optimization during patterning is possible by means of monitoring using FIB end-pointing or SEM imaging. The laser stage and software automation can be employed for conducting sophisticated test arrays and directly revisiting them for multiple process checks. In addition, result checks are truly 3-dimensional thanks to cross sectioning, and thus make FIB nanofabrication a versatile and flexible approach.



Apply direct and simplified processes

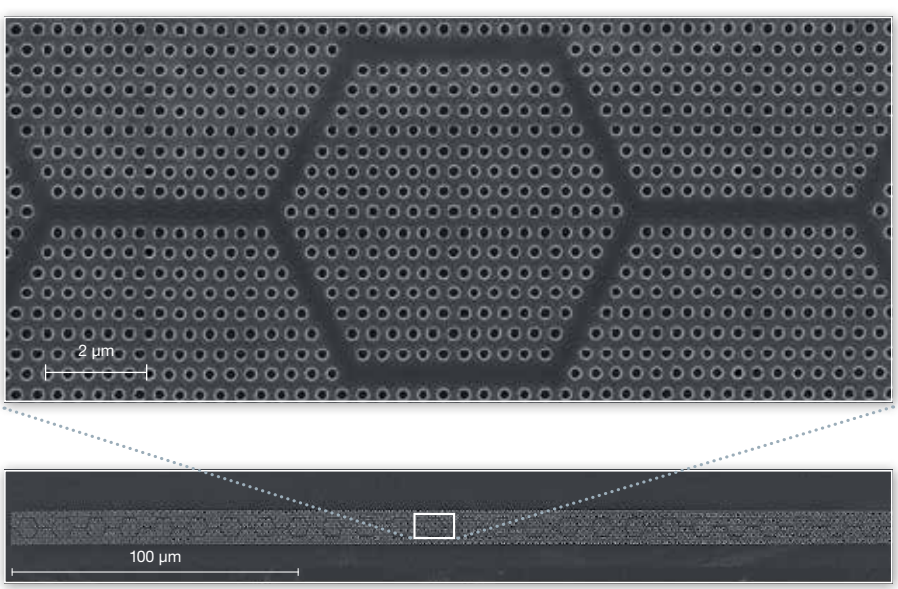
A FIB process usually exhibits a reduced number of steps compared to resist-based lithography, so that new results are faster and easier to achieve. Moreover, the milling and gas-assisted process directly create 3D structures and can be applied to highly topographic 3D samples such as MEMS or AFM cantilevers. Finally, new and exciting techniques like functionalization, hard masking, and ion implantation are emerging and show similar benefits.



Stable and automated FIB milling enables large arrays of high-resolution features, as required for plasmonic applications.

Repeat accurate results over extended time and area

A growing number of applications require accurate and reproducible work over extended periods of time, or areas larger than a single field of view. The unrivaled stability of platform and column, as well as the precision of the beam deflection with unique dynamic compensations, ensure reliable and accurate placement of structures even for hours at a time. The precision of the laser interferometer stage allows for multi-field patterning by stitching without edge-effect artifacts at the write field border. Raith's unique stage technology also enables sample navigation without the need for imaging within sensitive areas, and offers truly continuous writing strategies for structures spanning long distances without breaks.



Write field stitching allows for direct milling of long waveguides with offsets on the 10 nm scale only.

SEM for sample preparation and process control

Benefits of SEM column support for FIB processes

The field emission SEM column significantly expands the capabilities of VELION, both for live control during FIB sample preparation and for process checks of direct FIB patterning *in-situ*. By employing Raith's stage and software features, this is even possible over larger areas in a step-and-repeat manner.

Sample preparation

With the SEM column and key options like gas injection systems and nano probers, VELION provides all the required capabilities of a FIB tool for TEM, APT, or other sample preparation. Site-specific low-damage processes with easy and accurate end-point control are state-of-the-art. Advanced results and procedures are achieved with the high-resolution, low beam tails FIB performance in combination with the sophisticated patterning engine, stability, and automation of the system setup.

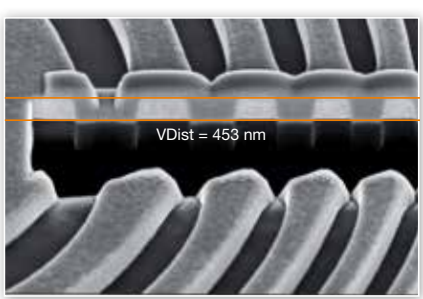
After deposition of a protective layer, a TEM lamella is cut out of the bulk sample at a specific site.

With the help of a nano manipulator, the pre-thinned lamella is transferred to a dedicated sample holder such as a TEM grid.

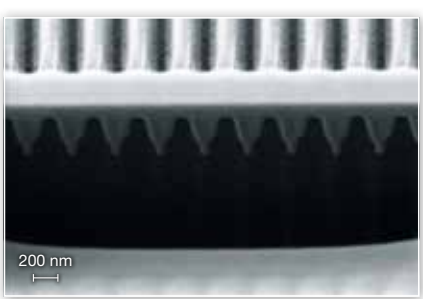
Once the lamella is connected to the TEM grid it is polished to the desired thickness, providing electron transparency.

X-section analysis

Besides supporting the sample preparation process, the SEM column is employed for high resolution imaging of FIB X-sectional cuts. Main applications are in depth control and optimization of 3-dimensional FIB processes, as well as X-section imaging and analysis of various samples for microscopy purposes.



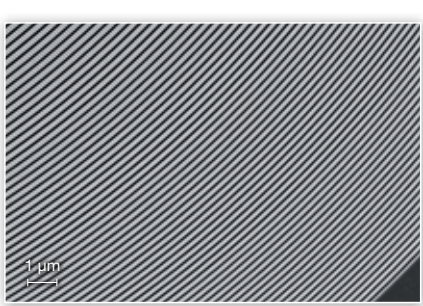
X-sectional process control of an X-ray Fresnel zone plate fabricated in 500 nm thick gold.



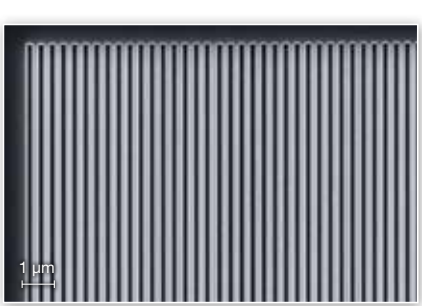
The 3-dimensional shape of a special antireflective grating is revealed by X-section analysis.

Process checks

Support of FIB and process development is complemented by top-down high-resolution imaging with the SEM column. The SEM resolution allows for inspection of all features created by the ion beam. Given the direct patterning techniques of FIB, it is possible to check results and optimize parameters in an *in-situ* closed-loop approach for very efficient process development.



Top-down high-resolution SEM imaging used for lateral process control of FIB milling results.



Placement, straightness and pitch of the 3-dimensional grating are checked by SEM inspection.

nanoFIB Three and IONselect

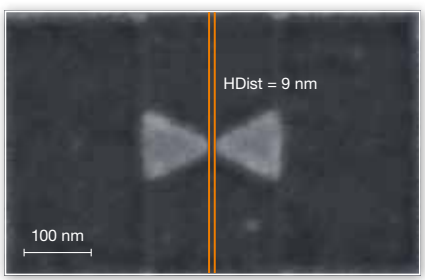
Unique FIB technology with gallium and beyond

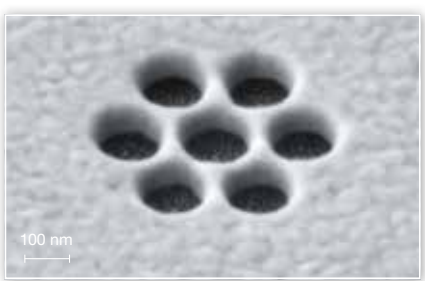
Raith's proprietary FIB technology continuously evolves to meet all the critical requirements of advanced nanofabrication. The latest-generation nanoFIB Three gallium column defines a truly new state of the art in FIB technology. It can also be chosen in the IONselect configuration providing stable delivery of gold, silicon, or other ions with nanometer beam diameters.

nanoFIB Three gallium ion column

The nanoFIB Three ion column is optimized for highest resolution and excellent spot characteristics because of its very short optical length and small working distance. It has a narrow central spot and record low beam tails, enabling high resolution nanofabrication.

Moreover, the nanoFIB Three technology shows exceptional long-term stability due to its liquid-flow optimized ion source and patented emission control. The guaranteed low drifts in probe current and beam position are combined with dedicated low-distortion octupole deflection for accuracy and reproducibility in long-term processes, within a writing field, and for stitching of multiple fields.



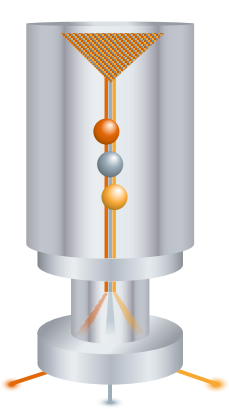


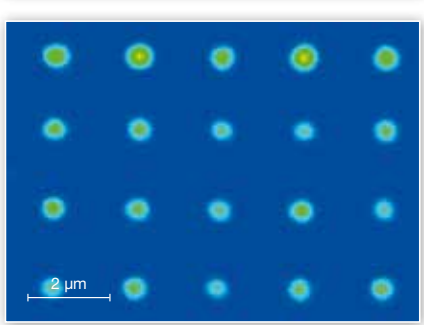
FIB cutting sub-10 nm features (1) and keeping a high aspect ratio ribbon (2) in challenging materials like polycrystalline gold.

IONselect multi-species configuration

The IONselect technology provides new ion species for unique processing and imaging. A range of species is available with the AuSi source and beyond, from doubly-charged light ions to heavy ions and clusters, all with excellent handling. The alloy ion source and low-aberration mass filter enable easy switching between multiple ion species from a single source.

Various ions allow for different interaction mechanisms, very specific processes, or other yet-to-be-explored nanofabrication techniques. Processing with low contamination, specific functionalization, higher resolution, and surface-sensitive milling will pave the way for new breakthroughs in next-generation research. In particular, controlled, direct, and maskless ion implantation applications in quantum technology research and prototyping ask for specific ion species to be implemented in computing, data storage, or sensing devices.





Heavy ions like Au offer higher sputter yield or surface functionalization (1), whereas ions like Si are specifically used for ion implantation (2).

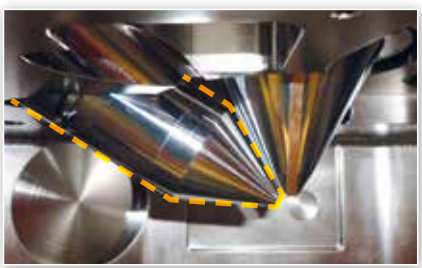
Raith's tailored field emission SEM column

SEM capabilities for inspection and lithography

Additional operation modes for VELION are achieved by using the SEM itself for imaging or metrology and electron beam lithography. Depending on the precise sample stage setup and system components, these techniques make VELION an extraordinary powerful and versatile instrument.

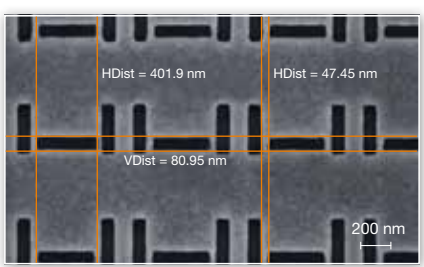
A tailored SEM solution

The optional field emission SEM has been designed as a tailored solution for supporting and preserving the FIB as the priority technique. It offers high beam resolution and a state-of-the-art beam energy range, so that sample inspection and live control of lamella preparation are possible. The design and technology of the SEM column are derived from Raith's proven EBL column. Based on electromagnetic focusing in combination with electrostatic deflection, it offers high beam resolution as well as precise and fast scan deflection in calibrated write fields.

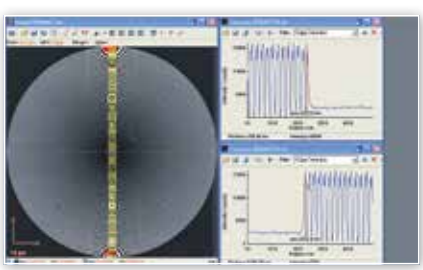


Checking processes and samples

SEM high-resolution imaging and automated metrology can be applied to various patterning results and microscopy samples. For sophisticated FIB test arrays or step-and-repeat processes, it is possible to use a correlated workflow directly and *in-situ*. With an advanced stage setup, this can be conducted on various samples and over extended areas or even on wafer scale, performing sample inspection with CAD navigation support and advanced automation.



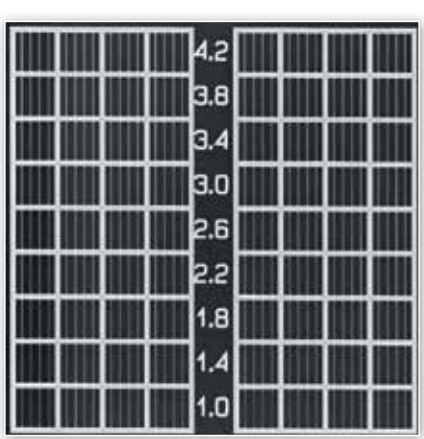
Detailed in-situ *SEM inspection of plasmonic features created by FIB milling.*



The roundness of an X-ray lens is checked by advanced SEM metrology line scans.

Electron Beam Lithography

With the optics design and powerful patterning engine for the SEM column too, the system offers EBL workhorse capabilities. As with any other Raith lithography tool, all well proven EBL features of the Nanosuite software package are available, including parameter control, patterning strategies, automatic scans or alignments, and proximity effect correction. This enables sophisticated applications in nano electronics, physics, and photonics, and combines with FIB nanofabrication in one instrument. VELION offers the unique opportunity of complementary advanced lithography with both ion and electron beams in a single dedicated nanofabrication system.



EBL test pattern for determining the line width for different dose factors.

Demo example (transistor like pattern) showing EBL overlay capabilities.

Configurable setups for extended versatility

Be ready for various applications, now and in future

VELION has been designed on a versatile, fully integrated, and configurable platform offering various optional software and hardware components or features. The system can be customized and upgraded for a wide range of applications, and helps to keep pace with emerging research trends by future tool options.

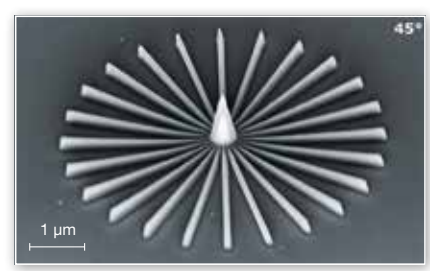
With multiple universal ports on the vacuum chamber, various hardware options in different configurations are possible, particularly single and multi-line gas injection systems as well as nano probers. Besides the standard chamber CCD and a top-down-view optical macroscope for navigation, other optical and NIR cameras can be selected. More optional components, such as plasma sample cleaner, automatic laser height sensing, EDX and different or customized sample holders, are available.

CAD view of a VELION setup including SEM, SE and EDX detector, 5-channel and two single line GIS, optical macroscope as well as two nano manipulators.

Gas Injection Systems

A must-have component for a FIB tool is a gas injection system that provides a local flow of gas over the sample. Gas-assisted etching shows increased removal rates, better selectivity, and less re-deposition. Moreover, ion-beam-induced deposition is applied for X-sectioning, TEM sample preparation, masking for subsequent processing, and wiring of nano objects. Different configurations – including multiple GISs from opposite directions – can be employed together with flexible software parameters to optimize for rate, resolution, resistivity, or planarity. Some precursors may also be employed in combination with the electron beam for complementary exciting FEBIP applications (focused electron-beam-induced processes).

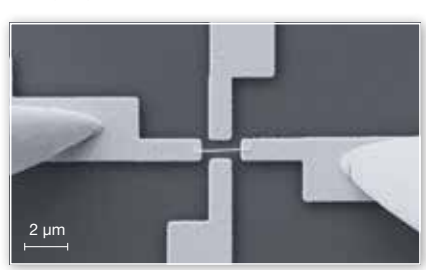
GIS setup with multiple nozzles for homogenous supply of various precursor gases.



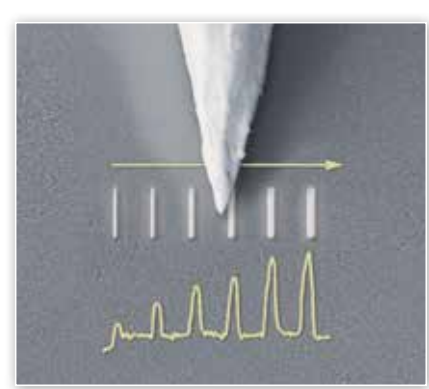
Electron-beam-induced deposition for a star-like test pattern of silicon oxide.

Nano probers and more

Nanomanipulators for intuitive control of metal tips and other end effectors can be used for various applications. Besides the mechanical manipulation of nano objects or lift-out of sample parts, the electrical connection of the tip can be used for *in-situ* electrical probing. The NanoSense option employs a surface-sensitive distance sensor with an existing nano manipulator. This can serve as a scout for the attached probing tip as well as for the other manipulators, for easy sample approach and reliable measurements. Finally, it can be used for nanoprofilometry, adding 3D process control to lateral secondary electron imaging information.



Tungsten deposit between prefabricated gold contacts used for electrical conductivity measurements with nano probers.

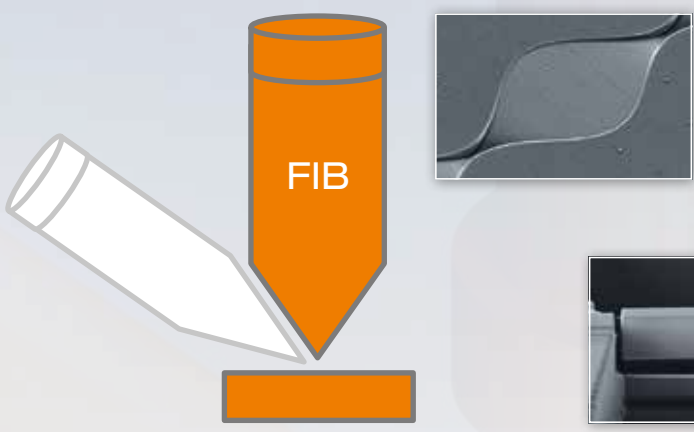


Nanoprofilometric line scan of deposits at various heights fabricated by EBID.

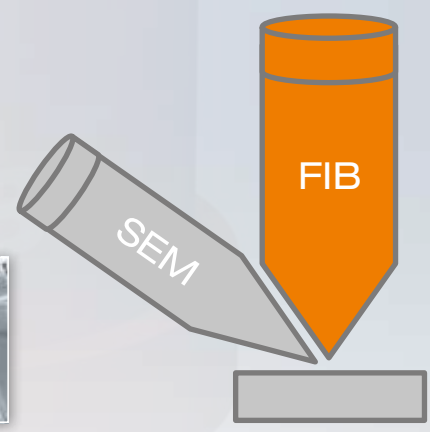
Four modes. Two Beams. One System.

FIB-SEM where FIB truly comes first.

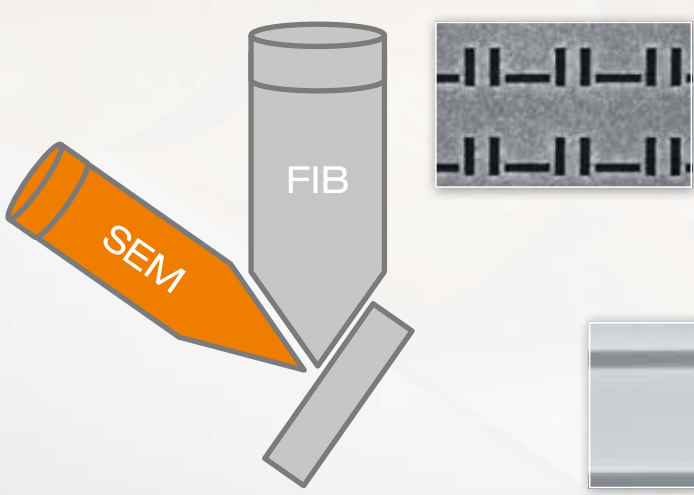
FIB
Nanofabrication



PREP
Sample Preparation



CHECK
Process Control



EBL
E-Beam Lithography

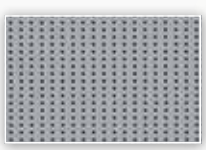
VELION

FIB nanofabrication

- Versatile and accurate sub-10-nm FIB nanofabrication
- Excellent beam spot characteristics and lowest beam tails (nanoFIB Three)
- Nanofabrication with multiple ion species beyond gallium (IONselect technology)
- Direct patterning using ion milling for fastest time to results
- Resist exposure, maskless ion implantation, and hardmasking
- Laser Interferometer Stage enables write field stitching and continuous writing

FIB preparation

- Ion-beam-induced deposition and gas-assisted etching
- X-sectioning at multiple sites for correlated inspection
- Site specific low damage preparation with accurate end-point control
- Nanomanipulators for *in-situ* lift-out, probing and profilometry
- TEM lamella, APT tips or other sample preparation

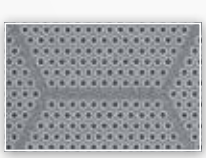



SEM inspection

- High resolution imaging and automated metrology
- Test arrays and repeated processes with *in-situ* correlated workflow
- In depth control of 3-dimensional FIB processes
- Advanced stage setup for large area sample inspection with CAD navigation

SEM lithography

- Column design with electromagnetic focusing and electrostatic deflection
- High lithography resolution and fast deflection in calibrated write fields
- Full software package with GDSII handling and various patterning strategies
- EBL capabilities for sophisticated applications in nano technology research




Devices and images in cooperation with Argonne National Laboratory (p. 3), Bilkent University (p. 5), MPI Stuttgart (p. 5 and p. 7), NMI Reutlingen (p. 5, p. 9 and p. 10), NTU Singapore (p. 6), Peking University (p. 4), Stanford University (p. 6), Swinburne University (p.3), Tel Aviv University (p. 10), University of Florida (p. 6), University of Stuttgart (p. 3, p. 4, p. 6 and p.7), Zhejiang University (p. 3).

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02–2018

Your challenge is our mission.

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NANOFABRICATION