

# Development of encapsulation material for ultra-barrier applications: latest results

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## Introduction

In order to turn the idea of the mass production of flexible, organic electronics (FOE) into reality, not only the functional layers themselves are in the focus of research and development. Also the encapsulation of those products in a flexible manner is an crucial point. The development of an encapsulation material, which is flexible, transparent and able to fulfil the high requirements resulting from the sensitive FOE devices has been one of the long-time research activities at Fraunhofer IVV. The most important property of such an encapsulation material should be an ultra-high barrier towards the permeation of water vapour and oxygen to avoid deterioration of the functional layers. The research at Fraunhofer IVV focuses on a strategy for fabricating ultra-barrier material at reasonable costs to prepare the industrial production of FOEs. The presentation will cover three key aspects of this research: experimental results of trials in lab and pilot scale, results of theoretical simulations of the permeation mechanisms and the status of the development of a measuring device for ultra-low water vapour permeation.

## Experimental Details

The principle of Fraunhofer IVV for establishing a flexible, transparent ultra-barrier material is to use alternating organic/hybrid and inorganic layers. In particular, on top of a polymer substrate, which delivers sufficient mechanical and thermal resistance, a stack of different transparent barrier layers is applied in such a way that the complete structure delivers the required barriers. Therefore, all layers have to be very thin for ensuring synergistic behaviour in terms of gas permeation. The typically used coating processes are physical deposition in vacuum (e-beam, sputtering) and ultra-thin wet coating. The production processes were monitored by extended permeation measurements, both with standard devices and devices that are able to detect very low permeation rates – one of them being the device for detecting ultra-low water vapour permeation that was developed at Fraunhofer IVV itself.

## Theoretical Details

These experimentally gained permeation data was also used as input for establishing a theoretical model for the permeation of water vapour and oxygen through ultra-barrier multilayer stacks. Based on this model, a simulation tool using Fick's law and a Finite-Differences approach was developed. Due to the vast amount of available experimentally gained permeation data, the model correlates extremely well with the measured reality. Hence, it was used successfully as a forecast tool for ultra-barrier materials.

## Results and Conclusions

During the last 3 years, the water vapour transmission (WVTR) was reduced by 1 order of magnitude, the oxygen transmission rate (OTR) even by 2 orders. With standard industrial coating processes it is now possible to produce roll-to-roll material of high water vapour and oxygen barrier: WVTR of  $10^{-3}$  g/(m<sup>2</sup> d) and OTR of  $10^{-4}$  cm<sup>3</sup>/(m<sup>2</sup> d bar). With such material it is possible to encapsulate flexible, electronic devices of high sensitivity, like organic photovoltaic cells. However, further effort is required for achieving even higher gas barriers, which will be essential for highly sensitive electronic devices such as organic light emission diodes. Very useful for this area of development will be the developed simulation tool as well as the measuring device for ultra-low water vapour permeation. The simulation tool is very efficient in reducing the amount of necessary coating trials and thus speeding up the experimental research when used in combination with the reported experimental data. The measuring device has proven very reliable for both standard and low permeation and we found it an easy to handle/maintain and non-destructive alternative to the otherwise used Calcium mirror test.

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