Evaluation of Return on Investment for Vacuum Web Coating System and Process Changes
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ABSTRACT
Whether battling with process challenges or trying to keep up with demand, vacuum coating systems are often in a state of change. This paper presents case studies for several roll to roll vacuum coating system modifications, their relative costs and how one change can affect multiple systems. Understanding which components and subsystems add value is critical to maximizing return on investment. This analysis focuses on pretreatment options, substrate thermal management, film thickness uniformity, and reactive sputtering made possible by deposition zone isolation.

INTRODUCTION
Does your vacuum web coating tool have untapped potential? While return on investment is routinely evaluated and precisely calculated during acquisition of new capital equipment, the benefits of upgrades made to tools currently in production are easily overlooked. Because of the significant capital expense associated with new vacuum coating equipment, tools are often left in service for extended periods of time, even tens of years. Retrofit of an older tool to include features made possible by advances in technology or which were otherwise not included in the original design can often increase throughput, yield, and enable the manufacturing of new types of coatings for a fraction of the cost of a new tool. It is possible that untapped profit margin potential resides in your existing coater and that retrofits ranging from simple to advanced may be available to make this happen.

SYSTEM CHANGES CONSIDERED
The following system changes are described and the approximate cost associated with each are estimated for a hypothetical coating tool:

1. Substrate pretreatment
   a. Contact methods
   b. Plasma based methods (Remote Plasma Sources, Linear Ion Guns)

2. Substrate thermal management
   a. Coating drum temperature optimization

3. Film Thickness Uniformity Improvement
   a. Binary gas manifolds

4. Deposition Zone Isolation
   a. Deposition zone isolation enables independent process control of adjacent coat zones. This can enable the implementation of throughput enabling technologies such as reactive processing or metal deposition zone adjacent to oxide sputtering zones.

COATER ARCHITECTURE USED IN EXAMPLES
In order to provide meaningful analysis of the return on investment it is necessary to identify a hypothetical baseline coater architecture, on which these upgrades will be considered. The architecture selected is not intended to be
representative of a specific existing make or model coating tool. Specific attributes of the coating tool used in this analysis are as follows:

- 1 meter wide polymer web
- Web path containing front side contact
- No capability for mask / interleave removal
- Excellent tracking of web throughout winding system
- Liquid cooled coating drum
- Coating drum chiller minimum temperature of +20°C
- Four deposition zones, each equipped with
  - One planar sputter magnetron
  - One mass flow controller
  - One plenum type gas manifold
- Asymmetric pumping design
- Three 2000 l/s high vacuum pumps located on the back of the main chamber. Effective pumping speed of 1500 l/s on the chamber from each pump
- One Meissner coil for water vapor pumping in the main chamber volume and in the deposition zones, with a total of 100,000 l/s water vapor pumping speed

This hypothetical 1m web coater operates at 1m/min and runs 80% of the hours in a year. Therefore the total web production is about 420,000m² of web per year. This figure will be used for ROI calculations.

**POTENTIAL RETURN ON INVESTMENT**

In order to accurately calculate return on investment many specific details must be known about what is being produced by the coater, the potential throughput and the prices the market will bear for those items. For each coater modification evaluated the author has made assumptions for specific applications to determine return on investment, but note that those assumptions may not be relevant to the reader’s application.

The relative ease or difficulty of each modification, approximate system downtime, and the approximate cost are presented for our hypothetical 1m coater. The cost is listed in full and as an annual amount based on a simplified 5 year straight line depreciation schedule. In this way the reader may make their own evaluation for return on investment based upon the changes in productivity or markets made possible in their specific situation.

**SUBSTRATE PRETREATMENT: CONTACT CLEANING METHOD**

Contact cleaning methods have been proven effective in removing particles from substrates prior to vacuum deposition (Hodgson, 2010), a crucial parameter for defect sensitive applications such as ultra-barrier films. These contact cleaning methods can be integrated within the vacuum system, allowing substrate cleaning immediately prior to deposition.

Particle removal improves yields for defect sensitive applications and should enable those applications which were otherwise not possible in the existing coating tool.

To modify our hypothetical coater a dual contact cleaning roller is selected utilizing a nip type configuration. This approach requires minimal space in the vacuum chamber. It is anticipated that the web will be under moderate to high tension at the cleaning roller location. This makes a nip approach better than an s-wrap which could be problematic because the cleaning roller material is an elastomer and
will deflect under web tension with an angle of wrap around the roller.

The contact cleaning rollers must be precisely aligned in the web system to avoid unwanted web steering and to ensure good contact with the web. The total coater down time required for this upgrade is estimated at 3 days including initial measurement, installation, alignment, and commissioning.

Adding the nip type contact cleaning roller set to the hypothetical 1m web coater will cost approximately $50,000, including engineering, hardware and installation. Based on the simplified 5 year depreciation schedule, this is equivalent to an annual cost of $10,000. Consumables and maintenance are estimated at $2,500 per year, for a total cost of $12,500/yr. For a system experiencing even minor yield losses attributable to particles, it is reasonable to expect this to be a worthwhile system change.

Return on investment for this modification exceeds 225% based on reduced yield loss for a moderate to high value application.

**SUBSTRATE PRETREATMENT: PLASMA BASED METHOD**

Plasma surface pretreatment improves thin film coating adhesion, enabling the use of lower cost substrates that would otherwise not be considered candidates. It also increases the number of markets and applications accessible by the coater and decreases yield loss due to adhesion failures. In many coaters plasma pretreatment can be inserted directly into the existing unwind zone because the heat load on the web is relatively low, thus not requiring a chilled roller to back the web during treatment. However, for high energy pretreatment or for thermally limited substrates, it is necessary for the plasma treatment to occur on a chilled roller. In an existing system this is most readily achieved on the liquid cooled coating drum but may require the conversion of a sputter deposition zone to a plasma treatment zone depending upon the design of the coater under evaluation.

The hypothetical coater under study contains a long length of web in contact with the drum prior to the first process zone and has a lot of space available to integrate the plasma source in this region, so all 4 coating zones were preserved.

The total coater downtime required for this upgrade is estimated at 4 days including installation, utility integration, control system upgrade, and commissioning.

Adding the linear plasma pretreatment source to the hypothetical 1m web coater will cost approximately $195,000, including engineering, hardware, installation and control system integration. Based on the simplified 5 year depreciation schedule this is equivalent to an annual cost of $39,000. Electricity and maintenance are estimated at $7,000/yr, for a total cost of $46,000/yr.

Based on 420,000m²/yr throughput, the cost of implementation for plasma pretreatment is $0.11 per m² substrate.

Perhaps a more compelling argument for plasma pretreatment is adhesion promotion. This characteristic could either open up new markets to be served by the coater or allow elimination of a sputter deposited adhesion promoting layer which is currently applied in one of the four available sputter zones. Evaluating the latter, the plasma pretreatment source could effectively increase throughput of
the coater by up to one third simply by virtue of making this sputter zone available for other purposes. For applications where this is the case the annualized cost of $46,000 is sure to be recovered in much less than a year.

For an application where an adhesion layer may be replaced by plasma pretreatment and where a single material is coated on the web, throughput of our hypothetical coater is increased by 33% by increasing the number of sputter zones from 3 to 4. The return on investment for this specific application exceeds 1000%.

**SUBSTRATE THERMAL MANAGEMENT:**

**DRUM CHILLER UPGRADE**

Optimization of the coating drum design and drum chiller system may enable increased deposition rate and improve overall system throughput and productivity, resulting in increased profitability. Many parameters in a web coating system have significant effects on heat transfer from a polymer web to a coating drum, such as: web tension; water content of the polymer web; surface roughness of the coating drum and of the web; coating drum temperature; whether a coated or uncoated web surface faces the coating drum; and even whether advanced techniques such as gas injection between the web and the drum are utilized. This analysis will consider only the coating drum temperature and it will assume that the coating drum itself has been designed with sufficient chill fluid flow rate and with appropriate flow passages in order to provide drum surface temperatures which are representative of the chill fluid.

By implementing a heat exchanger capable of reducing the drum temperature to -30°C the throughput of the coater can be improved. The lower drum temperature compensates for the higher heat flux resulting from increased deposition rates thereby enabling increased throughput.

Note that this upgrade requires more than just a new chiller; select components must be replaced for compatibility with the lower temperature, coolant lines must be insulated, rotary union replaced, and the coolant itself must be replaced with a low temperature, low viscosity fluid.

Coater down time for this upgrade is estimated at 5 days including removal of the existing chiller and select components, installation of new items, integration, and commissioning.

The cost of such an implementation is $190,000 including all engineering, hardware and integration costs, resulting in a five year depreciation of $38,000/year. Maintenance and operation expenses are $8,000 per year, for a total cost of $46,000 per year.

The actual improvement in throughput based on reduced drum temperature is dependent on many variables. For our example application, an increase in throughput of 10% is made possible, though some applications will realize significantly greater improvement. The return on investment for this upgrade in this application exceeds 350%.

**FILM THICKNESS UNIFORMITY IMPROVEMENT**

Uniformity of sputter deposited films is highly dependent on control of the distribution of gases in the process zone. Gas distribution separated into zonal control is important because it can help overcome asymmetric pumping in the coating zone or inherent
asymmetry of the deposition source. Independent control of multiple gas delivery zones permits trimming of the gas to compensate for these asymmetries.

Zonal control is accomplished via binary flow paths incorporated into gas manifolds with individual mass flow controllers. This gas control can be coupled with custom baffles in those cases where asymmetric pumping creates significant pressure gradients that are difficult to balance through gas control alone.

The outcome is improved film thickness uniformity which in some cases will eliminate the need for trim shields and as a result improves overall deposition rate and system throughput and profitability.

Our hypothetical coater has a symmetric pumping configuration so this thickness uniformity improvement requires binary gas manifolds, additional mass flow controllers and supporting gas distribution and control system upgrades.

Coater down time for this upgrade in all four process zones is estimated at 6 days including chamber modification, installation, integration, and commissioning.

Implementation of the film thickness uniformity improvement on the example coater costs $175,000 with a five year depreciation schedule of $35,000 per year. Maintenance and operation expenses are minimal at $1,000 per year, for a total annualized cost of $36,000. This cost must be balanced against new markets made possible by improved uniformity or by target material savings brought about by elimination of trim shields.

Uniformity improvement that justifies a product sales price increase of $0.25/m² results in a return on investment of nearly 200% based on the above costs.

**DEPOSITION ZONE ISOLATION (REACTIVE SPUTTER DEPOSITION)**

Whether this can be added and what adding this will cost is very dependent on the original system design. To be clear, this is a two-fold upgrade; first limiting conductance between adjacent zones to facilitate controllable reactive sputtering, and second, integration of a closed loop reactive sputtering controller.

Conductance limitation between adjacent coating zones in web coaters can provide turn down ratios ranging from 10:1 to 100:1. This allows for reactive sputtering in adjacent coating zones with very good stability in each zone. Optimized reactive sputtering provides nearly the metal mode sputter rate when depositing oxide films, thus increasing throughput and typically reducing target material costs. Several options for reactive sputtering control exist that provide for stable deposition rate and thin film stability. The best strategies incorporate independent control of coat zone pressure coupled with optical emission feedback (Bellido-Gonzalez 2009).

When these control methods are coupled with the uniformity improvements described above, a coater can realize up to a 2x or 3x increase in deposition rate at the same power density resulting in a dramatic improvement in coater throughput. Metal oxides that benefit from such implementation include but are not limited to: SiO₂, TiO₂, Nb₂O₃, Al₂ZnO and ITO.

Coater down time for this upgrade in all process zones is estimated at 12 days including initial inspection and measurement during the design phase, chamber modification, installation, integration, and commissioning.
The total cost for this upgrade including all engineering, hardware and integration in our hypothetical coater is $400,000, for an annualized cost of $80,000 per year over 5 years. Maintenance is estimated at $8,000 per year for a total cost of $88,000 per year.

Sources of return on investment for this upgrade include increased throughput and reduced target material cost, since pure metal targets are typically lower cost than oxide targets of specific composition. Considering the return on only increased throughput and assuming a modest improvement of 30%, the return on investment for the example application is greater than 200%.

CONCLUSION
Several modifications to a 1m vacuum web coating system have been described and the cost and return on investment for each has been presented. Many assumptions were made in order to estimate both the cost of the modifications and the resulting return on investment, and the results are not applicable to all coaters or all applications. However, the results provide some insight into what an owner of a 1m web coater might experience when making these modifications. Armed with this information and additional background knowledge of their specific system and application, the user can make judgments about which modifications to consider for retrofit into an existing roll to roll vacuum web coating tool.

References