AFM Analysis of HD-DVD Stampers

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Abstract: For an HD-DVD stamper, we report track pitch, height, width, length and wall angles as well as "AFM jitter", channel bit length, offset and the variation of size and shape with T-number.

OCIS codes: (210.4590) Optical disks; (210.4770) Optical recording

1. Introduction

HD-DVD and BD belong to the 3rd generation of optical discs. With each new generation, the features are smaller and the tolerances are tighter. The specified average track pitch for HD is 400 +/- 10 nm (on the replica) and the allowed range for individual values is +/- 20 nm. The shortest data mark is T2, with a length of 204 nm.[1] For comparison, in DVD, the track pitch is 740 nm (+/- 10 average, +/- 30 individual) and the shortest data mark is T3, with length of 400 nm.
New tools and new ways of using existing tools are required to make new discs. We are now in the early stages of manufacturing development. Disc analyzers and other test equipment compatible with these new formats are scarce. The Atomic Force Microscope (AFM) has long been used for qualitative and quantitative analysis of the topography of compact discs and DVDs. When used with appropriate software for calibrating and automating measurements from AFM images, 1 nm precision and accuracy can be achieved. We use this AFM analysis to measure the size, shape and position of the data marks. We can then see how a specific production process results in specific microstructure which in turn resulted in good playback characteristics.

2. Materials and Methods

An HD-DVD glass master was produced on a Singulus Mastering model LDM 3692 DUV recorder (257 nm laser), employing a standard I-line resist. We used the nominal signal, no write compensation strategy was employed. The recording intensity was selected based on replica results from earlier intensity step studies, but photoresist thickness was not optimized. Stampers were made by a standard family process. Replicas from the stampers typically showed sBER~10^{-8}, PSNR~27, 2Tasy~-0.02, 3Tasy~0.00 Stampers were imaged on a Veeco Instruments NanoScope® IIIA/Dimension 3100 AFM system. We used tapping mode, capturing 5-μm images at 6 different locations at each of two radii (25 and 55 mm) on the stamper. We also captured an image of a 292-nm period 2-dimensional calibration grid. We then analyzed the calibrator and stamper images using DiscTrack Plus™ software.[2]

3. Results

Overall Statistics. As shown in fig. 1, we measured 119 track pitch values in 12 images and found a mean value of 404 nm, standard deviation of 4.3 nm and range of 22.9 nm. The mean value was chosen slightly larger than nominal to allow for shrinkage of the replica relative to the stamper when these parts cool from the molding temperature. There was no change in track pitch between radius 25 mm (left half of graph) and 55 mm (right half).

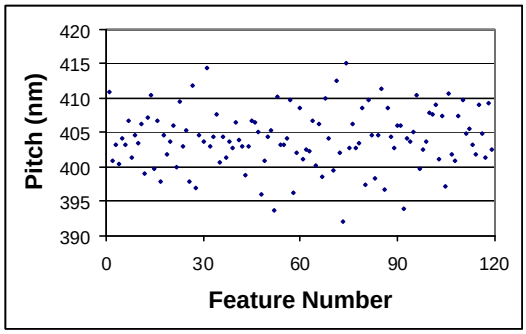

Fig. 1 Individual Pitch Measurements.

We measured 379 bumps at R=25 mm and 390 bumps at R=55 mm. The average bump width increased by about 6.7 nm in going from R25 to R55, height increased 3 nm and wall angles increased by 0.3-0.6°. Summary statistics are shown in Table 1. Width was measured at half height and was not corrected for tip width. Height was measured relative to the land between tracks.

Table 1. Width, Length, Height and Side Wall Angles

Location	Width (nm)	Length (nm)	Height (nm)	Left side angle (deg)	Right side angle (deg)	Back end angle (deg)	Front end angle (deg)
R25	152.0	312.5	59.9	40.0	34.9	29.8	23.6
R55	158.7	337.7	63.0	40.6	35.2	30.0	24.0

Length Analysis. Fig. 2 shows graphs of width and height vs length for R=55 mm. Note that the points are clustered at intervals of about 100 nm along the length axis. These clusters correspond to the T-numbers used by the digital code. Here, we found bumps belonging to T2 through T10 and T13. As is often found with DVD, width increased with length. It is particularly interesting that height also increased with length. The ca. 70 nm maximum height corresponds to the photoresist thickness. R=25 mm was similar.

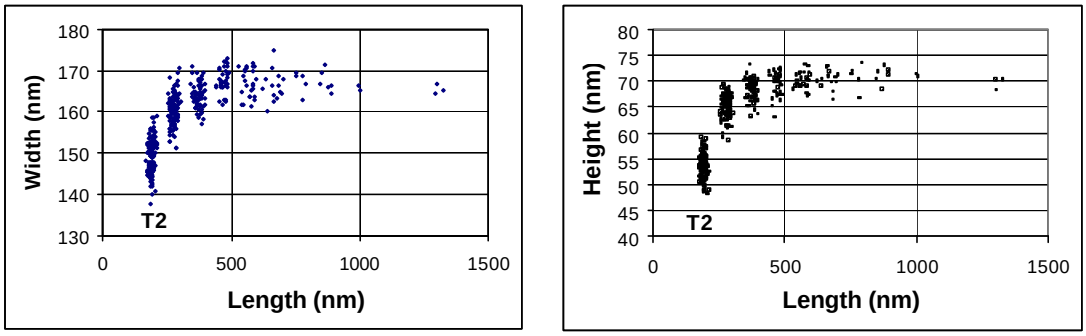

Fig. 2 Bump Width and Height at R = 55 mm

To get a closer look at the bump geometry, we selected one each T2, T3, and T6 bumps whose length and height placed them in the middle of their respective groups. Fig. 3 shows height profiles across the track (X direction) and along the track (Y direction).

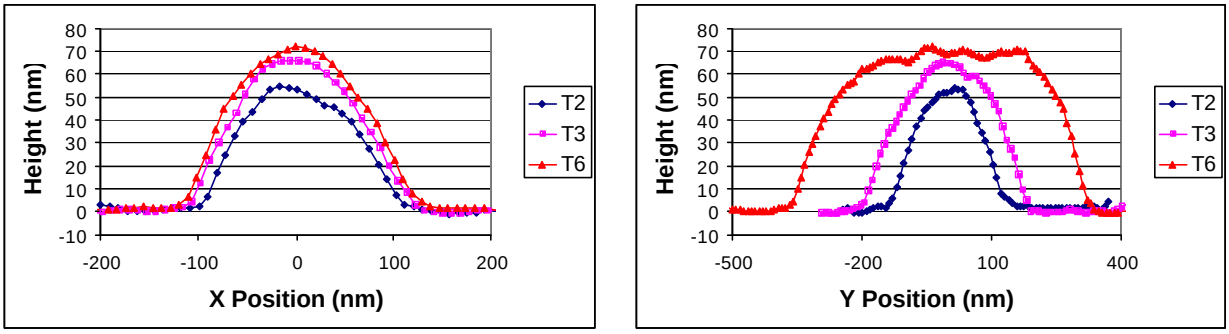

Fig. 3 Bump Profiles across track (left) and along track (right) at R = 55 mm.

The T2 and T3 bumps had generally rounded shapes in both the X and Y directions. This indicates that the corresponding photoresist pits were not developed down to the glass. The rounded shape of the T6 bump in the across-track direction and the nearly flat top seen in the along-track direction suggests that only the centerline of the photoresist pit was developed down to the glass. In comparison, DVD bumps made by a photoresist process often have an ideal trapezoidal height profile. Therefore, if it were a DVD, we would classify this master as grossly underdeveloped However, this geometry emerged as the one which gave best results on the replica, due to the characteristics of the equalizers defined for HD-DVD and of the detection scheme (PRML). At this time, we have not yet done any optimization of pit depth or write strategy, and we will present results of further experiments at the conference.

By labeling each bump (and each intervening land) with its proper T-number, the analysis software computed the "AFM jitter" results shown in Table 2. The jitter values represent a data-to-data calculation as previously described[3] and are expressed as a percentage of the apparent channel bit length. Even though there is no jitter specification when PRML signal detection is used, we believe these numbers give an indication of mastering quality by measuring the precision of edge placement. Whether the jitter values are also a good indication of playback quality remains to be investigated, by comparing data from discs with different playback quality. The use of a write compensation strategy to obtain best results in play back may very well spoil the AFM jitter.

Table 2. Jitter Analysis at R = 55 mm

	Bumps	Lands
AFM Jitter	6.08%	7.16%
Channel Bit Length:(nm)	97.65	100.70
Offset:(nm)	-10.16	26.27

Measurements of another stamper made from the same master showed even lower AFM jitter values: 4.8% (bumps), 7.24% (lands).

Additional indicators of mastering quality are obtained by a similar statistical analysis of the other geometric parameters. As shown in Table 3, the within group standard deviation was 3.8 nm for width and 2.1 nm for height.

Table 3. Within group standard deviations of size and shape parameters.

Width (nm)	Height (nm)	Left Angle (degrees)	Right Angle (degrees)	Front Angle (degrees)	Back Angle (degrees)
3.82	2.10	2.60	1.98	2.11	2.52

The mean bump lengths for each group (and their deviation from T*(channel bit length)) are shown in Table 4.

Table 4. Average Bump Length (nm) by T-number

T	2	3	4	5	6	7	8	9	10	13
Count:	58	42	24	15	11	9	3	6	2	1
Mean:	191.6	279.1	371.8	472.7	572.2	670.8	781.4	867.4	997.9	1,299.4
Nominal length	195.3	292.9	390.6	488.2	585.9	683.5	781.2	878.8	976.5	1,269.4
Mean -Nominal	-3.7	-13.8	-18.8	-15.5	-13.7	-12.7	0.2	-11.4	21.5	30.0

4. Summary

We produced HD-DVD stampers. Analysis of finished discs on a disc analyzer indicated good electrical characteristics. AFM analysis showed that the track pitch and track pitch variation were well within the specification. Measurements of the size and shape of several hundred bumps showed a clear pattern where both height and width varied with T group. Cross-section profiles of typical (middle-valued) T2 and T3 bumps showed a rounded shape and even a T6 bump showed significant rounding. This stands in contrast to DVD bumps, which normally have a distinct trapezoidal shape with a flat top. We conclude that the master would be classified as severely underdeveloped if it were a DVD. We report additional indicators of mastering quality derived from length classification and "AFM jitter" calculation. The full paper will report our further experiments optimizing photoresist thickness, write strategy and other parameters.

[1] DVD Specification for High Density Read-Only Disc (HD DVD-ROM)
[2] Advanced Surface Microscopy, Inc. www.asmicro.com
[3] Donald A. Chernoff and David L. Burkhead , "AFM Length Analysis of Data Marks: Measuring Jitter, Asymmetry, Process Noise and Process Position", in Optical Data Storage 2001, Terril Hurst, Seiji Kobayashi, eds, Proc. SPIE 4342, 515-523 (2002).