Fine-Tuning Nanowire Shape using 3D Focused Electron Beam Induced Deposition

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3D nanoscale direct-write has been demonstrated for complex, mesh style objects using focused electron beam induced deposition (FEBiD)[1]. Often, a single path exposure is used during 3D FEBiD. During single path exposure, a linear and sequential exposure of adjacent pixels occurs. Typically, a constant pixel spacing and a constant dwell time are used. In single path exposure (Figure 1a), the beam traces a path that is one pixel wide at a velocity (v_b) defined by a digital pixel point pitch (Λ) and a dwell time per pixel of (τ_d). Unfortunately, single beam exposure produces an elliptical nanowire cross–section when measured transverse to the nanowire long axis (Figure 2b) for a host of beam energies. Compensation for this phenomenon is critical since optical[2] and mechanical[3] properties have been enhanced by the modification of nanowire cross-sections from non-circular shapes to circular.

A multi–path exposure procedure that makes it possible to deposit nanowires of circular cross–section will be presented. A 3D FEBiD simulation was used to design and test a beam interlacing method to circularize the nanowire cross–section during growth using multiple beam paths. During the multi–path FEBiD exposure, the thickness of the nanowire is tailored starting from the cross–section determined during single path exposure (Figure 1b). Complementary experiments confirmed the utility of an inverse problem to predict beam interlacing – starting from the desired circular cross–section, the non–linear least squares approach was used to derive unknown variables for a Gaussian superposition function. The role of beam heating on 3D geometry will also be discussed.

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[2] Hwang, J., Lee, H. and Woo, Y. (2016). Enhancing the optical properties of silver nanowire transparent conducting electrodes by the modification of nanowire cross-section using ultra-violet illumination. *Journal of Applied Physics*, 120(17), p.174903.

[3] Vazinishayan, A., Yang, S., Duongthipthewa, A. and Wang, Y. (2016). Effects of cross-section on mechanical properties of Au nanowire. *AIP Advances*, 6(2), p.025006.

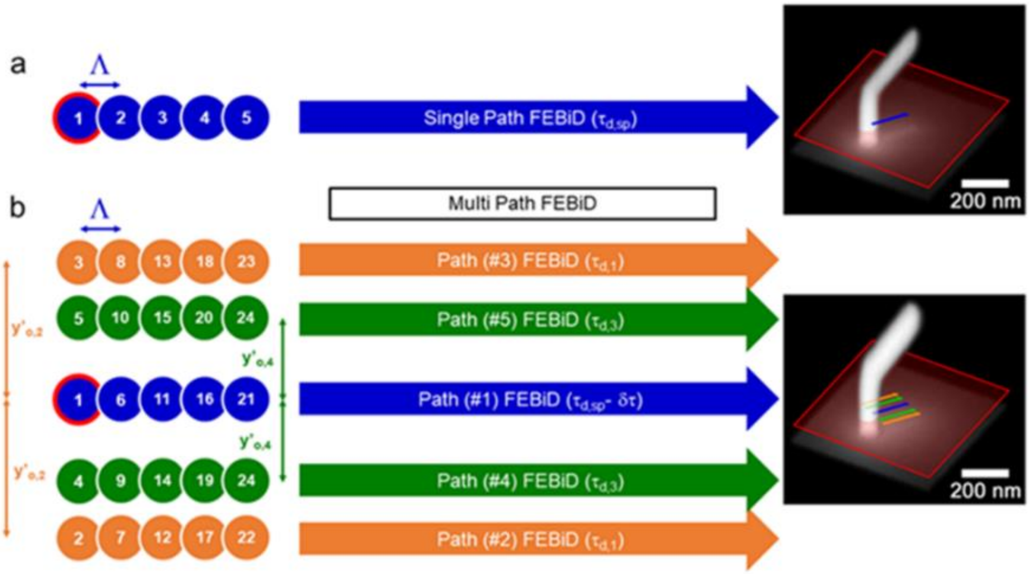

Figure 1: Single and multi-path nanowire exposure modes: (a) Single path FEBiD exposure, the nanowire orientation in space is defined. During (b) multi–path segment FEBiD exposure, the thickness of the segment is tailored starting from the cross–section determined during single path exposure.

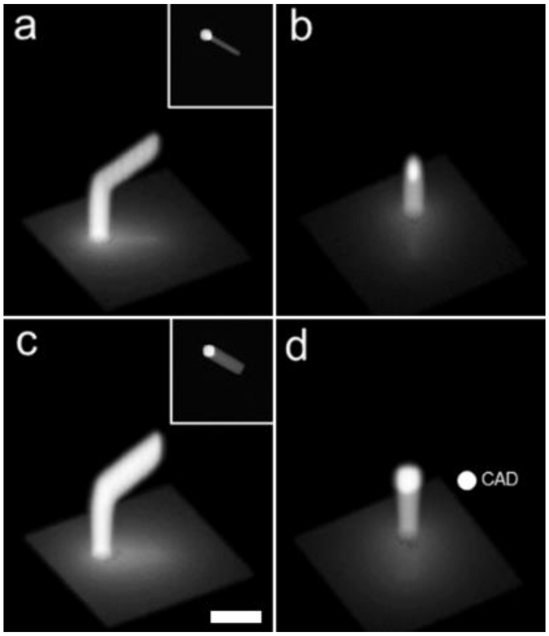

Figure 2: Virtual SEM images: Single (a–b) and multi– (c–d) path nanowire exposure modes. The FEBiD conditions were 10 keV, 49 pA, targeting a segment angle of 40°. Tilted virtual SEM images are shown in (a & c) while transaxial segment cross–sections are shown in (b & d). Inset shows the top down view of the nanowire. The cross–sectional radius of the segment was specified as r = 38 nm. Scale bar = 200 nm.