Manufacturing Technology of the Compact Disc

SENRI MIYAOKA

Disc Development Division, Sony Corporation, Tokyo, Japan

0 INTRODUCTION

The Compact Disc (CD) and the optical video disk have basically the same cross-sectional structure of the pit and the same track pitch. However, there are three considerable differences between the two. First, the diameter of the CD is 120 mm, approximately one-third the diameter of the optical video disk. Second, the music signal is directly recorded on the CD in digital form without analog modulation. Third, the signal is picked up by a near-infrared beam from a semiconductor laser diode. These differences suggest that, for the most part, CD manufacturing will be less complex than optical video disk manufacturing, but we can expect some difficulties. So far we have only video disk production experience to go on.

We have recently completed the installation of our production line and have just entered the preproduction phase, so you will see that there are some aspects of production with which we have little experience. Also, because some of this material is still proprietary, we will not be able to go into all the details.

First, we describe the structure of the disk, and then review the production process, from master-tape editing to final disk finishing. Finally, some signal characteristics will be pointed out, which should be carefully monitored.

1 COMPACT DISC STRUCTURE

Fig. 1 shows the cross section of the CD. It is similar to that of an optical video disk. The signal is picked up from a semiconductor laser diode using a laser beam, penetrating a transparent plastic material, 1.2 mm thick. The 1.2-mm thickness prevents signal disturbance by dust or defects on the incident surface of the disk, just as in the video disk. But, as noted, the diameter is only 120 mm, approximately one-third the 300-mm diameter of the video disk. This means that the CD is comparatively rigid because of its thickness-to-diameter ratio. The disk rotates at a speed of between 200 and 600 r/min at a 1.25-m/s linear velocity. The acceptable range of vertical deflection, that is, the acceptable variation in flatness of the CD, is greater than that of a video disk, but the CD is played with a semiconductor laser diode of 780-nm wavelength, compared with the 633-nm wavelength of the helium–neon gas laser used for the video disk. Therefore the numerical aperture of the pickup optics must be increased from 0.40 to 0.45 in order to obtain the same small 1.5-μm focused spot for readout. Because a large numerical aperture corresponds to a smaller focus depth, and because a variation of the normal to the disk surface causes deterioration of the readout spot due to the coma aberration effect, the maximum angular deviation is specified.

Fig. 2 shows the main specifications for mechanical accuracy. Maximum angular deviation is specified as ±0.6 degree. When a spherical or umbrella-shaped deformation occurs, the 0.6 degree corresponds to a 0.32-mm vertical deflection. Because this tight 0.6-degree value is applied only to the signal surface formed by a precise mechanical mold, not by a galvanic nickel

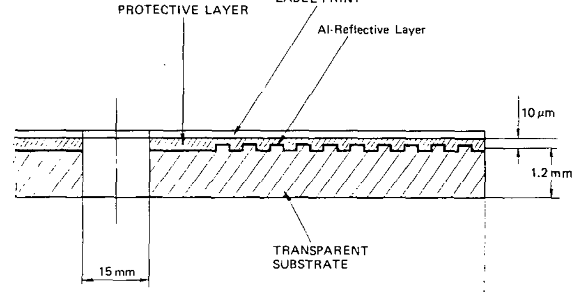

Fig. 1. Cross section of CD.

stamper, it is not difficult to realize this accuracy. The CD maximum angular deviation is not as tight as that of the video disk. The two halves of an optical video disk made of PMMA material are bonded to each other in order to prevent the umbrella-shaped deformation caused by vapor absorbed through the incident surface. The CD is designed to play more than 74 minutes of music per side, so from a software point of view a double-sided disk is not needed. We tried to make a one-piece disk of PMMA material, but we found that during the climate test, vapor absorption warped the disk. After much testing we decided to use a polycarbonate material.

The single-piece polycarbonate disk passes the climate test because the vapor absorption of this material is about 70% less than that of PMMA, and it has sufficient strength. Unfortunately we found that polycarbonate had difficulty meeting the birefringence specification, a maximum of 100 nm. This value of 100 nm is greater than the 35 nm of the video disk birefringence, because a lower carrier-to-noise ratio is acceptable with digital signal processing.

To produce a disk with low birefringence, we found that compression molding was most appropriate, but injection compression could be used. It was most difficult to produce a low-birefringence disk by injection molding. In terms of productivity, injection molding is best, followed by injection compression and, finally, compression molding. In compression molding and injection-compression molding there are difficulties such as small air bubbles inside the disk. A separate molding machine to form the center hole and a long molding index time were required. Because injection molding is the highest yield, we concentrated our efforts on injection molding and a polycarbonate material.

As the innermost and outermost areas of the disk are critical, we tried many kinds of mold shapes and molding conditions until we succeeded in manufacturing a single-piece polycarbonate disk. Fig. 3 shows the typical birefringence characteristic of our sample disk. Fig. 4 is an example of the relationship between the skew angle and the vertical deflection of the disk.

After injection molding, the signal surface is covered with a layer of aluminum to provide reflectivity. Although the thickness is not specified, the reflection coefficient of this aluminum layer, including the double-pass substrate transmission, is specified to be between 70 and 90%. To obtain this reflectivity, a thickness of 20 or 30 nm is sufficient. However, a thickness of 50 nm or more was chosen to prevent long-term deterioration of the aluminum layer from the deposition side. The aluminum is covered with a photopolymerized layer which is 20–30 μm thick and protects the aluminum from the label-printing process, moisture, and other harmful effects. The label is printed directly on this protective layer.

Materials for these two layers were carefully selected to eliminate stress between the layers and the disk substrate, which could cause disk deformation. The main dimensions of the incident side of the disk are shown in Fig. 5. The maximum eccentricity of the track radius

	Compact Disc	Video Disk
1. Maximum deflection		
ΔX	±0.4 mm	+0.23 (1.5), −0.39 (−2.5) mm
θ_1	0.78°	
2. Maximum angular deviation of signal surface θ_1	±0.6°	Not specified
3. Maximum angular deviation θ_2 (incident surface nonparallel)	±1.6°	Not specified

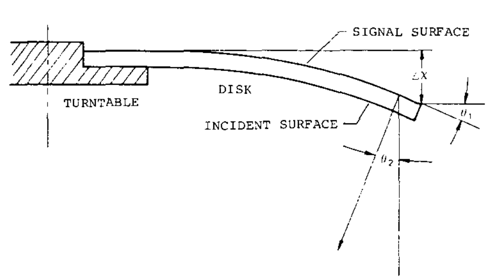

Fig. 2. Mechanical accuracy of CD.

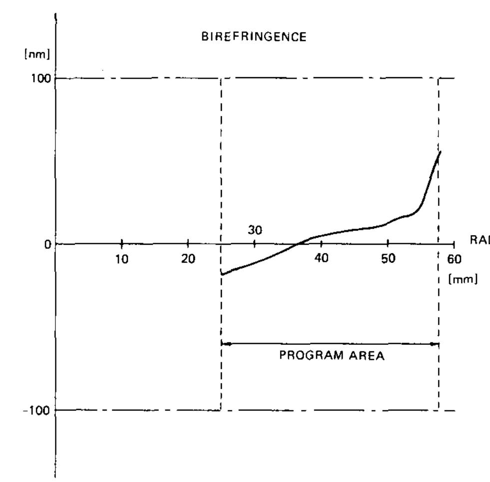

Fig. 3. Typical birefringence characteristic.

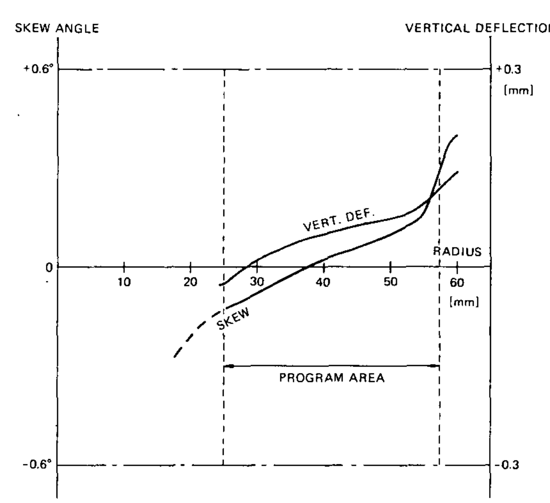

Fig. 4. Typical vertical deflection and skew angle.

relative to the center hole is ±70 μm. The diameter of the center hole is 15 ± 0.1 mm. We have found during manufacturing that this tolerance range is not difficult to work with.

2 BRIEF REVIEW OF DISK MANUFACTURING

Next, we will review briefly the CD manufacturing process which consists of three parts: premastering, mastering, and duplication. As shown in Fig. 6, premastering is the stage up to the preparation of the digital master tape used in the cutting process. Mastering is the process of preparing the glass master from which a nickel stamper is made. Duplication, using the nickel stamper, is the process from molding to final packaging.

2.1 Premastering

As shown in Fig. 7, we start mastertape editing using the DAE-1100, the PCM-1610, and the BVU-200B. When we use analog sources, we must convert the signal to a digital format using the PCM-1610 and BVU-200B before editing. All systems are controlled by a SMPTE time-code signal from the DAE-1100. Therefore, we can make the music script with the SMPTE time-code signal. We decided to provide a user's bits area in the CD system, which has eight channel bits. Only two channel bits are in the user's area called the P.Q. channel. The P.Q. channel is very useful, because in it are the table of contents, music number, and absolute-address time code, which make random access and disk identification possible. To make this P.Q. channel signal, we must use a cue editor after editing from the cue editor keyboard to assign, for example, the music number, the beginning of the music, and the end of music.

We decided to enter this signal with the cue editor in an audio channel at the beginning of the U-matic master tape. The P.Q. channel signal and the digital audio signals are modulated into the CD format during disk cutting.

2.2 Polishing and Mastering Process

In mastering we start with lapping and polishing, as shown in Fig. 8. To prevent contamination of the recording area by dust or other particles which tend to stick to the center-hole edge, we use a glass master having no center hole. The glass master dimensions are 220 +0, −0.1 mm diameter and 6 mm thick. Before polishing, the glass plate is washed first in an alkali

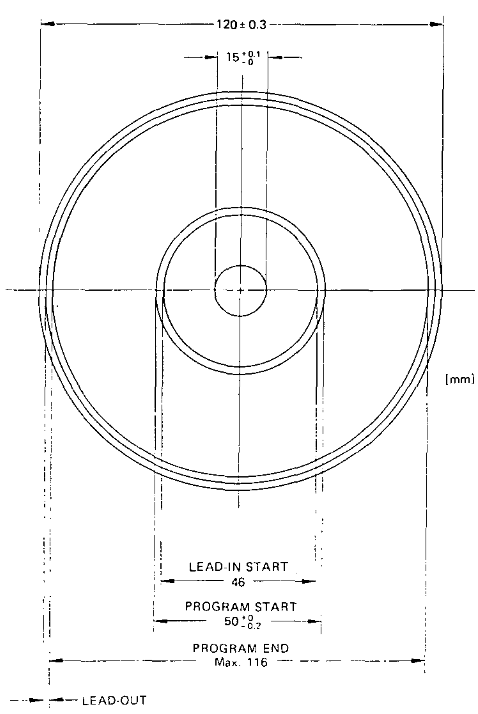

Fig. 5. Dimensions of program area.

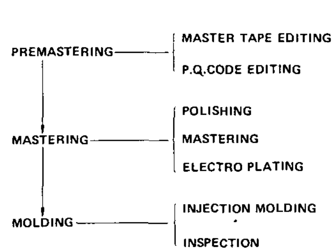

Fig. 6. Manufacturing process of CD.

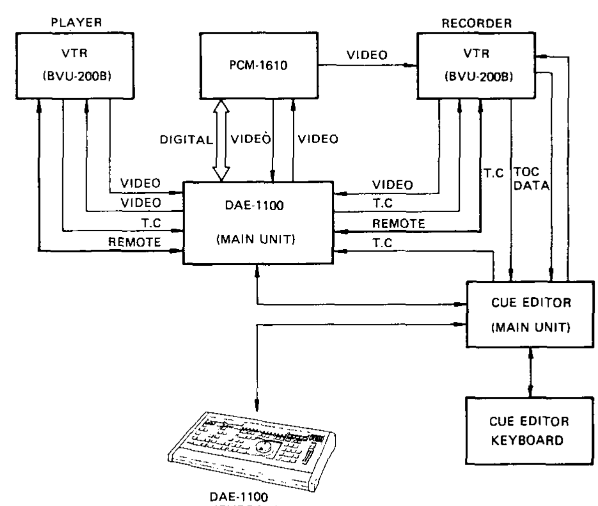

Fig. 7. P.Q. code editing system.

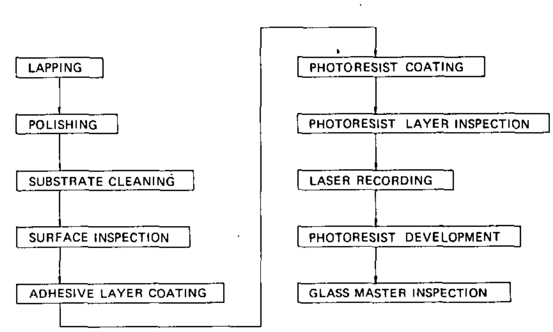

Fig. 8. Polishing and mastering.

solution, then in a Freon solution, and later dried by Freon. As conventional float glass is used, only a final mirror polishing with a CeO_2 optical polisher is necessary.

In the next step, the substrate cleaning process, the plate is washed with deionized water and isopropyl alcohol in an ultrasonic washing station and dried after being dipped in a Freon solution. During surface inspection, the surface cleanliness is measured with a drop-out counter which counts the number of dropouts in the intensity of a focused helium–neon laser spot reflected from the measured surface. Any deviation of more than 10% from the average reflected intensity is counted as a dropout. At a disk rotation speed of 900 r/min ten dropouts per second is our specified limit; but even if there is only one spike dropout of under 50% in reflected intensity, or a burst dropout of less than 90% intensity over a 20-μm length, the disk is rejected and repolished. Following surface inspection, an adhesive layer is applied to obtain enough adhesion between the glass surface and the photoresist layer. The positive photoresist layer is applied by a spinning coater. The thickness of this layer is kept within 105–115 nm over the recording area of the disk. Laser recording is done with our custom-made cutting machine. The recording quality is determined mostly by characteristics of the cutting machine: accuracy of groove pitch, stability of turntable rotation, precision of the optical stylus, and automatic system control, which eliminates careless mishandling of the machine by an operator. Fig. 9 is a schematic sketch of the cutting machine. The turntable is driven directly by a brushless motor with its center shaft supported by an air bearing. The optical stylus block is supported and moved by an air-float linear slider. The base of the machine is cushioned by an air damper to minimize vibration noise from the floor. Fig. 10, which gives the pit pattern of a recorded surface, shows the accuracy of this machine. Fig. 11 is the system block diagram of the cutting machine. The entire operation is controlled through the main central processing unit (CPU) and its memory, so an operator can do all the cutting work simply by keying in an operation statement from the CPU keyboard and by setting the glass master plate on the turntable and then removing it. The recording optics is shown in Fig. 12. Only low laser cutting power is needed, and the constant linear velocity is about one-tenth lower than that of the video disk. A helium–cadmium laser, which can generate 15 mW of output power at 441.6 nm wavelength and which is modulated by an acousto-optic (AO) modulator, is used for recording exposure. A helium–neon laser, which does not affect the photoresist, is used as a focus-error detector in the focus servo-control system. The numerical aperture (N.A.) of the objective lens is 0.9. By restricting the aperture of the objective lens, a lower numerical aperture can be obtained in order to achieve the desired pit shape and size.

After recording, the exposed glass master is developed by an automatic developing machine in which developer is sprayed on the photoresist layer. During developing, a helium–neon laser beam simultaneously monitors, through diffraction, the engraving depth of the photoresist layer. When the beam detects the proper engraving depth, development stops automatically. After drying, the developed surface is inspected with a microscope to check the pit pattern.

2.3 Electroplating process

Fig. 13 shows a flow diagram of the electroplating process. Silvering is done by sputtering silver on the inspected glass master. The process from master (father) electroplating to stamper (son) forming is similar to the electroplating process of an ordinary analog LP disk. Of course, the various aspects of nickel plating, such as composition of plating solution, plating bath, temperature control, solution flow, plating current distribution, and so on, are specially designed and tuned to obtain a fine surface and accurate thickness of the nickel plate. These adjustments are completely different from those needed for an analog disk. The nickel master plate and the nickel stamper plate are inspected by measuring the replicated test disk from each plate by means of photopolymerization. The photopolymerized test disk is also used as a reference in comparing the characteristics of the final molded disks. After peeling off the nickel master plate, the glass master plate is polished again, then recycled. If there is a need to

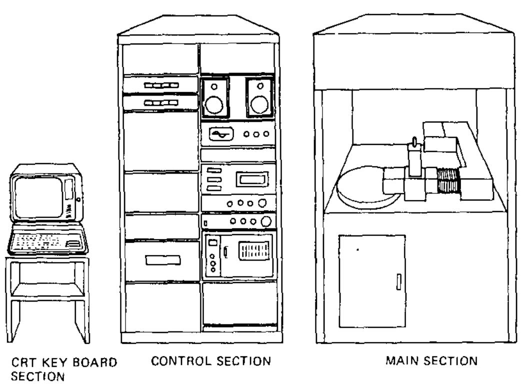

Fig. 9. Schematic sketch of cutting machine.

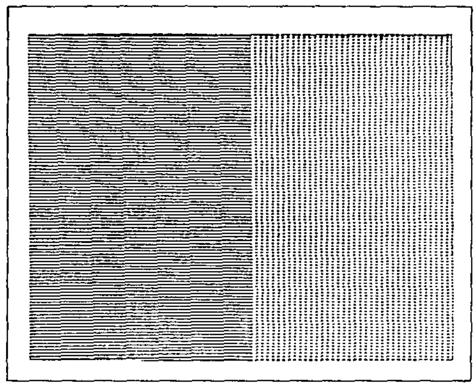

Fig. 10. Accuracy of cutting machine: groove pitch and rotation speed.

exchange master plates between companies for custom pressing in the future, we will exchange the nickel mother or stamper plate, not the glass master.

2.4 Stamping and Disk Inspection Process

A diagram of the stamping and disk inspection process is shown in Fig. 14. After cleaning the stamper, it is set in the mold of the injection molding machine. As mentioned earlier, polycarbonate raw material is used because it has a low vapor absorption coefficient (0.13%). This material was specially developed to have a higher flow rate in order to obtain lower residual stress or lower birefringence after molding. Thus the temperature of the material when injected and the mold temperature must be higher than that needed for PMMA. Injection molding of polycarbonate material allows a short cycle time of only 20 seconds. After injection, and while the disk is still in the mold, the center hole is punched out, so the final shape of the disk is obtained without trimming after the disk is removed from the mold. After molding, a layer of aluminum approximately 100 nm thick is evaporated onto the signal surface. Sputtering can be used instead of evaporation as its yield is good, but special care should be taken to prevent weak adhesion caused by gas formed from the bombarded substrate. A spin-coating machine applies a protective film on the aluminum layer. The transparent film is an ultraviolet-cured acrylic resin, about 10 μm thick. The disk is inspected by visual observation for aluminum pin holes and black spots.

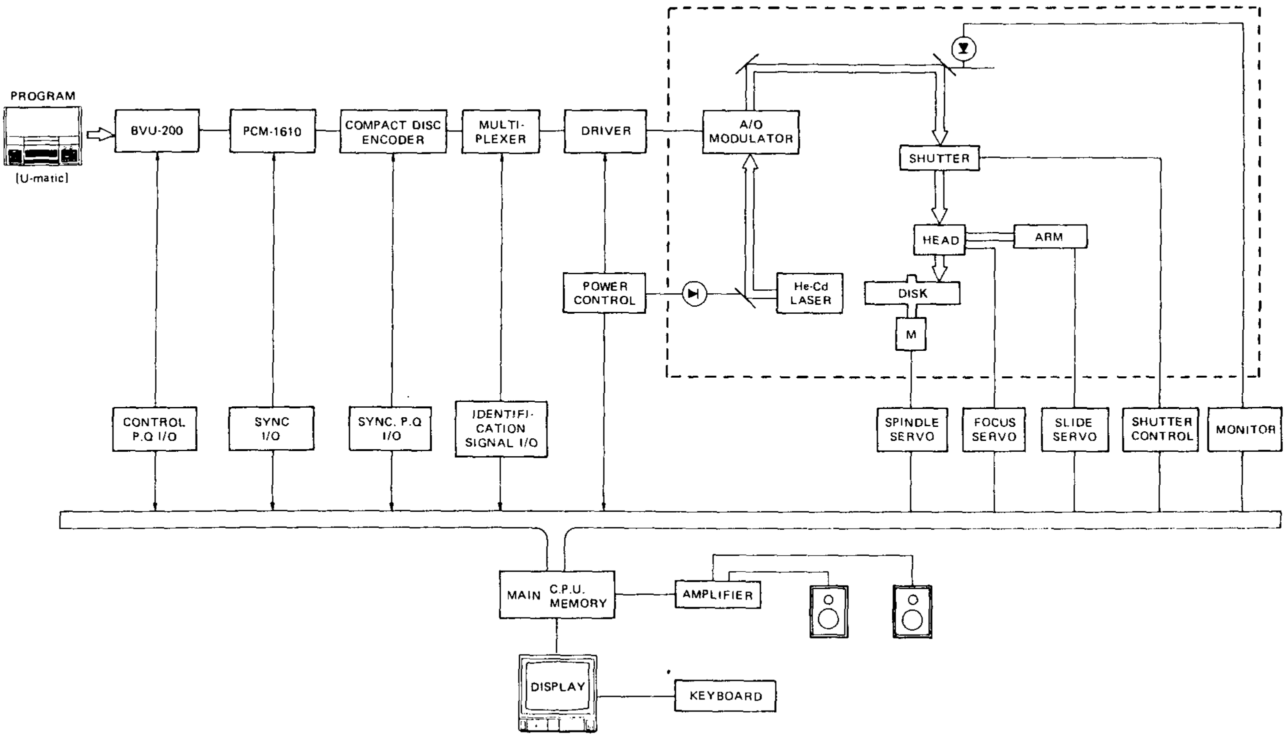

Fig. 11. Block diagram of cutting machine.

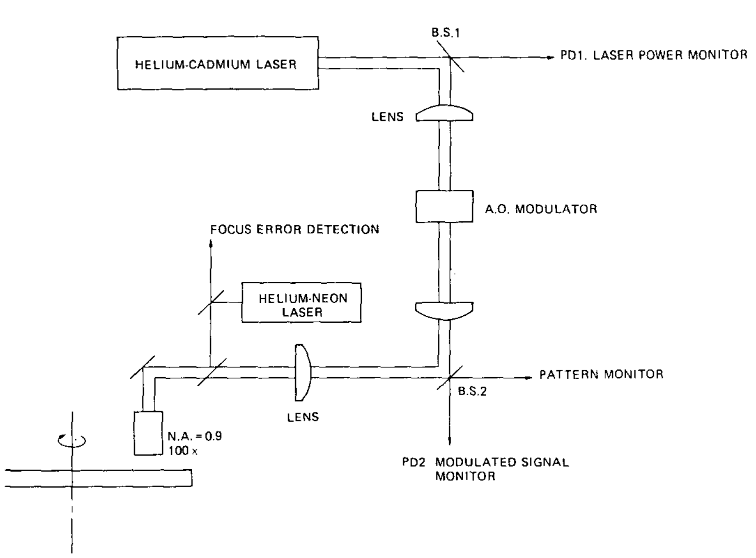

Fig. 12. Recording optics.

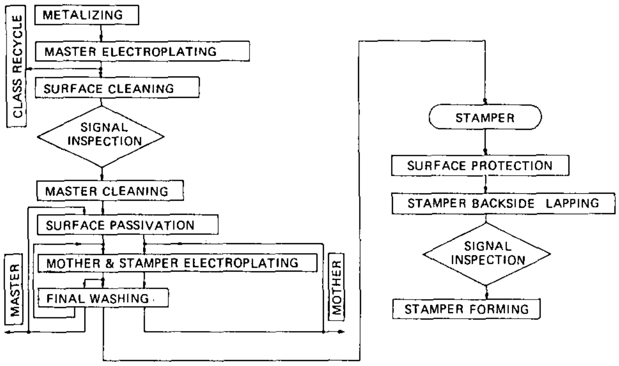

Fig. 13. Electroplating process.

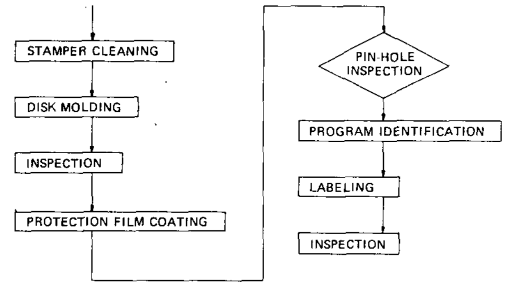

Fig. 14. Molding and disk inspection.

The label is directly printed on this protective layer by screen printing.

2.5 Final Inspection

For perfect reproduction of the music signal, the CD digital audio system incorporates error correction and error concealment in the design. It is therefore important to have close tolerances during final product inspection. However, we have not yet decided what characteristics should be inspected 100% nor what sampling rate would be reasonable for quality control.

We are now investigating appropriate inspection systems in this early stage of production. The quality of the basic signal characteristics—high-frequency signal modulation amplitude, symmetry of the eye diagram, track-following signal, and so on—is mostly determined by the recorded master plate. It is important, especially for the track-following signal (not a matter for concern with the video disk), that very strict quality control be observed during the mastering process. As far as the digital signal is concerned, the block error rate, the table of contents in the lead-in area, and the P.Q. code are the three main points in final disk inspection. Quality control of birefringence characteristics in the molding process is also very important.

This year marks the beginning of mass-production technology for the CD. Step-by-step improvements will come about as we learn to improve its quality and reliability. At the same time, we will make every effort to maintain volume production at the lowest possible cost.

THE AUTHOR

Senri Miyaoka was born in Buenos Aires, Argentina, in 1937. He studied physics at the Gakushuin University, Tokyo, Japan, earning a B.Sc. degree in 1959. He received a Ph.D. degree in engineering from the Tokyo Institute of Technology in 1975.

In 1959 Dr. Miyaoka joined Sony Corporation and developed high-frequency power silicon transistors for television sets. In 1962, he moved to the color picture development group where he researched various types of color picture tubes and electron guns. He is the co-inventor of the Trinitron system.

In 1975, Dr. Miyaoka established a development group to develop an optical video disk. While serving as general manager of the Disc Development Division, Sony Corporation (1979–1982), his group jointly developed the new Compact Disc digital audio system with Philips. In 1983 January he became director of Audio/Video Technology Center.

Dr. Miyaoka has published several papers in the field of color television and has many patents in Japan and other countries. He has received many awards including the Purple Ribbon Prize of Japan and the Vladimir K. Zworykin Award of the IEEE. He is a member of the IEEE and the Institute of Television Engineers of Japan.