Transparent Barrier Coatings on Polymer Films

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1 Introduction

Thin transparent layers on polymer films are being used to drastically enhance the permeation barrier properties of polymer films while at the same time maintaining the flexibility and optical transparency of the polymer film. Applications range from food packaging films to encapsulation films for solar cells or flexible electronics.

Solar Cells and organic electronic devices require an encapsulation to ensure sufficient life time. Key parameters of encapsulation films are water vapor and oxygen permeation barrier, UV stability, temperature stability, optical transmission spectra and mechanical stability. Several work groups suggest multilayer stacks to meet the barrier requirements. Besides these technical parameters, an important parameter is production cost. To meet the cost requirements, roll-to-roll coating is a must for deposition of barrier films onto flexible materials.

2 Applications and requirements for transparent barrier films

Barrier films are used to protect sensitive products from water vapor and oxygen. An important property of a barrier film is hence the effectiveness of the barrier against the permeation of water vapor and oxygen. A fundamental distinction is made between transparent barrier films (namely films which are light-permeable) and opaque (light-impermeable) barrier films. Figure 1 shows an overview of the various applications of barrier films with the corresponding values for the required water vapor permeation rate. Depending on the barrier requirements, various technologies are employed to generate the barriers. In general it can be stated that plastic films have to be vacuum coated in order to achieve low permeation values. Vacuum coating can be combined with other processes. Where there are lower requirements on the barriers, uncoated films or plastic films with a chemical coating (lacquers, polymers) are used.

Beyond barrier performance, there are also other properties which have varying importance depending on the application (Table 1).

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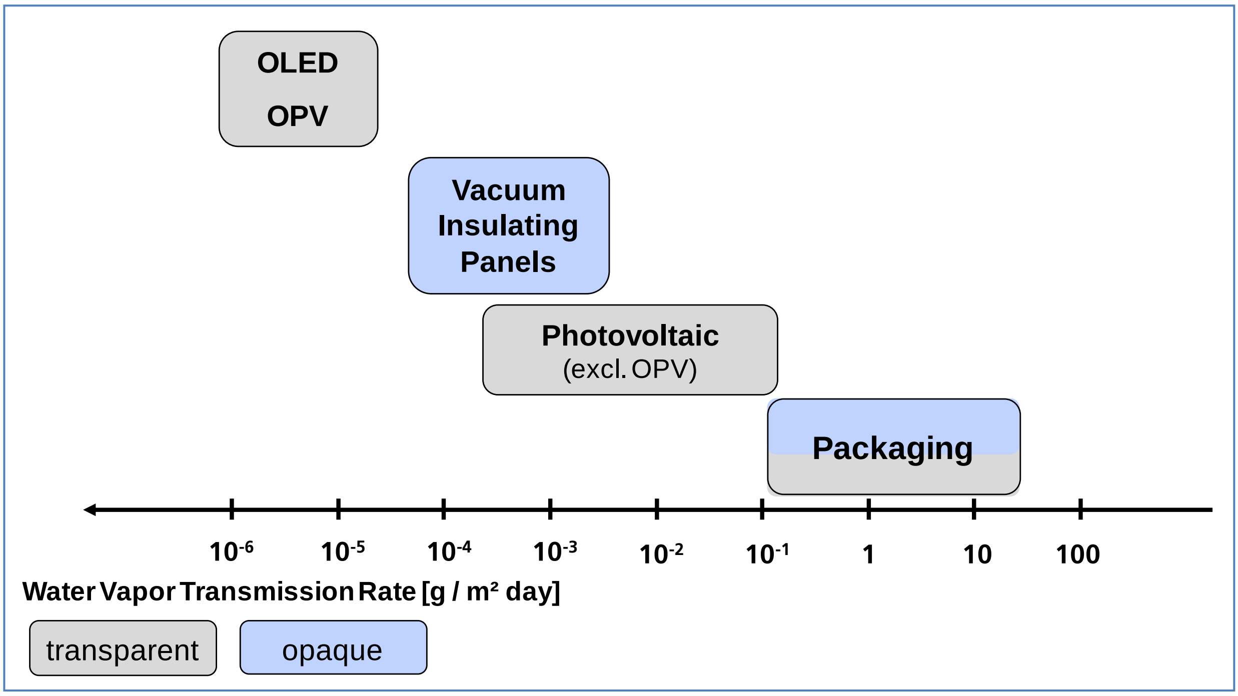


Figure 1: Applications and requirements of barrier films

Product Property	Remark
Optical properties	• Transparency (VIS, NIR, UV)
mechanical resistance	• resistance of barrier against bending, elongation
electrical properties	• high voltage resistance • sheet resistance
temperature resistance	• heat resistance (converting, laminating), e.g. laminating of solar cells 140°C • e.g. solar cells: -40°C to +85°C
resistance to weathering	• UV stability • temperature • water, water vapor • hail
Price	• web speed, web width • overall throughput • investment cost
...	

Table 1: Requirements for transparent barrier films beyond barrier performance

3 FEP' vacuum coating technologies

Models suggest, that barrier performance is controlled by defects or pores in the barrier layer whereas the bulk diffusion through the layer can be neglected. Hence, there are two basic ways to improve barrier performance

- reducing the number of defects within the single barrier layer
- reducing the permeation by multilayer barrier stacks

Fraunhofer FEP follows several approaches as listed in Table 2:

Method	Approach
Hollow cathode Activated Deposition HAD (AlOx)	➢single layer • high rate • low defect by plasma assisted deposition
Sputtering	➢single layer • low defect layer by enhanced process control
magPECVD + Sputtering	➢multilayer • low stress layer stack • tortous path effect
Sputtering + ORMOCER®	➢multilayer • smoothing layer • filling of pores, tortous path effect

Table 2: Approaches of Fraunhofer FEP for transparent barrier coatings
ORMOCER®: Developed within Fraunhofer POLO

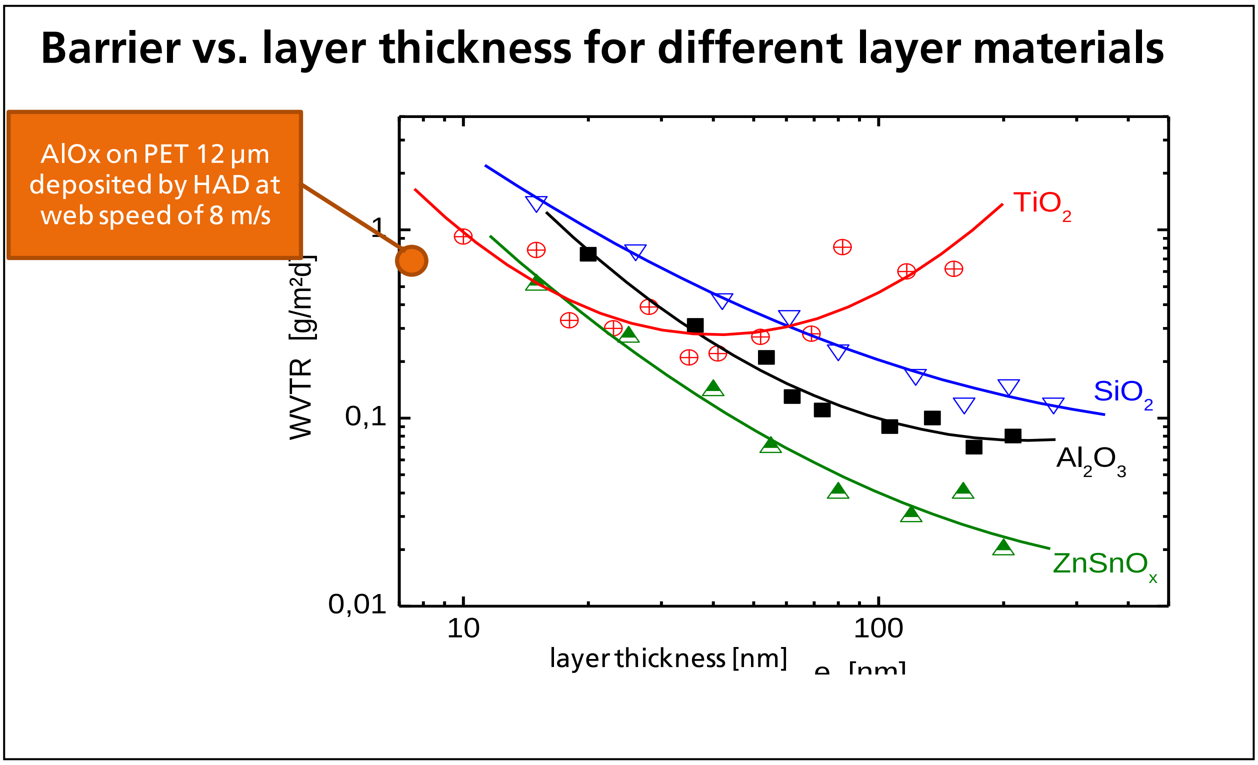
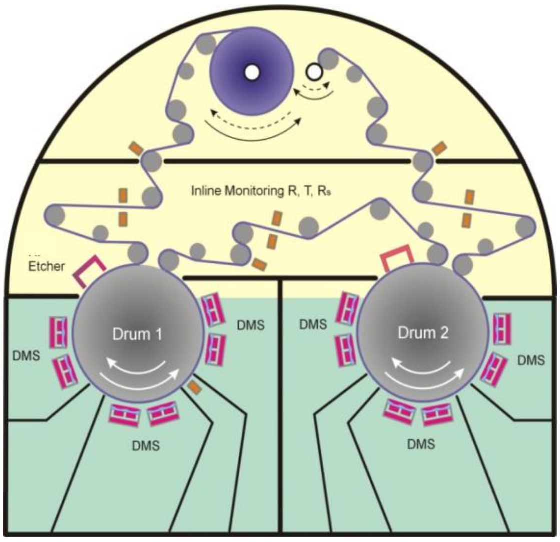
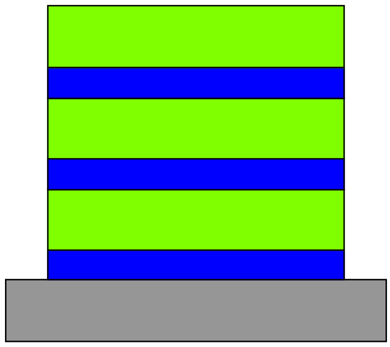


Figure 2: Barrier performance of single layers deposited by sputtering. For comparison to these values, one value is given that has been obtained by evaporation technology (HAD process).

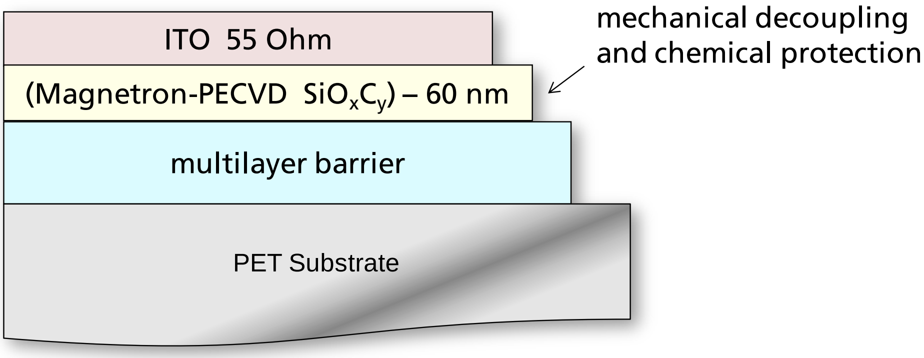
As to the multilayer approach, FEP has developed an all-in-vacuum-technology which is based on the combination of magnetron sputtering and magnetron based PECVD.





all-in-vacuum roll-to-roll deposition of barrier-layer stacks

Example for multifunctional layers with TCO topcoat



- no damage of barrier stack after patterning (chemical etching) of ITO
- successfully tested as substrate for OLED devices and solar cells

4 Summary

- Models suggest that permeation is controlled by defects/pores
- There is no easy relationship between permeation theory and technology development. The only straightforward recommendations given by theory to improve barrier performance are:
  - low defect layers
  - multilayer structures
- Fraunhofer FEP is following several approaches
  - Hollow cathode activated deposition (HAD): single layer, high speed
  - magnetronsputtering: single layer
  - mag PECVD/sputtering: multilayer approach
  - sputtering/ORMORCER®: multilayer approach
    in cooperation with Fraunhofer POLO