The Role of Tip-based Measurement in a Hybrid Metrology Framework for Roll-to-Roll Nanofabrication

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As the boundaries of minimum feature size, pitch, and aspect ratio are pushed back in the rapid evolution of roll-to-roll (R2R) nanoimprint and nanoprinting manufacturing, a new approach to nanoscale measurement for process control must also be developed to keep pace. Where in traditional R2R manufacturing or micro-replication processes direct optical inspection, and indirect methods such as scatterometry, ellipsometry, and diffractometry have been sufficient to provide defect detection and process control measurements in current art, as fabricated features shrink below the diffraction limit of visible light, new metrology techniques must be employed [1]–[12]. Further, while typical out-of-line methods such as critical dimension (CD)- and Tilt- scanning electron microscopy (SEM) and CD- atomic force microscopy (AFM) are adequate for run-to-run process control in the traditional semiconductor fab environment, these slow, out-of-line tools do not sync up with the large-area, high-speed processing environment of R2R nanomanufacturing [5], [13], [14].

To fill this metrology gap and provide direct, nanoscale topography data on fabricated features for in-line process control, a novel tip-based measurement device is employed – the single chip (sc)-AFM (ICSPI Corp.). The micro-electro-mechanical system (MEMS) architecture leveraged by the sc-AFM packs all sensing and actuation necessary for nanometer scale topography measurements onto a compact ~1.1 mm^2 footprint device at an incredible low cost (~$250) as seen in Figure 1 [15]. This research seeks to leverage the extremely compact packaging and resilient, micro-scale sensing and actuation mechanisms of sc-AFMs to achieve in-line, nanoscale process control through a proof-of-concept metrology system which positions an sc-AFM above a flexible web in a R2R system with less than ± 10 nm (1σ) certainty in position in Z and machine directions as seen in Figure 2. This concept tool can provide true nanometer scale topography measurements of flexible, hierarchical, and nanofeatured patterns in a 60 second step-and-scan process as shown by the scan of a butterfly wing seen in Figure 3.

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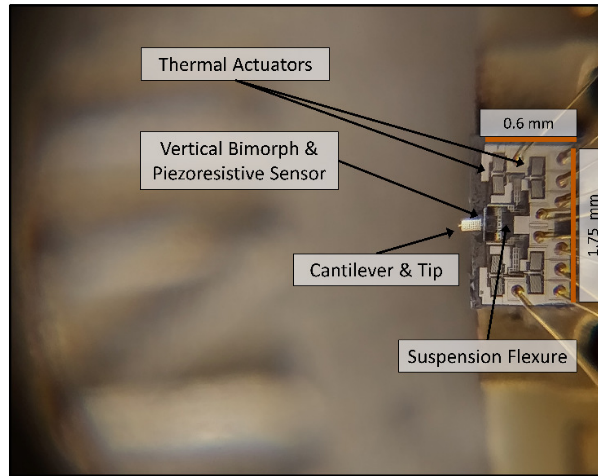

Figure 1. sc-AFM MEMS device next to the N in United on a US Quarter

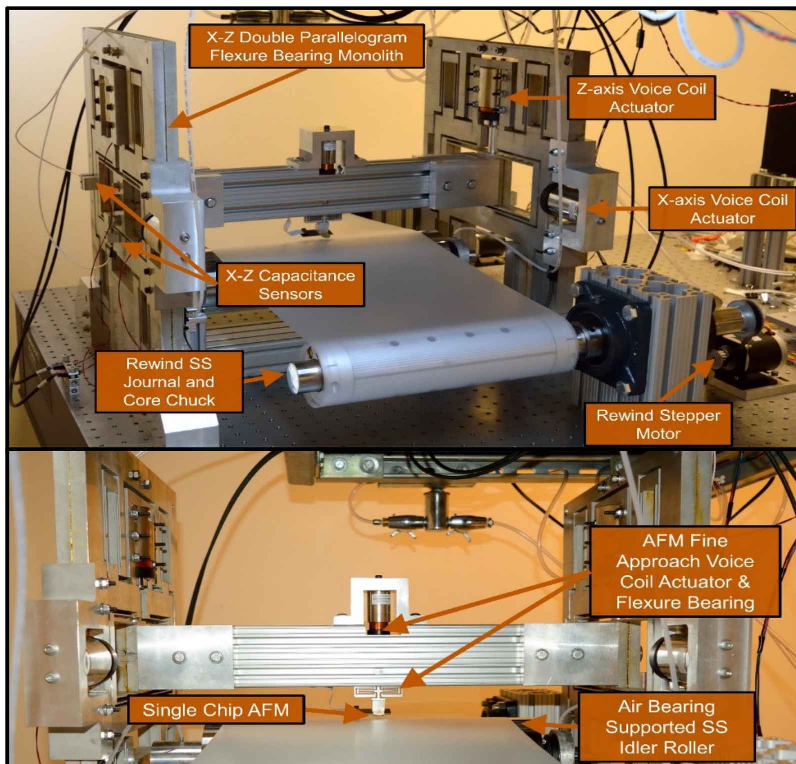

Figure 2. Nanometrology Proof-of-Concept Prototype System Overview [16]

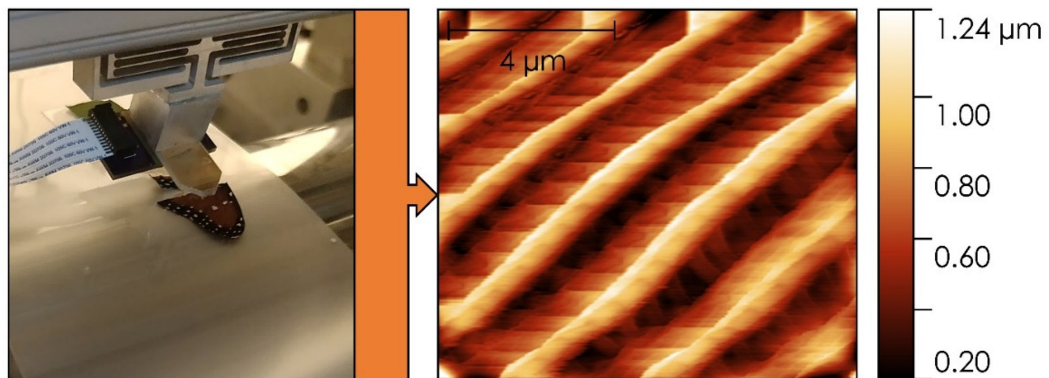

Figure 3. In-line sc-AFM Scan of Queen Butterfly Wing on Polycarbonate Substrate [16]