Nanoelectronics Dimensional Metrology:
Understanding the Differences between Secondary and Backscattered Electron Imaging

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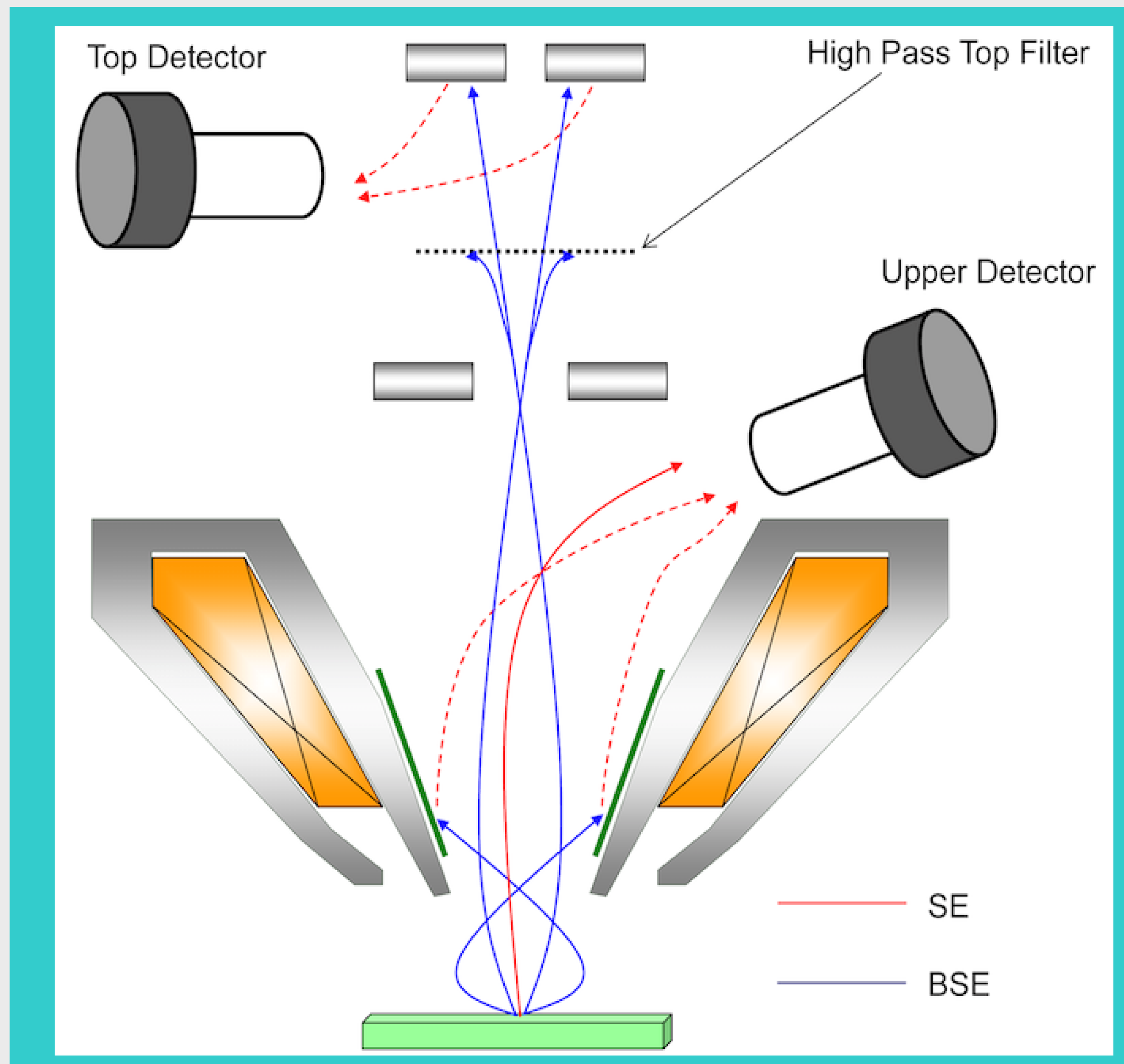
Dimensional measurements of NIST Reference Material (RM) 8820, a grating sample, from secondary electron (SE) images were compared to those from backscattered electron (BSE) and low-loss electron (LLE) images. With the commonly used 50 % threshold criterion, the amorphous Si lines consistently measured larger in the SE images. Since the images were acquired simultaneously by Hitachi SU 8200* instrument with the capability to operate detectors for both signals at the same time, the differences cannot be explained by the assumption that contamination or drift between images affected the SE, BSE or LLE images differently. Simulations with JMONSEL, an electron microscope simulator, indicate that the nanometer-scale differences observed on this sample can be explained by the different convolution effects of the primary electron beam with finite size on signals with different symmetry (the SE signal's characteristic peak vs. the BSE or LLE signal's characteristic step). This effect is too small to explain the >100 nm discrepancies that had been observed in earlier work on different samples. Additional modeling indicated that those discrepancies could be explained by the much larger sidewall angles of the earlier samples [Ref.], coupled with the different response of SE vs. BSE/LLE profiles to such wall angles.

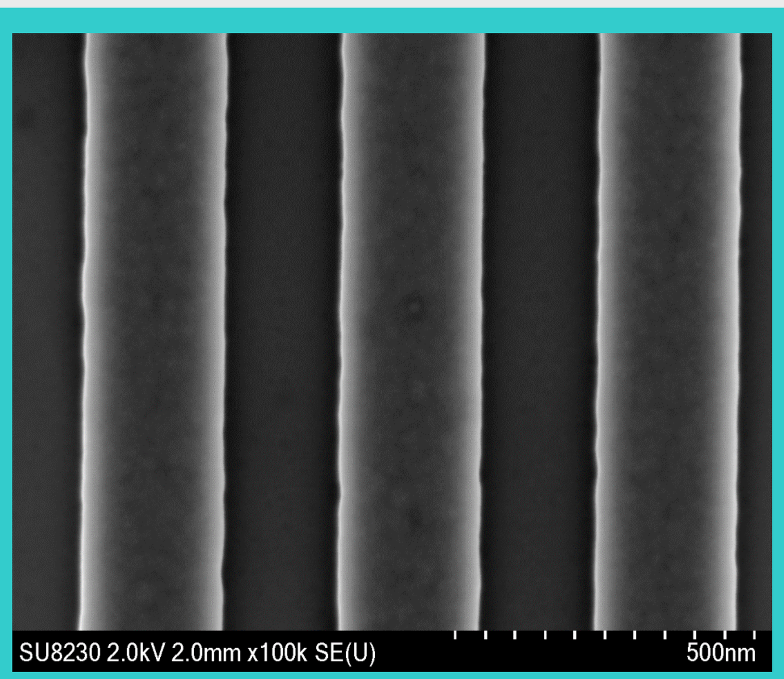
The study, presented here, extends the early work by utilizing high-resolution field emission SEM coupled with optimized in-column electron detectors. Newer design electron detectors and with multichannel electronics also permit the acquisition of pairs of secondary electron/backscattered electron and secondary electron/low loss images simultaneously, thus reducing some of the experimental issues revealed in the previous work [Reference]. JMONSEL, an electron beam-solid state interaction model, was used to verify and assist in interpreting these phenomena.

In summary, this work: (1) Demonstrated, for the first time, by simultaneous imaging that the previously observed bias between SE and LLE/BSE images is real, not just an artifact of charging, drift, detector positioning, or some other measurement error; (2) Documented the measurement variation inherent in algorithm choice both on modeled and experimental data; (3) Clearly pointed out that modeling of the image formation is necessary if you ultimately want an accurate measurement and (4) explained the previously observed mysterious difference in the measurement results with a simple phenomenological model supported by a more complete Monte Carlo model.

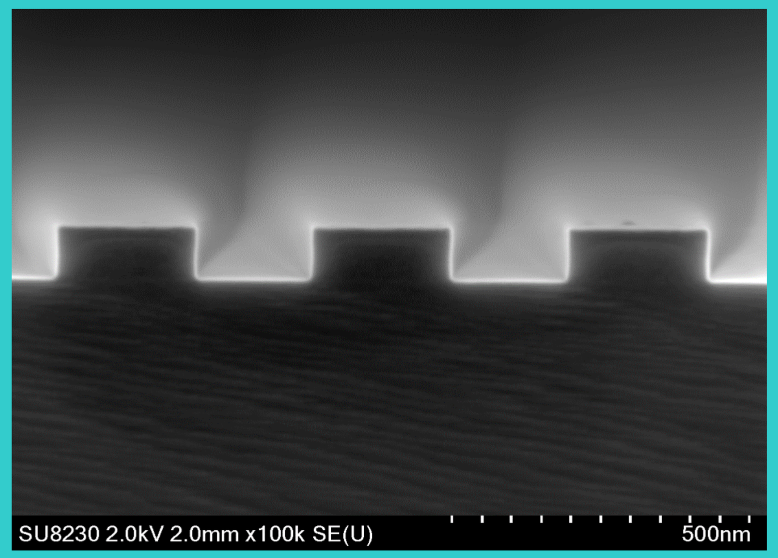
The potential value of BSE and LLE has not been fully exploited for dimensional metrology, but has not been forgotten. Some of the early results and further experimental and modeling work coupled with modeling are sufficiently promising that prompt continued exploration into the possibilities that BSE and LLE afford to metrology in standards development and to determine the necessary information related to design parameters necessary for its implementation.



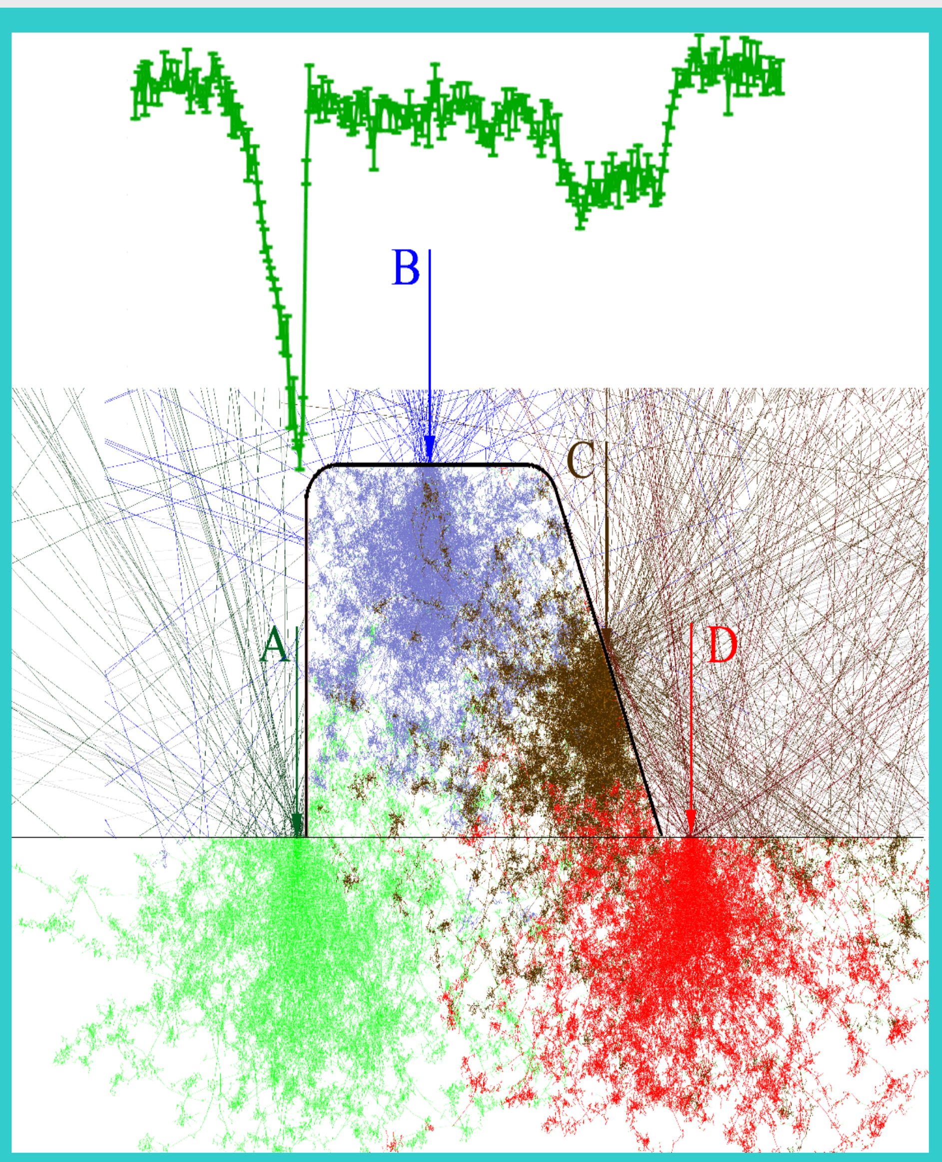
Schematic drawing of the electron optical column of the instrument used in this work. Shown is the detector configuration. The Upper detector was used to collect both secondary electrons and backscattered electrons. The Top detector was used to collect the secondary electrons generated following collision and amplification with the conversion plate by the energy filtered, or un-filtered backscattered electrons coming back up the column through the high pass filter. (Not shown is an additional secondary Lower detector in the sample chamber which was not used in this study.)



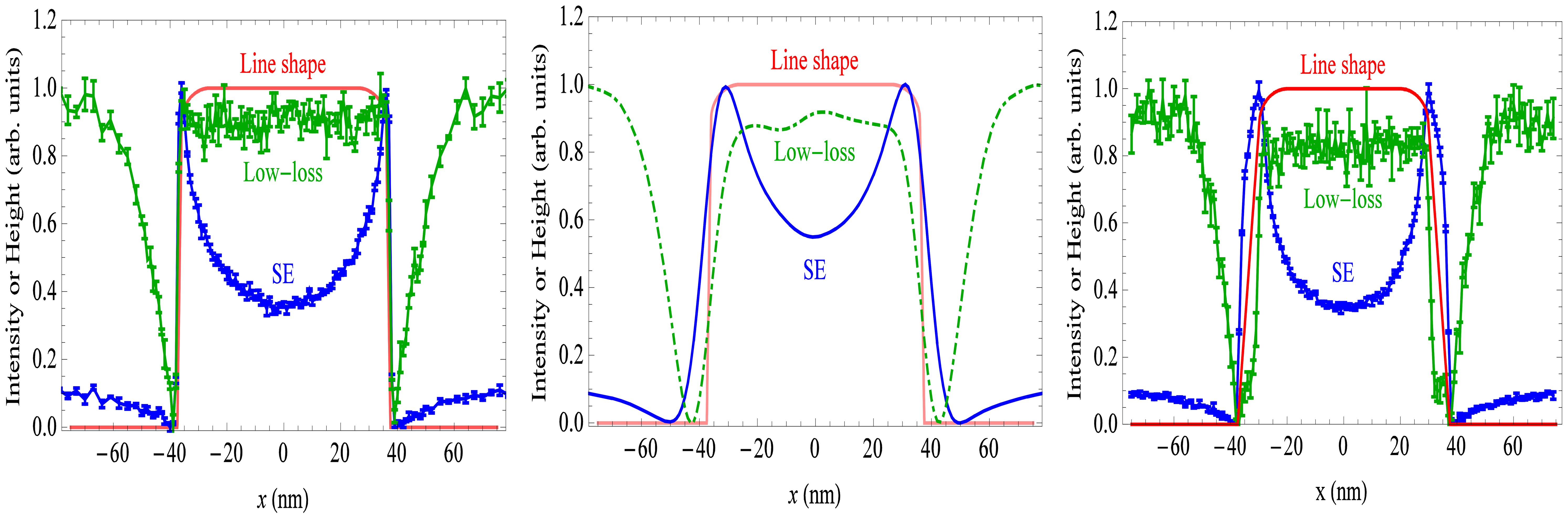
Scanning electron micrograph of RM 8820. SE Image at 0° tilt (Horizontal field width (HFW = 1224 nm).



Cross-section of RM 8820 cleaved polysilicon lines (HFW = 1224 nm).



Model relationship of LLE signal to sample geometry. The upper (green) curve shows the modeled low-loss yield from the line with near-vertical (left) and sloped wall (right) cross section shown in the lower portion. Electron trajectories at 4 landing positions, labeled A-D are superimposed on the sample geometry.



JMONSEL modeled data. (left) Modeling of a vertical-walled silicon structure mimicking the structure of RM 8820, imaged with a sharp beam. (middle) Modeling of the same structure, but with a 5 nm (1 standard deviation) Gaussian beam. (right) JMONSEL simulations of a structure with 5° sloped sidewalls supporting the broadening of the measurements due to wall slope. The line cross-section is shown in red, the simulated SE and LLE images are in blue and green respectively.

Reference: Postek, M. T., Vladar, A. E. and Villarrubia, J. and Atsushi Muto 2016. Comparison of Electron Imaging Modes for Dimensional Measurements in the Scanning Electron Microscope. Microscopy and Microanalysis 22: 768-777.

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