Roll-to-roll Technology for Transparent High Barrier Films

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1 Introduction

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.

To address the need for roll-to-roll deposition of transparent high barrier coatings, we have developed a concept to deposit multilayer stacks by an in-line combination of reactive pulsed sputtering and a novel magnetron based PECVD-process.

2 Basic concept

The basic concept is illustrated in Figure 1. As several work groups, we suggest a multilayer barrier approach. The common understanding of such a multilayer and working hypothesis is the so called tortuous path effect. Defects within the single barrier layers are being decoupled by the interlayer, such creating a tortuous path for the permeation of gasses.

Our concept is based on the combination of two processes:

- a reactive, MF sputtering process to deposit barrier layers
- a PECVD process using a magnetron as plasma source

The sputtering process is used to deposit single layers with good barrier properties. It is possible to use a wide range of coating materials. The selection of the coating material not only is determined by the required barrier properties but also by deposition rate and refractive index.

The interlayer is deposited by the magnetron PECVD process.

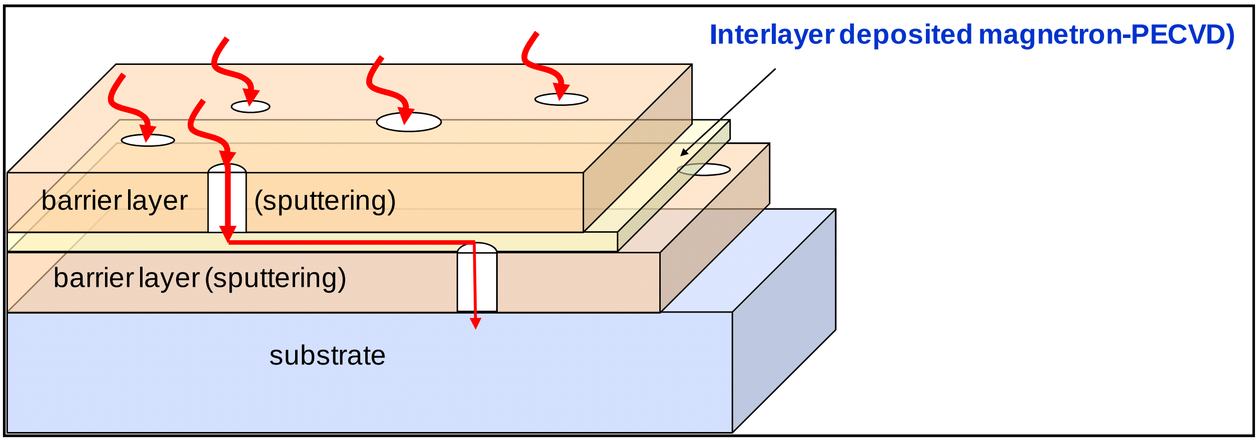

Figure 1: Basic multilayer barrier concept. The barrier layers are being deposited by dual magnetron sputtering whereas the interlayer is being deposited by magnetron PECVD.

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3 The magnetron PECVD-Process

Figure 3 shows the concept of the magnetron PECVD process. A dual magnetron is used as plasma source for the PECVD process. Special attention is being paid to the pulsing mode and power supply. A biploar power supply iPulse®, a joint development by Fraunhofer FEP and Thüringer Leistungselektronik GmbH, works at a pulsing frequency of 50 kHz. In addition to the sputter gas argon, oxygen and a monomer (e.g. HMDSO) is supplied to the process chamber. The monomer is cracked by the magnetron plasma and SiOxCy layers are deposited.

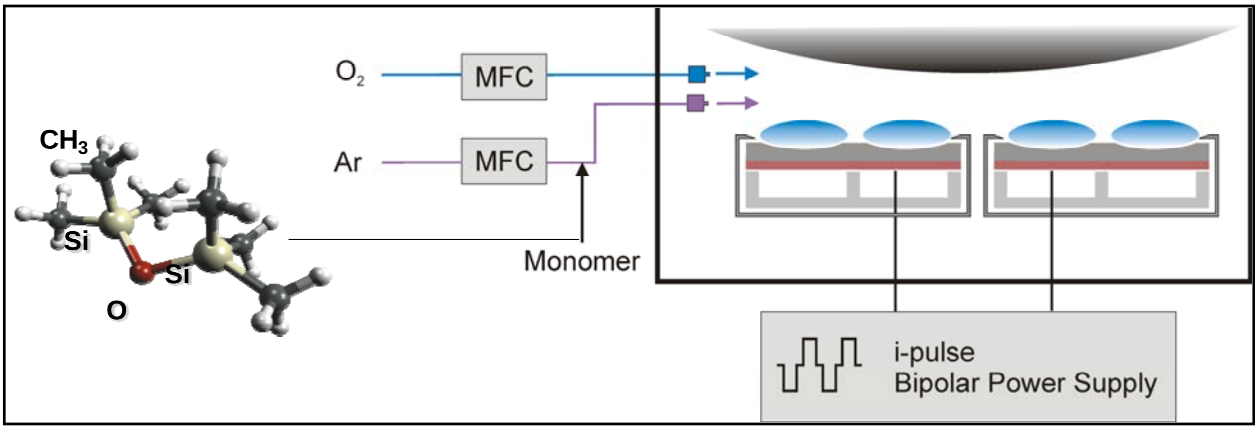


Figure 2: Concept of the magnetron PECVD process

The magnetron PECVD process has been installed into the pilot roll coater *novoFlex®600* (cf. Figure 3). Under these scale-up conditions, the deposition rates have been investigated. Figure 4 shows the deposition rate in dependency on the monomer flow and power level. At an appropriate power level and monomer flow, a deposition rate in excess of 400 nm•m/m can be achieved.

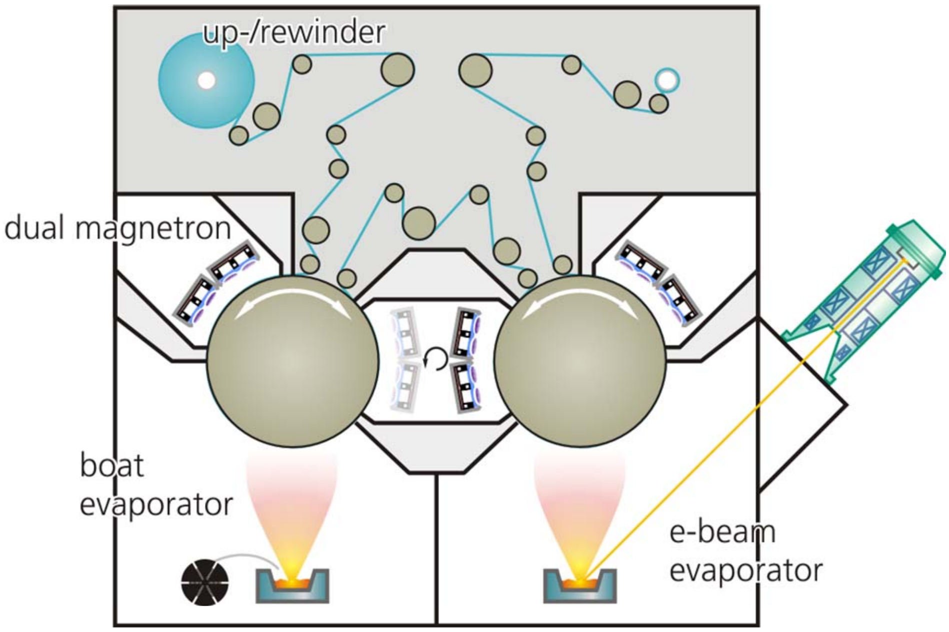
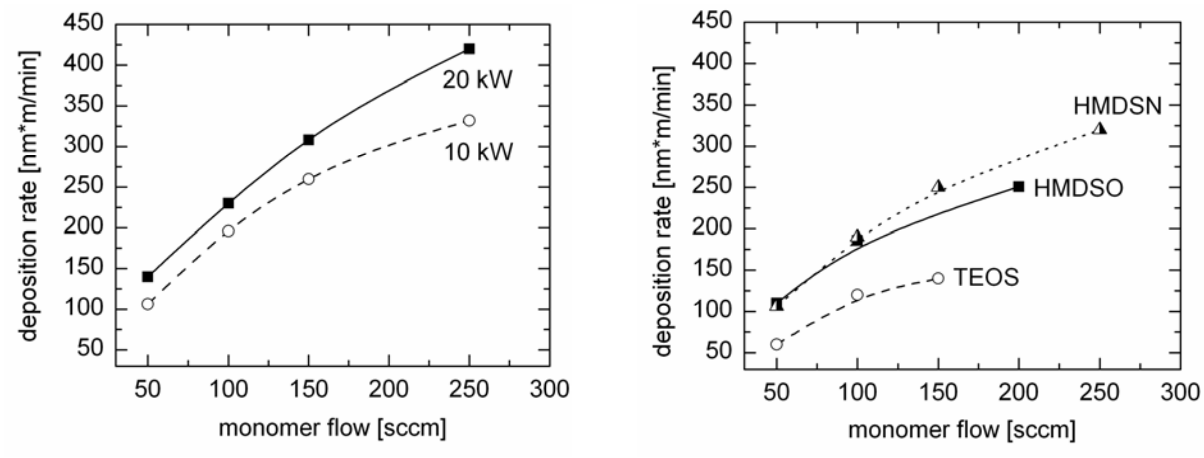


Figure 3: Pilot roll coater *novoFlex®600*



(a) (b)

Figure 4: Deposition rate of the magnetron PECVD process in dependency on the monomer flow
a) for HMDSN at two different power levels
b) for several monomers at a fixed power level of 10 kW

4 Layer properties

Figure 5 shows the composition of a SiOxCy layer in dependence on the relation of the HMDSO flow to the total flow of HMDSO and O_2. As it can be seen in the chart, the content of Si, O, and C, respectively, is influenced by the gas flow composition. With increased HMDSO-flow relative to the total flow, the content of C is increased.
Figure 5 also shows the content of the target material titanium of the magnetron. Only at a low HMDSO-flow some titanium can be found in the layer.

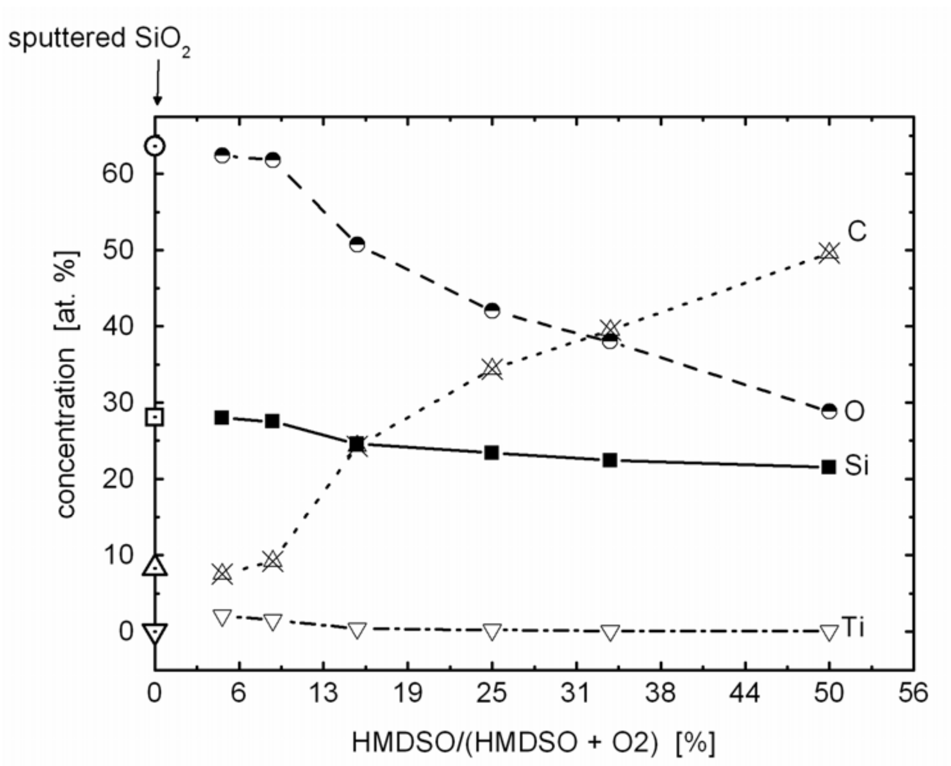


Figure 5: Composition of SiOxCy-layers in dependency on the gas flow of HMDSO and O2 (layer composition determined by XPS).

SiC_xO_y show a lower hardness and a lower internal stress, when compared to SiO2 or SiN layer deposited by sputtering (cf. Figure 6),

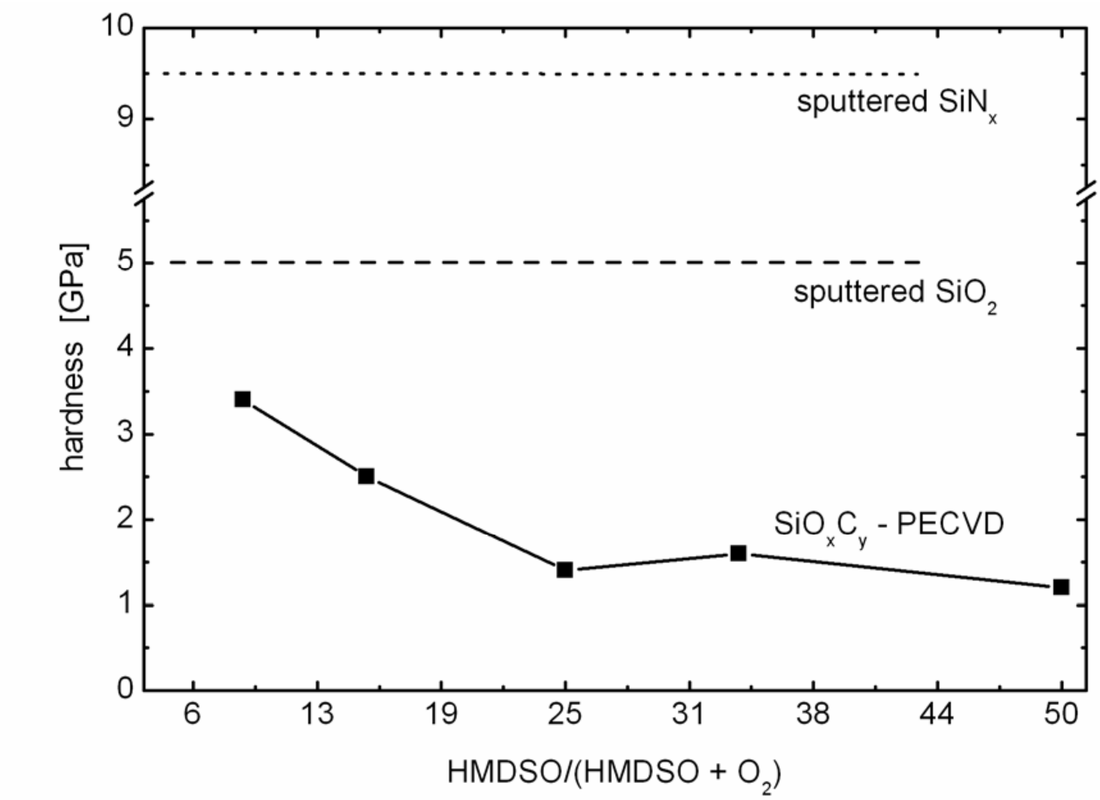


Figure 6: Nanohardness of SiO_xC_y layers in dependency on the gas flow of HMDSO and O_2 (substrate PET, as reference, the typical hardness of SiN_x and SiO_2 layers is shown)

Figure 7 shows the WVTR of a SiO_xC_y-layer, deposited by magnetron PECVD. As it can be seen, the WVTR values decreases with increasing thickness for a relation of HMDSO to O_2 of 7:73.

Figure 9 shows the WVTR of a three layer stack in comparison to a single layer (Figure 8).

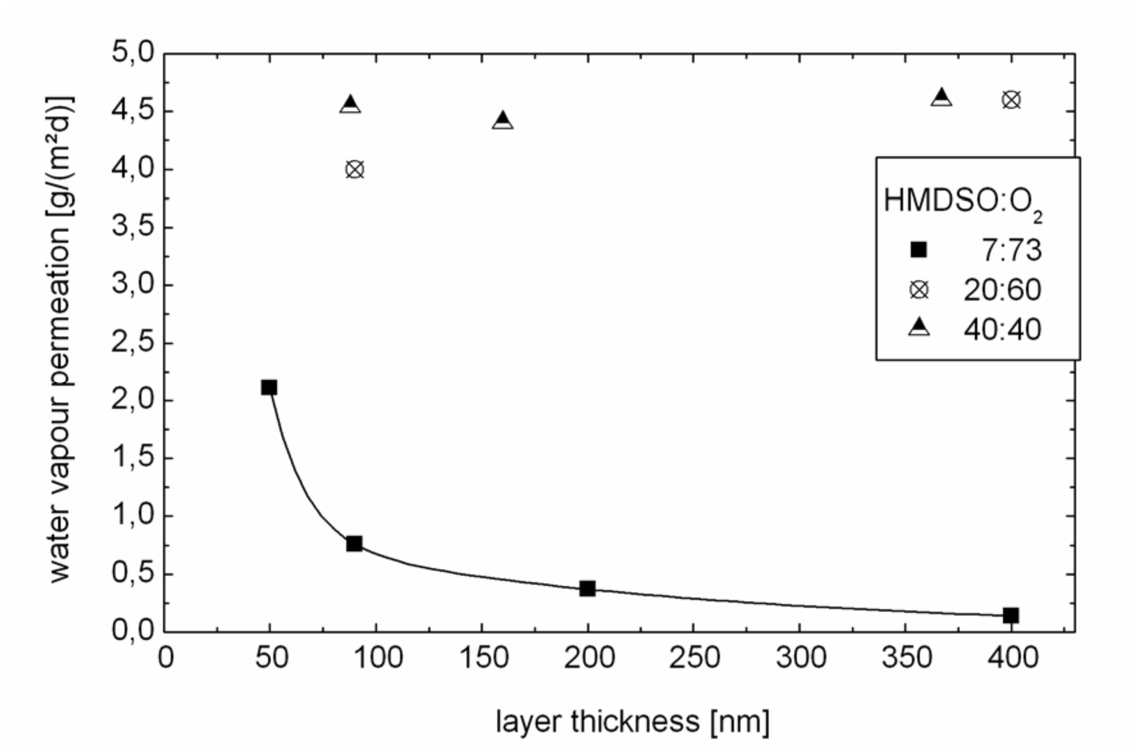


Figure 7: Water Vapor Transmission Rate of SiO_xC_y layers, deposited by magnetron PECVD (Substrate PET, 125 µm, WVTR measured at 38°C and 90% r.h.)

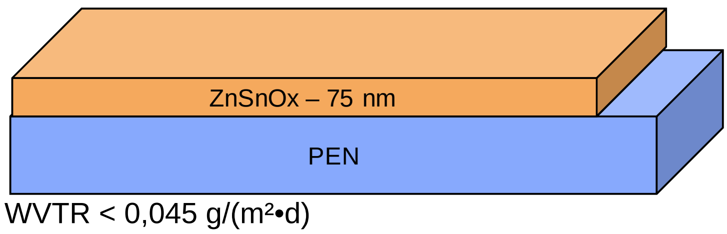


Figure 8: Single ZnSnOx layer, deposited by sputtering (substrate 75 µm PEN, WVTR measured at 38°C and 90% r.h.))

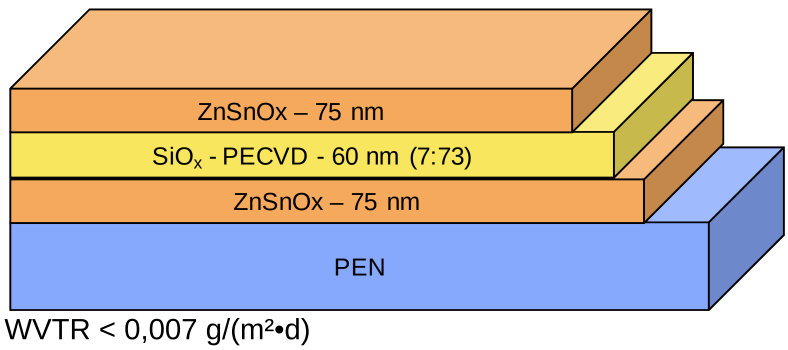


Figure 9: Three layer stack ZnSnOx (sputtering)/ SiO_xC_y (magnetron PECVD)/ ZnSnOx (sputtering) (substrate 75 µm PEN, WVTR measured at 38°C and 90% r.h.))

5 Summary

A novel concept for the all-in-vacuum, roll-to-roll deposition of multilayer barrier stacks has been presented. The basis of the concept is the in-line combination of magnetron sputtering and a magnetron PECVD-process.

The magnetron PECVD process offers several benefits

- low working pressure of 0.5 Pa up to few Pa, thus allowing the in-line combination with sputtering process
- wide range of properties for SiO_xC_y layers
- high potential for large area processing by using dual magnetrons as power source
- high coating rates (> 400 nm•m/min)

Our basic concept allows an all-in-vacuum roll-to-roll deposition of multilayer barrier stacks. The process has been installed in a pilot-cale multi-chamber pilot roll to roll coater. Development work is currently going on to optimize the deposition technology and layer stack to achieve high barriers.