High-Accuracy Measurements of Patterned Media

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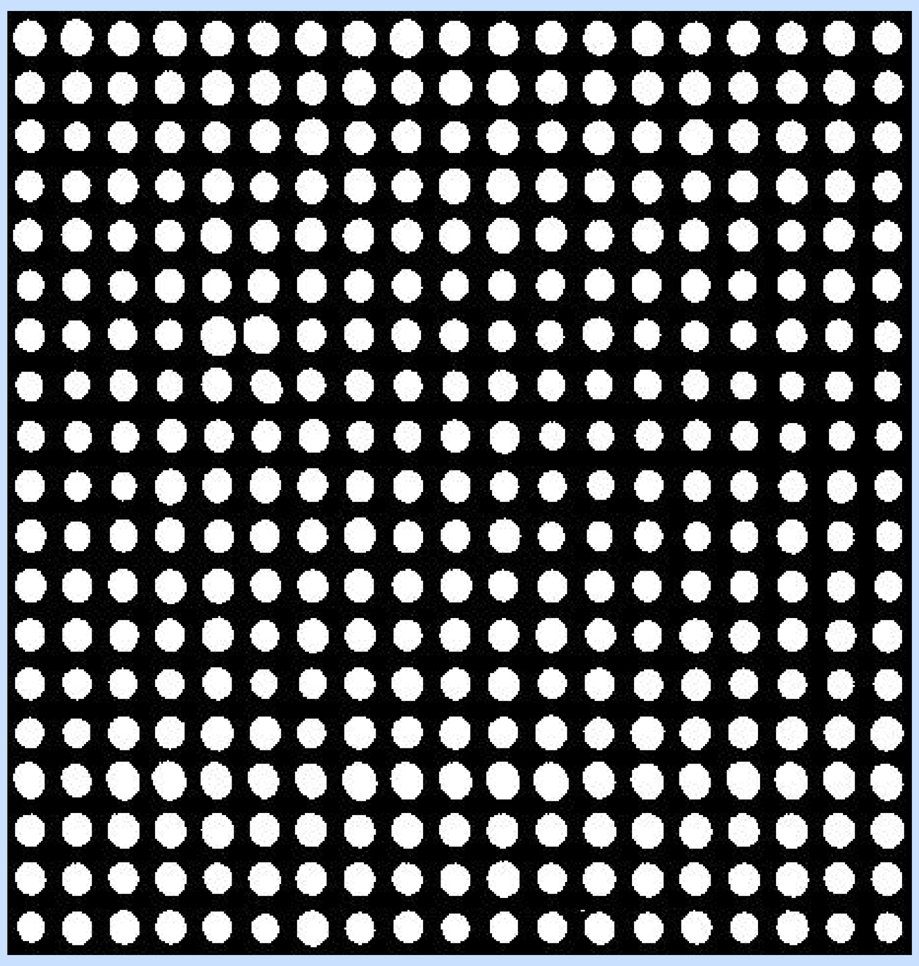
Abstract

Track pitch and feature size variation in pre-patterned magnetic media cause noise and must be controlled. We use a standard open-loop AFM with offline calibration and measurement software to measure pitch and pitch variation. We demonstrate measurement quality using a 144-nm pitch 2-dimensional square grating. We found 1 standard deviation of individual pitch values = 0.55 nm and 1 s.d. of feature width = 2.2 nm. This method also works with SEM and can be applied to smaller patterns.

Fig. 1 – Concept: Array of isolated magnetic dots.



Introduction

Figure 1 shows the concept of pre-patterned media where each bump is an isolated magnetic dot. When such media are replicated (e.g. by nano-imprint), any errors on the master are copied. The size, shape and position of the bumps must be measured and then controlled in order to achieve low noise recording and playback.

Measurement Goals

- Measure the topography directly by AFM (atomic force microscopy) or SEM (scanning electron microscopy)

- Compute position and size information very accurately. For example, track misregistration (track pitch variation) should be measured with a precision of better than 3% of the pitch (3 s.d.).

We helped make DVD possible by developing AFM calibration and measurement procedures and software for measuring optical disc samples such as DVD, HD-DVD, and BluRay masters, stampers and replicas. Here we apply the same techniques to finer patterns.

Materials and Methods

AFM: Veeco Dimension 3100 with standard open-loop scanner
Calibration and test samples: See figures 2 and 3.
Data capture: Alternate scans of the calibration and test samples.
Analysis software: Advanced Surface Microscopy DiscTrack™ Plus.
Calibrate each test sample image using the preceding and following calibration images.

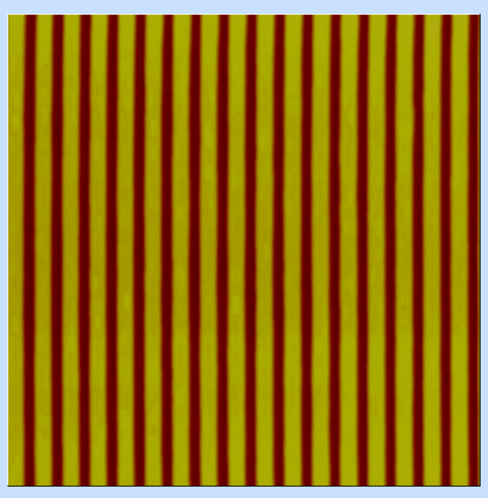


Fig. 2 Calibration standard: 292-nm pitch, 1-D holographic grating of Ti lines on Si.
Mean pitch = 292.096 ± 0.015nm
(measured at PTB)

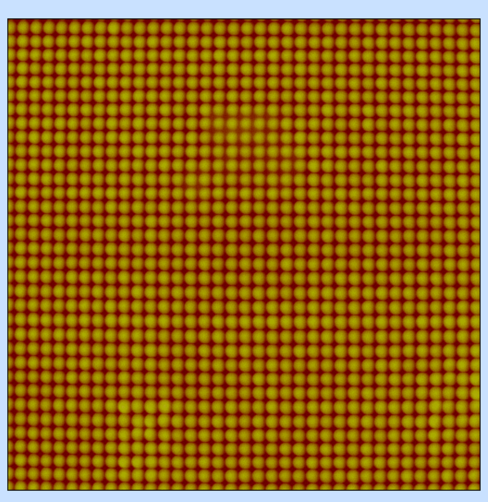


Fig. 3 Test sample: 144-nm pitch, 2-D holographic grating of Al bumps on Si.
Mean pitch of X axis = 143.928 ± 0.015 nm
(measured at PTB)

Results - Track Pitch – using AFM

Fig. 4 shows 30 independent measurements of pitch from one image (data set 2) were all within a 2 nm range.
Table 1 summarizes the results from 10 data sets. The overall average pitch (pooled results) from the AFM measurements agreed well (within the experimental uncertainty of at least 2*Std.Error of Mean, or 0.064 nm) with the PTB measurement of average pitch by optical diffraction. This successful calibration transfer from one standard to another with smaller pitch gives us confidence in our methods and we expect to be able to measure samples with even smaller pitch values.
Furthermore, the 0.55 nm standard deviation is only 0.4% of the mean pitch. Here, 3 s.d. is only 1.2% of the pitch. This is 2.5x more sensitive than the goal we set for measuring track misregistration/pitch variation.

Fig. 4

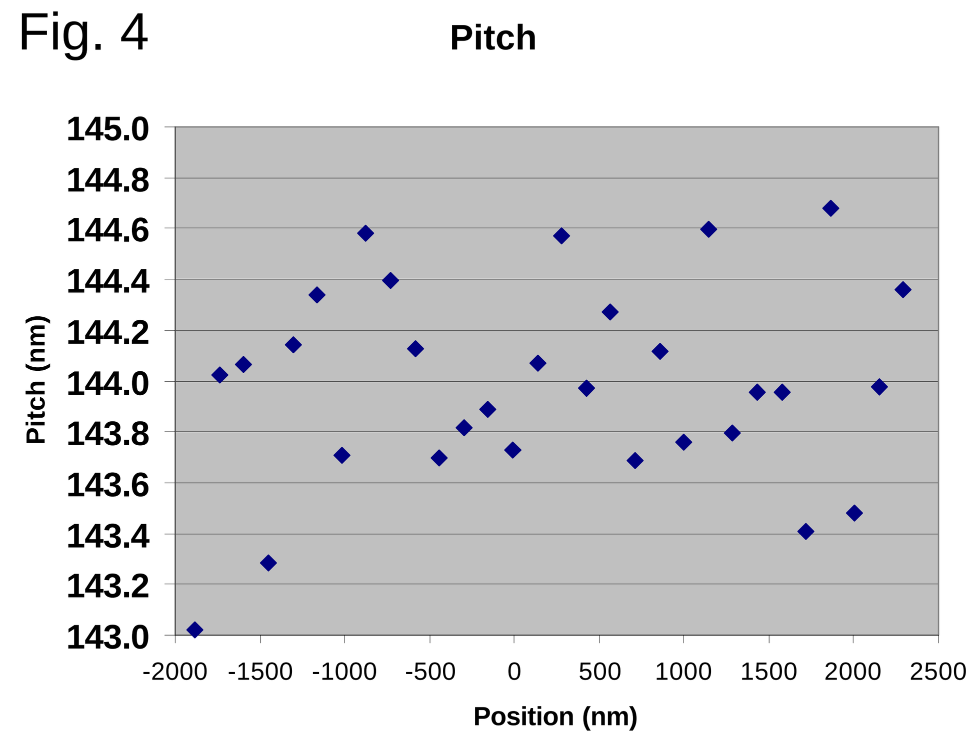


Table 1		Pitch Results (nm)		
Data Set	Count	Mean	Standard Deviation	Standard Error of Mean
1	30	143.85	0.42	0.08
2	30	143.98	0.40	0.07
3	30	143.83	0.55	0.10
4	30	143.98	0.64	0.12
5	31	144.05	0.69	0.12
6	31	143.86	0.58	0.10
7	31	143.89	0.50	0.09
8	30	143.81	0.55	0.10
9	31	143.92	0.55	0.10
10	30	143.77	0.59	0.11
Average Pitch using AFM and DiscTrack Plus		**143.89**	**0.55**	**0.032**
Pitch using optical diffraction at PTB (PTB is German equivalent of US NIST)		**143.928**		
Difference		**0.033**		

Results - Pitch using SEM

We used a Hitachi S4700 Field Emission SEM at 5 kV. Fig. 5 shows the image we analyzed. In our analysis, we calibrated the image with itself, so we look only at the pitch variation, not the mean value. Fig. 6 graphs the individual pitch values. The results show that SEM can be as precise in measuring pitch as AFM.

Fig. 5

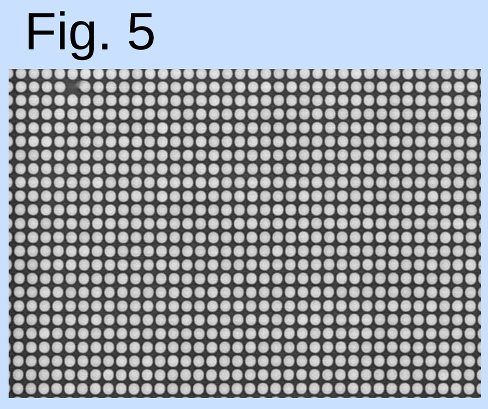
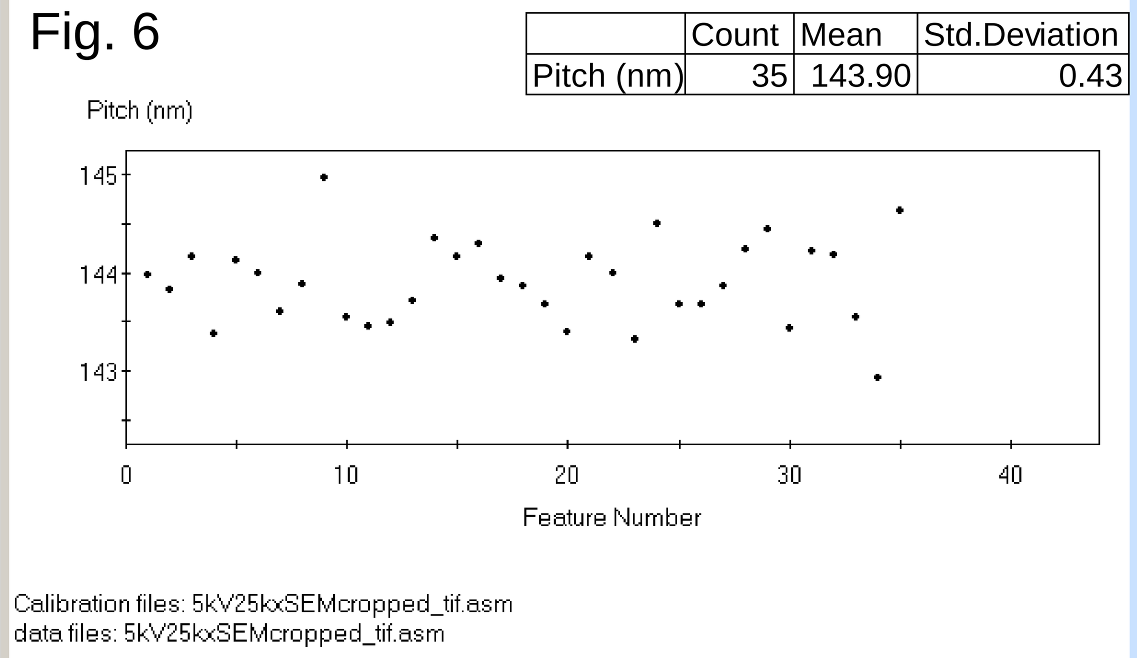


Fig. 6

	Count	Mean	Std.Deviation
Pitch (nm)	35	143.90	0.43



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Results – Bump Geometry – using AFM

Small variations of feature size in data storage media can lead to large differences in performance. Precision measurement of pre-patterned media can help minimize variation and ensure product consistency. We demonstrate measurement of length, width, height, and four wall angles on a test sample consisting of a two dimensional array of small bumps. By making many measurements we can detect subtle correlations.

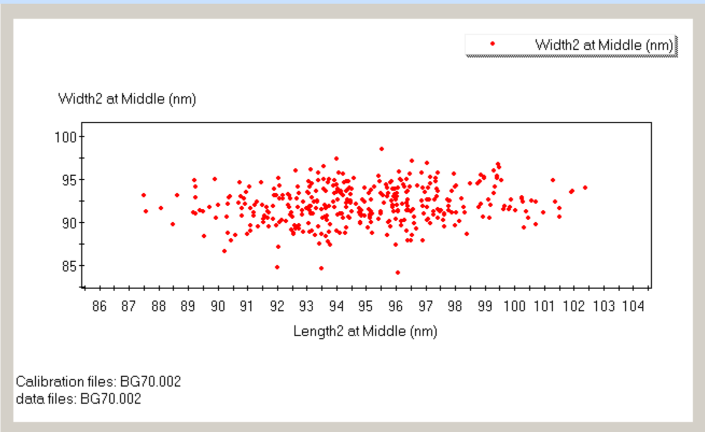

Fig. 7. Scatter plot of Width vs. Length and Width of bumps. Each point represents one bump. Feature length varied from 88 to 102 nm and width ranged from 84 to 94 nm. There was no apparent correlation between length and width.

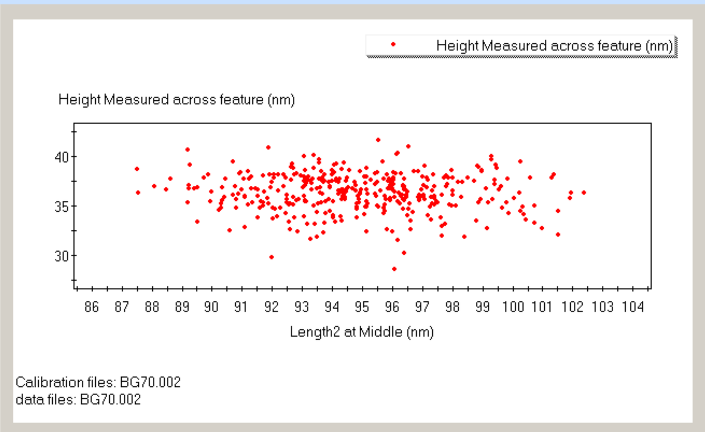

Fig. 8. Graph of height vs length. Height is measured between the top of the bump and the land to the side (direction parallel to the X axis in the image). There was no significant correlation between these two parameters.

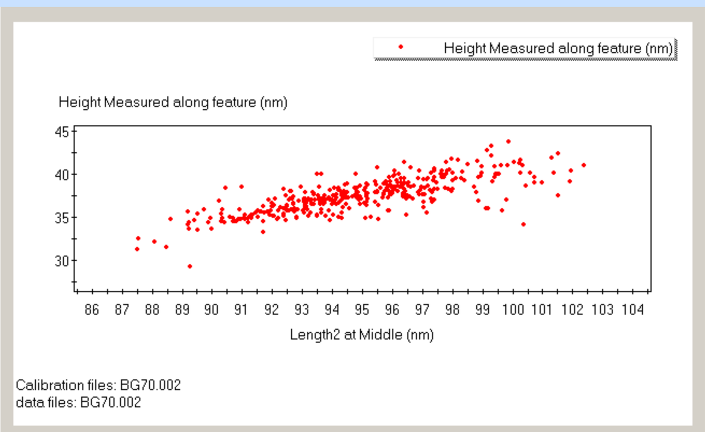

Fig. 9. In this chart the height is measured between the top of the bump and the land either in front of or behind it (parallel to the Y direction in the image). The longer bumps tended to be taller. A similar chart (not shown) showed a correlation between height measured across the bump and the bump width. These correlations indicate that the side and end wall angles did not change noticeably with bump size.

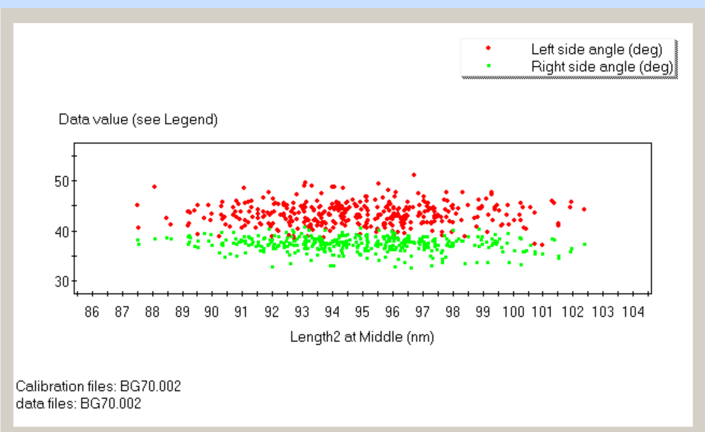

Fig. 10. This chart directly shows that the side wall angles did not correlate with bump length, remaining relatively constant over the range of feature lengths.

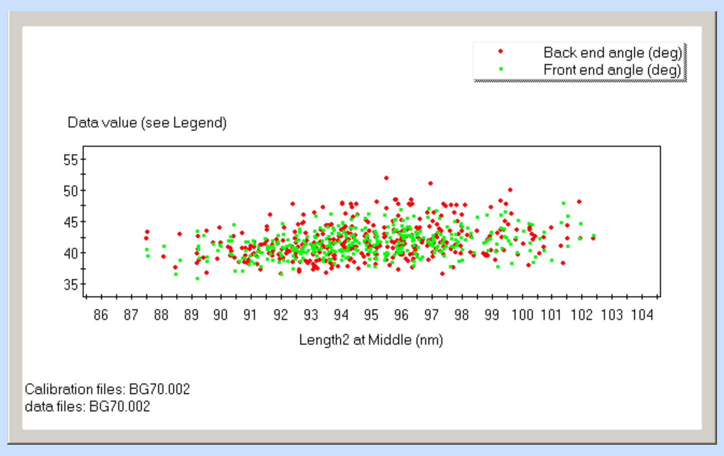

Fig. 11. As with left and right angles, the front and back angles remained approximately constant with feature length, or perhaps increased slightly.This slight correlation is probably not significant.

Table 2. Numerical summary of the AFM bump geometry measurements.

Table 2	Width2 at Middle (nm)	Length2 at Middle (nm)	Height Measured across feature (nm)	Height Measured along feature (nm)	Left side angle (deg)	Right side angle (deg)	Back end angle (deg)	Front end angle (deg)
Count	377	377	377	377	377	377	377	377
Mean	92.02	94.88	36.31	37.44	43.31	37.36	41.78	41.58
Standard Deviation	2.19	2.89	1.92	2.03	2.23	1.46	2.76	2.05
Standard Error of Mean	0.11	0.15	0.10	0.10	0.11	0.07	0.14	0.11
Maximum	98.43	102.37	41.71	43.73	51.03	40.70	51.88	47.96
Minimum	84.10	87.52	28.57	29.30	37.23	32.56	36.56	35.92
Range	14.33	14.86	13.14	14.43	13.80	8.15	15.32	12.04

Results – Bump Geometry – using SEM

Since the SEM can't measure height, we can only look at length and width.

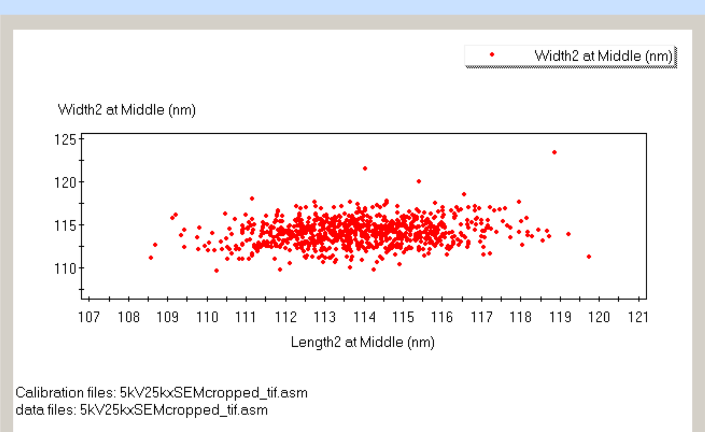

Fig. 12. Graph of width vs. length. There was no correlation.

Table 3	Width2 at Middle (nm)	Length2 at Middle (nm)
Count	828	828
Mean	114.07	113.90
Standard Deviation	1.54	1.81
Standard Error of Mean	0.05	0.06
Maximum	123.35	119.75
Minimum	109.62	108.58
Range	13.73	11.17

Table 3 gives a numerical summary of the width and length measurements from the SEM image. The apparent width and length values were about 20-22 nm larger than in the AFM images. This disagreement is not surprising, since AFMs and SEMs form images by very different mechanisms.

Summary

We present a novel way to measure the size, shape and position of topographic features on pre-patterned media. Instead of making just one or a few measurements at each image spot, as is done with critical dimension SEMs (CD-SEM), we make dozens or hundreds of measurements in each image. Instead of using a special "metrology" microscope, we use a high-quality, general-purpose AFM. We obtain high accuracy by using specific calibration and measurement procedures along with automated analysis software.

As a test sample, we used a 144-nm pitch, 2-dimensional holographic grating. The most basic measurement of position is track pitch. The standard deviation of individual pitch measurements was 0.55 nm, so 3 s.d. was just 1.2% of the pitch. This level of precision is more than sufficient for the task of measuring track pitch variation ("track misregistration") when the variation must be controlled to 10-20% (3 s.d.) of the basic pitch. To gauge our absolute accuracy and provide traceability to the international meter, we compared our AFM measurement of average pitch with an independent measurement of the same specimen at PTB (the German counterpart of NIST) using optical diffraction. The difference was 0.032 nm, well inside our 95% confidence interval based on random effects.

Looking next at the size and shape of individual features (bump geometry), we measured length, width, height and wall angles for more than 350 bumps in a single image. The large quantity of data allowed us to detect a slight correlation of height and size: cross-track width increased with cross-track height and down-track length increased with down-track height.

The same analysis methods used for AFM appear to work with SEM.

Based on our experience in the optical disc industry, this measurement approach will be valuable for equipment qualification, process development and trouble-shooting in the fabrication of pre-patterned magnetic media.

Further Reading

1.a. "High precision calibration and feature measurement system for a scanning probe microscope", Donald A. Chernoff and Jason D. Lohr, U.S. Patent # 5,644,512, issued July 1, 1997.

b. "High precision calibration and feature measurement system for a scanning probe microscope", Donald A. Chernoff and Jason D. Lohr, U.S. Patent # 5,825,670, issued October 20, 1998.

c. "Automated, high precision measurement of critical dimensions using the Atomic Force Microscope", Donald A. Chernoff and David L. Burkhead, J. Vac. Sci. Technol. A 17, 1457 (1999).

2. "AFM Length Analysis of Data Marks: Measuring Jitter, Asymmetry, Process Noise and Process Position", Donald A. Chernoff and David L. Burkhead, in Optical Data Storage 2001, Terril Hurst, Seiji Kobayashi, Editors, Proceedings of SPIE vol. 4342, pp. 515-523 (2002).

3. "Pitch Metrology by Optical Diffraction and Atomic Force Microscopy", Donald A. Chernoff, Egbert Buhr, David L. Burkhead, and Alexander Diener, abstract submitted to SPIE Conference on Advanced Lithography, Metrology and Inspection, 2008.

4. "Patterned Magnetic Media", http://www.hitachigst.com/hdd/research/storage/pm/index.html.

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