# Breakthrough of STEM and FIB Automation in Wafer Manufacturing Metrology

Jianxin Fang, Wei Hong, Jose Gajardo, Juanita Castillo, Zhipeng Li, and Haifeng Wang

*Western Digital Corporation, Materials Characterization*
*44100 Osgood Road, Fremont, California 94539, USA*

## INTRODUCTION

As modern electronics become increasingly portable and power efficient, designers and manufacturers face tremendous pressure to miniaturize components while maintaining or increasing system performance, particularly in the data storage and semiconductor industries. With growing demand for greater data storage capacity driven by a vast amount of online social activities and rapid transition to digital content generation by the worldwide population, areal density boost is becoming a technical challenge as well as an economic viability for the storage industry. This has resulted in the thin film magnetic recording head dimension inside the drive continuously shrinking mercilessly. Many critical layers in both the writing and the reading sections of the recording head have been reduced to nanometers, and some of them are in the angstrom range. Manufacturing control capability at the sub-nanometer scale is essential to consistent high yield wafer production.

Conventional scanning electron microscopy (SEM) based in-line metrology, e.g., critical dimension scanning electron microscopy (CD-SEM), despite its high volume and instant access to data, is becoming less sensitive to nanometer to sub-nanometer structural variation due to imaging resolution limitation. Other optical based metrologies rely on specially designed test areas to correlate to device level structures. Transmission electron microcopy (TEM) imaging has been used successfully but is limited to building the correlation between test site metrology and actual device dimensions.

## PROCEDURES

The technique, CD-STEM as opposed to CD-SEM, consists of three key steps: (1) focused ion beam (FIB) sample preparation, (2) ex-situ sample transfer, and (3) automated imaging and measurement. Each step is described below.

- **FIB Sample Preparation**: TEM samples are automatically sectioned from the wafer using recipe-driven FIB processes. Automated FIB milling includes creating reference marks for milling accuracy and drift compensation, fine tuning stage movement, rough trim on both sides of the lamellae, bottom release milling, and final polishing to achieve the required thickness. The FIB automation provides high positioning accuracy and precision to achieve about 60nm-thick TEM lamellae with ~1 sigma of 3nm consistency, as shown in Figure 1.

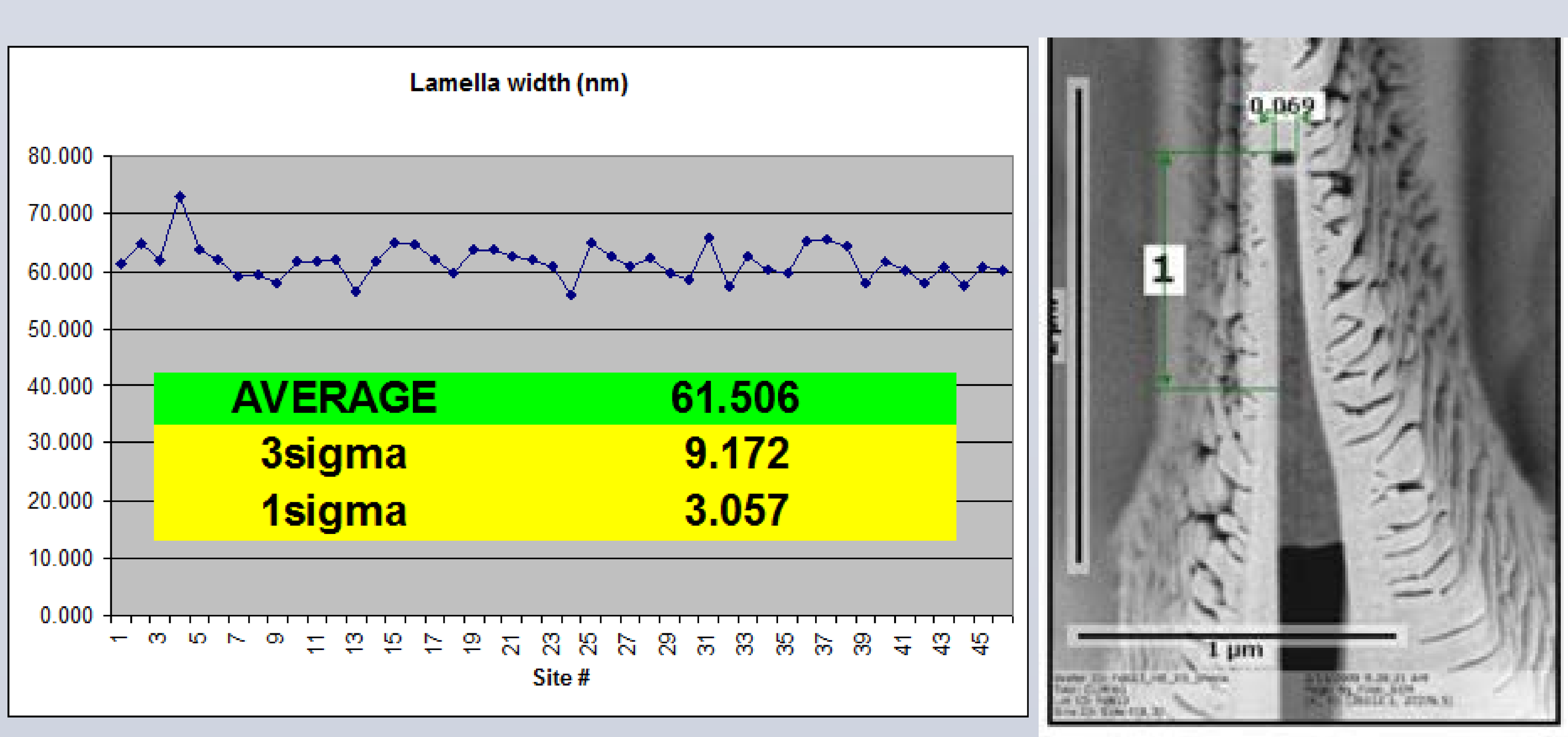


**Figure 1. Thickness consistency of TEM samples prepared via automated FIB**

- **Ex-situ Sample Extraction and Transfer**: Lamellae sectioned on the wafer are extracted and transferred to a 3mm TEM grid via a semi-automated proprietary procedure. The process includes innovative probe design and a computer controlled motorized stage. The new probe, a hollow glass tube, uses vacuum force to ensure a reliable pick and place operation. A host computer controls the motorized stage of the transfer station, navigating automatically to sample locations reported from the FIB system to pick samples from the wafer and to grid locations to place samples onto the grid. Automation has greatly improved the speed, precision, and reliability of the transfer process, which provides a uniquely high success rate and high throughput. A large number of samples are placed on a single grid with each sample similarly oriented, as shown in Figure 2. Placing multiple samples in similar orientation simplifies the tilt adjustment during imaging and allows acquisition of edge-on STEM images of multiple samples by one single adjustment of the common orientation.

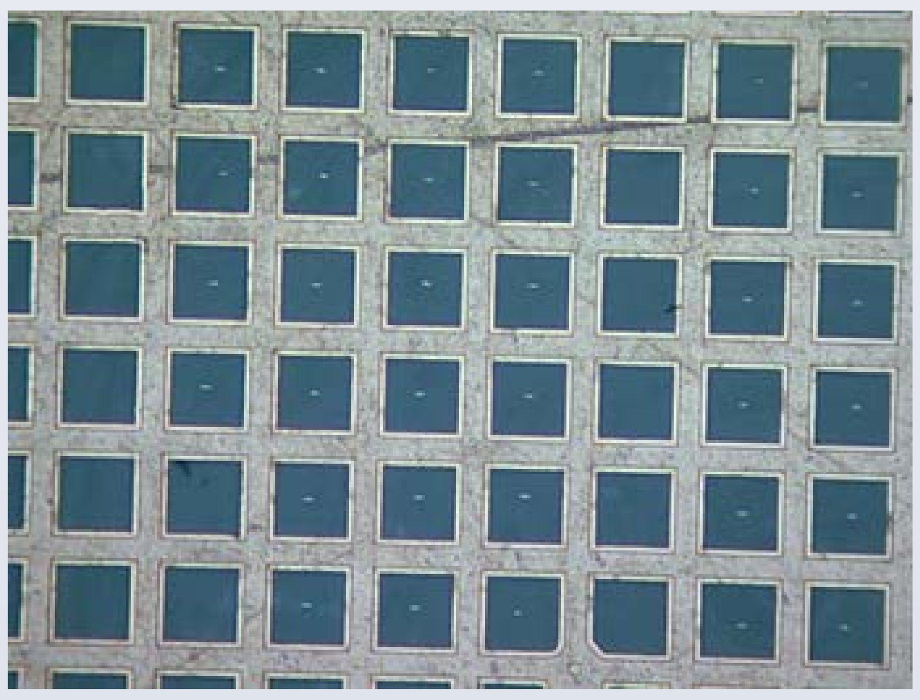

**Figure 2. TEM grid with multiple** samples

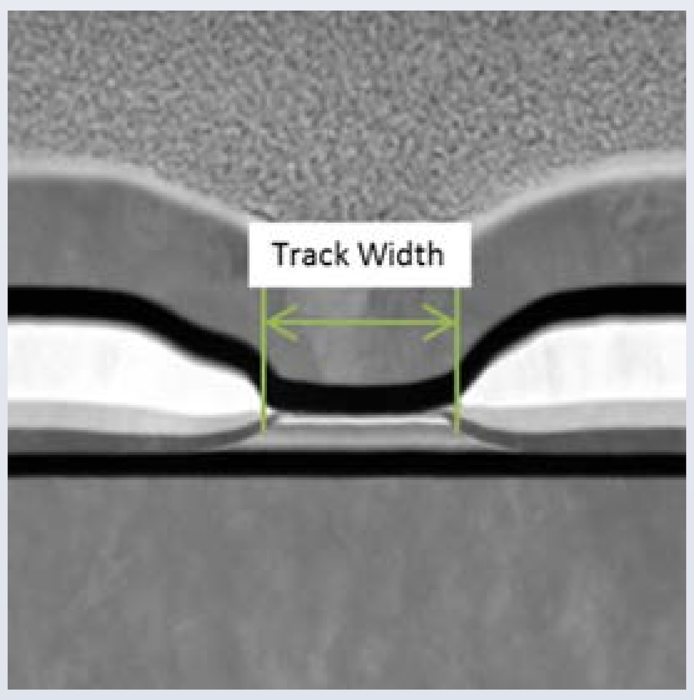


Figure 3. STEM image showing strong material contrast of a GMR reader

- **Automated Imaging and Measurement**: STEM images shown in Figure 3 are acquired using sophisticated imaging automation on TEM, including auto-eucentric height and auto-tilt adjustment. Dimensions are measured on the acquired STEM images using image analysis, including feature recognition and edging finding algorithms. Gauge study has shown that one sigma of 1.0 A has been achieved, as shown in Table 1.

| | | Operator 1 | | | | | Operator 2 | | | | | Operator 3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | al value | M1 | M2 | M3 | Mean | Var | M1 | M2 | M3 | Mean | Var | M1 | M2 | M3 | Mean | Var | Mean | Var<m> | <Var> |
| 1 | 0_6_14, | 38.63 | 38.73 | 38.44 | 38.6 | 0.022 | 38.44 | 38.68 | 38.44 | 38.5 | 0.019 | 38.37 | 38.37 | 38.49 | 38.4 | 0.005 | 38.509 | 0.0089 | 0.0151 |
| 2 | 2_30_16, | 38.94 | 39.04 | 39.01 | 39.0 | 0.002 | 39.04 | 39.31 | 39.01 | 39.1 | 0.028 | 39.18 | 39.01 | 39.27 | 39.2 | 0.017 | 39.090 | 0.0067 | 0.0160 |
| 3 | 3_18_5, | 38.66 | 38.55 | 38.56 | 38.6 | 0.004 | 38.44 | 38.61 | 38.56 | 38.5 | 0.008 | 38.90 | 38.44 | 38.45 | 38.6 | 0.071 | 38.574 | 0.0011 | 0.0275 |
| 4 | a_66_22, | 39.03 | 38.87 | 38.96 | 39.0 | 0.006 | 38.76 | 38.71 | 38.96 | 38.8 | 0.018 | 38.77 | 38.97 | 38.90 | 38.9 | 0.010 | 38.881 | 0.0051 | 0.0112 |
| 5 | c_67_17, | 36.47 | 36.46 | 36.48 | 36.5 | 0.000 | 36.35 | 36.59 | 36.48 | 36.5 | 0.014 | 36.47 | 36.49 | 36.41 | 36.5 | 0.002 | 36.467 | 0.0001 | 0.0055 |
| 6 | f_66_10, | 38.47 | 38.53 | 38.41 | 38.5 | 0.003 | 39.38 | 38.57 | 38.41 | 38.8 | 0.270 | 39.29 | 38.29 | 39.17 | 38.9 | 0.299 | 38.725 | 0.0534 | 0.1910 |
| 7 | h_44_18, | 34.87 | 34.56 | 34.89 | 34.8 | 0.035 | 34.73 | 34.95 | 34.89 | 34.9 | 0.013 | 34.72 | 34.84 | 34.71 | 34.8 | 0.005 | 34.796 | 0.0028 | 0.0178 |
| 8 | k_31_17, | 36.00 | 35.91 | 35.78 | 35.9 | 0.012 | 35.63 | 36.06 | 35.78 | 35.8 | 0.046 | 35.63 | 35.87 | 35.76 | 35.8 | 0.015 | 35.826 | 0.0050 | 0.0244 |
| 9 | w_4_22, | 38.38 | 38.36 | 38.07 | 38.3 | 0.031 | 38.45 | 38.21 | 38.07 | 38.2 | 0.037 | 38.51 | 38.27 | 38.31 | 38.4 | 0.016 | 38.292 | 0.0040 | 0.0280 |
| 10 | m_28_1 | 37.72 | 37.67 | 37.62 | 37.7 | 0.002 | 37.69 | 37.74 | 37.62 | 37.7 | 0.004 | 37.82 | 37.62 | 37.72 | 37.7 | 0.010 | 37.691 | 0.0006 | 0.0052 |
| | | | | | | | | | | | | | | | Global Mean: | | 37.685 | | |
| | | | | | | | | | | | | | | | Reproducibility sigma: | | | 0.094 | |

## CONCLUSIONS

Automated CD-STEM metrology includes automated FIB sample preparation, ex-situ sample extraction, and automated imaging and measurement. With these advances, CD-STEM can provide both the resolution required to accurately characterize nanoscale structures, speed and repeatability, and the reproducibility required for high volume manufacturing processes in the magnetic head industry. These remarkable benefits can also be appreciated in many other microelectronics industries that focus on controlling nanostructures in the manufacturing process.



Contact: Haifeng.wang@wdc.com, +1-510-683-7448