

# An Unconventional Tradespace of Focused-Ion-Beam Machining

Andrew C. Madison<sup>a</sup>, John S. Villarrubia<sup>a</sup>, Kuo-Tang Liao<sup>a,b</sup>, Craig R. Copeland<sup>a</sup>, Joshua Schumacher<sup>a</sup>

Kerry Siebein<sup>a</sup>, B. Rob Ilic<sup>a</sup>, James A. Liddle<sup>a</sup> and Samuel M. Stavis<sup>a,\*</sup>

<sup>a</sup> National Institute of Standards and Technology, Gaithersburg, Maryland, United States of America

<sup>b</sup> University of Maryland, College Park, Maryland, United States of America,

\*samuel.stavis@nist.gov

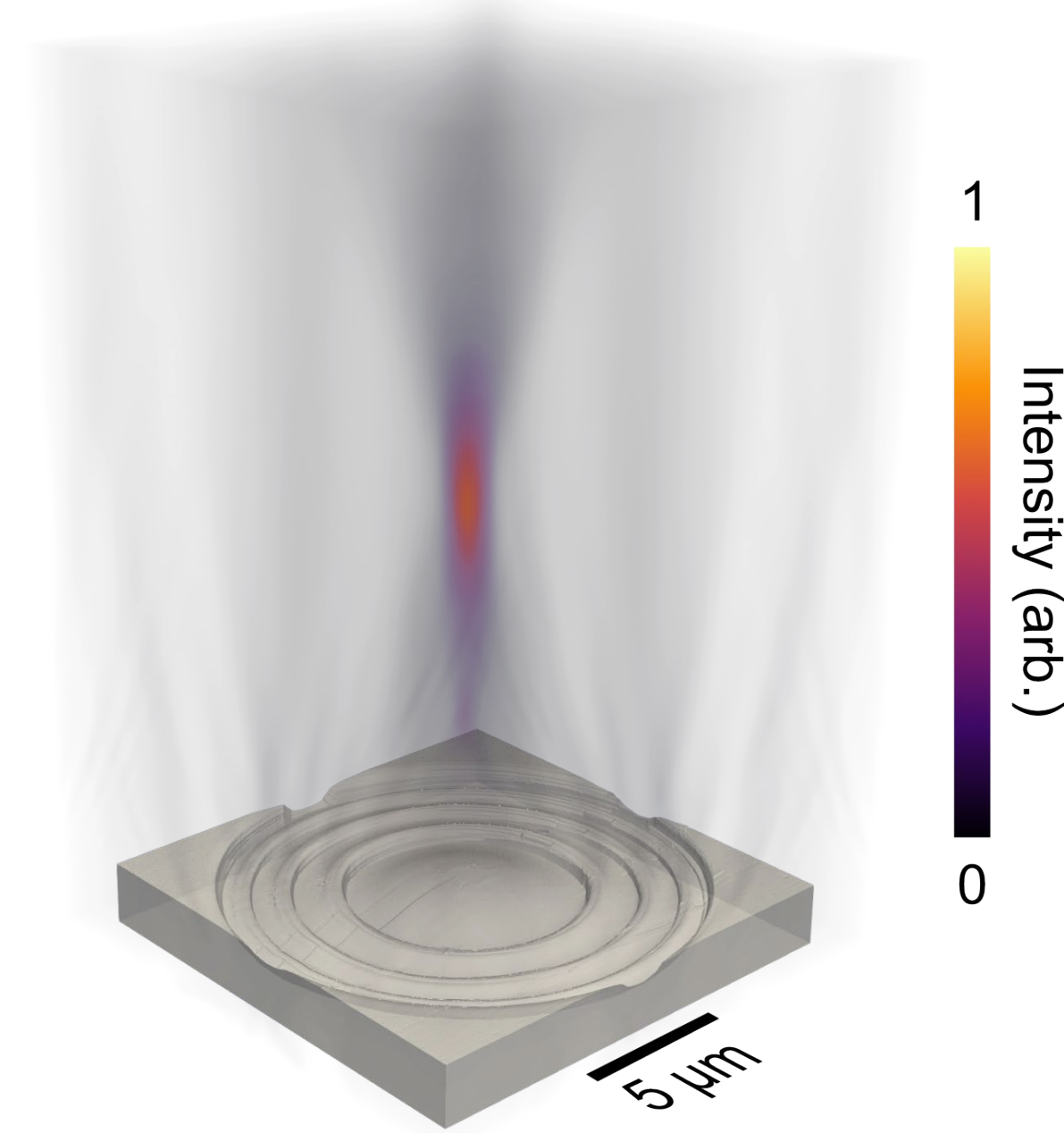
## A Motivation

- Sacrificial masks are useful for super-resolving the edges of nanostructures formed by focused ion beam machining.
- But current understanding of the spatial masking process is incomplete.
- Our study suggests that the old paradigm of spatial masking to improve patterning resolution offers dramatic improvements to fabrication throughput, which we quantify.

## B Key findings

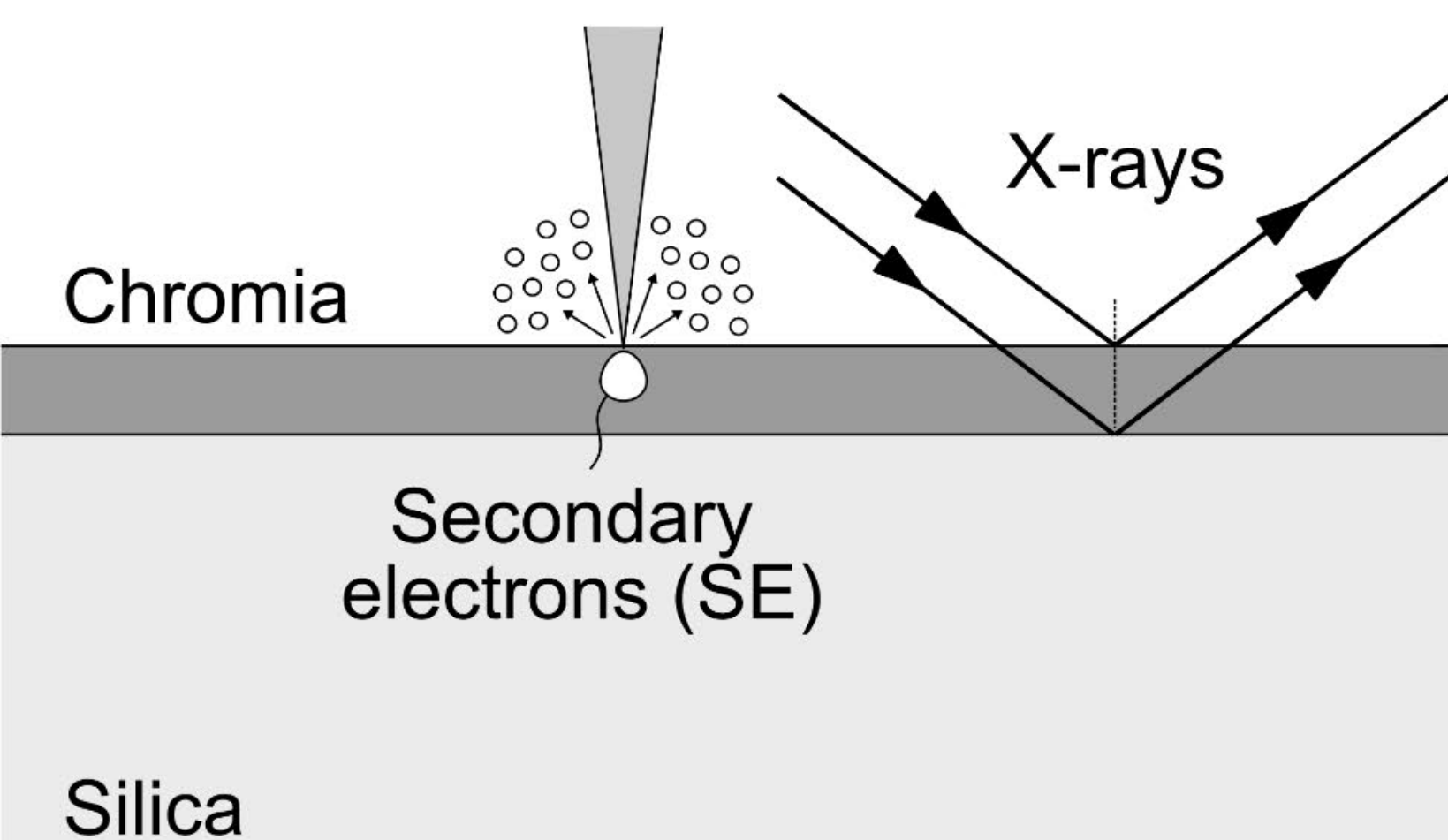
- Chromia ( $\text{Cr}_2\text{O}_3$ ) sputter-deposits with nanometer roughness, is mostly amorphous, and resists charging.
- An efficient method of in-line metrology enables rapid and quantitative adjustment of the focus of the ion beam.
- We observe super-resolution factors as high as  $6 \pm 2$  and model the effect with good experimental agreement.
- The dominant effect of the super-resolution process is temporal, improving throughput for equivalent resolution by 1 to 3 orders of magnitude.

## C Future applications



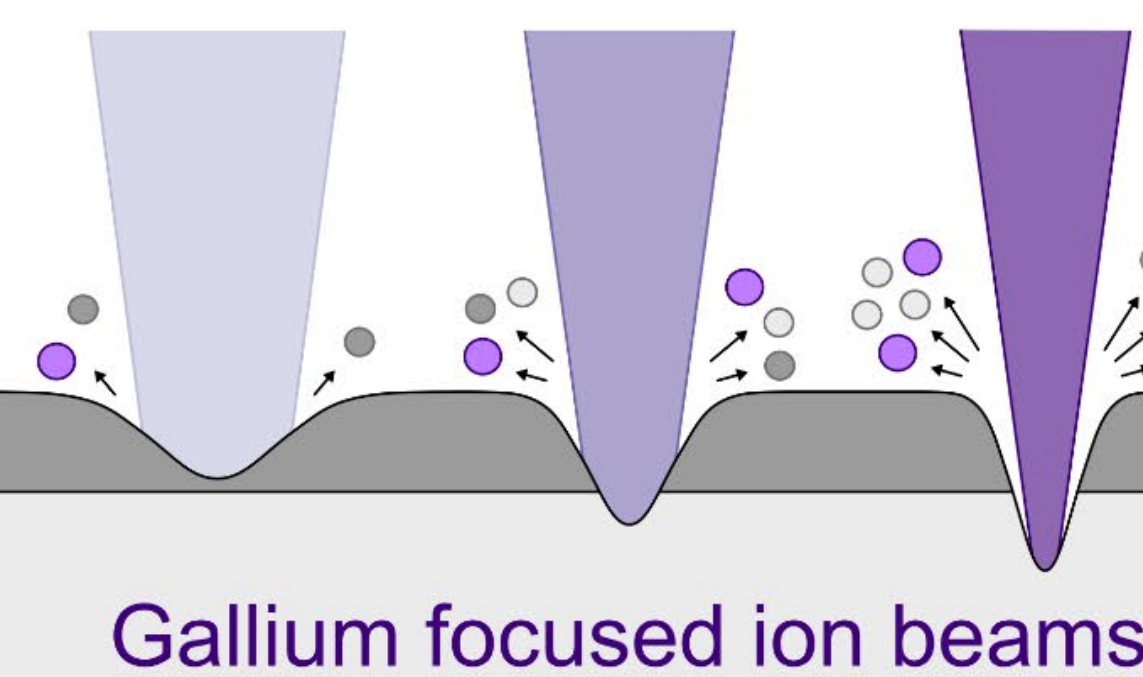
D

### Chromia characterization



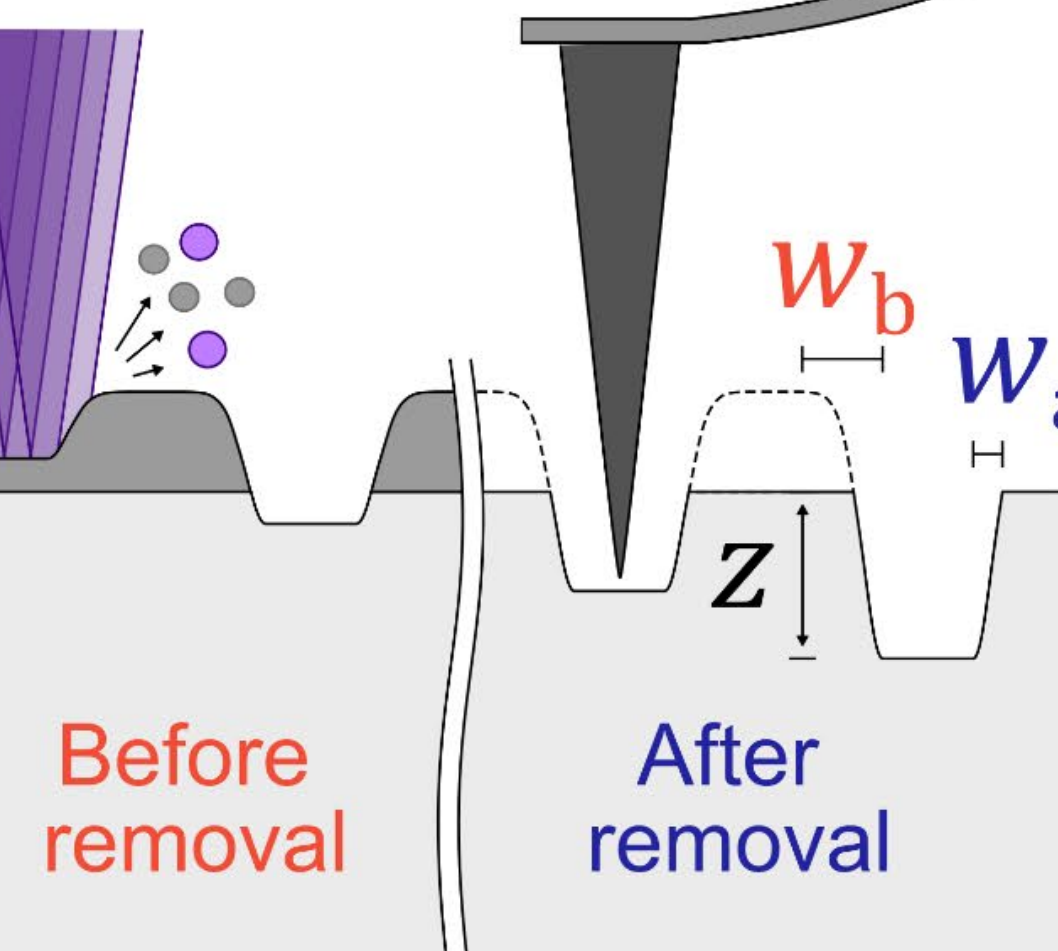
E

### In-line resolution metrology



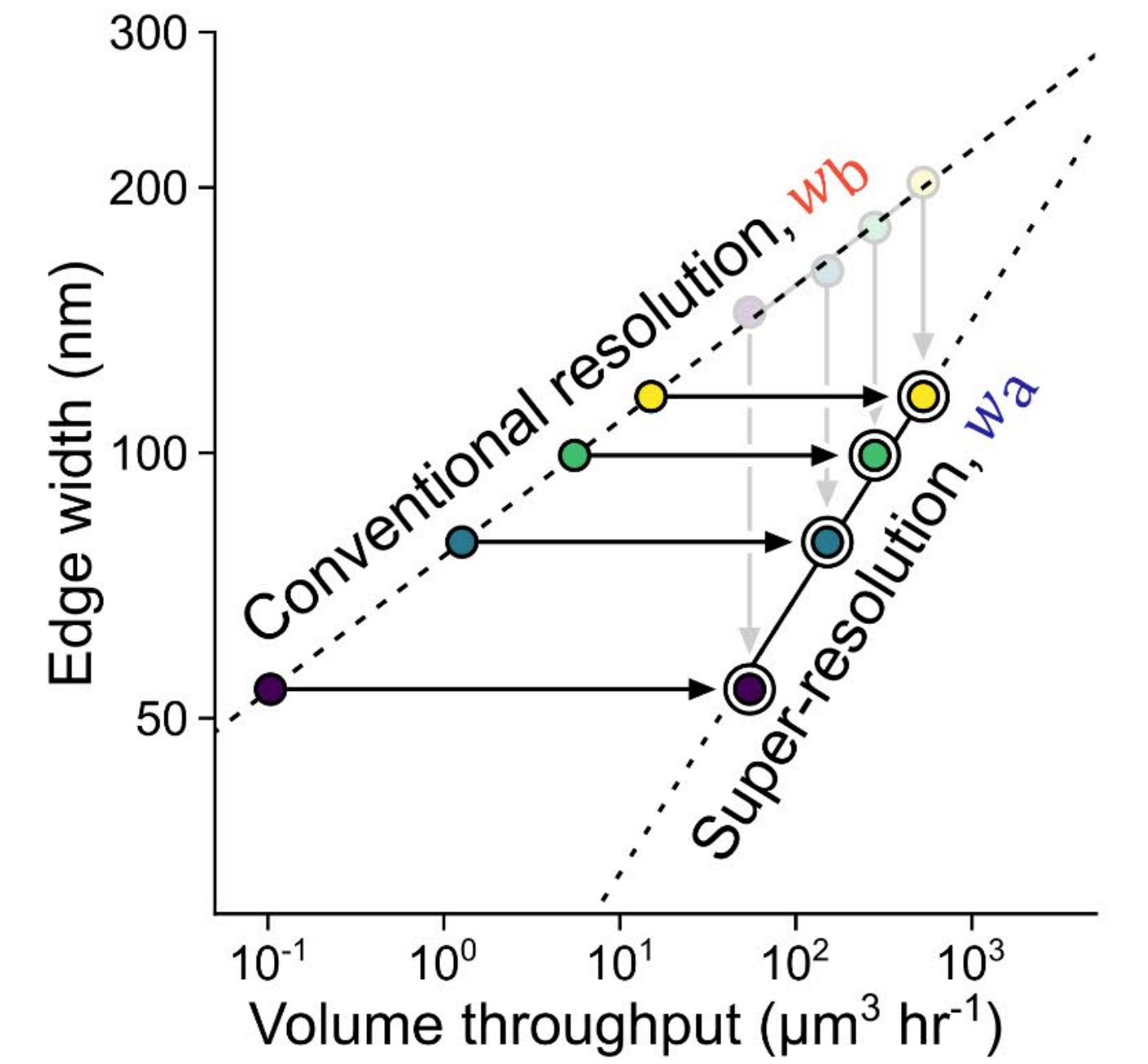
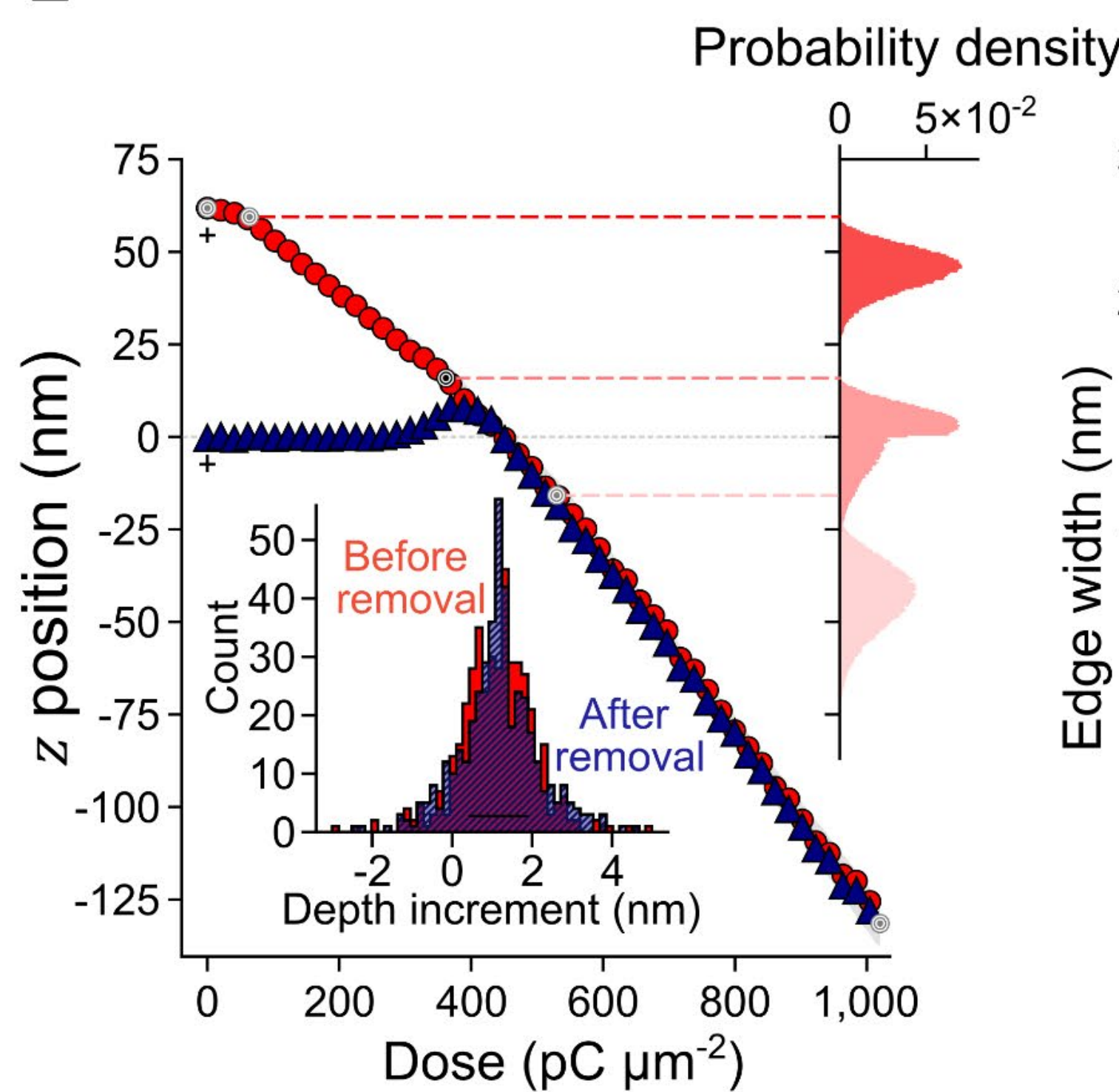
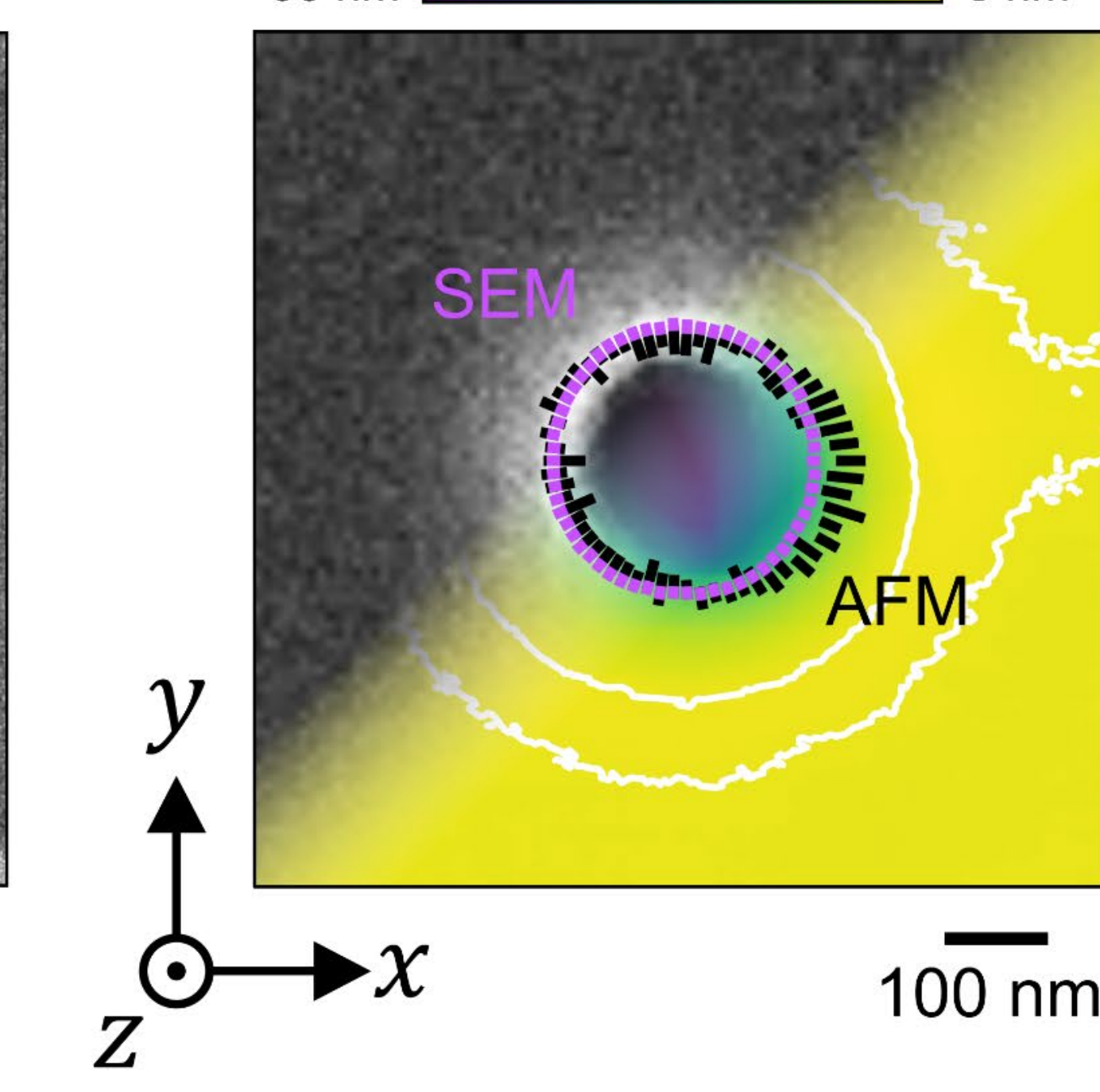
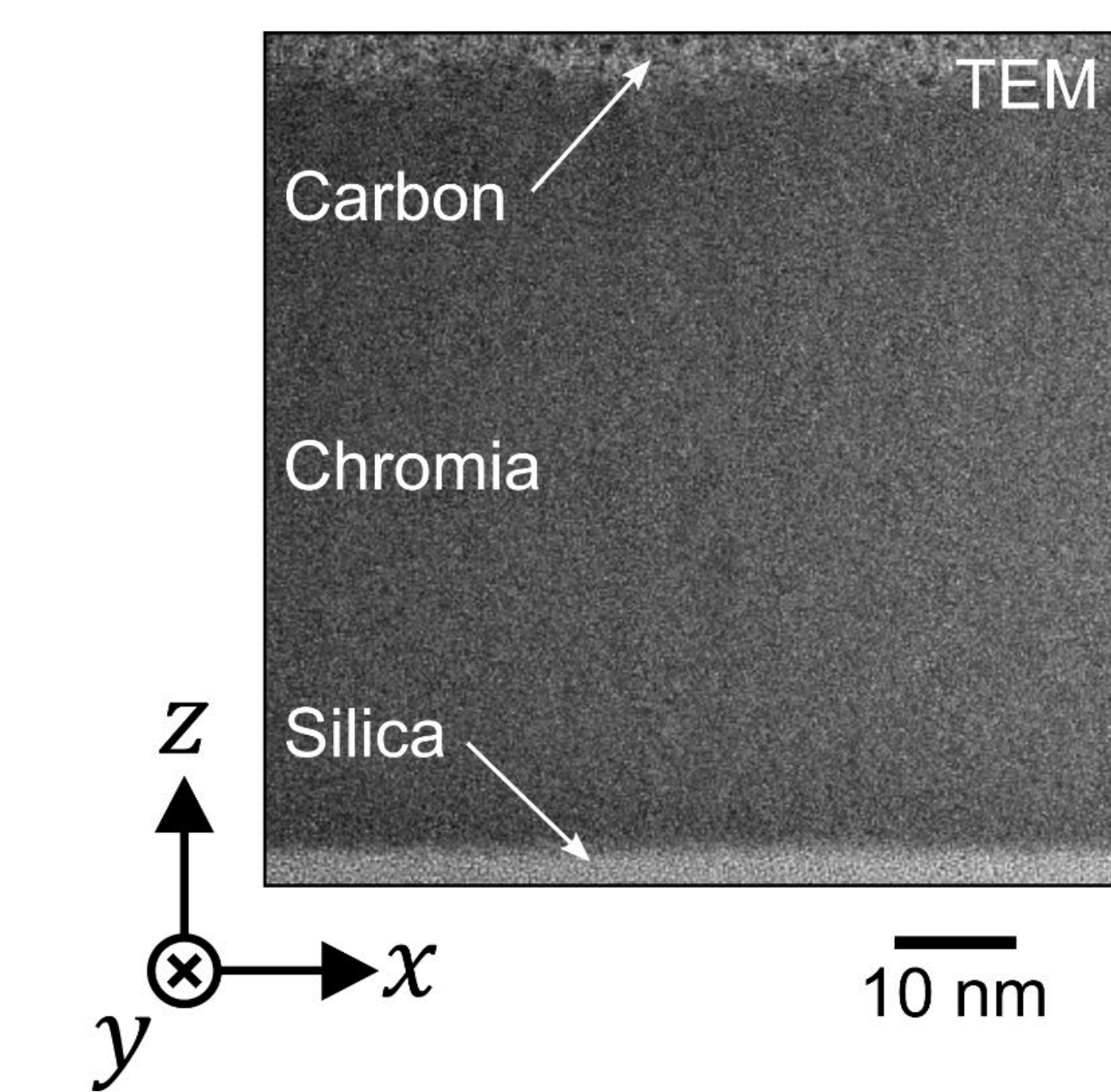
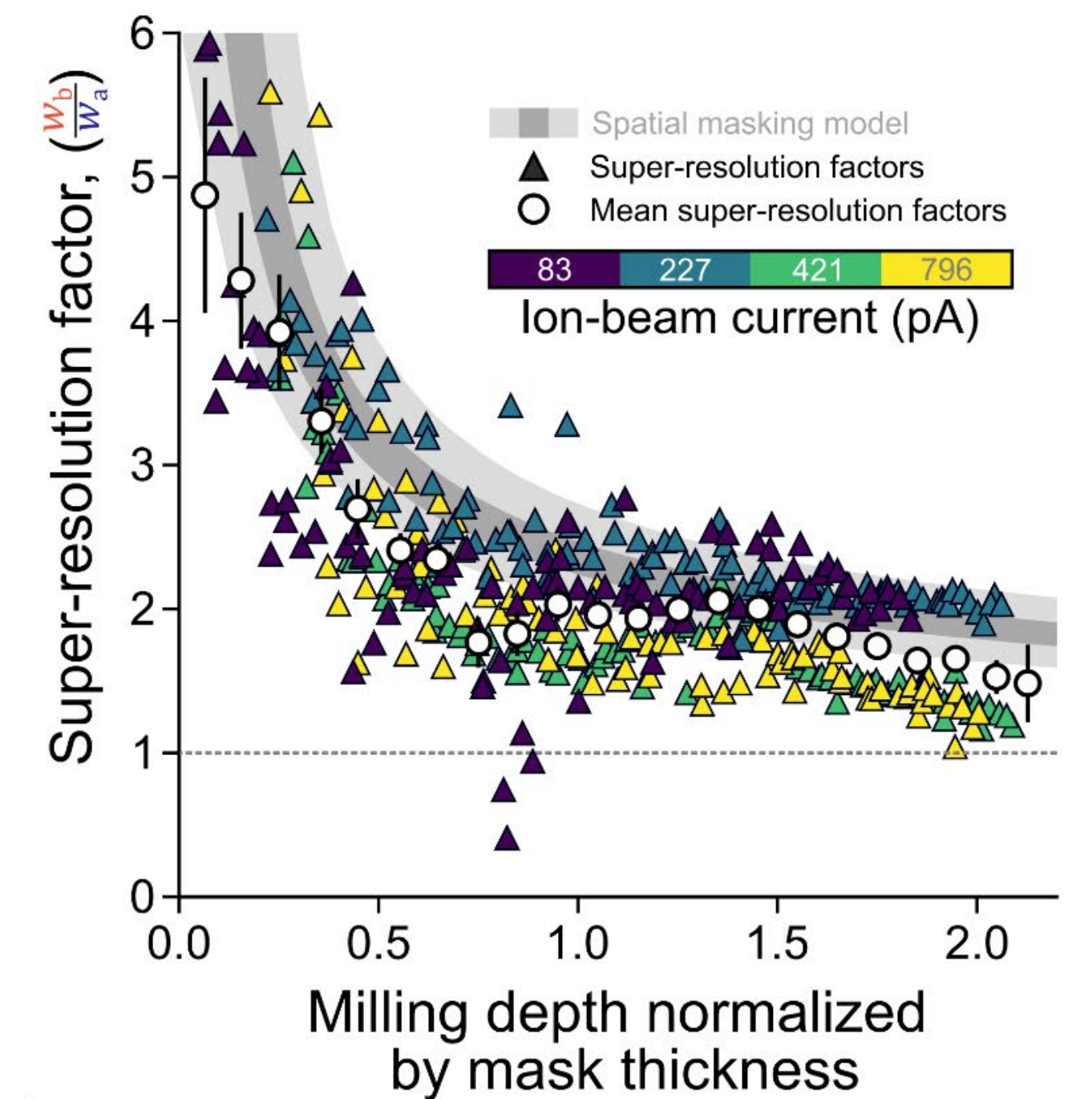
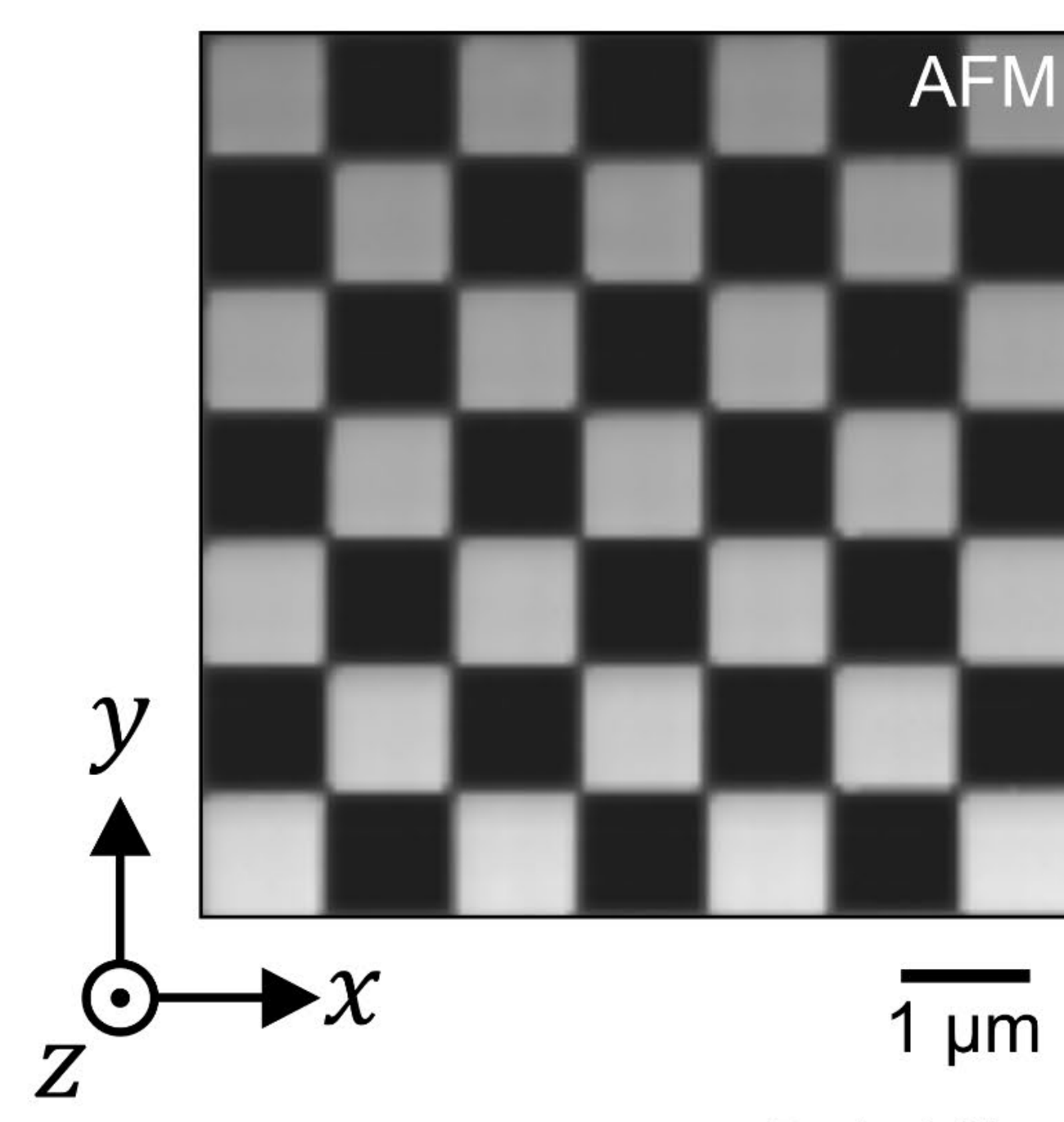
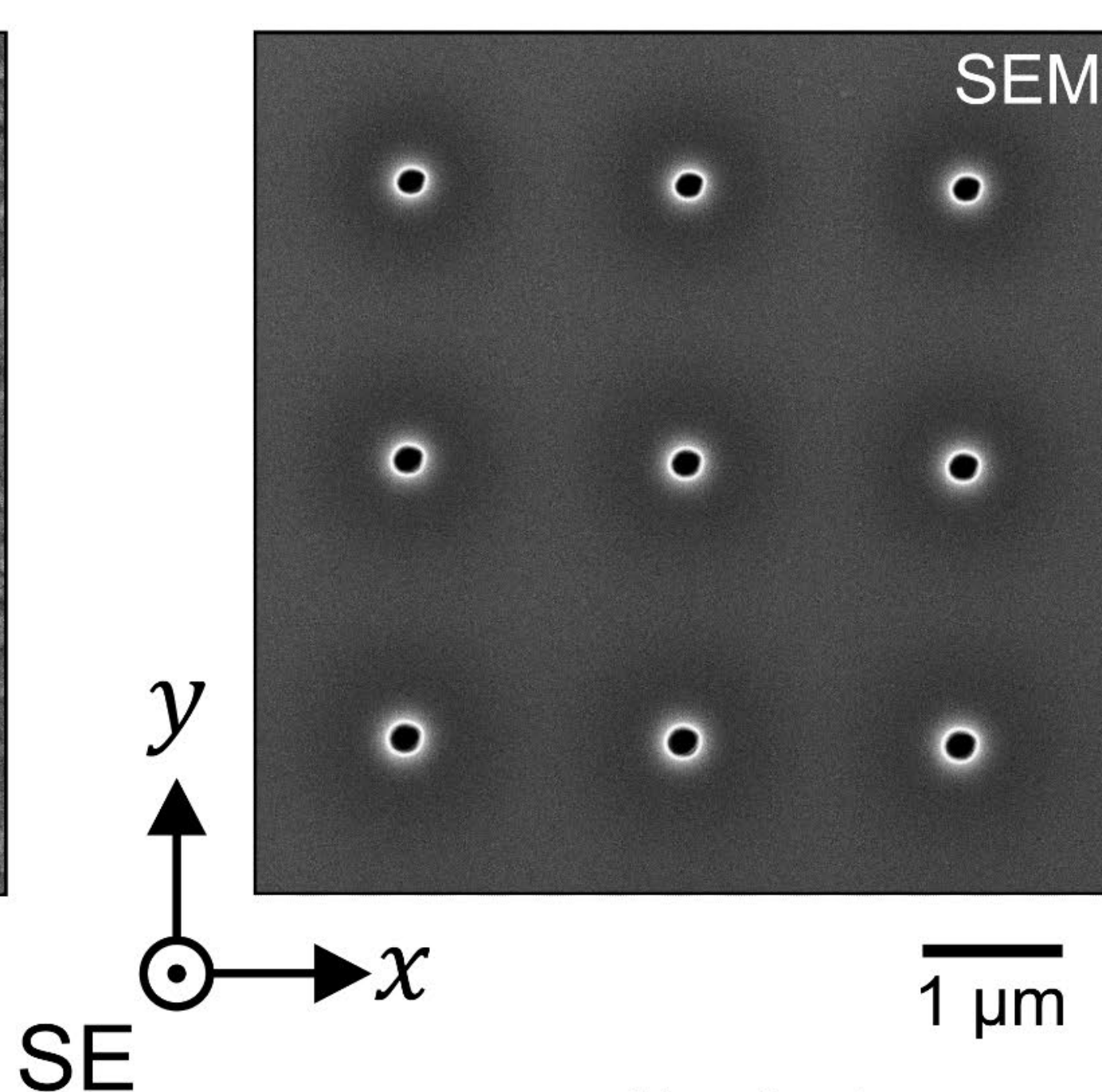
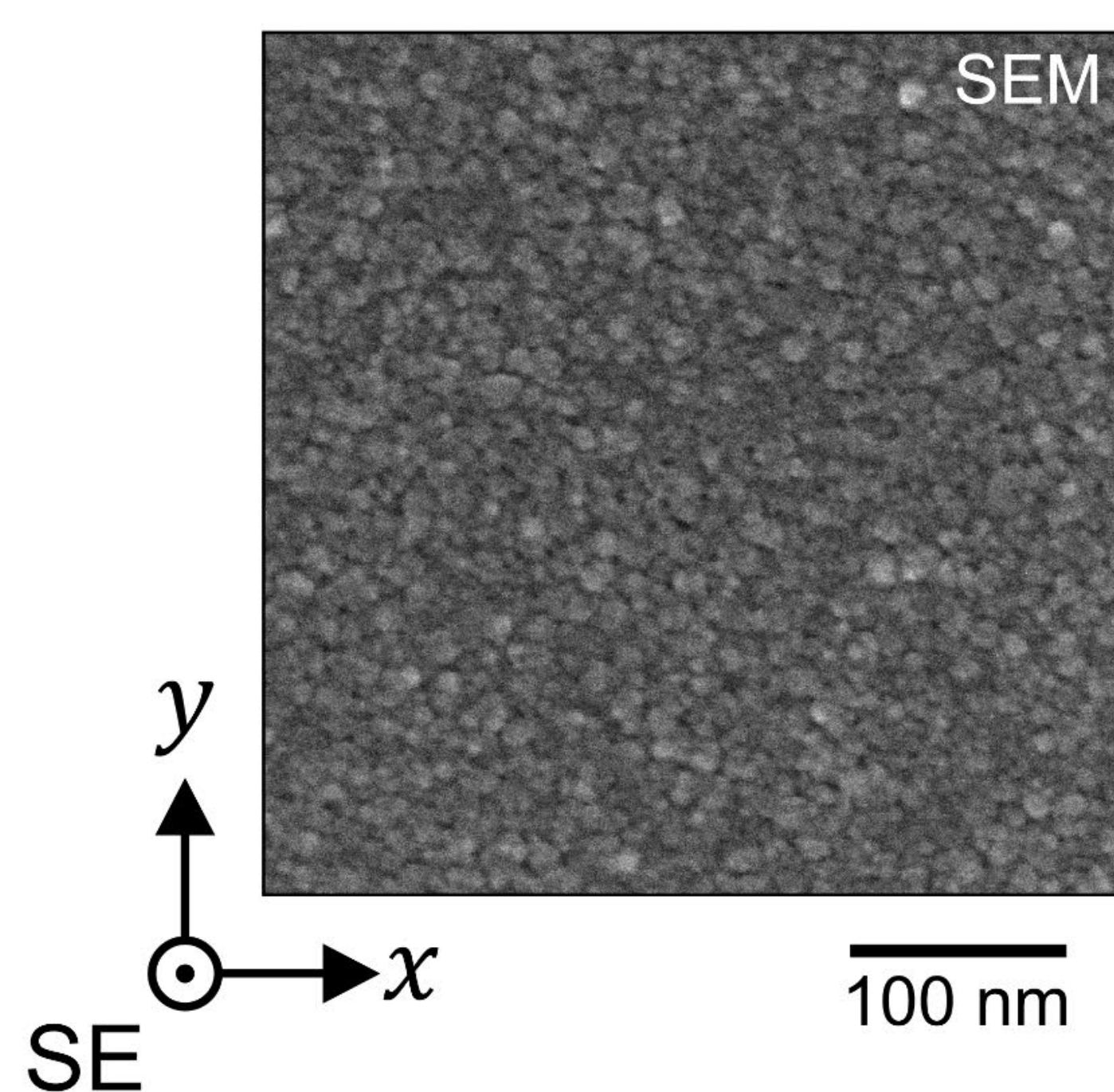
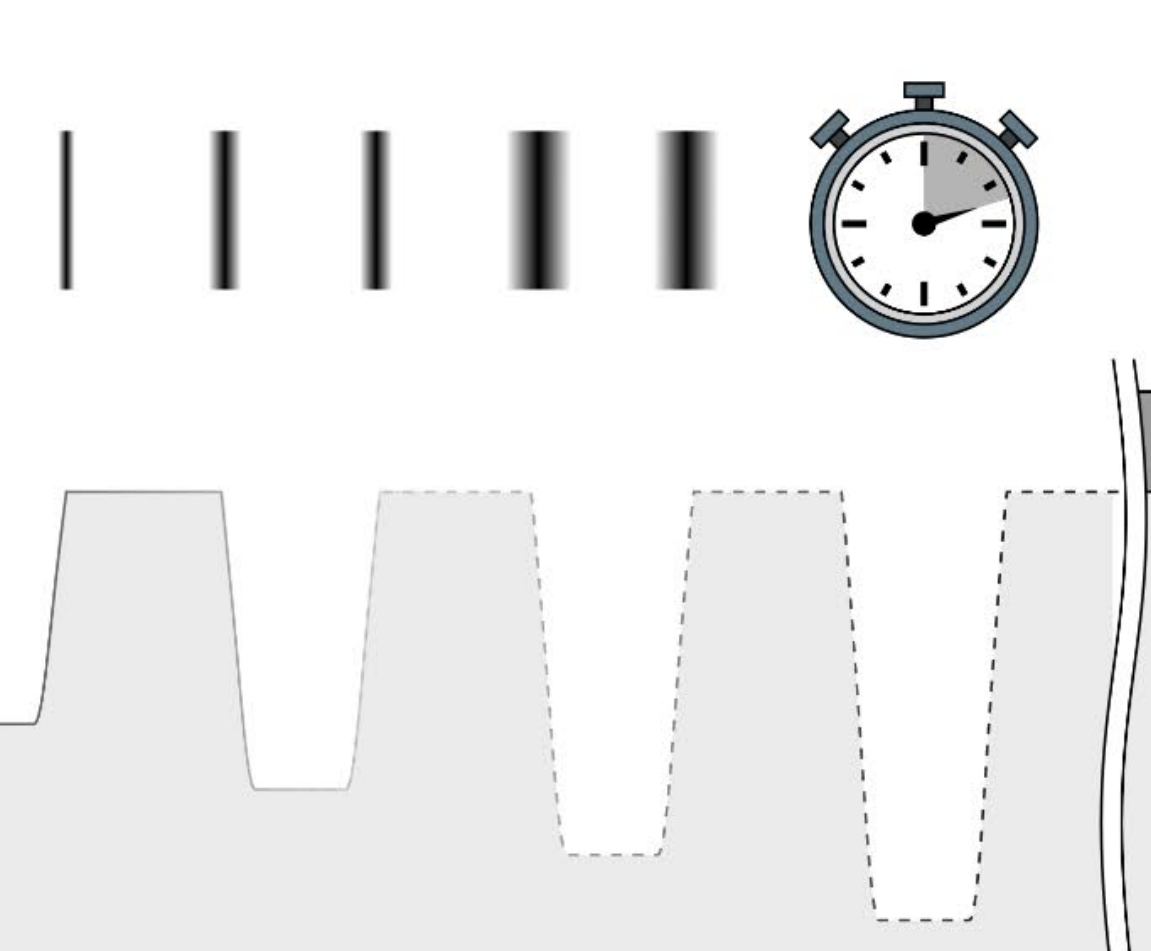
F

### Complex test structures



G

### Resolution and throughput



## H References

A. C. Madison, *et al.* Super-resolution and ultrahigh-throughput of focused-ion-beam machining, *arXiv* (2020).



## I Funding

The National Research Council supports this work through a postdoctoral fellowship administered by the Research Associateship Program.

