

Localization microscopy for nanoelectronic manufacturing

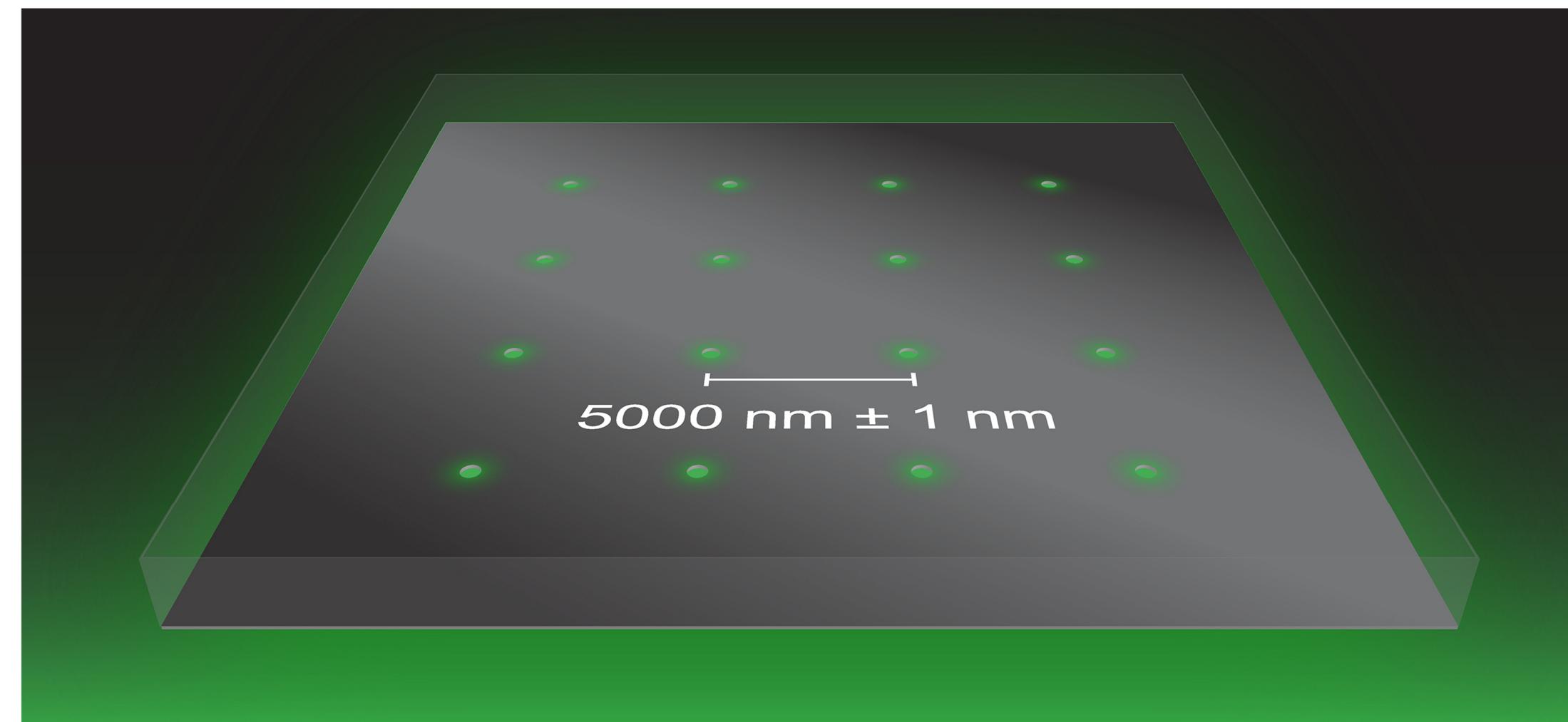
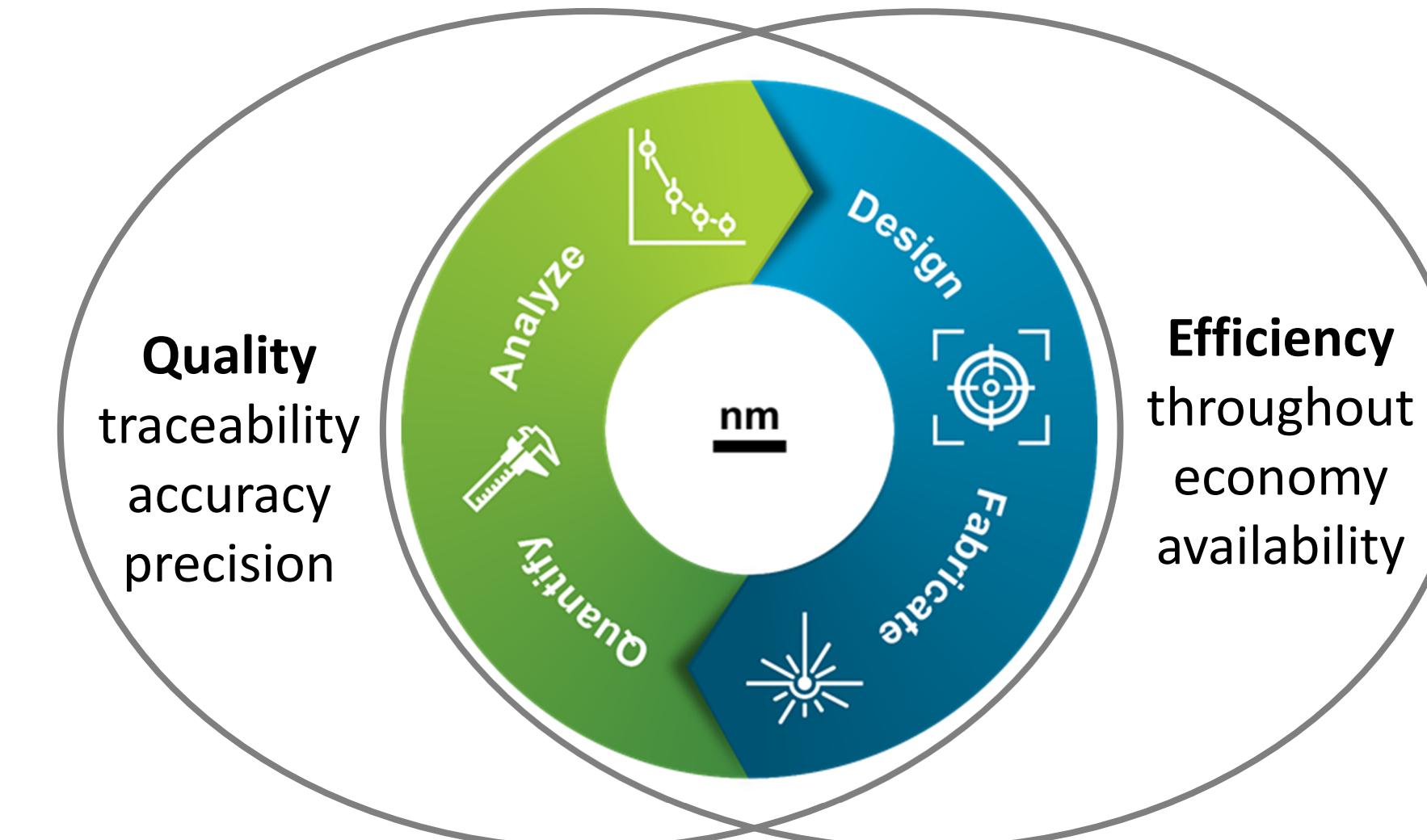
Craig R. Copeland¹, Ronald G. Dixson¹, Andrew C. Madison¹, Adam L. Pintar³, B. Robert Ilic^{1,2}, and Samuel M. Stavis¹

¹Microsystems and Nanotechnology Division, ²CNST NanoFab, ³Statistical Engineering Division, National Institute of Standards and Technology, Maryland USA

NIST

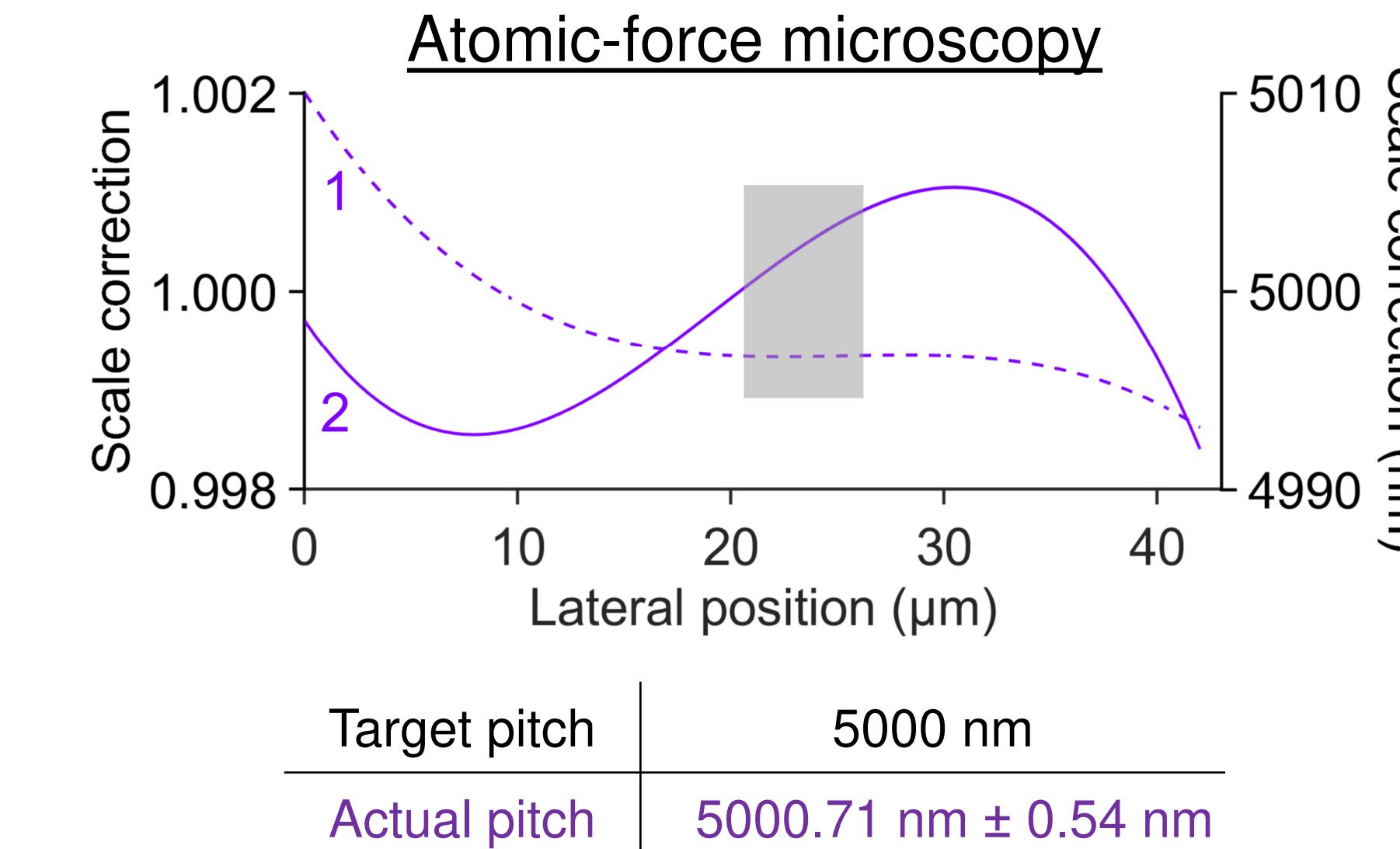
Deployable standards

A virtuous cycle of making and measuring nanostructures

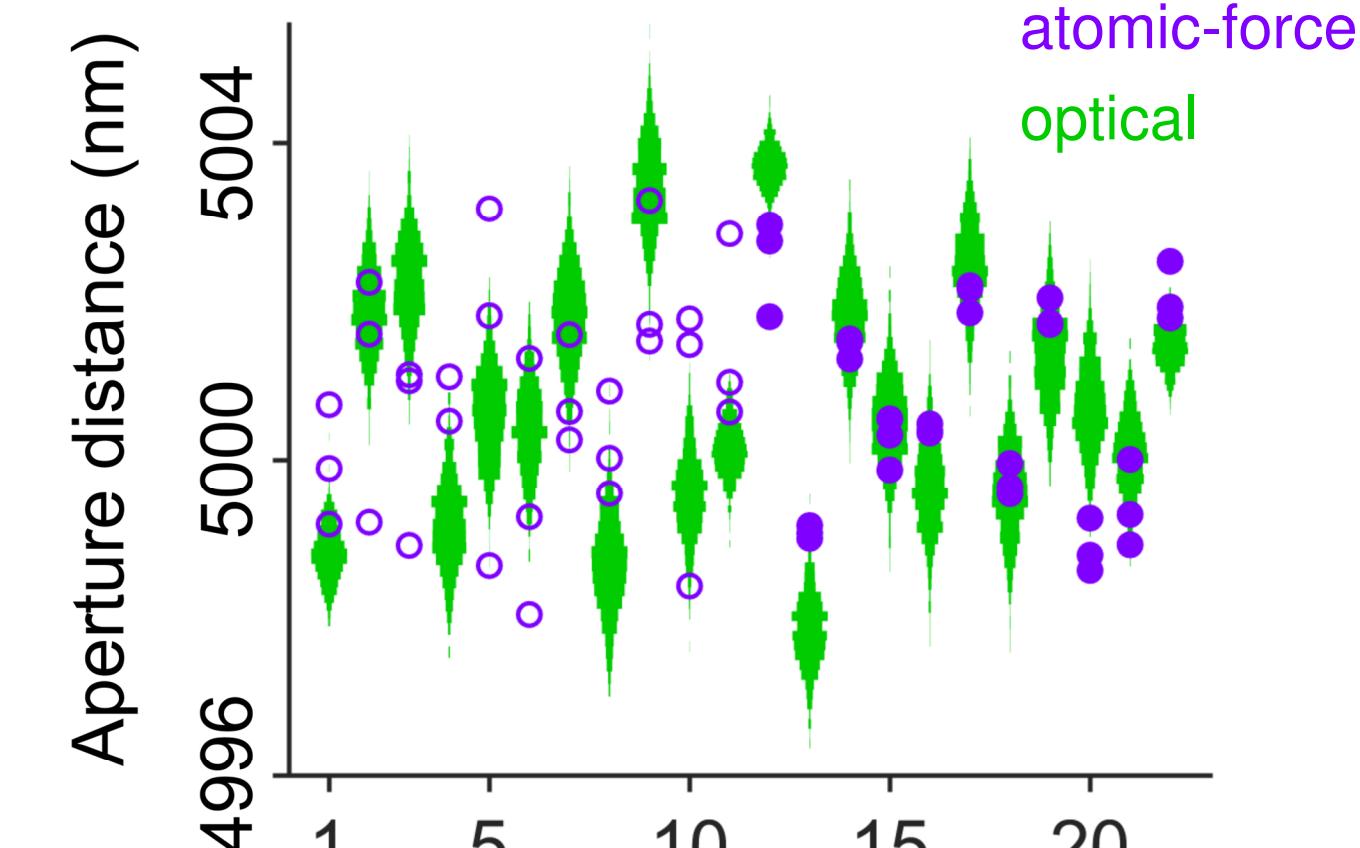


Arrays of nanoscale apertures as position standards for localization microscopy

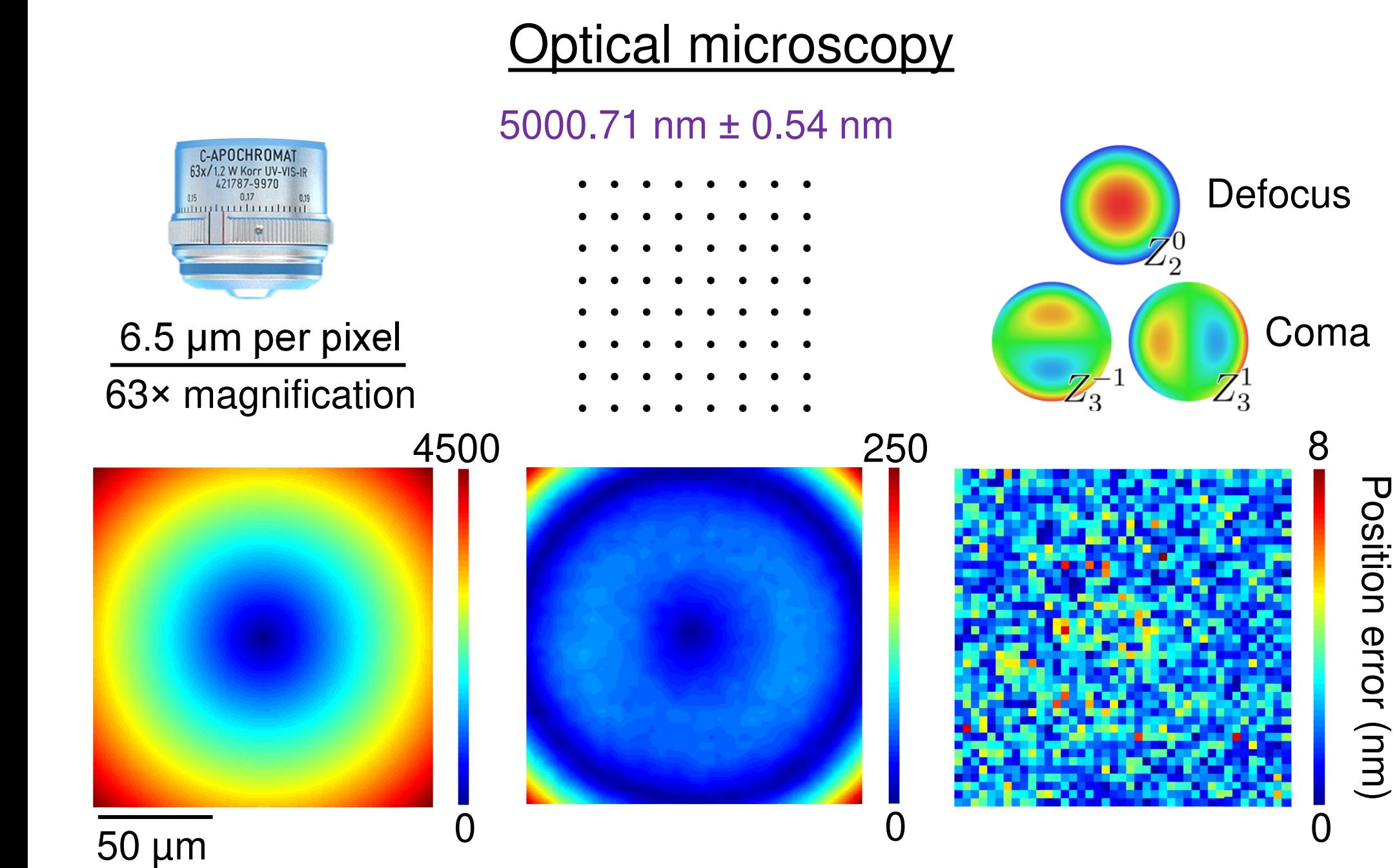
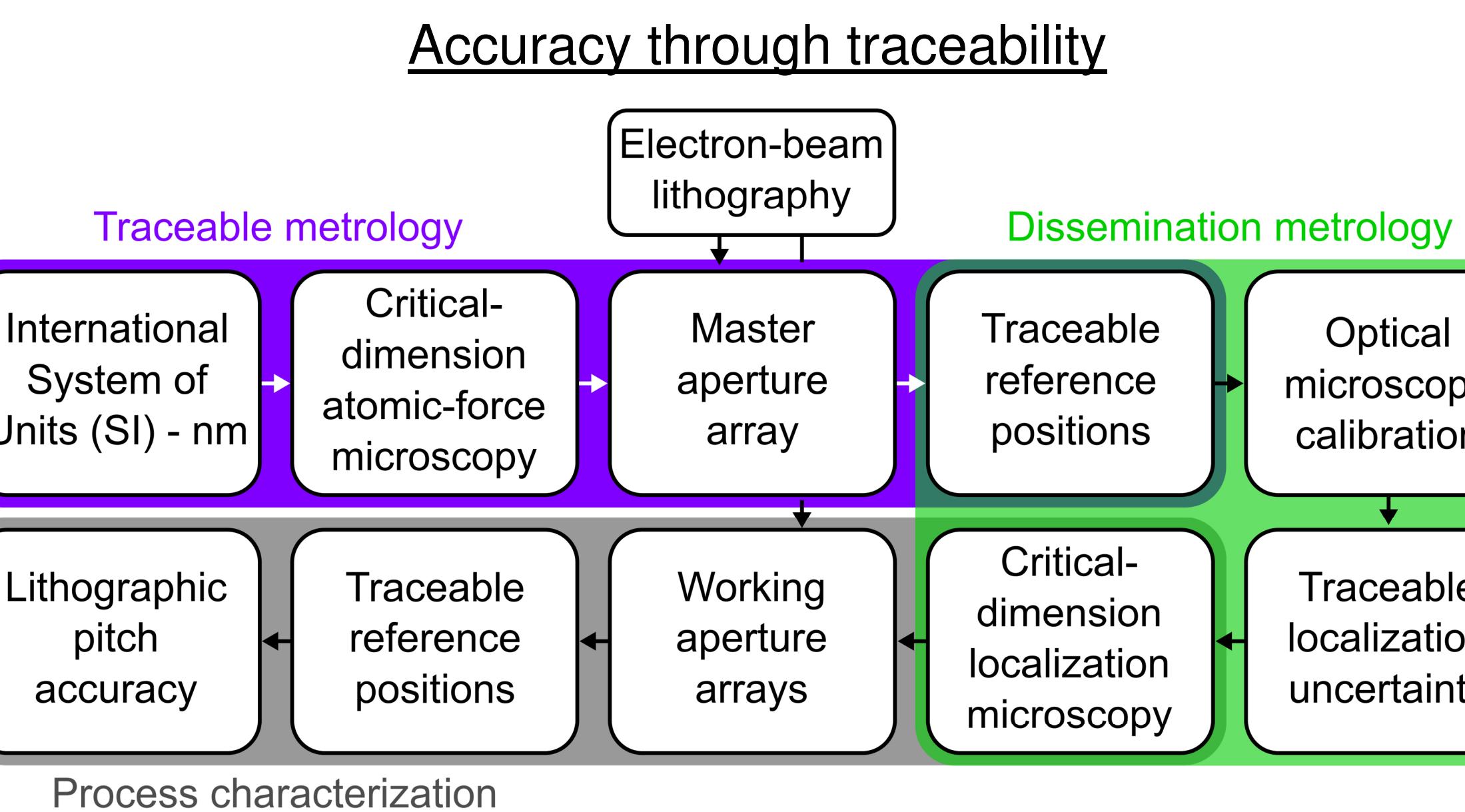
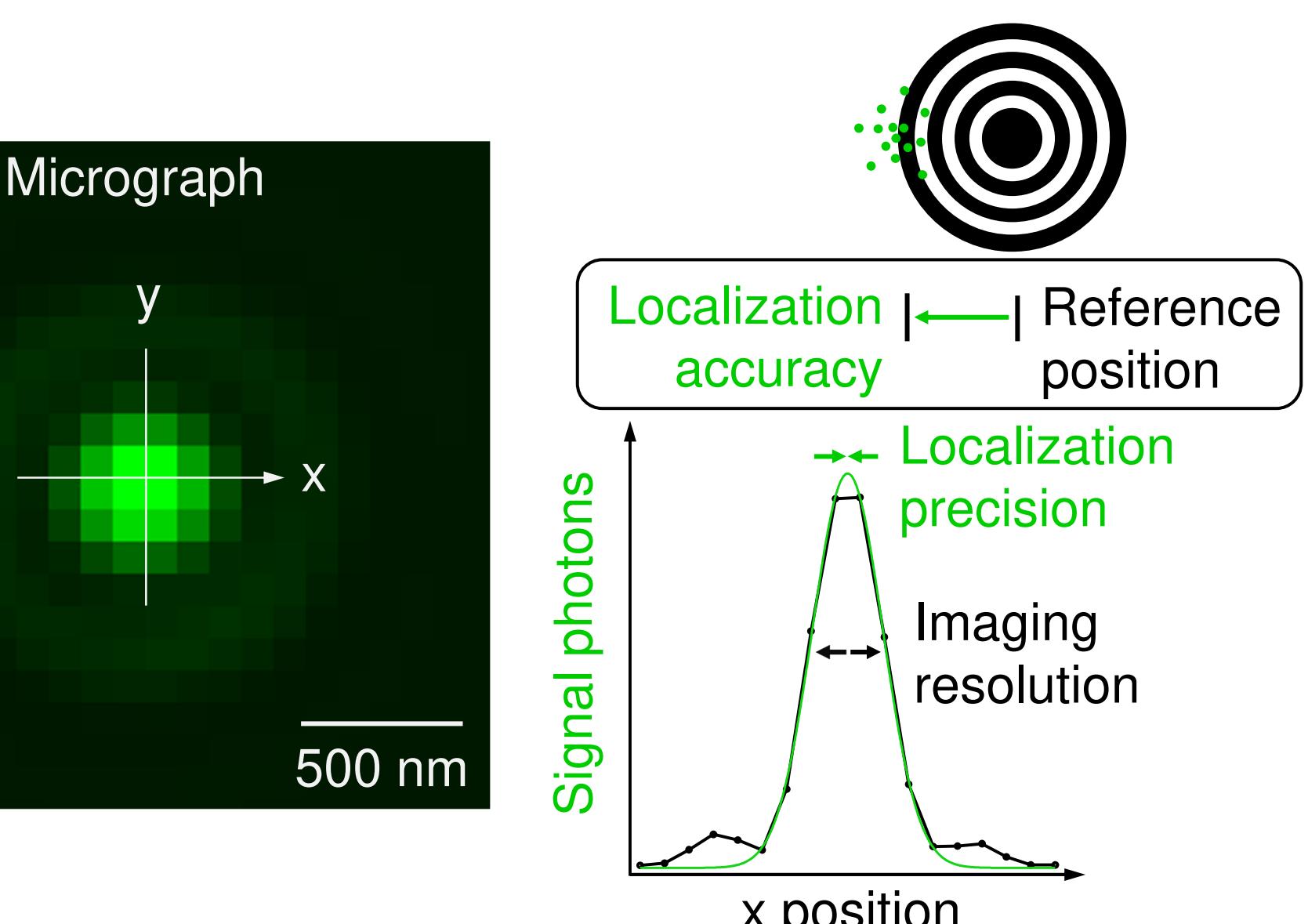
Scale calibration



Distance measurements



Localization microscopy



Distance deviations facilitate uncertainty evaluation

Traceable localization uncertainty

$$\sigma_{D^{OM}-DAFM}^2 = \sigma_{d^{OM}}^2/n_{D^{OM}} + \sigma_{\delta^{OM}}^2 + \sigma_d^2/n_{DAFM} + \sigma_{\delta^{AFM}}^2$$

Observable

Unobservable

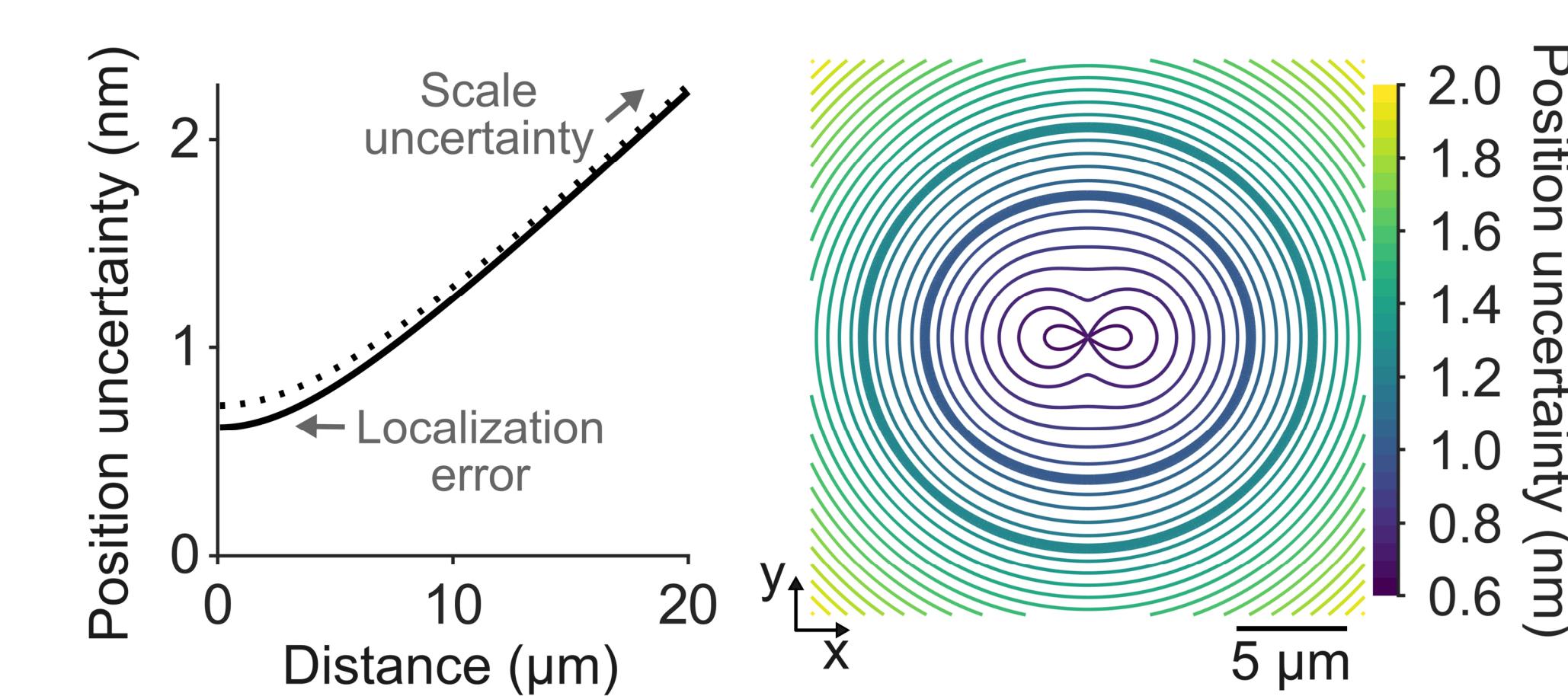
0.76 nm in x, 1.06 nm in y

< 0.02 nm

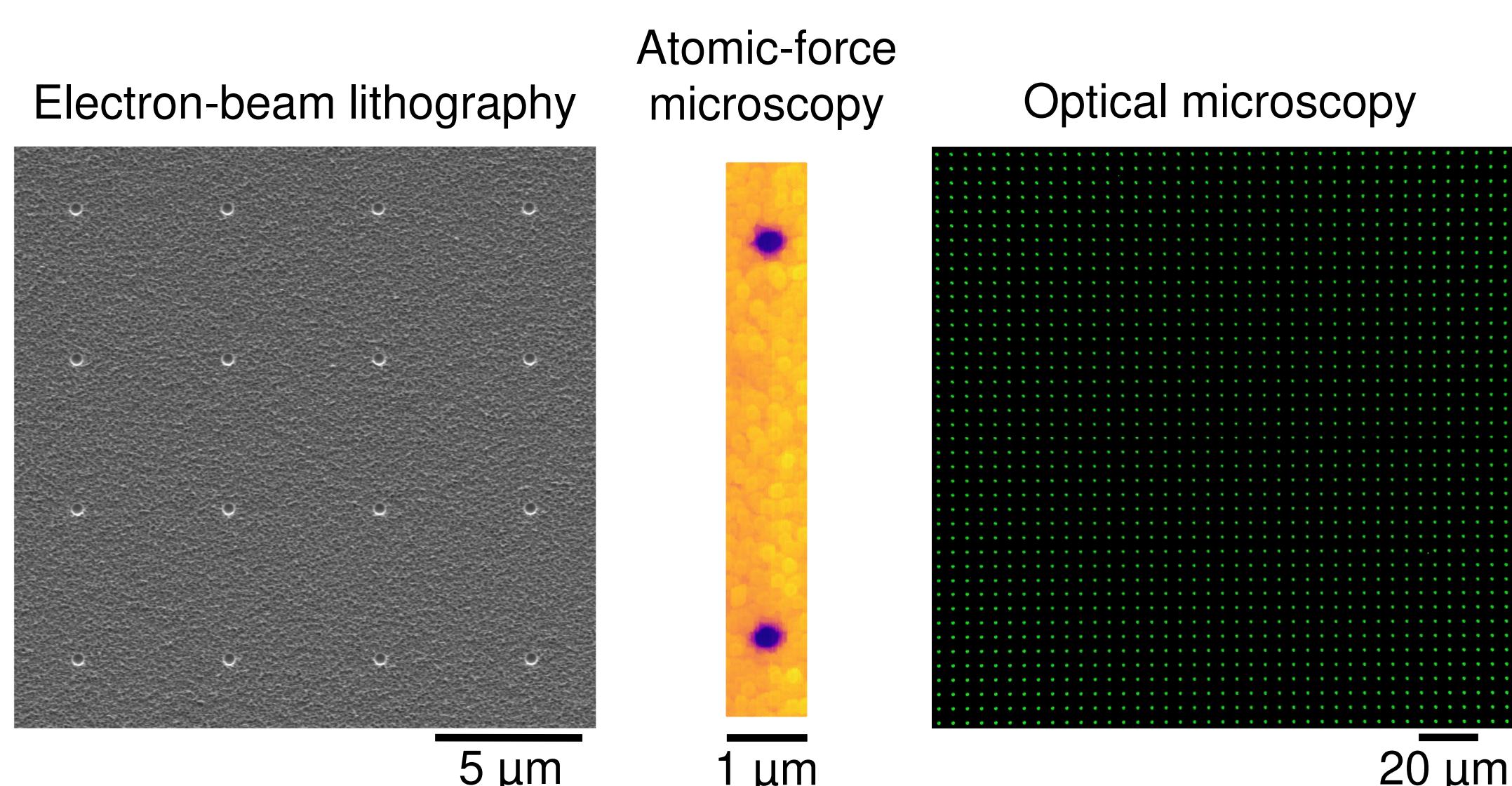
Traceability uncertainty limit: $\sqrt{(\sigma_{\delta^{OM}}/\sqrt{2})^2 + (D^{OM} \times \sigma_{scale}/\sqrt{2})^2}$

0.87 nm in x, 1.03 nm in y

1.07 × 10⁻⁴

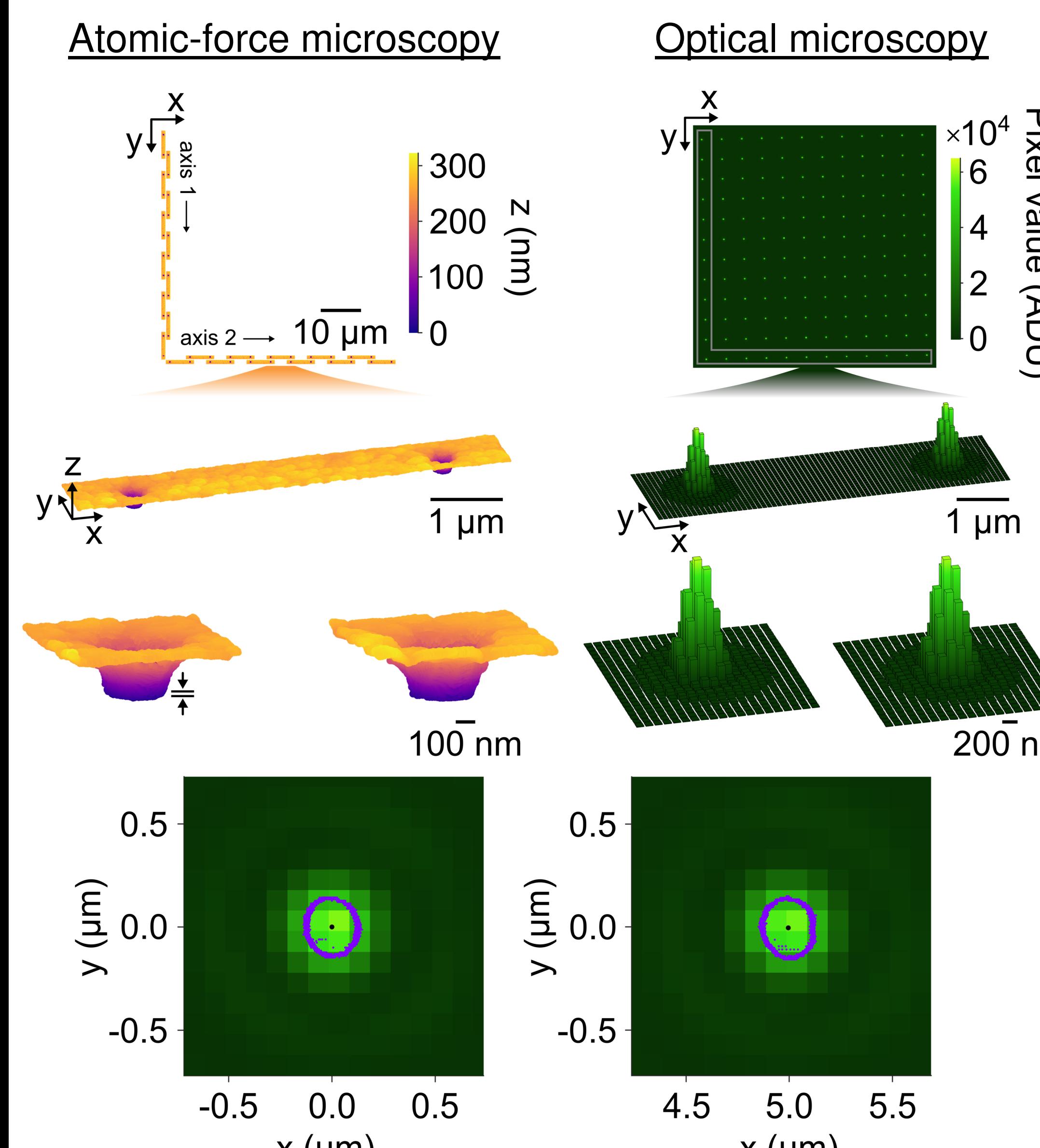


Aperture array



- Fabricate position standard by electron-beam lithography
- Estimate pitch by critical-dimension atomic-force microscopy
- Calibrate optical microscopy using traceable value of pitch
- Characterize traceable uncertainty of optical microscopy
- Apply traceable optical microscopy to rapidly characterize new standards, devices, and fabrication processes

Correlative microscopy



Feedback to fabrication

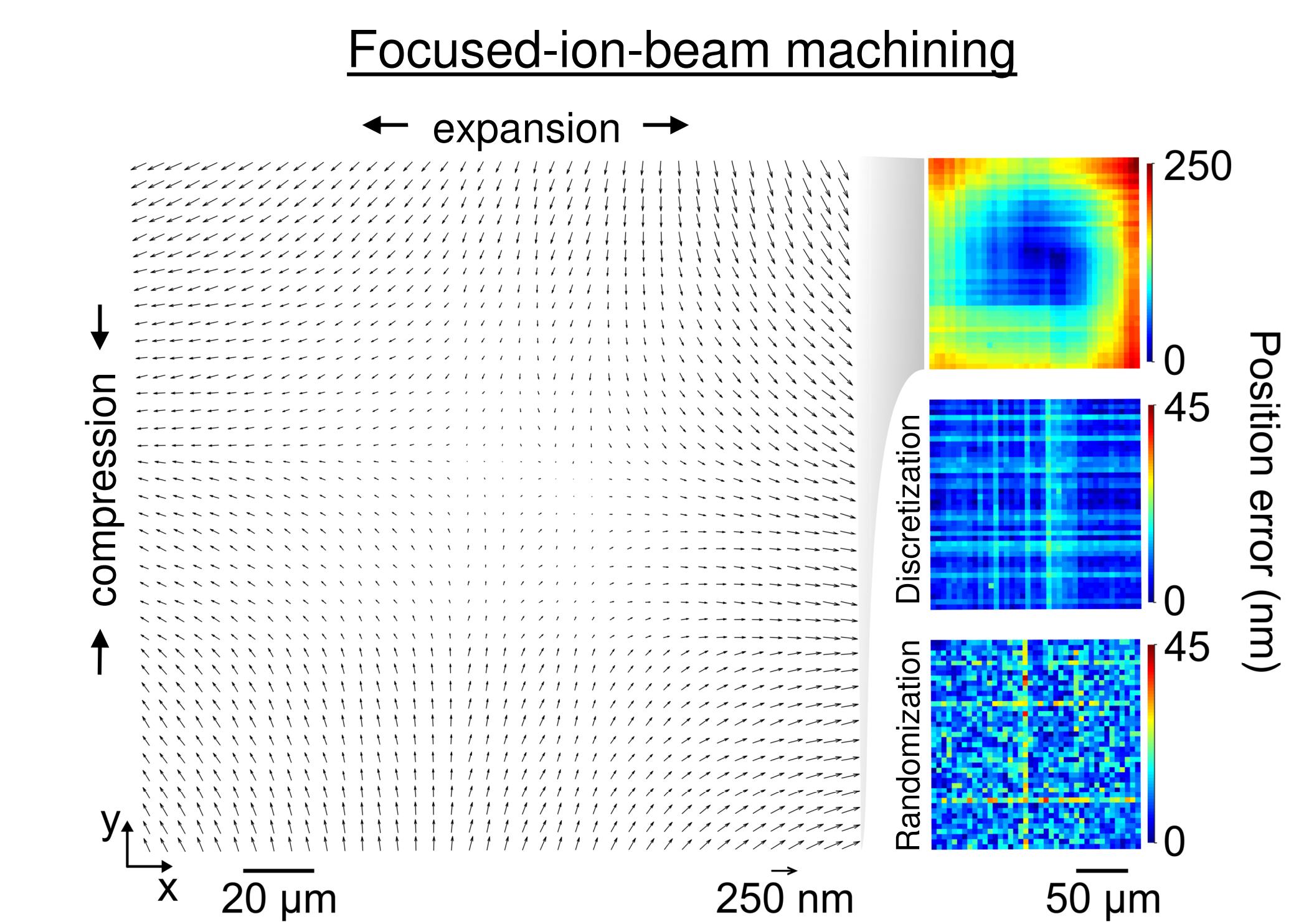
Electron-beam lithography

Traceable characterization of fabrication accuracy

Array	Pitch (nm)	Standard Error (nm)	Uncertainty (nm)
1	5000.71	0.13	0.54
2	4999.90	0.03	0.54
3	5000.30	0.01	0.54
4	5001.45	0.03	0.54
5	4997.30	0.08	0.54
6	4996.44	0.08	0.54

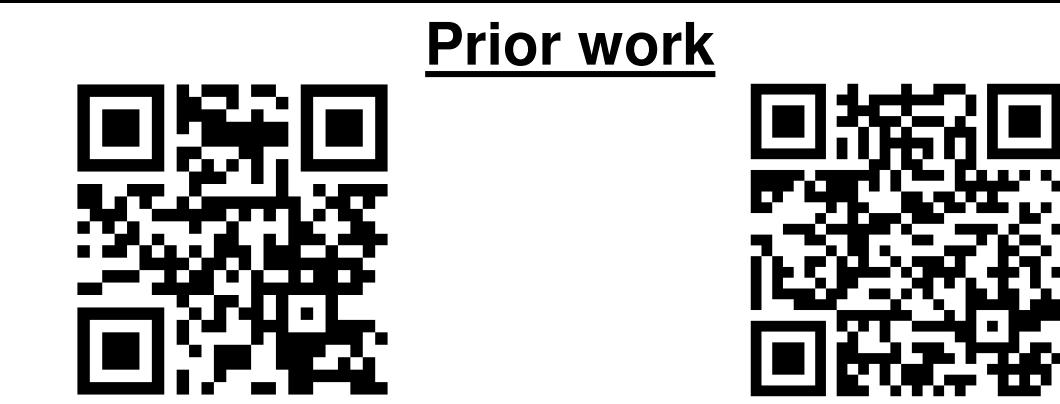
Consensus mean pitch: 4999.34 nm ± 1.00 nm

Prediction interval: 4999.40 nm ± 2.34 nm



The authors acknowledge funding from the NIST Innovations in Measurement Science Program and the NIST Office of Reference Materials.

Contact: samuel.stavis@nist.gov



10.48550/arXiv.2106.10221 10.1038/s41377-018-0031-z