

High Density Photoresist Mastering

The last weeks have seen the announcements of two proposals for a high density, 5" optical disc format. The aim of both is to deliver an entire movie on a single disc with picture quality better than any current domestic video carrier, and to deliver it at a unit cost as close to that of current CDs as possible.

Sony / Philips have proposed a disc which will contain 3.7 GigaBytes of data in a single layer, and twice that much in a dual layer disc still under development by 3M. Time Warner / Toshiba have proposed a disc which will contain 5.0 GigaBytes on each side. Broadly speaking, all the companies who have been working on high density discs for the last few years have aligned themselves with one or other of these groups. Of the two proposals, the Time Warner / Toshiba is the more highly specified.

The ability to get 5.5 times as much data as a standard CD in the case of the Philips / Sony, and 7.5 times as much in the case of the Time Warner / Toshiba proposal is a combination of two factors:

1. Increased pit density - the physical number of pits on the disc
2. Improved modulation system - the coding process which converts raw digital data into the pattern of pits and lands on the disc.

From the point of view of a company manufacturing CD mastering equipment, the first of these factors is the significant one. Who has the ability to cut standard CD masters with pits of the right shape for successful cost effective manufacture has been the point of issue within the specialist group of mastering equipment companies for almost two years. Since mid 1994 however pressure has been put on mastering equipment suppliers to develop a system that can be installed in a production environment and turn out much higher density masters with the same reliability as for the current standard.

Time Warner / Toshiba chose Nimbus mastering equipment as the basis of a production system for their four times standard physical density format. The first such system is now installed at WEA Manufacturing, Olyphant, PA.

In the development of a new specification for optical disc, it is essential to have the ability to adjust individual parameters to find the optimum compromises of pit size, depth, shape and spacing. The Nimbus Mastering System offers independent control over all the parameters of pit geometry. Nimbus equipment also offers the reliability which comes from ten years of use in production environments, ensuring that, once the precise specification has been achieved, the process can be repeated in a production environment.

Back To Basics - Pit Geometry

The shape of the pits on a CD has a profound effect on reliability of both manufacture and play-back.

For easy replication, an ideal CD stamper would have no sharp cornered pits, and the pit edge slope would be as shallow as possible. This makes the injection moulding process easier. The closer the pit sides are to being vertical, the more likely they are to be damaged when removing the replica from the stamper.

However, for best playability there are different requirements. The pit should have a flat bottom, steep edges and a depth of one quarter the effective wavelength of the play-back laser. This shape produces a sharp contrast between pits and lands, and the depth results in the beam reflected from the bottom of the pit reaching the sensor 180° out of phase with that reflected from the land, producing the strongest HF signal.

The HF signal is the output of the photo diode sensor in the CD play-back head. The amount of light reflected differs depending on whether the laser is shining on a pit or a land, and the time between changes in this amount varies according to their length. The photo diode converts this reflected light into a voltage, which can be described as a wave. (Figure 1)

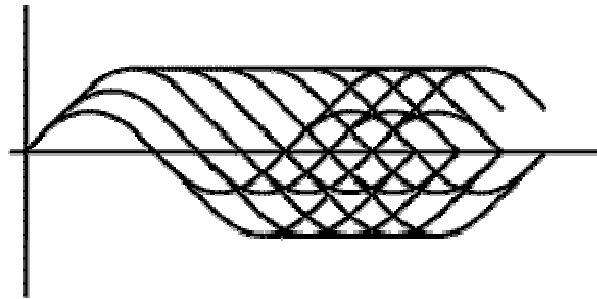


Figure 1 - An HF signal

The significant area of this wave is the diamond pattern immediately above and below the centre line. A good HF signal will produce a well defined, symmetrical central pattern, which will enable the encoded data to be decoded accurately.

There is a conflict between the requirements of play-back and manufacture. For best play-back, the pit walls should be steep, for easiest replication they should not. In order to produce the best compromise, it is necessary to have independent control over the pit geometry parameters - depth, width and angle of edge slope. This control has always been the basis of the Nimbus photo-resist Mastering System.

Pit Depth Control

The Nimbus Mastering System uses a glass disc coated with a precise thickness of photo-resist.

The Nimbus Spin Coater can coat a glass with a layer of photo resist both very accurately and very consistently. The Spin Coater deposits a puddle of photo resist on the glass while spinning it at low speed. It then accelerates the glass to a much higher speed, forcing the excess liquid off the glass. The thickness of the coating can be controlled either by the dilution of the photo resist or by the speed at which the glass spins. The simpler way of the two is to keep a constant dilution of photo resist and to vary the speed of glass rotation. The graph in Figure 2 shows the relationship between coating thickness and rotation speed. As the speed of final rotation can be adjusted in increments of one r.p.m, the eventual thickness of coating can be controlled very accurately.

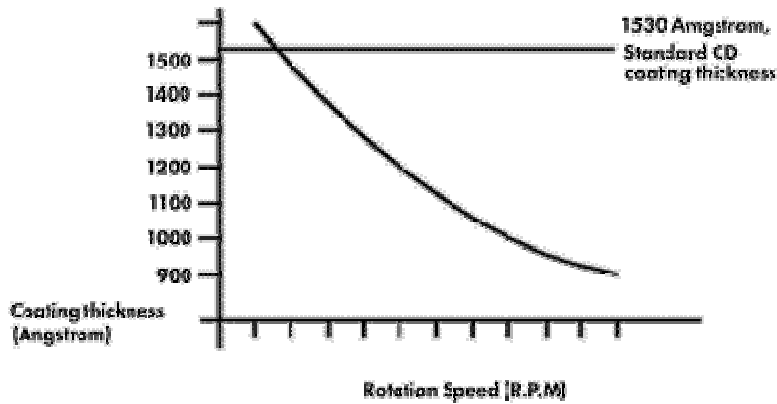


Figure 2

Coatings made on this equipment typically show a variation of less than half a percent over the cutting area, and less than half a percent between consecutive glasses. For a standard CD coating, half a percent is about eight Ångstrom units, or 0.0008 μm .

When the master is cut using the Nimbus Laser Beam Recorder (LBR), the laser exposes right through the photo-resist layer to the glass, therefore the degree of control over the coating thickness directly relates to control over the eventual pit depth.

Pit Shape Control

In order to achieve the best compromise between the requirements of play-back and replication it is essential to be able to control the slope of the sides of the pits.

If the slope is too steep (ie. too close to vertical), the pits on the replica may be damaged when separating from the stamper, causing a scraping on the side of the pits, called "plowing", which can result in a phenomenon on the finished disc referred to as "clouding", "stains" or "flowlines". This effect is highly visible and, while it has little effect on playability, it is still unacceptable on the finished disc.

If the slope is too shallow, the point of change between pits and lands will be less easily distinguished, giving a confusing HF signal which is difficult to decode and can cause play-back problems.

There are two parameters which affect the pit shape - cutting intensity and developing. These two factors can be adjusted to change the width and edge slope of the pits.

Cutting

The spot size of a given laser is unaffected by the power of the laser beam. It is defined by the wavelength of the laser itself and the optics used to focus that laser. Within that spot size, the intensity of the beam is greater at the centre than it is at the edge (Figure 3). At the centre of the spot the photoresist is therefore more highly exposed than it is at the edge, and the level of exposure can be controlled by adjusting the power of the laser beam. The power of the recording beam on the standard Nimbus LBR can be smoothly varied from 0 to 30 mW. A typical peak power for a standard CD cut would be 5 mW.

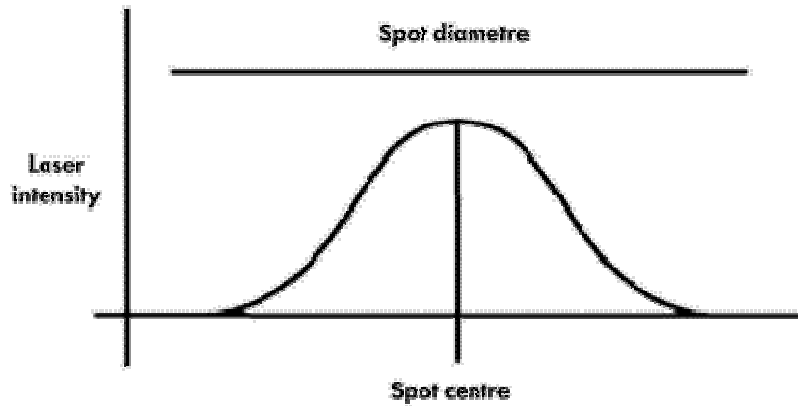


Figure 3

Developing

Once the master has been exposed, the photoresist layer is developed in the same way as a photographic negative. The developing solution is spun evenly across the surface of the disc and eats through the areas of photoresist exposed to the laser. A typical developing time for a glass master is ten seconds depending upon the strength of the developing solution.

The rate at which the developer attacks the photoresist increases with the intensity of exposure, and is therefore greatest at the centre of the spot. The pit develops first as an increasingly deep depression until the surface of the glass is reached. After that time, the edges of the pit recede and become steeper. Thus it is possible to use the combination of laser intensity and developing time to control the width of the pit and the angle of the edge slope (Figures 4 and 5).



Figure 4 - With increased cutting laser power the pits become wider while maintaining a constant edge slope



Figure 5 - With increased developing time the pits become wider with steeper edge slope

For a constant concentration of developer and a constant average pit width, increasing the intensity of the laser and reducing developing time will produce a shallower edge slope, while decreasing the intensity and increasing the developing time will produce a steeper edge slope (Figure 6). By balancing the exposure intensity with the developing time it is possible to optimise pit shape and width for injection moulding.

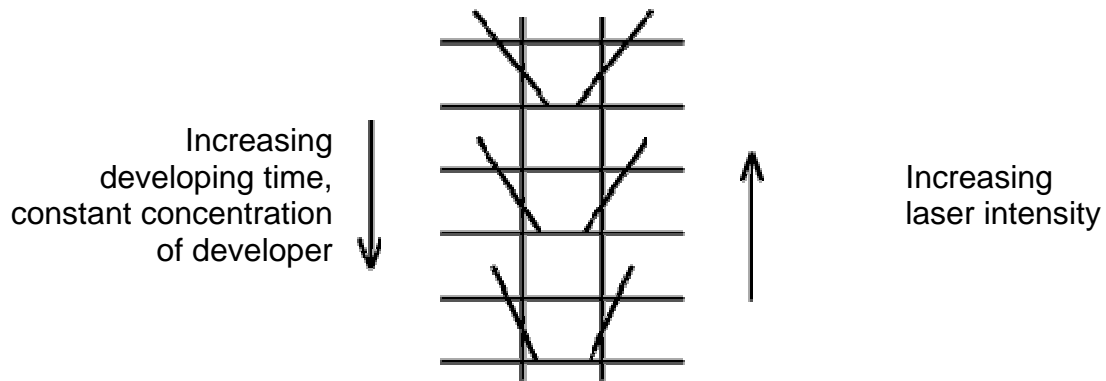


Figure 6 - Constant average pit width

As the photoresist chemicals are very consistent in the way they react in developing, it is possible both to have a very high level of control over this important part of the process and for the results to be repeatable.

Asymmetry Control

Asymmetry is a measurement calculated from the HF signal output from a disc. It describes the variation in length between pits and lands. On a standard CD, the pits and lands vary in nominal length from three units to eleven units long. On the diagram representing the HF signal (Figure 1), the area above the centre line represents the lands and the area below represents the pits. If pits and lands of the same nominal length, ie. a 3 unit pit and a 3 unit land, are not of the same effective length, the central diamond pattern will be either above or below the centre line. This makes the pattern asymmetrical and more difficult to decode.

The length of the pits can be controlled in two ways, through the modulation of the laser beam and through the developing of the pits. On the Nimbus LBR, the timing of the transition between pit and land can be adjusted in increments of 0.05 μs . A typical duration for which the laser beam is on to cut a 3 unit pit is 0.7 μs . By adjusting the timing of the modulation and the developing time of the master it is possible to control the length of the pits and therefore produce masters with optimum asymmetry readings.

High Density Mastering

All of the above factors are relevant to the current 1x physical density CD standard. They will be even more so with the advent of high-density CDs. A system which is at the edge of its tolerances when cutting standard CDs may not be able to be modified to cope with higher densities.

The original development of the Nimbus Mastering System took into account the probability of a higher density format in the future. The unique design of the LBR makes it mechanically capable of mastering up to fifty times standard CD density, and the photo resist system has a reserve of performance higher even than that. Its design makes the upgrade from standard to high density capability relatively simple. The only significant modification required to convert a standard Nimbus LBR is the replacement of the blue cutting laser with an ultra violet laser and its associated optics and focussing controls. The modified system is versatile enough to be able to cut standard CDs as well as all of the proposed new formats.

Summary

There is more to high density mastering than getting enough pits onto the CD - the pits have to be the right shape, depth, length and distance apart, and without a full understanding of the CD system, it is not possible to produce equipment that will achieve this reliably in a production environment (Figure 7). A combination of expertise, experience and profound understanding of optical disc technology has made Nimbus Technology & Engineering the company chosen by Time Warner / Toshiba to supply the equipment used to make the most highly specified standard for optical disc that has ever been proposed a production reality.

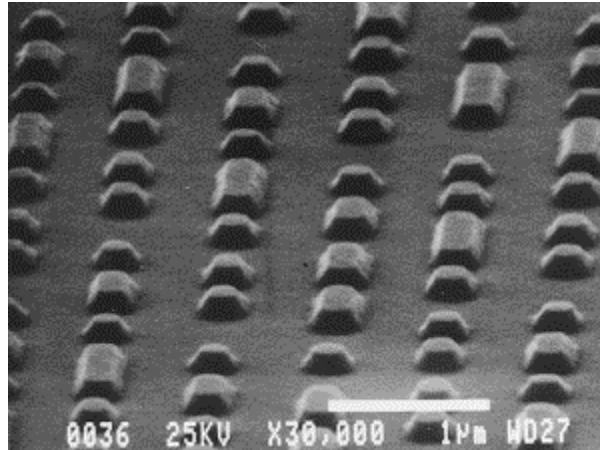


Figure 7 - An S.E.M (scanning electron microscope) image of a 4 times density stamper, track pitch $0.725 \mu\text{m}$, cut using the Nimbus Mastering System with the Ultra Violet laser upgrade, magnified 30,000 times. The pit shape has been chosen to give the best compromise between ease of replication and playback.