Recent Technological Advances in Vacuum Web Metallising: From Packaging to Functional applications

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Abstract

The technology of vacuum web metallising has been undergoing continuous changes and improvements to meet current and future demands for high quality new products. Meanwhile, the converting industry is also moving from basic decorative to more functional applications, where uniformity, thickness, visual appearance, etc becomes important factors in the performance of the end product.
This article is aimed at highlighting the recent technological advances in vacuum web metallising and will discuss some of the new processes/products that can be done inside a standard metalliser.

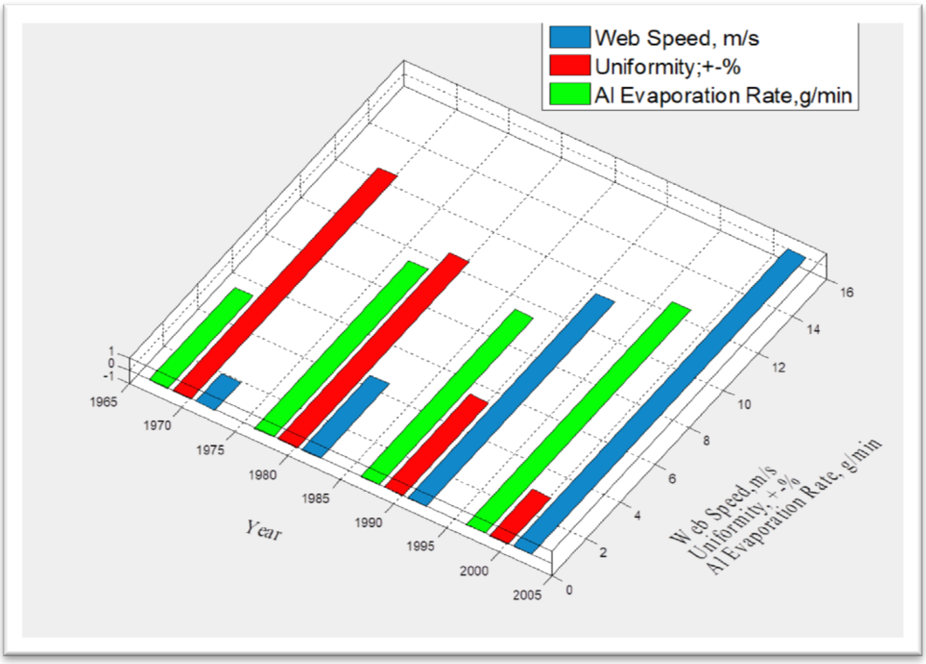
Introduction

At present, there is a growing demand for vacuum web metallizers with higher speed and performance to metallize films with various thicknesses for flexible packaging and functional applications. For example, the new generation of equipment for packaging applications requires a line speed of more than 10m/s with coating thickness uniformity below ± 5% [1]. For solar window film application the uniformity requirement is below ±2%. Modern metallisers are now designed to handle a wide variety of different film types including heat sensitive films and thin gauge substrates The increase in machine efficiency has focused the attention on improving the adhesion, thickness, uniformity, visual appearance and durability of the deposited layer across the width and down the length of a moving film web. Adhesion and uniformity are the most important characteristics reflecting machine performance. Poor adhesion or uniformity often leads to splitting and banding effect on metallized film. The various properties of the metallized film are influenced by many parameters including film type, film quality, surface wettability (i.e surface energy), level of vacuum in the evaporation zone, design of evaporation source, inline optical monitoring and control of evaporation and deposition rates [2]. Other factors such as thermal load on the metallized film is also very important. To improve uniformity across web width the evaporation source arrangement has to be modified to accommodate wide web film. Coating optical monitoring techniques with associated closed loop feedback systems have also been redesigned or altered to improve uniformity. In line optical density monitoring employing light sources such as lasers is now used to control the evaporation rate and line speed via a computer controller closed loop feedback system [3a,b]. Another addition to standard metallizing process is the improvement of plasma pre-treatment systems to improve substrate surface wettability and adhesion, hence to reduce problems of adhesion, banding and non- uniformity. The interaction of plasma with the polymer surface removes contaminants and increases surface activation by cross-linking native film polymers [4]. This depends on type of gas mixture used, plasma energy and the nature of substrate surface.

Therefore, there are so many challenges for technical innovations in both equipment and processes to meet the increasing demands for added value functional products. One example is the demand for better barrier properties of flexible packaging against the permeation of gases, of water vapour and of flavour substances. Other products include functional metallized films for medical, optical, wear resistance and security applications, which requires specific properties in performance.

2. FUNDAMENTALS OF WEB METALLIZING

Over the past many decades, there has been a tremendous growth in the use of web coaters for many applications. The early applications concentrated mainly on the capacitor industry to supply metallized zinc and aluminium on paper, polyester and then polypropylene films. Then the stamping foil industry became a large user of aluminium metallized polyester [5]. After that, new developments and applications have accelerated throughout the 80's and 90's with continuous growth. This technology has been marked with continuous evolution of development between machine design and process requirements as shown in Figure 1.



The concept of aluminium web metallizing is shown in Figure 2. The process involves the use of unwind/rewind zones and a deposition zone. The vacuum chamber is evacuated using a combination of mechanical and oil diffusion pumps. The film moves from the unwind zone onto a process cooled drum to the deposition zone where the film is coated with aluminium (or other materials) then moves to the rewind zone. The evaporation source is mounted underneath the cooled drum. The process chamber is optimised for each individual deposition technology. For example, size and cooled deposition drum, pre and post lead-in rollers, nip rollers, number and placement of load cells, pre and post chill drums, vacuum pumping and gas flow requirements.

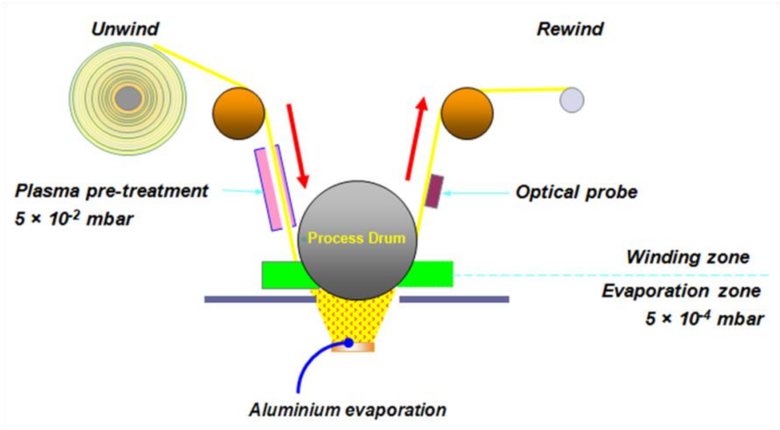


Figure 2. Schematic of vacuum web metallizer

The design of new generation of metallizers will focus on the following major items:

1- Vacuum level

2- Cooling

3- Tension control/Film winding system

4- Plasma pre-treatment

5- Evaporation source/Evaporation control

6- Defect monitoring

7- Optical monitoring of film

8- User friendly automation & control

9- Value added new products

1- Vacuum Level

It is important that the pumping system of the chamber is to provide uniform pumping gradient across the web. In modern metallizers the vacuum diffusion pumps are located underneath the chamber rather than connecting at the end of the chamber. In this case, diffusion pumps are close to the evaporation source and should be protected from debris to ensure consistant pumping. Variable speed motors are used for mechanical pumps for soft starting and power saving. Also, better vacuum zoning are designed to enhance pumping speed. More efficient Cryogenic system with higher condensation capacity are used.

pumping group is robust and has a compact design with shorter pipe lengths giving the lowest footprint in the industry; it comprises of dry rotary screw pumps with a consistently high vacuum performance, booster pumps that operate at double the normal speed for maximum efficiency and floor mounted diffusion pumps located underneath the evaporation zone eliminating the risk for backstreaming of oil on to the film.

2- Cooling

The cooling of the deposition drum will also become asignificant factor. Typically the drum is cooled by achilled liquid that is fed into & through to one end of the drum where it is directed to the drum outer walls andreturns and is drained out of the other end. Simplistically,moving up from a 3m to a 10m width machine is over a3x increase in the drum width and this will lead to anincrease in the temperature rise of more than 3x, for the same flow. The increased temperature of the returningliquid may be reduced by increasing the throughput of thecooling liquid coupled with a larger capacity chiller to remove the extra heat from the liquid. The additionalproblem that is of more concern is that there will be asignificant temperature difference from one end of thedrum to the other. This temperature difference will needIn order to improve film cooling efficiency the cooling capacity chilled drum has to achieve a temperature of -20 deg C. Also, a gas injection is used behind the film to improve heat exchange between film and drum.

, the machine incorporates a Ø600mm coating drum providing the largest coating window in the industry that increases aluminium collection efficiency by up to 16% resulting in less consumables, an extended boat life and a 10-15% energy reduction. It also provides better film cooling due to the increased surface area of the drum; additional cooling is also given by the 2-zone gas wedge which provides better conduction of heat between the substrate and the drum which is important for heat sensitive films such as CPP and LDPE.

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3- Tension Control

In order to achieve efficient tension control particularly for thin films (<5 microns) there is a need for good film path design to provide steady film support and guide during winding. Other design features include inertia and High modulus rollers materials for firm web path control at high rotation speed, advanced winding control with multiple differential tension zone, smooth roller surface finishing for winding-induced defects minimization to handle different properties materials such as thermally sensitive films or stretchable films.

winding mechanism incorporates a 6 drive system giving 3 independent tension control zones. It provides low tension winding with adjustable bowed rollers to produce a virtually wrinkle-free metallization process and an optional pre-drum vari bow for better handling of thinner substrates.

The K5 VISION can handle a wide range of substrates including thin gauge films and enables quick changeover of different film types making it the ideal machine for converters. It is also able to handle heat sensitive films such as CPP and PE which makes it perfect for film producers of these thermally sensitive materials.

2.1 Evaporation Sources

Evaporation system is the most critical part in the metallizer. Web metallizing process involves the production of a vapour from a material, such as aluminium, placed in a heated source inside a vacuum chamber. The source is generally heated either by electrically resistance boat or electron beam guns. The process is carried out in a vacuum chamber at a vacuum level of $1x10^{-4}$ to $5x\ 10^{-4}$ torr to minimize any scattering or reaction with impurity gas atoms. Because vacuum evaporation is a line -of-sight coating process the evaporation sources are spaced in certain geometry to obtain uniform coating. For efficient evaporation the boats are equally spaced for intense vapour density to provide a coating uniformity of <±5%. This can be in the shape of staggered boats geometry. More work been done to improve aluminium wire feeders and to isolate them electrically to achieve vibration and spitting free evaporation. The power distribution across each boat which carry a current of up to 1000A is improved to avoid electromagnetic interference from the high current flow.

The variation in the vapour plume, and hence n, depends on many parameters including the condition of the boat. Therefore, any fluctuation in the electrical current passing through the boat, wire feed rate or presence of cracks or defects on boat surface will affect the shape of the plume and leads to banding. Figure 8 shows a thickness uniformity prediction of boats with stable and fluctuated evaporation temperature.

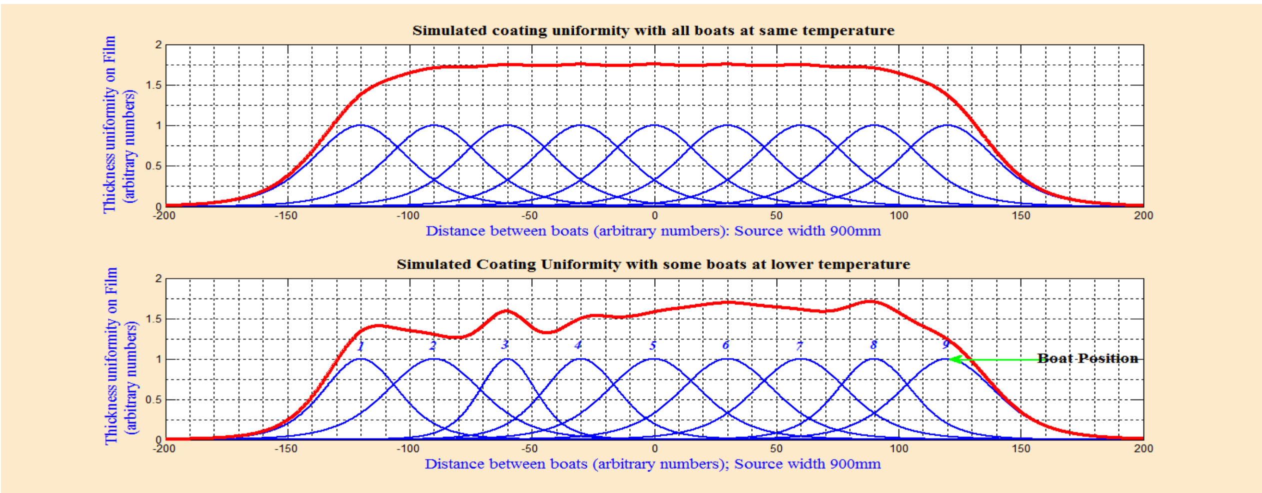
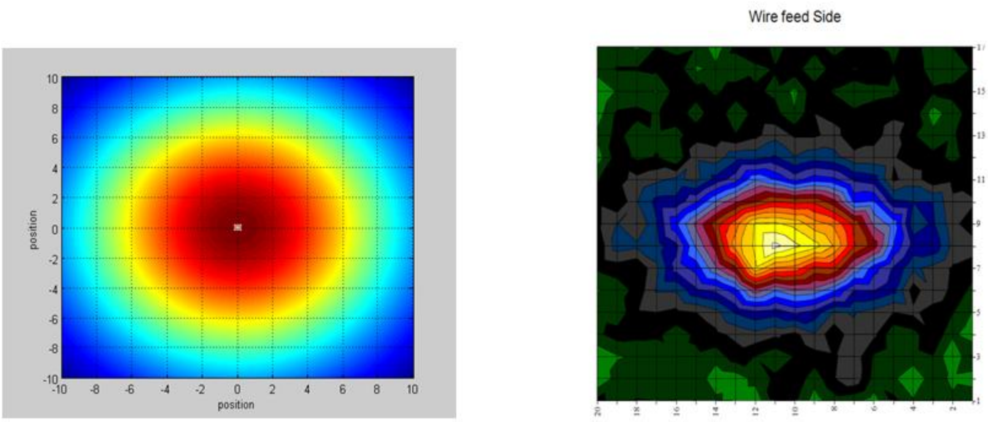


Figure 8. Simulation of thickness uniformity of boats with stable and fluctuated temperature.

The experimentally measured shape of the vapour plume of a single boat is shown in Figure 9. This was measured using a stationary glass substrate with Al evaporation rate of 9g/min for a period of 10 sec [15a,b] with h=150mm. For comparison, this figure also illustrates a mathematical prediction of the vapour plume for a single boat. It is believed that the spread out of the measured plume to the sides of the boat is due to the formation of a virtual source with a vapour pressure difference between the centre and sides of boat [11].



Simulated Measured

Figure 9: Comparison between experimental and predicted vapour plume shape.

4.4 In Line Plasma Pre-treatment

Most films for metallization receive some form of pre-treatment to improve adhesion and uniformity and consequently barrier. This includes corona, flame and chemical wet treatment. Such pre-treatment methods are carried out in atmosphere with no control over treatment environment. Increasing demand for enhanced coating properties led to the utilization of in-line plasma sources in vacuum to treat polymer films on a moving web. The interaction of plasma with the polymer surface removes contaminants and increases surface activation by cross-linking native film polymers and incorporating onto the surface species from the plasma gas. This depends on type of gas mixture used, plasma energy and the nature of surface. Consequently, this promotes the interaction between depositing atoms and substrate surface, thus increasing surface energy and improving wettability, adhesion and uniformity [4,25].
Plasma sources use Pulsed DC, medium frequency AC or RF generators to strike the discharge. Medium frequency AC excitation sources may have either planar or tubular electrodes or electrode arrays to allow higher treatment powers with no arcing problems, that can sometimes plague DC discharges. Plasma sources use magnetic fields or hollow cathode discharges to produce intense and directed plasma at low gas pressure. Figure 13 illustrates the typical arrangement of a plasma source. In some metallizers, plasma treatment sources with 5-20kW, 40kHz power supply are employed to generate plasma [26,27]. The plasma treatment is carried out using a gas mixture of argon and oxygen under constant pressure control at around 0.05 torr. The plasma source is installed in the unwind zone so that the film is treated before passing to the coating zone (see Figure 2).

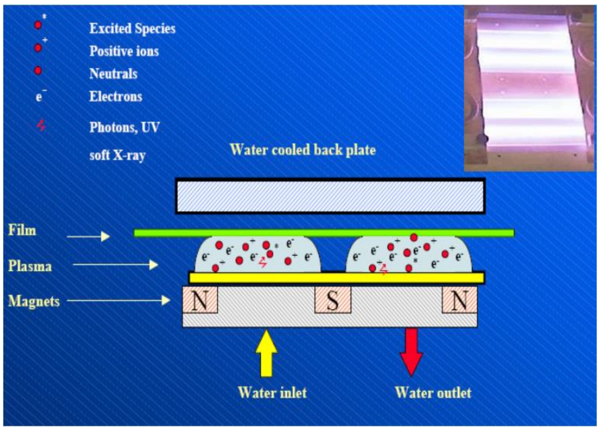


Figure 13. Schematic of plasma treatment source

4- Advantages of Plasma Treatment

Plasma processes have been developed to attain a variety of specific surface properties. This includes:

a- *Surface Cleaning*

b- Adhesion promotion

c- Enhancement of surface energy

d- Improving surface cross linking

The BOBST AluBond® process provides high metal adhesion with values up to 5N/15mm and improves dyne level retention through vacuum metallization,eliminating the need for chemically treated films. AluBond® is an advanced hybrid metal coating technology which achieves higher barrier properties on BOPP and CPP films than conventional metallizing processes.

There are different designs of plasma treaters available in the market. Most manufacturers use a dual magnetron approach to generate plasma. Others use a dual magnetron hollow cathode approach to generate dense plasma. The basic design of the magnetron plasma treater is shown in Figure 2. This consist of a water cooled cathode with magnetic assembly to capture secondary electrons to create a dens plasma near the cathode surface (target). The film passes between the cathode and opposite water cooled grounded plate to receive the plasma treatment. There are different variation to this design to include un-balanced magnetic arrangement.

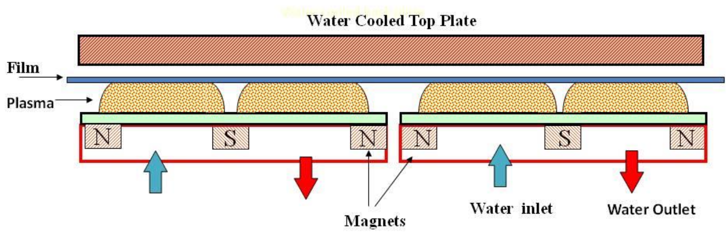


Figure 2. The Basic Design of Dual Magnetron Plasma Treater

In the hollow cathode design the treater has magnets located on the opposite (untreated) side of the substrate. In this case, the plasma field is more directed toward the film surface. All of this leads to a higher performing plasma treater, with a more compact design and efficient treatment. In this system the plasma action is ocused on the Film. Plasma is generated from both the hollow cathodes and the magnetic field, to remove adsorbed moisture, low molecular weight polymer (and additives) and to functionalize the film surface. Medium frequency power is used to strike the plasma and the electrode system is designed to reduce film charge build up (Figure 3).

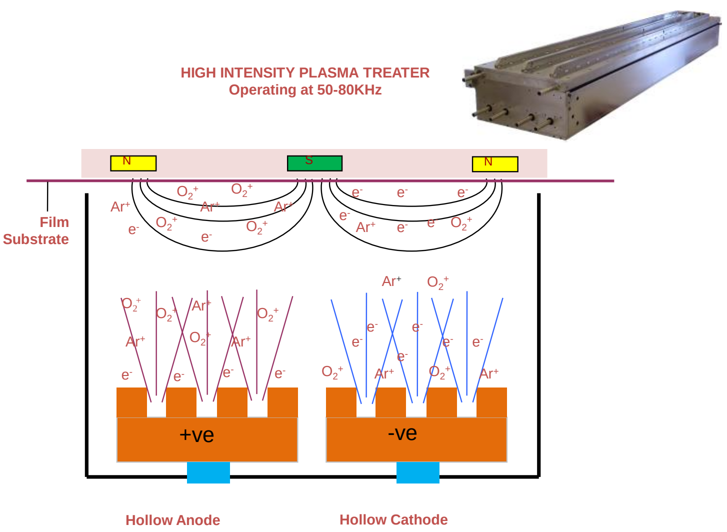


Figure 3. How Cathode Plasma Treater (Reprinted with permission from Sigma Technologies Int.).

Plasma treaters differs in their designs and the type of power used to generate plasma. Many designs and operating parameters aim at determining the most convenient gas mixture and power to achieve optimum plasma treatment. The design takes into account gas mixture rate, flow rate, power settings and voltage, etc. For example, the use of poor ceramic insulators would lead to a breakdown inside the plasma treater when certain level of power is applied. Consequently, this would affect the final treatment of the polymeric film surface.

In operation, a wide variety of parameters can greatly affect the physical characteristics of a plasma and subsequently affect the surface chemistry obtained by plasma modification. Processing parameters, such as gas types and mixture rate, treatment power, treatment time and operating pressure, can be varied by the user. However, system parameters, such as electrode location, selection of insulators, magnetic field design, gas inlets and arrangement of water cooling are set by the design of the plasma equipment.

The selection of the excitation frequency supplied by the plasma power supply is an important factor that can influence the efficiency and end result of plasma treatment. Research has shown a strong correlation between excitation frequency and the efficiency of surface activation or treatment. Most manufacturers of plasma equipment employ medium frequency (MF) of about 30-100 KHz to excite and trigger the plasma. Others use DC, pulse DC or high frequency (13.56 MHz).

The standard mixture of gases used in plasma treatment of polymeric films is Oxygen:Argon. The ratio of Oxygen:Argon differs according to the plasma treater design. Some manufacturers recommend 20:80, while others recommend 70:30. It should be noted that with continuous operation the electrode target plate above the magnetic assembly become eroded at the race track and oxidised. This requires regular maintenance and cleaning to achieve uniform plasma density.

Pre plasma treatment can also involve the deposition of a seeding layer to improve adhesion between film and metallised layer. This can be done by injecting special monomer into the pre treatment plasma which is then cured by the plasma to deposit on the film as a seeding layer. Thickness of the seeding layer is only few nanometer but can improve adhesion and barrier.

Plasma Post Metallization Treatment

In this geometry plasma is used to passivate metallised aluminium in the rewinding zone. This keeps a stable surface energy for the converting stage. It was also found that posta plasma treatment can also improve the oxidation and transparency of the AlOx coating.

The technology involves the deposition of a hybrid coating layer, which has a tailored coating stoichiometry & gradient that exhibits vastly enhanced anchoring properties to the base polymer substrate. Thus, adhesion levels comparable to those obtained on chemically coated/treated films can be achieved, without the additional cost and complexity of the latter and, more importantly, without impairing the barrier performance of the metallized product. In fact, results are showing a rather positive impact on barrier performance, especially noticeable for cast polypropylene (CPP) and biaxially oriented polypropylene (BOPP) substrates when metallized using AluBond® technology. In addition to the benefits of adhesion and barrier enhancement, AluBond® metallized films can also offer higher surface energy levels of the metallization layer and better retention of surface energy (dyne) level with time when compared to standard metallized films. This paper will therefore present and discuss our latest results in terms of adhesion levels on various substrates, assessed via a range of peel test methods, dyne level retention and barrier performance for AluBond® metallized polymer films.

3.6 Monitoring System

The demand for improved uniformity has led to the development of advanced monitoring systems and closed loop feedback to control individual deposition sources. There are two systems available to monitor and control the thickness of the deposited aluminium layer. The first is a non-contact resistance monitoring system. It measures the deposit on the substrate at 100mm intervals by measuring eddy current fluxes. A flux is produced from an RF coil, which links with the coated substrate [3a]. The resultant induced current in the substrate is measured and fed back to a controller /monitor unit. The controller unit controls the wire feed to each individual evaporator based on the eddy current resistivity read at the sensing coils. The controller constantly compensates the wire feed rate to reduce the error between the reading and the actual set value. This function goes to a stand-by mode if the resistivity of any given position varies more than ±15% of the target specification. This is helpful in that the controller will not over compensate the wire feed rate for flaws, which may be unrelated [3a]. The second type of monitors is the optical monitor system [3b]. Light transmission is measured at numerous points across the web using light sources or lasers and the data is directly translated into O.D. readings. This system has the ability to measure very low OD, which is required for solar window films and clear barrier coating. For high OD, non-contact resistance monitors would be preferred. Modern metallizers have live cam inside the chamber for inspection. Also, new defect monitors are installed to monitor defects formation during metallisation for quality control.