Practical Solutions for Gold Sputtering of Recordable Compact Discs

A. LeBlanc and D. Parent, First Light Technology, Inc., Saco, ME

Keywords: Gold films; Sputter deposition; CD coatings; CD-R Coatings

ABSTRACT

The emergence of specialty CD markets and the rapid growth of CD-Recordable applications have increased the need for gold sputtering in Compact Disc formats. Traditionally relegated to just a few manufacturers who specialized in these processes, gold sputtering is now becoming a common requirement for manufacturers intent on developing their technology base in parallel with emerging disc formats. This paper investigates process and practical issues of Au sputtering for CD-R applications. Practical solutions to achieve production capable processes are presented.

INTRODUCTION

Few things have the universal appeal as pure gold. It represents the foundation of currencies and rings of marriage. In the compact disc business, gold films bring a higher reflectivity that allows compatibility in a recordable CD format. First brought forth as a technology by Taiyo Yuden of Japan, the product was developed by Eastman Kodak as the foundation of its digital imaging future: Photo CD. This succeeded in bringing CD-R to a mass volume consumer market, which provided a solid application to ensure its future. Once promoted by Kodak, the obvious applications as recordable and compatible CD-ROM ensure that this technology is only at the threshold of its future growth as an optical disc format.

As CD-R demand grows and traditional disc product margins erode, disc manufacturers have an opportunity to enter an emerging market with careful consideration given to the process and practical issues involved in the production of CD media.

Although process and practical manufacturing issues are highly inter-related, we have tried to categorize specific issues or techniques into these two categories for clarity.

CD RECORDABLE FORMAT

CD-R discs differ from CD-Audio and CD-ROM formats through the addition of a organic dye polymer layer shown in Figure 1 which is located between the polycarbonate substrate and the reflective film. Gold replaces aluminum as the sputtered layer due to its higher reflectivity. This compensates for the absorption properties of the dye polymer at the read laser wavelength of a standard CD player. In this way, a CD-R disc is read by a standard player with the same readback signal amplitude as an aluminum coated CD or CD-ROM. This backward compatibility of CD-R with any CD drive is perhaps the format's greatest strength.

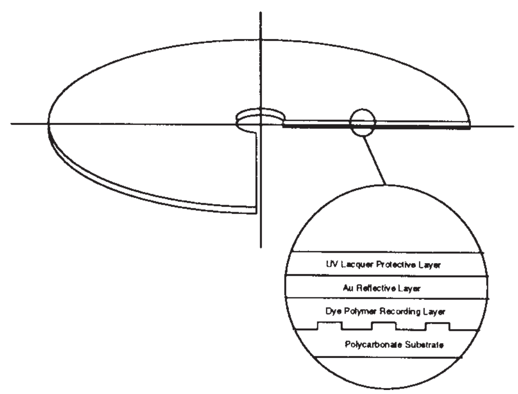

Figure 1, CD-R Format

MANUFACTURING CD-R

From a production standpoint, CD-R processing is similar to standard processing as shown in Figure 2. The unrecorded substrate is molded using a grooved stamper which forms the sidewalls of the recorded pits. Once molded, the disc is thermally stabilized and spincoated with the dye polymer recording layer. The coated disc is then sputtered with gold vs. aluminum and then finished with the same manufacturing steps as a standard CD. The sputtering process of gold (Au) onto a dye coated substrate is the focus of this investigation of process and practical issues for CD-R manufacturing.

38th Annual Technical Conference Proceedings (1995) ISSN 0737-5921

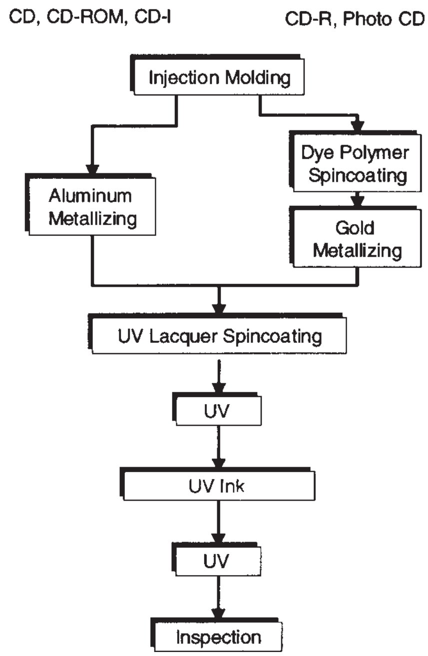

Figure 2, Comparative CD and CD-R Processes

The dye polymer material on the surface of the disc complicates the sputtering process. The dye polymer material is thermally sensitive and interactive in vacuum. It can be easily damaged by energy from the plasma and deposition of Au atoms. The Au is also extremely expensive and must be recycled and reprocessed. In addition, Au sputtering generates more heat than equivalent aluminum processes. These are some of the issues discussed in the following sections regarding process and practical issues involved in the sputtering of CD-R discs.

PROCESS ISSUES OF AU SPUTTERING

Sputtering Process Control

Stable and capable manufacturing processes are necessary to produce quality product. Some processes are intrinsically stable and capable because they either don't impact the performance of the product, or they don't add significant cost. This is the case with aluminum sputtering on conventional CD's. In such a process, the primary criteria is that sufficient aluminum must be applied to the disc to assure that the Red Book 70% minimum reflectivity criteria is met. Too much aluminum means that improved reflectivity will be achieved, with the sole cost being machine process cycle time. And if metallization is not in the process critical path, there may in fact be no impact on process cycle time. Therefore, for aluminum CD sputtering, more aluminum is better. There is no upper bound on thickness.

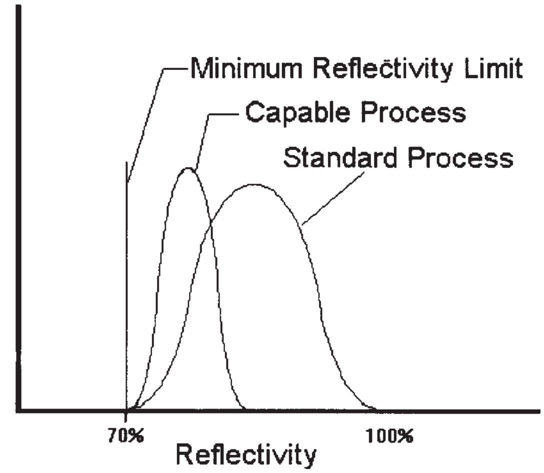

Figure 3, Required Process Capability

However such is not the case with Au sputtering. With Au sputtered CD's, the cost of Au is a major component in the material cost of the final product. The manufacturer is faced with two constraints:

- Too little gold causes the disc to not achieve the minimum reflectivity of 70%. Given that in-line inspection systems verify this minimum reflectivity value, a process which operates too close to the 70% reflectivity specification will suffer from excessive yield loss due to discs rejected by the scanner (Figure 3). Additionally, the dye layer attenuates the read laser, requiring a thicker gold layer to achieve the same overall reflectivity.
- Too much gold adds cost by adding to the material cost of the manufactured disc. Also the spectrally selective organic dye layer is subject to damage from the sputtered gold atoms. For this reason, applying a minimally thick gold layer will minimize the exposure of the dye to the sputtered gold atoms.

An ideal Au CD sputtering process would achieve an ideal balance of just enough gold to achieve the minimum reflectivity while minimizing the total amount of gold actually applied.

Conventional CD sputtering technologies sputter for a preset time period to achieve a desired metal layer thickness. However, sputtering deposition rates are not constant over the life of a target. As a rule, sputtering deposition rates (and plasma power) decline as targets approach their end of life. Therefore, without some form of intervention the sputtered layer becomes progressively thinner as the target ages.

Fortunately, there is a reliable correlation of total energy applied to the cathode plasma to the thickness of aluminum on the disc. This correlation can be used to close an implicit feedback loop around the metallization process. This is accomplished by integrating the instantaneous power applied to the plasma over time. The summation of the integration increases until a predetermined set point is reached (Figure 4). That set point is the total energy deposited to the plasma. Since the total energy deposited is then constant from disc to disc, the deposited layer thickness will also be consistent from disc to disc.

Other means are also employed to compensate for varying sputtering rates. An empirically developed compensation curve is often used to modify the sputtering time based upon the elapsed target life. This method improves upon the standard technique of sputtering for a fixed time, however it is intrinsically open loop. There is no disc to disc verification of the sputtered layer thickness.

Plasma Arc Control

Arcing during the sputtering process causes dye damage, either directly or through the inclusion of particulates in the growing film. Such arcs are singular events and don't directly impact a process' capability in a traditional sense. However, arcs do impact product quality and must be controlled.

Power supplies are now available which control and limit arcs, preventing damage to the dye layer. These devices function as normal DC power supplies during normal plasma operation. However, when an arc event is detected, action is taken to limit the energy of the arc and to prevent its recurrence once it has been quenched.

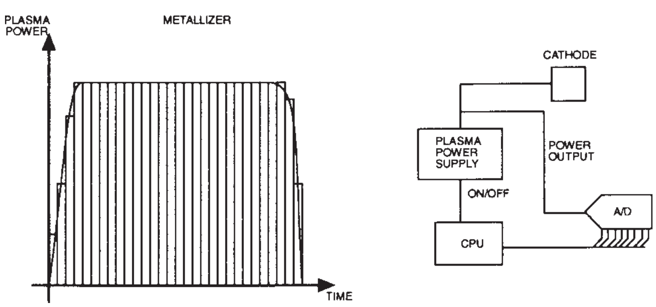

Figure 4, Plasma Power Integration for Deposition Layer Thickness Control

An arc event is detected by monitoring the current and voltage applied to the plasma. When an arc occurs, current to the cathode increases substantially, since an arc is essentially a short circuit. This current surge is supplied by the energy stored in the capacitance of the output stages of the power supply. The voltage supplied by the power supply begins to drop to zero since it cannot support the current surge in the steady state (Figures 5 and 6).

Upon detecting this current surge, the energy stored in the power supply output stage is quickly re-directed from the cathode to a passive energy absorber. This extinguishes the arc by eliminating its energy source.

Re-starting the plasma at this point risks a recurrence of arcing since the plasma region contains residual charges (electrons) which could initiate a new arc. Active reversal of the cathode voltage to a value of about one-eight of the applied plasma voltage quickly sweeps residual charge from the plasma region. The plasma can then be reestablished in a controlled manner with reduced risk of an arc recurrence.

The entire arc quench/charge clear/re-start cycle occurs within less than 15 microseconds. Its effect on process cycle time is not significant. In fact, the user will perceive little except that the sputtering process will seem well controlled and stable.

Mask Heat Removal

Gold sputtering processes run hot. That is, more heat is deposited on the disc masks than in a conventional aluminum process. Disc masks are subject to high heat fluxes which come from two main sources. The sputtered Au atoms contain higher thermal energy than the aluminum atoms from a conventional process and the plasma itself is a source of thermal radiation.

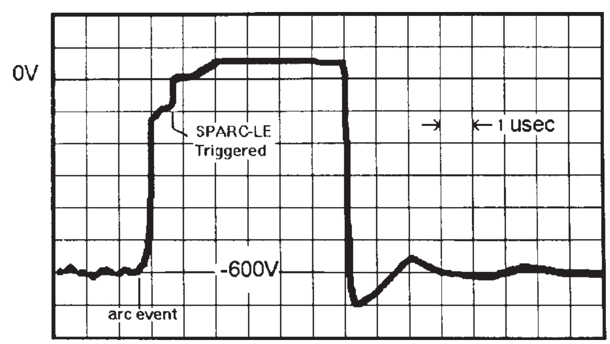

Figure 5, Voltage Waveform, Arc Triggered

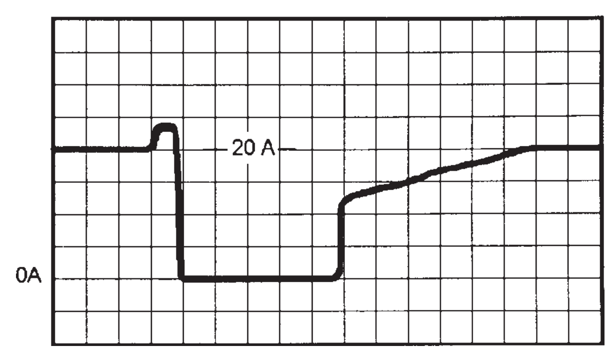

Figure 6, Current Waveform

Heat deposited on the masks from these sources must be removed at a rate such that the average power removed from the masks is equal to the average power deposited on them. If a masking system has poor thermal performance, mask temperatures will be driven to high values to force the removal of this heat. This can cause disc damage through thermal damage of the dye, and in a severe case, actual melting of the disc surface.

Proper design of disc masking systems will assure good thermal performance thereby yielding low mask temperatures.

There are numerous strategies for achieving this capability. Heat transfer in a vacuum chamber is primarily through thermal radiation and conductance through materials.

A radiation shield which intercepts the incident thermal radiation and conducts it to a cooling chamber before it goes to the mask will substantially lower mask temperatures. Such a shield would be proximate to the disc mask, yet not in direct contact, thereby preventing direct conduction. Re-radiation of the shield to the mask does occur, but the shield temperature is considerably lower than plasma temperature. Since thermal radiosity is proportional to T^4, the radiation heat flux to the mask is considerably lower. Also, the use of low emissivity shield materials, such as stainless steel, further reduce heat flux incident to the masks from the shields.

The mask itself must have low thermal impedance to the cooling chamber. In this way, any heat which does get to the mask will be conducted away with little increase in mask temperature. Excessive thermal impedance of the mask to the cooling chamber causes the mask to attain higher temperatures to eliminate the incident heat flux.

Self-Centering Masking

Contact of disc masks to the organic dye layer cannot be tolerated in a CD-R process. Long format (74 minute) CD-R discs require excellent control of OD mask concentricity to the disc axis since the outer diameter of the gold layer is very near the outer diameter of the disc itself.

Self-centering masking systems assure proper alignment of the OD and ID masks to the disc axis.

This is accomplished by registering the OD and ID masks and the disc to a registration platter. This platter contains machined-in concentric features which locate features on the masks and an arbor which locates the disc (Figure 8).

The OD and ID masks are dynamically aligned with each metallization cycle. The first cycle causes the masks to shift position and align to the disc. The masks then remain in that position until they are removed. Mask concentricity of ± 0.1mm are routinely achieved with such a system. An additional benefit is that mask change or clean times are significantly lowered since no alignments are necessary.

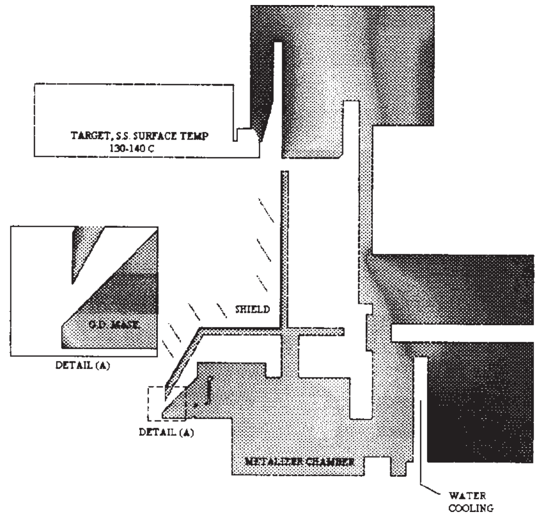

Figure 7, Finite Element Model of Sputtering Chamber

High Argon Pressures

The organic dye layer is subject to damage by the thermal energy of the sputtered Au atoms. This damage can be reduced by increasing the argon pressure in the sputtering chamber. Higher argon pressure increases the probability of collisions between the impinging gold atoms and the ambient argon atoms. These collisions reduce the thermal energy of the gold atoms as they traverse the distance between the cathode target and the disc surface.

High argon pressures place higher demands on vacuum pumping systems than a more conventional aluminum process. A proper CD-R system will have a vacuum pumping system capable of pumping the higher than normal argon flows at the desired process vacuum levels.

Figure 8, Self-Centering System

PRACTICAL ISSUES OF AU SPUTTERING

While processing of CD-R discs is critical to disc quality and production yields, the manufacturing cost is also of importance for the success of this media. Sputtering of gold requires efficient use of the raw material, and flexibility in switching over equipment to its use. Four practical issues related to Au sputtering are of particular importance and are presented in the following section.

Au Film Uniformity
To minimize gold usage, a uniform film is desired on the compact disc so that minimum reflectivity is satisfied in all areas without extra gold being applied in other areas of the disc.

Uniformity is a combined parameter balanced in the design of a cathode with sputtering rate and target life issues. For CD audio, sputter rate and target life are the priorities in the design. For high volume CD-R manufacturing, the cathode design must focus on uniformity as the primary objective. Figure 4 shows two cathode designs that are optimized for different goals. Cathode A offers the best uniformity at a lower deposition rate, and longer target to substrate distance. Deposition rates are lower since the fraction of sputtered gold actually deposited in the disc is low. The long sputter time is not important as it is not in the critical path of the manufacturing cycle. Uniformity, however, is significantly improved.

Au Target Options
Buying a solid gold target is a significant investment. Depending on order sizes or long term volume of production, the manufacturer can choose to purchase either laminated or solid gold targets. Depending on volumes, laminated targets are a good option for short runs or orders that are spaced apart enough that you don't want to tie up capital in gold between orders. For serious production of CD-R discs, however, solid targets offer the lowest cost due to lower fabrication costs and longer time intervals between target changes.

Au Reclamation
As with any sputtering system, not all of the sputtered material finds its way to its intended target. Some of the Au is deposited on the OD and ID masks and the chamber shields. The value of the gold on these surfaces becomes substantial in a very short time.

Effective methods are available for recovering this gold. First Light Technology sputtering system masks and shields are made of stainless steel. These components are mechanically rugged and can be easily cleaned of deposited gold. Removal of gold from copper masks is more difficult due to their intrinsic susceptibility to damage. Release agents are available for copper masks which facilitate gold removal. Such release agents are not as necessary for stainless steel components.

Dual Process Chambers
Changing over a system from aluminum to gold sputtering involves a target/mask/shield change and process changes in argon pressure, pumping speed, etc. This changeover is time-consuming, and it adds to security demands by increasing the amount of handling required for chamber components.

This problem is eliminated through the use of dual process chambers. Such systems are equipped with a turbo drag pump to operate at high pressures if required, and are equipped with two vertical sputtering positions. Each position can be set up to run either aluminum or gold, making process switch-over a simple software selection.

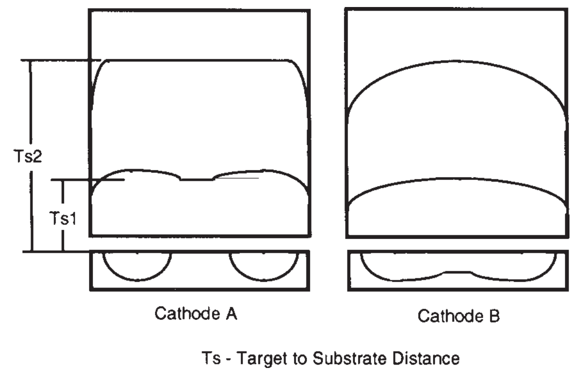

Figure 9, Layer Uniformity vs. Substrate Distance and Cathode Target Utilization

CONCLUSION

CD-R manufacturing presents challenges not commonly experienced in the manufacture of conventional compact discs. Some of these are:

Process Issues of Au Sputtering
- Sputtering Process Control
- Plasma Arc Control
- Mask Heat Removal
- Self-Centering Masking
- High Argon Pressure

Practical Issues of Au Sputtering
- Au Film Uniformity
- Au Target Options
- Au Reclamation
- Dual Process Chambers

Manufacturing CD-R discs requires special attention to these issues. With appropriate equipment design, consumable selection, and process control, CD-R manufacturing can offer a new opportunity of growth and profitability for optical disc replication.

REFERENCES

1. K.C. Pohlmann, The Compact Disc Handbook, 2nd ed., pp. 249-255, A-R Editions, Inc. Madison, Wisconsin, 1992.

2. R. Scholl, "A New Method of Handling Arcs and Reducing Particulates in DC Plasma Processing", 36th Annual SVC Technical Conference Proceedings (1993), pp. 405-408

3. J.F. O'Hanlon, A User's Guide to Vacuum Technology, 2nd ed., John Wiley & Sons, New York, 1989.

4. J.P. Holman, Heat Transfer, 6th ed., McGraw-Hill Company, New York, 1986.