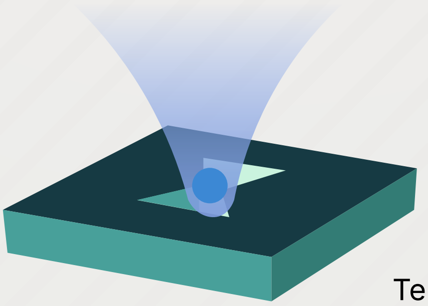
Advanced Solutions for Nanophotonics: Accelerating Nanofabrication and Nanomaterials Research

What is Nanophotonics?

The manipulation of light at the nanoscale is used to create smaller, more efficient devices with advanced optical properties



Key applications

- Telecommunications
- Computing
- Electronics
- Energy
- Biomedicine

Understanding Nanomaterials

Nanomaterials for photonics applications include:

- Plasmonic quantum dots
- Functional photonic materials

Created in different forms:

- Thin films
- Nanowires
- Quantum dots
- Two- and three-dimensional (3D) structures

What Determines Performance?

Optical properties of materials depend on:

- Exact size
- Dimensions
- Crystallinity

The Nanophotonic Challenge

One of the main challenges in nanophotonic research is understanding the correlation between structure and properties in device fabrication

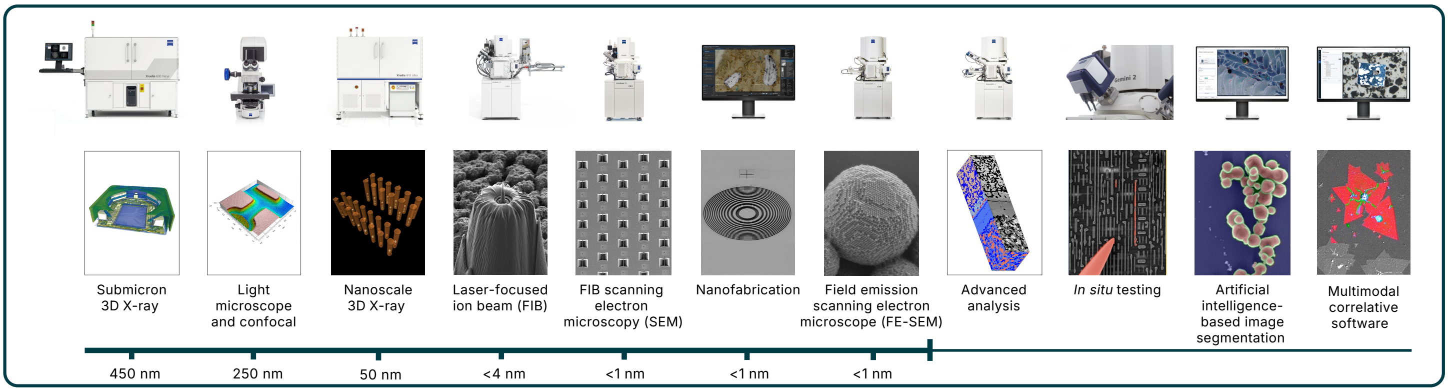
The Solution: Microscopy

Electron microscopy (EM) is indispensable for:

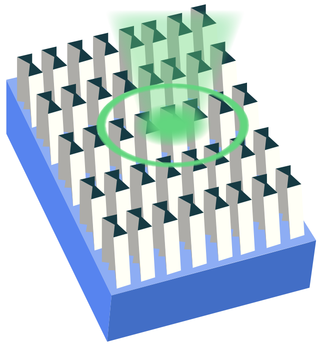
- Studying nanophotonic materials
- Developing architectures and nanomaterial prototyping

ZEISS Multi-Scale Workflow

- Supports unique 3D correlative imaging
- Enables multi-scale analysis by linking ZEISS light microscopes, X-ray microscopes, and EM technology



Engineering Plasmonic Nano-Antennas



Researchers developed electrochemically switchable metallic nanostructures that dynamically control thermal radiation—a critical advancement for augmented reality displays and thermal sensors

Creating these nano-antennas requires precise control at the nanometer scale. The antenna's optical properties depend critically on the exact geometry, surface quality, and metal composition. A fabrication error of just a few nanometers can completely change the resonance frequency

From Design to Working Device

Design	Verify	Test	Refine
Electron beam lithography patterns complex 3D structures with sub-10 nm features	High-resolution imaging confirms structure matches specifications	Optical measurements reveal how structure affects performance	Feedback loop between imaging and redesign accelerates optimization

Multi-Scale Imaging was Essential

Verifying nanometer-scale features while understanding device-level performance requires imaging at multiple scales. ZEISS correlative microscopy bridges this gap:

- FE-SEM revealed 5 nm fabrication defects that degraded performance
- Energy-selective backscatter detection identified metal contamination that was invisible to optical methods
- Seamless transition from millimeter device arrays to atomic-scale surface structure

Impact

Understanding the structure-property relationship enabled tunable thermal emission for adaptive control, precise antenna arrays for vivid AR displays, and nanometer-precision thermal sensors

Modern nanophotonics requires tight integration between fabrication and characterization. Researchers can now fabricate nanostructures, image immediately without removing them from the chamber, adjust parameters based on observed results, and re-fabricate in the same session. This rapid feedback loop reduced development time from months to weeks

Nanofabrication for Smartphone Optics

Fabrication of nanophotonic devices, like plasmonic or dielectric structures, involves micro-structuring. Structuring smaller devices is not easy—one of the main challenges is the need for appropriate nanostructure tools

Smartphone cameras require aspherical microlenses with nanometer surface precision. Traditional trial-and-error mold development takes 6–12 months per design

Injection molding requires molds with inverse surface precision—any mold imperfection creates lens defects. The solution: Use focused ion beam milling to create ultra-precise mold surfaces, then verify them immediately with integrated SEM imaging

Result: Iterative mold refinement in hours instead of weeks

Precision Milling Meets Precision Imaging

Mill	Image	Measure	Iterate
FIB creates aspherical surfaces with 10 nm precision	Integrated SEM verifies surface quality immediately	Detect sub-nanometer imperfections	Adjust and re-image in the same session

Why Integration Matters

Separating milling and imaging would require removing the sample from the vacuum, transferring it to a separate SEM, and re-locating the exact milling site—nearly impossible at the nanoscale. Integrated FIB-SEM systems enable 10+ iteration cycles per day instead of one per week

Results

- Development time: 6–12 months → 3–6 weeks
- Prototype iterations needed: 70% fewer
- Time to market: 5x faster

Advanced Multilayer Lithography

Combining electron beam lithography (precise patterning) with ion beam lithography (3D shaping) creates complex optical structures impossible with either technique alone—enabling multi-focal optics, gradient-index lenses, and diffractive elements for AR/VR

Key advantages

Nanometer precision: Verify features at the scale they're fabricated

Accelerated development: Multiple refinement cycles per day

Design freedom: Iterate rapidly on complex 3D geometries

***In situ* verification:** Catch defects before they propagate to production

From Lab to Manufacturing

- Research demonstrates feasibility. Manufacturing demands repeatability, throughput, and quality control at the nanometer precision across millions of devices
- Nanophotonics has moved from academic curiosity to commercial reality in telecommunications, consumer electronics, and sensing. Research needs flexibility to explore new materials, high resolution to understand mechanisms, and correlative workflows. Manufacturing needs repeatability, automation, high throughput, and non-destructive testing

Case Study: Optical Switch Production

A photonics company developed a novel optical switch using plasmonic waveguides. Lab prototypes worked perfectly, but early manufacturing runs showed a 40% failure rate. Using high-resolution FE-SEM with automated inspection, engineers discovered waveguide width varied by ±8 nm across wafers (spec: ±3 nm), metal deposition created grain boundaries that scattered light, and edge roughness exceeded acceptable limits

Solution: Adjusted deposition parameters based on SEM feedback, implemented automated inspection at critical process steps, and created a feedback loop to fabrication equipment

Result: Failure rate dropped to <5%, enabling a commercial launch

Multi-Scale Imaging Serves All Development Stages

The same core technology serves different needs across development

- **Research discovery:** FE-SEM for characterization | FIB-SEM for prototyping | Correlative workflows
- **Process development:** Automated imaging | High-throughput defect detection | Integration with fabrication
- **Production quality control:** In-line SEM | Automated defect classification | Real-time process adjustments
- **Device level (mm-cm):** Large field of view inspection identifies location of defects across arrays
- **Feature level (µm):** Medium magnification reveals pattern fidelity and alignment
- **Structure level (nm):** High resolution confirms critical dimensions and surface quality

Real-World Impact

Telecommunications components	Consumer optics	Photonic sensors
• Development cycles: 18 months → 9 months	• Prototype iterations: 15–20 → 5–8	• Defect detection: manual sampling → 100% automated inspection
• First-pass yield: 60% → 85%	• Time to production: 12 months → 4 months	• Manufacturing cost: reduced by 35%

These improvements come from tight integration between characterization and fabrication enabled by modern EM

Multi-scale EM accelerates nanophotonic innovation from fundamental research through manufacturing:

- **Research:** **Understand structure-property relationships at atomic scales**
- **Development:** **Rapid prototyping with *in situ* verification**
- **Manufacturing:** **Automated quality control with nanometer precision**

The same imaging principles that reveal scientific insights enable commercial production—transforming nanophotonics from laboratory demonstrations to everyday technologies in smartphones, networks, and sensors

Further Resources

Wiley Event: Register for free to watch the recording of:
Fabrication in Nanophotonics: Techniques and Applications

Wiley Publications:
Active plasmonic nanodevices: From basic principles to emerging applications
Nanophotonics with Plasmonic Nanorod Metamaterials
Plasmonic Nanoparticle-on-Nanoslit Antenna as Independently Tunable Dual-Resonant Systems for Efficient Frequency Upconversion