Innovative Clear Barrier Technology for the Packaging Industry

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1 Introduction

The trend towards transparent barrier coatings for flexible packaging gains momentum. Product visibility is a powerful marketing tool. Vacuum coated transparent barrier film has been pushed forward during the last years mainly by electron beam evaporation technology with equipment installations in Japan and Europe. But as the investment cost for electron beam web coaters is high, and also as most metallizing companies are not familiar with this process, the number of running electron beam web coaters, compared to the number of Al metallizers using boats, is low.

To use this basic technology of standard Al evaporation from boats also for the production of transparent barrier layers was a dream since many years. In this presentation a new development, carried out at the Fraunhofer FEP, will be described. Based on the combination of an innovative plasma-technology with standard Al evaporation from boats, transparent barrier coatings with outstanding barrier performance and optical clarity on BOPP and PET films have been achieved.

A close cooperation between an equipment manufacturer, an R&D institute, and a BOPP film producer, all three partners being leaders in their fields, has boosted this innovative development. An adapted production machine has been manufactured by APPLIED MATERIALS and up scaling of this technology to production level was done in close cooperation between APPLIED MATERIALS and Fraunhofer FEP. A first production machine, using this process is under operation since 2008 on customer’s site.

2 Basic Technology

Figure 1 depicts the basic configuration of a web coater for plasma assisted reactive deposition of aluminum oxide. As in a standard web coater, the evaporation of aluminum takes place from boats with continuous wire feed. For the reactive deposition, gas inlet nozzles are placed in close position to the evaporation zone. In addition, a modular plasma system is installed. An in-line monitoring system is used to continuously measure the optical transmission of the coated film and provide a control signal for the oxygen flow set point.

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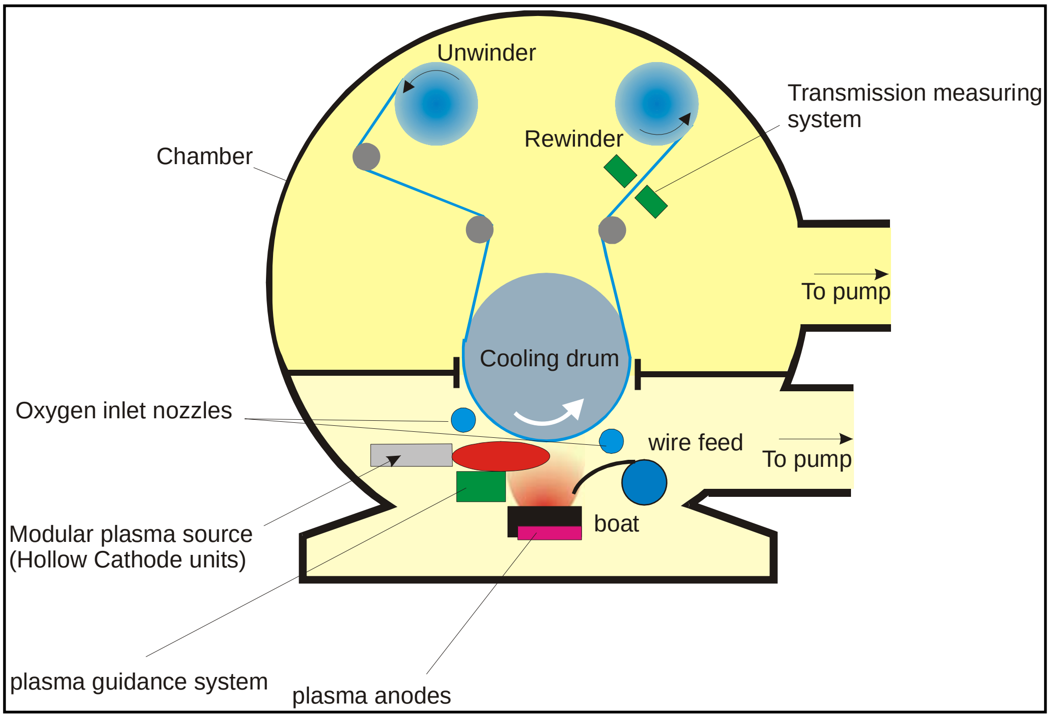

Figure 1: Basic configuration of a web coater for plasma-assisted reactive deposition of aluminum oxide on polymer films.

3 Reactive evaporation of aluminum

Aluminum reacts easily with oxygen; aluminum oxide layer can be produced in standard aluminum metallizers by feeding oxygen to the evaporation chamber. A major challenge, however, is to deposit an aluminum oxide layer at high productivity with high optical transmission and good barrier properties. An important question is the oxygen utilization. To obtain a low pressure in the deposition chamber it is necessary to ensure that a rather high proportion of the admitted oxygen is bound by the aluminum in the layer so that only a low proportion has to be pumped off by the vacuum system. Figure 2 illustrates this question. By a suitable positioning of the oxygen nozzles, high oxygen utilization can be obtained. The level of oxygen utilization also depends on the partial pressure of the oxygen in the evaporation chamber. With increasing oxygen pressure, for example achieved by lowering the pumping capacity, the oxygen utilization will be increased. However, increasing the pressure in the coating chamber will destroy barrier properties of the coated films. The need for good optical transmission and good barrier properties leads to a certain process window for the oxygen flow as depicted in Figure 2.

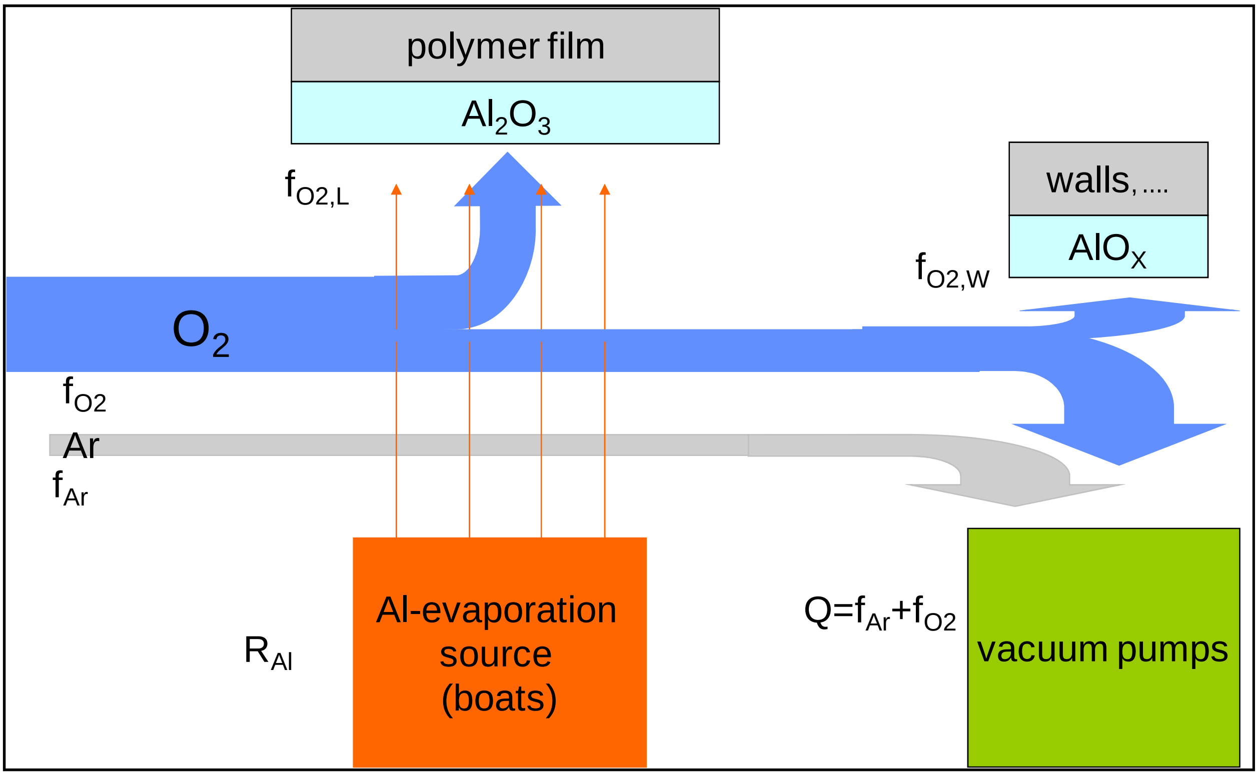

Figure 2: **Gas flow during reactive evaporation of aluminum**

f_{O2}	total flow of oxygen introduced to the web coater
$f_{O2,S}$	flow of oxygen that is bound by aluminum in the layer
$f_{O2,W}$	flow of oxygen that is bound by aluminum on walls, shields etc.
$f_{O2,P}$	flow of oxygen that is pumped off by the vacuum pumps
f_{Ar}	flow of argon (working gas of the plasma system)
Q	pumping capacity of the vacuum pumps
R_{Al}	evaporation rate of aluminum

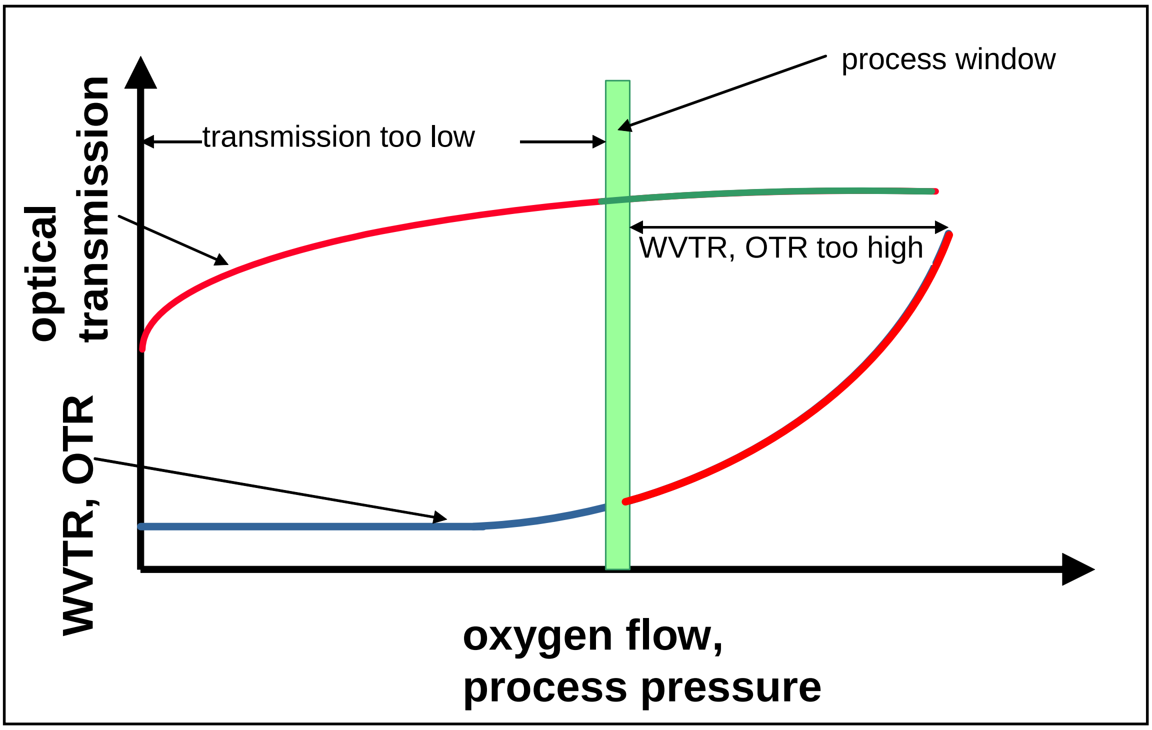

Figure 3: Definition of the process window during reactive.
OTR: Oxygen Transmission Rate; WVTR: Water Vapour Transmission Rate

4 The plasma system

The plasma system is of a modular design. It consists of hollow cathodes which are arranged side by side across the cross web direction. The hollow cathodes are supplied from VTD VAKUUMTECHNIK DRESDEN GmbH and have been modified by Fraunhofer FEP to meet the requirement of industrial, high rate reactive evaporation of aluminum. To enhance the effect of plasma, an additional anode ("booster anode") is placed in close position to the evaporation boats. The basic design of the plasma source is shown in Figure 4. Figure 5 shows plasma units that are mounted onto a bearing flange ready for installation into an industrial web coater.

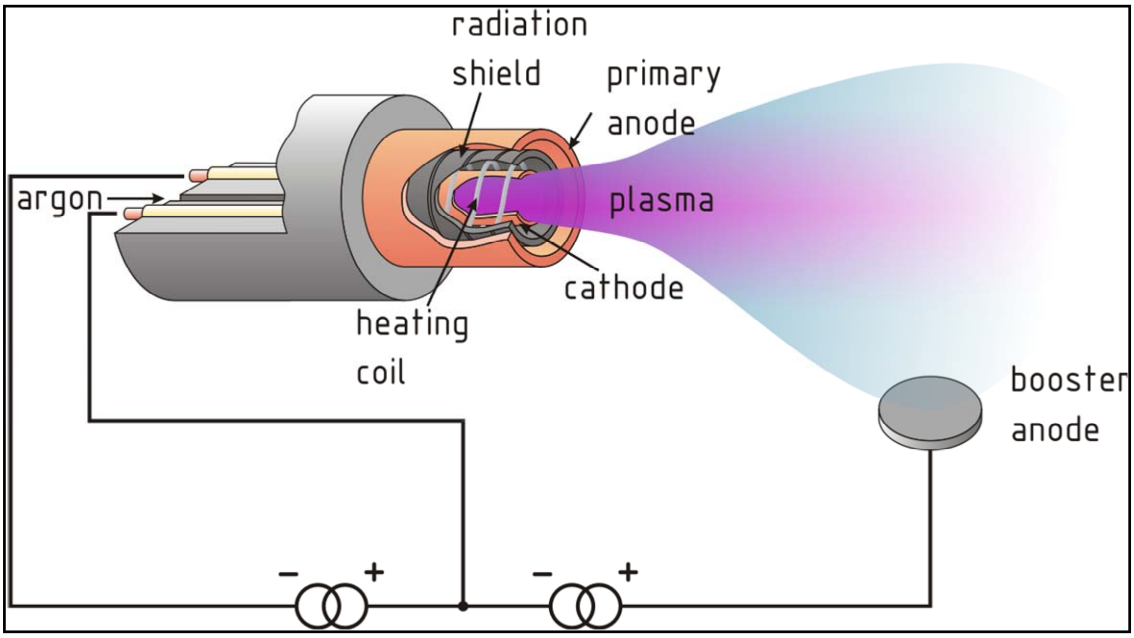

Figure 4: Section view of the plasma unit.

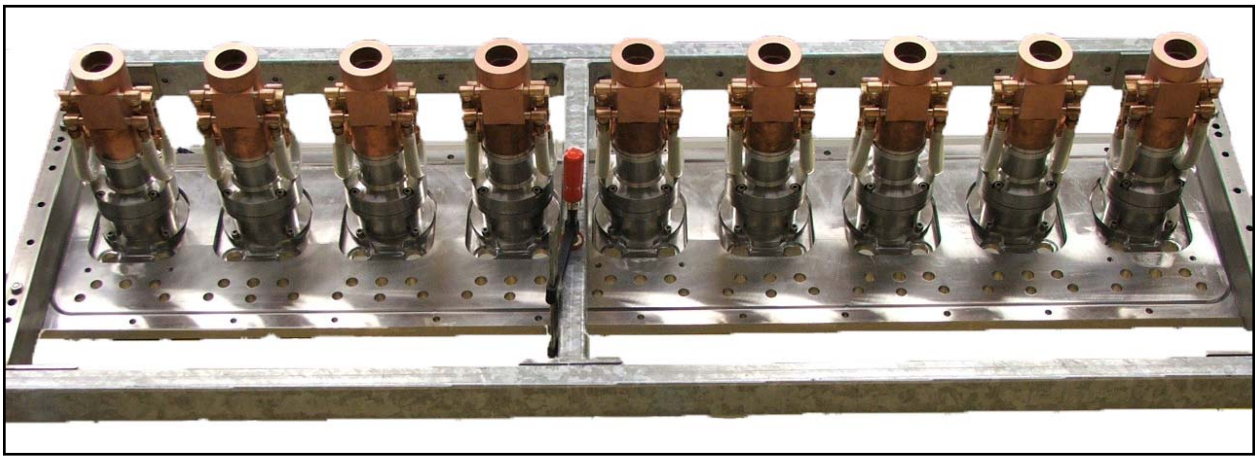

Figure 5: Plasma units mounted onto a bearing flange

Applying the plasma during reactive evaporation will enhance the process window towards higher oxygen pressure as shown in Figure 6. The plasma discharge enhances the kinetic energy of the layer forming particles, thus compensating the negative effect of the high pressure in the coating chamber.

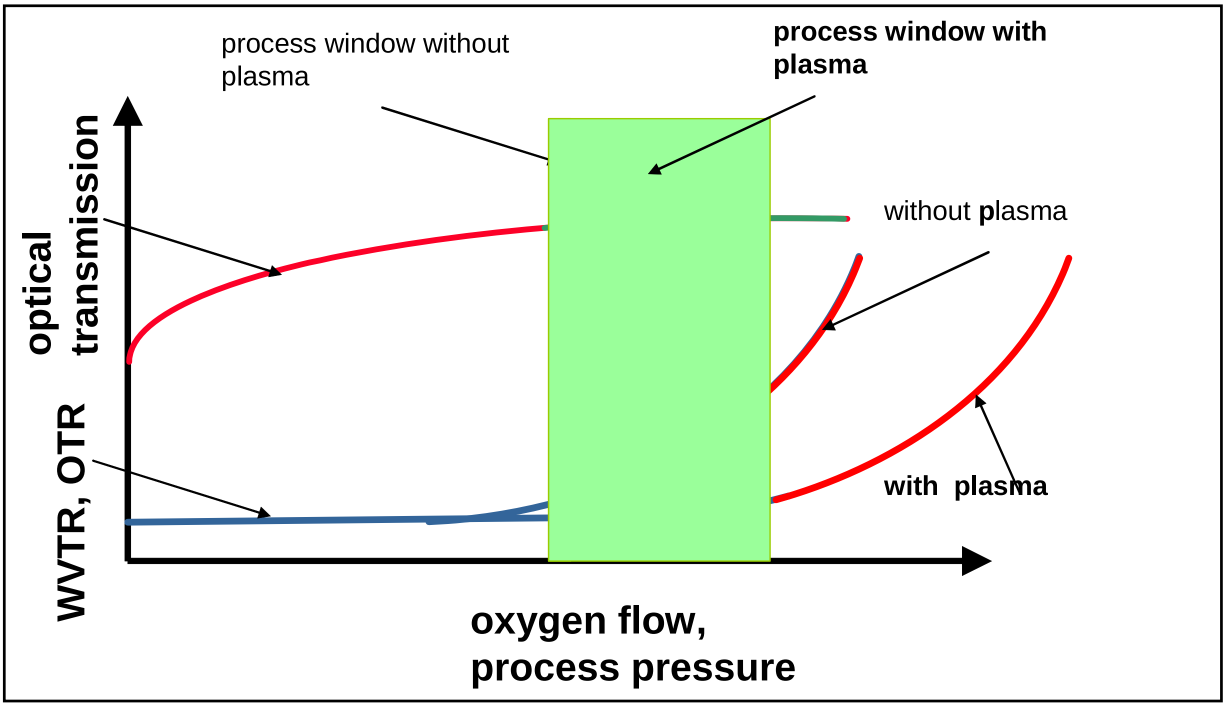

Figure 6: Process window of the reactive evaporation with and without plasma.

5 Layer and product properties

Table 1 summarizes the barrier properties of several aluminum oxide coated polymer films. The optical transmission of the coated film is higher than 98%. The minimum web speed during the coating process is 8 m/s.

Table 1: Barrier properties of aluminum oxide coated polymer film in comparison to the uncoated film **(**PET: Polyethylenterephthalat; BOPP: Bi-oriented Polypropylene; PLA: Polylactic Acid; WVTR: Water Vapour Transmission Rate; OTR: Oxygen Transmission Rate)

Polymer film (thickness)	**WVTR** [g/(m² d)] (38°C, 90 % r. h.)		**OTR** [cm³/(m² d bar)] (23°C, 0 % r. h.)	
	uncoated	**coated**	**uncoated**	**coated**
PET (12 µm)	16 (@ 23°C, 85% r. h.)	<1	110 (@23°C, 50% r. h.)	<2
BOPP (17µm	6	<1	2500	<100
PLA (20 µm)	496	<25	1085	<25

6 Scalability considerations

Scalability of the technology has to be discussed from two aspects: increase of web width and increase of web speed. The coating technology described above has been installed into a web coater with 1,65 m web width and a web speed of more than 8 m/s has been proven under production conditions. A scale up of the web width is supported by the modular design of the plasma units. Also the pumping capacity to pump off the remaining oxygen can be easily scaled up along with the web width. To increase the web speed, the aluminum evaporation rate also has to be increased which will lead to an increase of the amount of oxygen that has to be pumped off by the vacuum system. Naturally, there are some technical limitations to increase the pumping capacity (without increasing the web width and size of the coating chamber). However, experimental investigations have already indicated that due to the plasma enhancement, web speeds well beyond 10 m /s can be reached.