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Industrial Production of Encapsulation Materials for Solar Cells

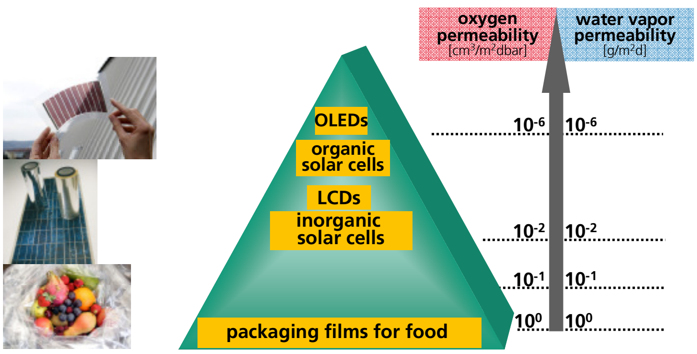
"Development and Upscaling of Nanoscale Transparent Barrier Lacquers based on Hybrid Polymers"

Author: Dr. Sabine Amberg-Schwab
Fraunhofer Institute for Silicate Research (ISC)
Department: Hybrid Coatings and Coating Technology
Address: Neunerplatz 2, 97082 Würzburg, Germany
Phone: +49 (0) 931/4100-620
Email: sabine.amberg-schwab@isc.fraunhofer.de
Website : http://www.isc.fraunhofer.de; http://www.polo.fraunhofer.de

Extended Abstract

Transparent flexible films with high barrier properties are currently in the focus for applications in technical fields like the encapsulation of electronic and optical devices. Electronic devices such as thin film solar cells are very sensitive to environmental exposure due to the high sensitivity of their active layers and electrodes to moisture and oxygen.

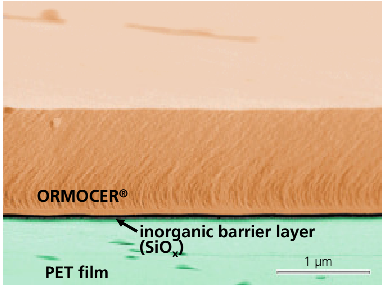
Barrier films for different applications



Polymer films show high flexibility, but have undesirably high permeation values.
To avoid device degradation and to ensure a sufficiently long lifetime the devices need to be enclosed and protected by an encapsulant with high barrier properties. However, the required oxygen and water vapor barrier values are orders of magnitude beyond what can be achieved by current state-of-the-art industrial polymer technologies. Lowly permeable polymer systems have already been achieved by using thin inorganic oxidic coatings via vapor-deposition methods. For very demanding applications like the encapsulation of solar cells their permeability is still too high. Thus, in order to further improve the barrier performance, new multilayer systems have been developed by using nanoscale inorganic-organic hybrid polymers (ORMOCER®s) in combination with vacuum-processed vapor borne or sputtered inorganic thin films like SiOx.

The POLO® concept
High-barrier films

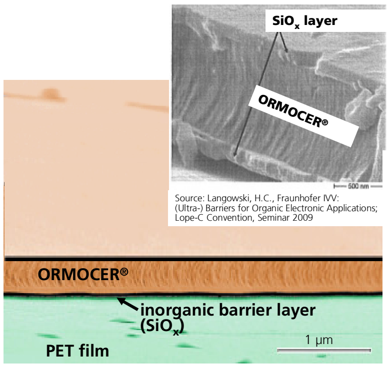
Inorganic vacuum deposited layers
(evaporation, sputtering)
in combination with
thin barrier coatings
based on **hybrid polymers (ORMOCER®s)**
deposited by lacquering techniques



Transmission electron micrograph of a thin hybrid polymer coating on SiOx deposited on a flexible PET film

The POLO® concept
Ultra-barrier films

Inorganic vacuum deposited layers
(evaporation, sputtering)
in combination with
thin barrier coatings
based on **hybrid polymers (ORMOCER®s)**
deposited by lacquering techniques



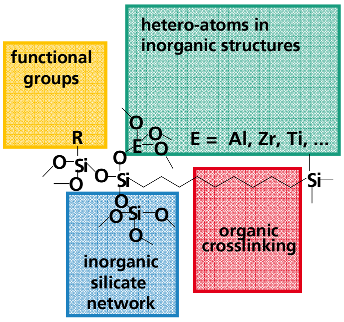
Transmission electron micrograph of a thin hybrid polymer coating on SiOx deposited on a flexible PET film

The barrier coating materials, based on inorganic-organic hybrid polymers, have shown that it is possible to obtain very good barrier properties with respect to the permeation rates of oxygen, water vapor. In combination with inorganic layers (i.e. SiO_x) high and ultra-high barrier properties can be realized. These combined barrier structures are developed and produced within the Fraunhofer Alliance „Polymer Surfaces", POLO® (www.polo.fraunhofer.de). The Fraunhofer Alliance POLO® offers the development of materials and processes for production of polymeric ultra barrier films.

A speciality of Fraunhofer POLO® are barrier coating materials based on hybrid polymers (ORMOCER®s, Trademark of the Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. in Germany). These materials are processed by wet chemical techniques. Their properties can be controlled on a molecular scale between "more inorganic glass-like" and "highly flexible polymer-like". Such nano-composites have strong covalent or ionic-covalent bonds between the inorganic and the organic phases. The materials combine the key properties of their constituents: high transparency, hardness, chemical and thermal stability (glass-like), low processing temperatures, functionalization, toughness (polymer-like) and flexibility (silicone-like). The hybrid polymers are synthesized via the sol-gel process. Organoalkoxysilanes are used as starting materials.

Structural units of hybrid polymers

ORMOCER®s
Trademark of
Fraunhofer-Gesellschaft
zur Förderung der angewandten
Forschung e.V. in Germany



The hybrid polymers show technically interesting properties when applied as coatings on various substrates and are already used on an industrial scale, e.g. as transparent abrasion resistant coatings and for barrier packaging for food and pharmaceutical products.

These coating materials with barrier properties have also been qualified for the encapsulation of inorganic solar cells. Since the solar cells are intended to withstand extreme weather conditions and temperatures, suitable barrier materials had to be developed to meet these requirements. Moreover, the films have to be

robust enough to withstand all the processing and encapsulation processes. Environmentally friendly barrier coating materials have been developed which meet all the required properties for the front side encapsulation of inorganic solar cells.
For large-scale manufacture, cost effective production is a key requirement. Therefore, our barrier lacquers were adjusted for the roll-to-roll coating process and the lacquer synthesis was scaled-up into the production scale.

Transfer of the barrier concept to the market

Beside the barrier properties additional properties had to be achieved:

- **lacquer components that are nonhazardous to health and environmentally friendly**
- **stability in the damp-heat-test (85 °C / 85 % r. h.: 2000 hours)**
- **UV-stability**
- **sufficient stability of the lacquers during processing**
- **long shelf life of the lacquers, preferably without cooling**
- **R2R-processability under production conditions with reproducible and stable coating qualities**

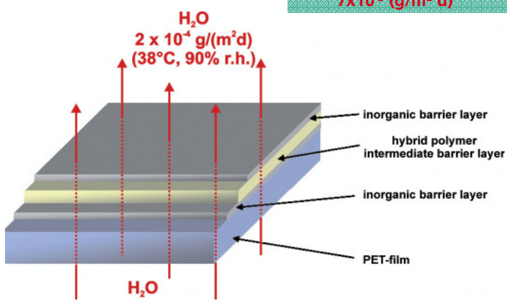
Break-through:
Industrial production of low-cost encapsulation materials for inorganic solar cells at ISOVOLTAIC AG in Austria

ISOVOLTAIC AG in Austria now uses this technology to produce encapsulation films for inorganic solar cells on production scale. New processes for flexible solar cells that enable significant cost reductions in manufacturing flexible photovoltaic modules are now available.

For the encapsulation of OLEDs and organic solar cells ultra-barrier films are required. The Fraunhofer Alliance POLO® has developed a technology for modifying polymer films with a layer system that is almost impermeable to water vapor and oxygen, without significantly influencing the flexibility and optical transparency of the produced films. The technology is based on inorganic barrier layers deposited by reactive sputtering, which are separated by an intermediate barrier layer based on hybrid polymers. The intermediate barrier coating interrupts defect growth in the sputtered layer and provides ideal growth conditions for the second sputtered layer. A commercially available standard PET film was used as polymer substrate. At 38°C and 90% relative humidity the coated film had a water vapor transmission rate of less than $2 \cdot 10^{-4}$ g / (m²d). Adaptation of the layer system to other substrates or according to specific customer requirements is possible.
The films are produced in pilot scale (roll width: 460 mm, roll length: 500 m).

Pilot R2R production of barrier films
Sandwich structure

Calculated for ambient conditions
(23 °C, 85 % rh; factor 2,8)
$7x10^{-5}$ (g/m² d)



Pilot R2R production of barrier films
Sandwich structure

Property	Value
substrate material	PET (Melinex 400 CW, 75 µm)
WVTR* at 38°C/ 90% r.h. (Aquatran)	$< 5 \times 10^{-4}$ g/(m²d)
at 38°C/ 90% r.h. (HighBarSens)	4×10^{-4} g/(m²d)
at 38°C/ 90% r.h. (calcium mirror test)	2×10^{-4} g/(m²d)
at 23°C/ 50% r.h. (calcium mirror test)	8×10^{-5} g/(m²d)
OTR** at 23°C / 0% r.h. (OX-TRAN 2/20)	< 0.05 cm³/(m²d bar)
VLT*** (spectrum adaptable to application)	82%
roll width	max. 460 mm
roll length	max. 500 m

) The water vapor transmission rate was measured on a large area (≥ 100 cm²) at different positions on the film; **) Oxygen transmission rate; *) Visual light transmission*