MECHANICAL DURABILITY OF SINGLE AND MULTI LAYER PERMEATION BARRIERS ON FLEXIBLE SUBSTRATES

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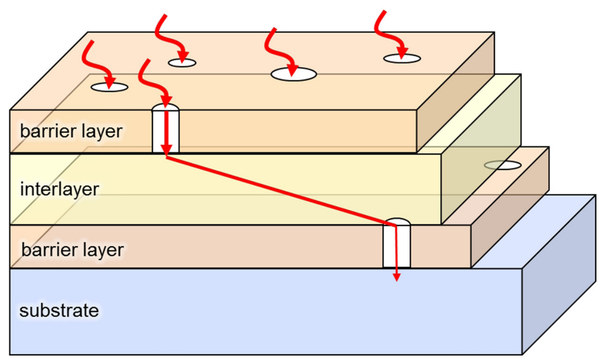
INTRODUCTION

Permeation barrier layers are not only used for food packaging but also needed to encapsulate flexible electronic devices. Multilayer barriers are suggested by many groups for ultra-high barrier applications. Water vapor transmission rates of 10^{-4} g/(m²d) and below can be achieved using multilayers with at least 2 barrier layers and an interlayer (see figure).

The linear strain test is a good method to determine mechanical flexibility and durability of permeation barrier layers and layer stacks covering different types of mechanical load during processing and application (see table below). This paper uses the linear strain test to characterize the flexibility of multilayer barriers that consist of reactively sputtered barrier layers and interlayers grown by magnetron PECVD.

web tension in roll-coaters	200 N @ 400 mm (75 µm PET: E = 3700 MPa)	strain at 20°C: 0.16% strain at 120°C: 0.64%
bending on rollers	3.75 cm radius (75 µm PET)	strain: 0.17%
themal expansion	PET: 7×10^{-5} K^{-1}, ΔT = 100 K	strain: 0.70%



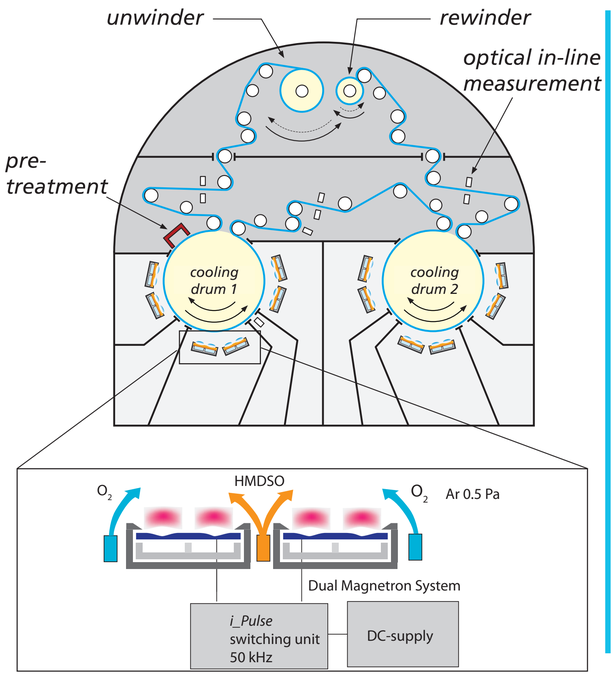
TASKS OF THE INTERLAYER:

- interrupt growth of defects
- reduce mechanical stress compared to thick single layers
- improve flexibility of the system compared to thick single layers
- cover particles with polymer layer and smoothen the substrate surface
- lengthen the path of diffusion for long defect distance in barrier layers

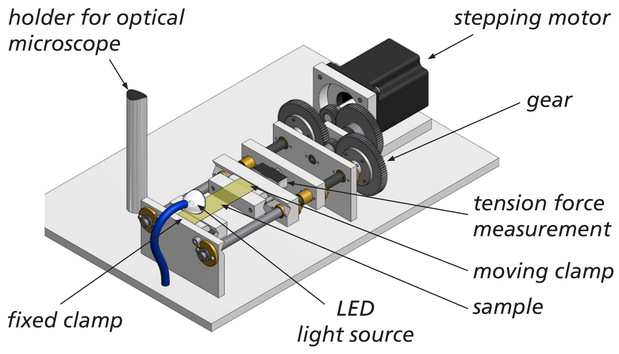
ROLL-TO-ROLL COATING

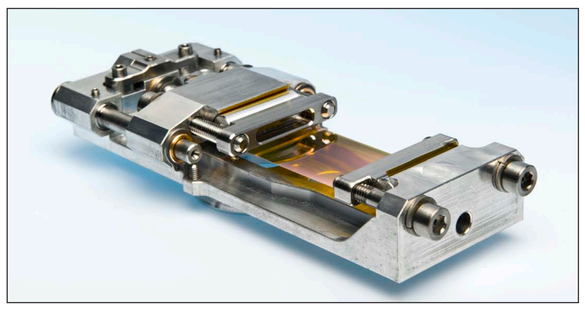
coFlex® 600	
coating width [mm]	600
web speed [m/min]	01. ... 100
coating stations	6
base pressure [Pa]	< 10^{-3}
typical roll length [m]	up to 1000 (@ 75 µm)
substrate thickness [µm]	12 ... 200
substrate materials	polymers, thin metal foils, textiles

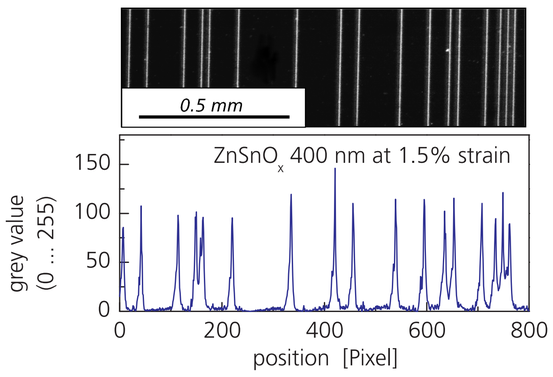
- reactive dual magnetron sputtering of zinc tin oxide (ZTO) from metal target (Zn-52 wt.% / Sn-48 wt.%)
- dual magnetron PECVD using Ti-Targets and HMDSO precursor gas for $SiO_XC_YH_Z$ interlayers

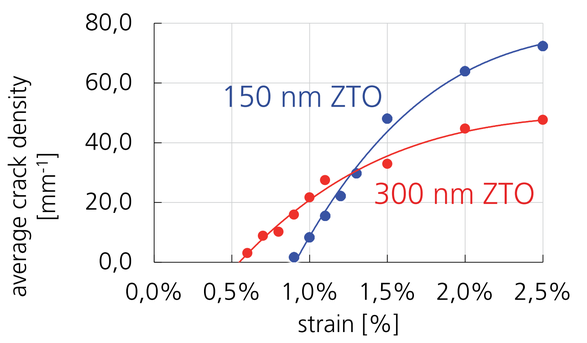


STRAIN TESTING



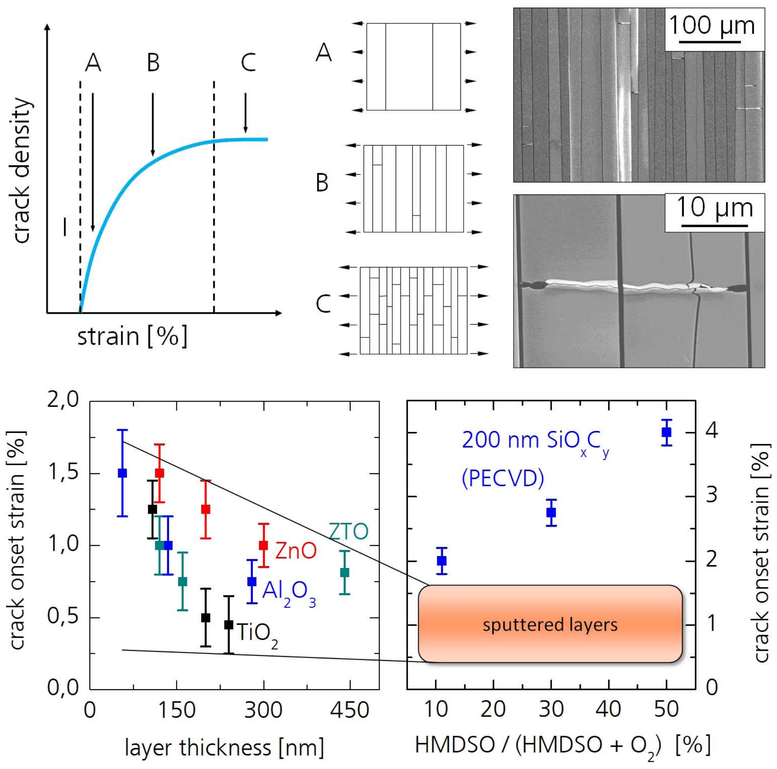




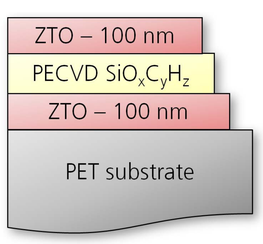


PROPERTIES OF THE MULTILAYER BARRIER

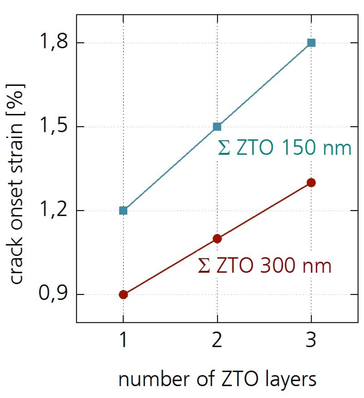
Crack onset in single layers

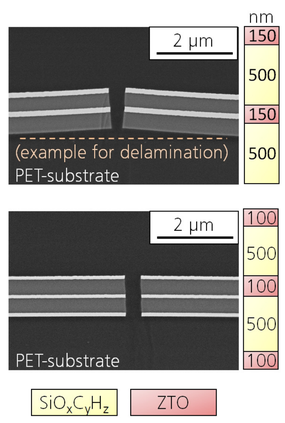


Crack onset in multilayers

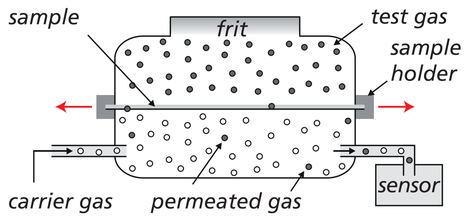


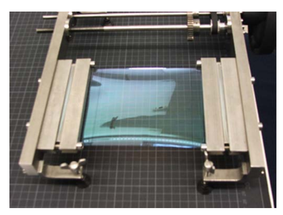
- ZTO … zinc tin oxide Zn_2SnO_4
- multilayer: higher crack onset strain than single layer at same total ZTO thickness
- delaminiation at high strain with PECVD layer first

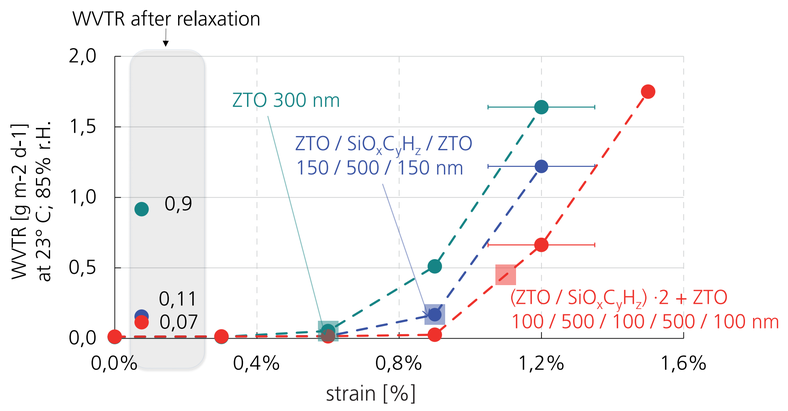




Permeation barrier under strain condition

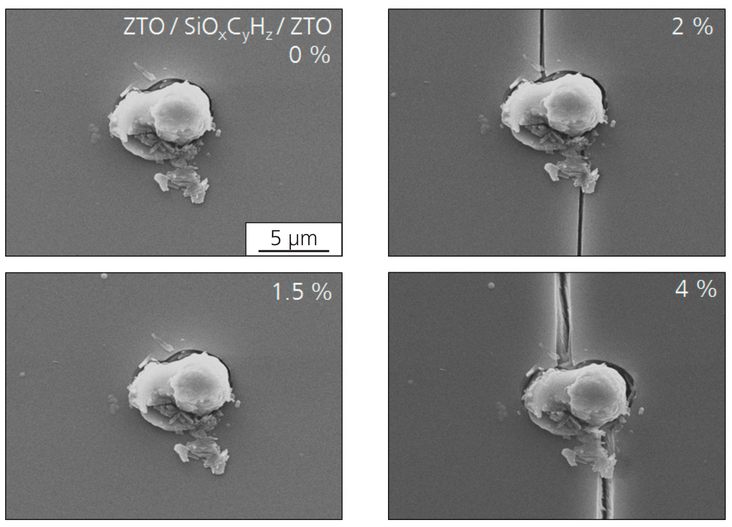






SUMMARY

- crack onset strain of sputtered single barrier layers below 1,5% → cracking at typical processing conditions possible
- PECVD plasma polymer layers: higher crack onset strain
- multilayer stacks increase critical strain compared to thick single layers
- water vapor transmission rate increase postponed to higher strain in multilayer
- low WVTR partially restored in multilayers after strain and relaxation.
- role of large defects in crack onset: no preferred crack onset on large defects observed



OUTLOOK

- characterization of WVTR increase before reaching crack onset strain → calcium test needed
- role of small and larger defects in cracking and WVTR increase under strain
- characterization of different types of multilayers such as the POLO® ultra barrier stack with 2×10^{-4} g/(m²d)
- behavior of ALD barrier layers
- behavior after relaxation: multiple strain and relaxation tests
- relationship between bending and linear strain

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