Electron Beam Curable Varnishes –

Rapid Processing of Planarization Layers on Polymer Webs

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Introduction

Transparent planarization layers can be used in various fields of applications. These include the wide filed of flexible electronics, where planarization layers are necessary for organic electronics like thin-film transistor displays, light emitting diodes or photovoltaics. Additionally, planarization layers can be utilized for antimicrobial surfaces.

In recent years, a range of transparent planarization layers have been developed. However, there is still a need to reduce the amount of defects on the surface of different flexible substrates while reducing the production costs.

Electron beam (EB) cured varnish layers can be an approach to economically realize planarization layers on all kinds of flexible substrates, e.g. polymer webs.

Electron beam cured varnishes

The EB technology is characterized by a high production speed, compact, robust equipment and a low temperature impact on the used substrates. These properties enable the EB technology to be integrated in a roll to roll coater.

The EB varnishes consist of monomers, oligomers and different kinds of additives, which all contain reactive carbon-carbon double bonds and crosslink to a solid film. Hence, all components influence the properties of the varnish film. Solvents and photoinitiators are not required and the varnishes have a high conversion level.

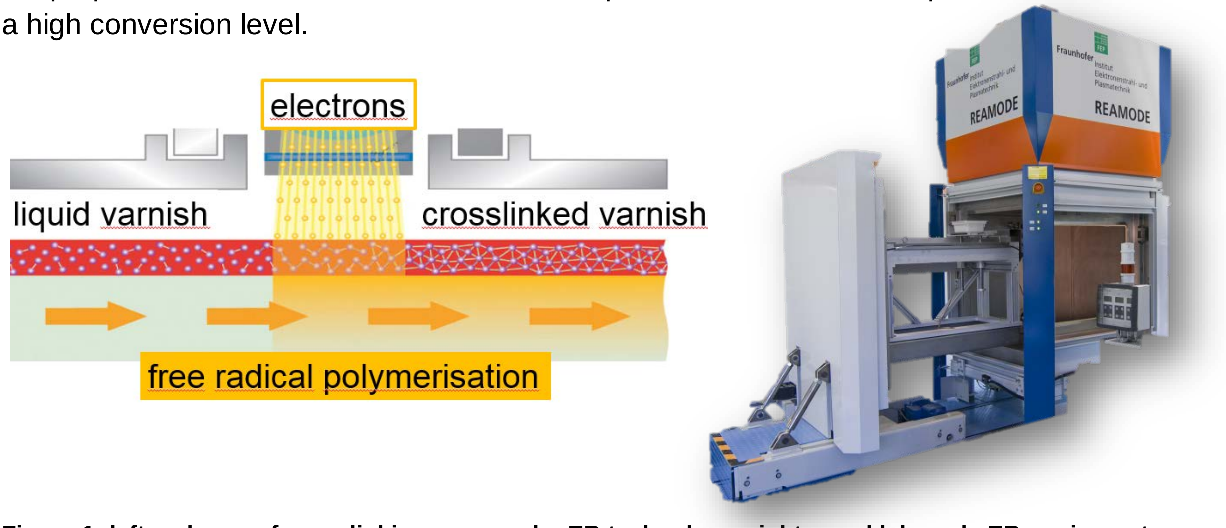


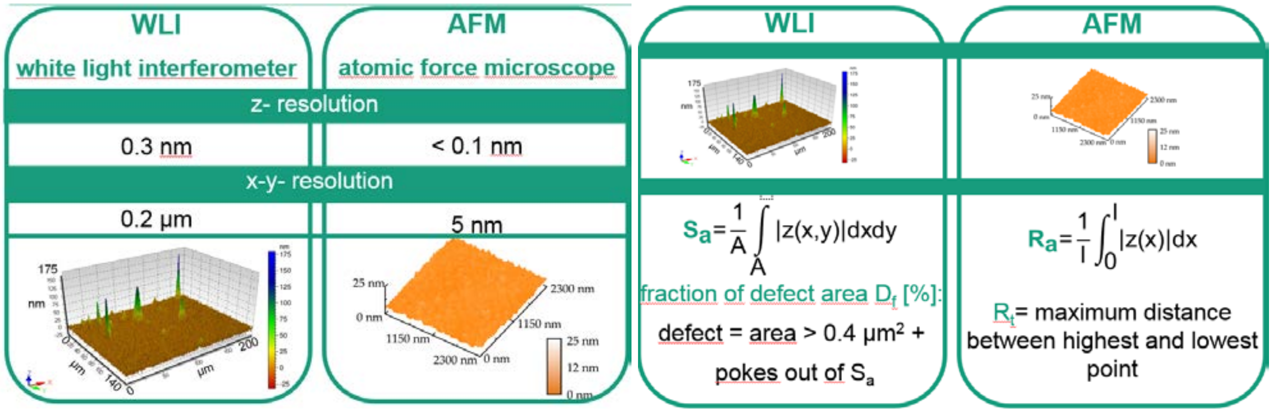
Figure 1: left: scheme of crosslinking process by EB technology, right: used lab scale EB equipment

<u>Experimental setup and parameters:</u>

- substrate: polyethylene terephthalate (PET) *Melinex 401 CW,* A5 format
- varnish deposited by wire-bar applicator
- wet varnish layer thickness: 20 µm

- EB parameters:
  - EB dose: 45 kGy
  - EB acceleration voltage: 150 kV
  - EB current: 6 mA
  - motion speed of the coated web: 266 mm/s

Characterization methods:



The morphological characteristics of the EB cured coatings were evaluated by white light interferometry (WLI) and atomic force microscopy (AFM). The gained data were filtered using a robust Gaussian filter (ISO 16610-31) with a cut-off wavelength of 16 µm. Furthermore, the surface was cut by 10% around the edges to compensate for errors caused by the filter. The resulting surface was used to estimate the arithmetic average surface roughness (S_a) (ISO 25178-2) and the fraction of defect area. The latter is defined as an area which is covered by defects relating to the total measured area. Everything which exceeds an area of 0.4 µm^2 and a height or depth larger than the S_a value is defined as a defect.

AFM images of the coatings in non-contact mode were recorded by an *Explorer* atomic force microscope by *Topometrix* using a silicon tip (tip diameter: 7 nm) and a scan speed of 4.6 µm/s. The profile roughness parameters arithmetic average roughness (R_a) and total height of the roughness profile (R_t) were determined according to ISO 4287.

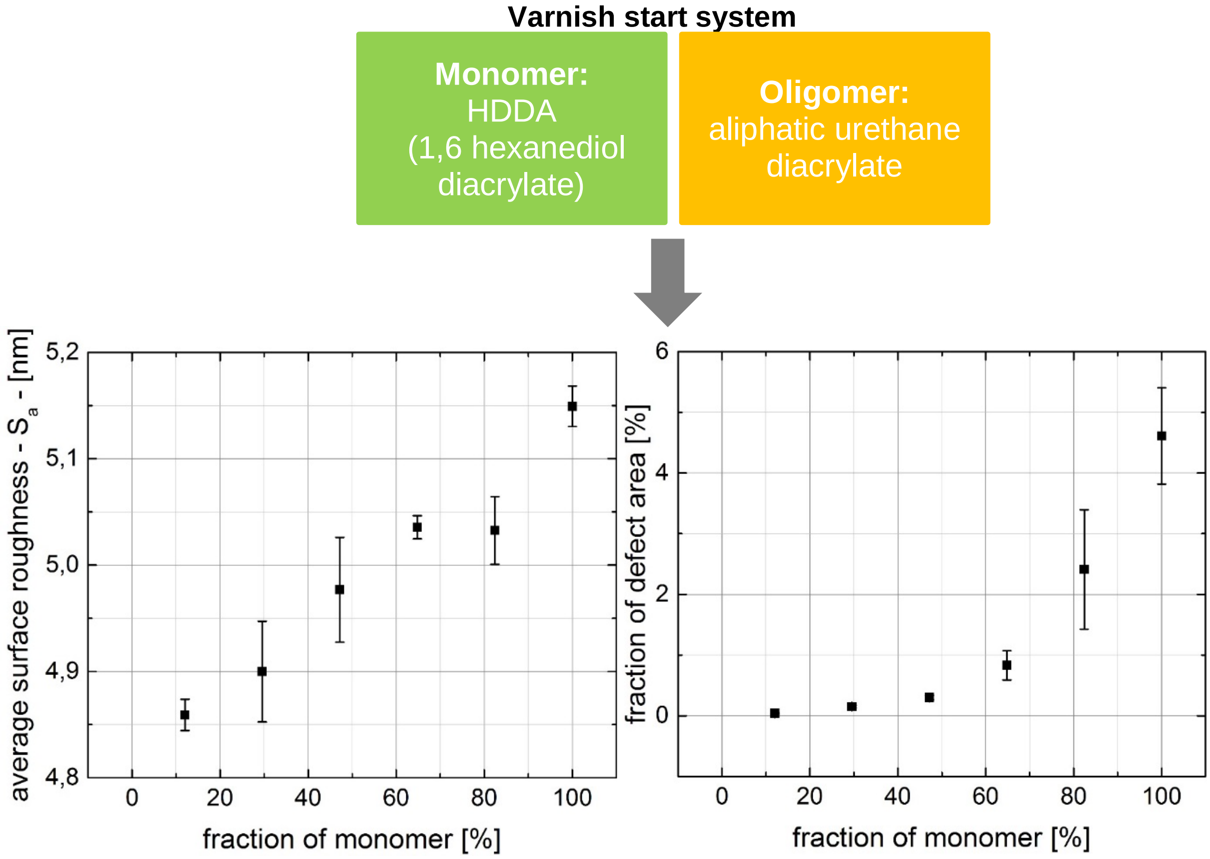


Figure 2: average surface roughness and fraction of defect area in relation to the fraction of monomer

The average surface roughness and the fraction of monomer both increase with increasing monomer content of the varnish.

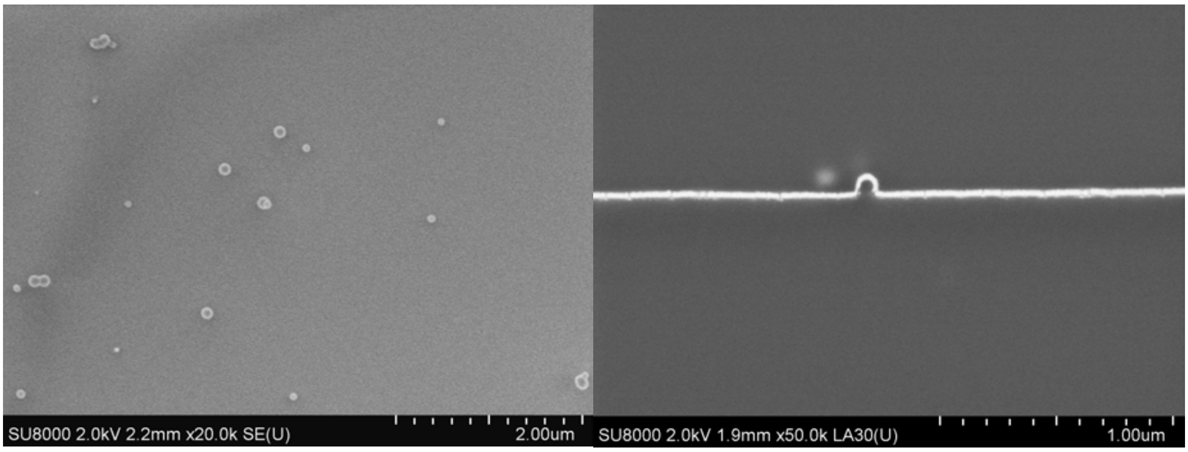
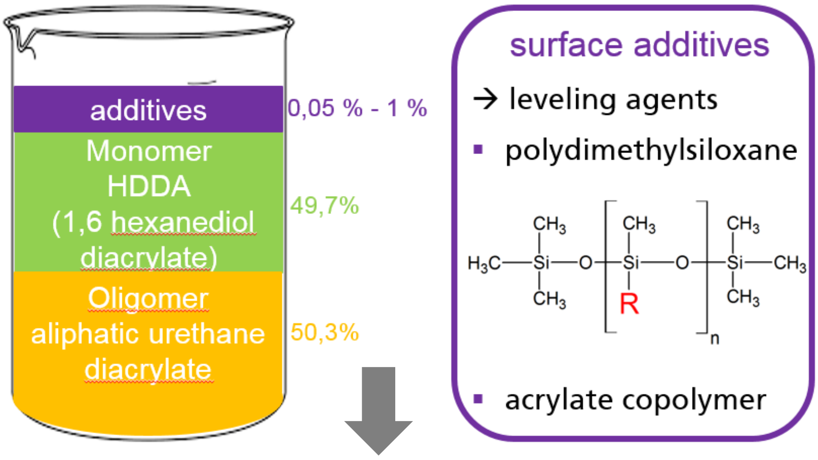


Figure 3: SEM images of defects on varnish surface

The defects could be caused either by polymer aggregates, which are generated during the polymerization process, by cyclization or the generation of free polymer chain ends.

Varnish start system with surface additives



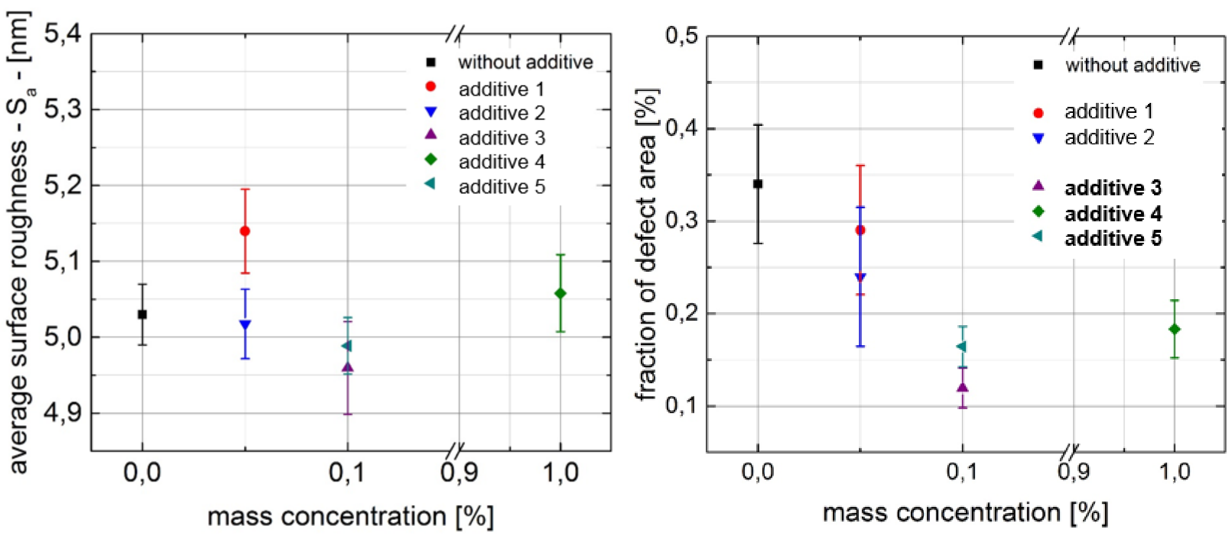


Figure 4: average surface roughness and fraction of defect area in relation to the fraction of monomer

There is no change in the average surface roughness, when surface additives were added. A significant decrease of the fraction of defect area for the additives 3,4 and 5 is demonstrated.

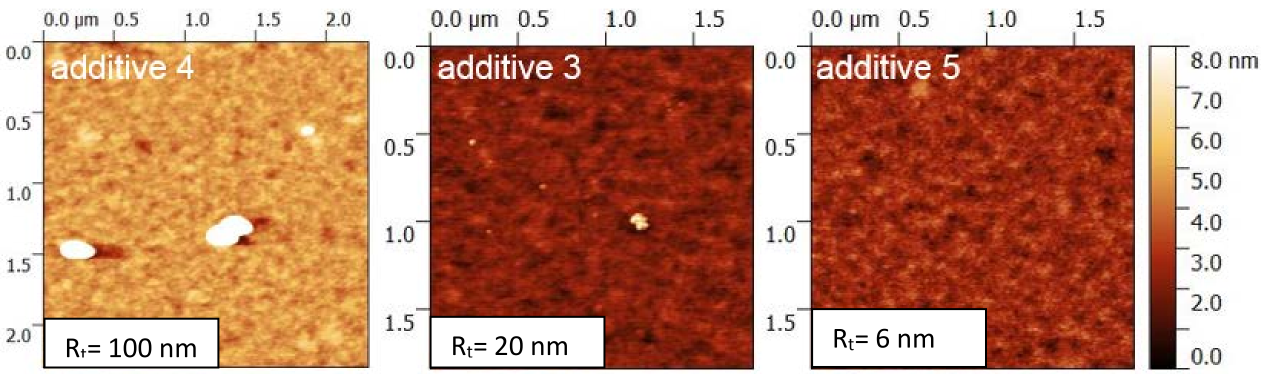


Figure 5: AFM images of varnish with different surface additives

The AFM images show decreased defect heights by using the surface additives 3, 4 and 5.

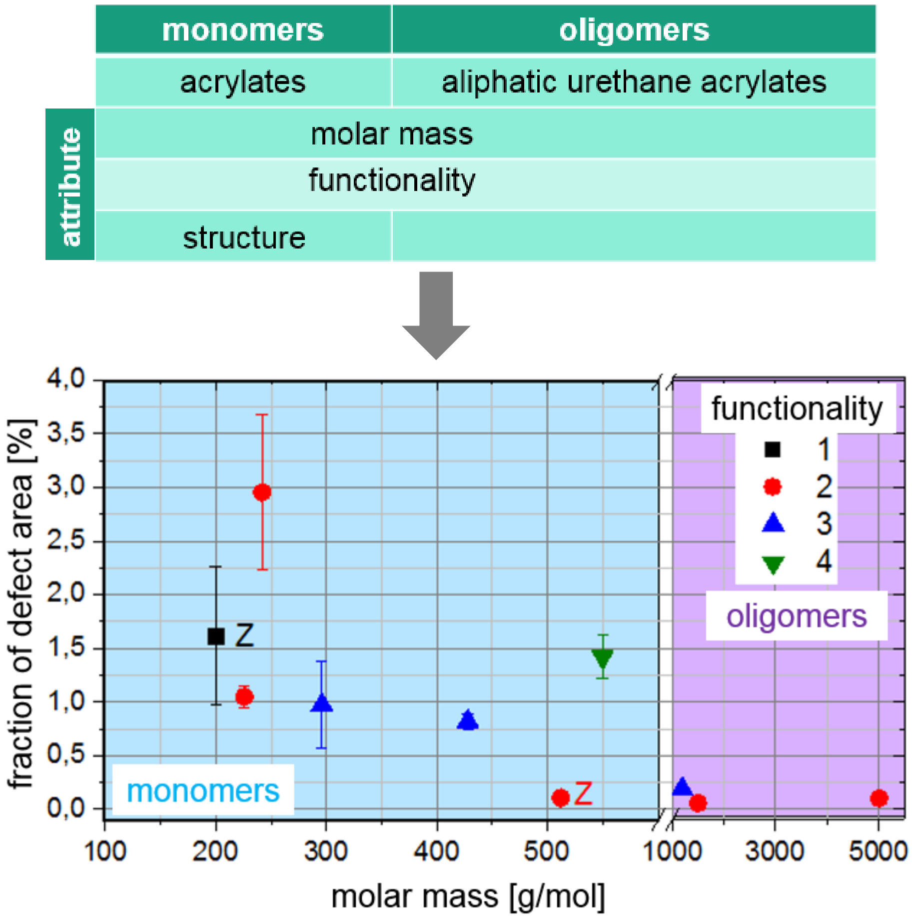
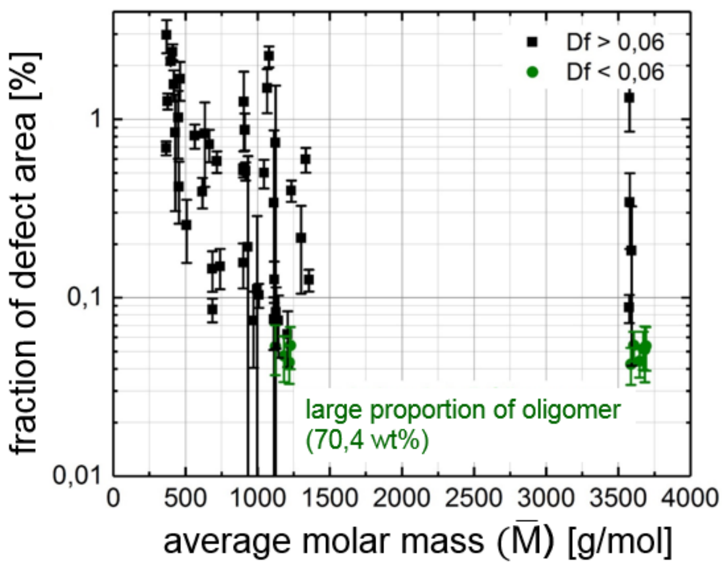


Figure 6: fraction of defect area in relation to the molar mass of various pure monomers and oligomers (Z= cyclic structures in monomer)

The fraction of defect area is decreasing with increasing molar mass. An influence of the functionality of the components (monomers and oligomers) and the fraction of defect area cannot be seen.



$$\bar{M} = x_{monomer} \cdot M_{monomer} + x_{oligomer} \cdot M_{oligomer}$$

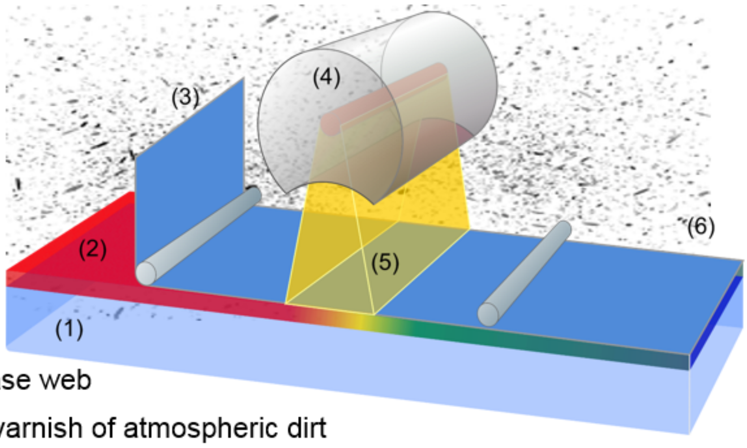
Figure 7: fraction of defect area in relation to the average molar mass of various varnishes

A fraction of defect area of less than 0.06% could be reached with some varnishes with an average molar mass of approximately 1200 g/mol and some with an average molar mass of approximately

3600 g/mol. The similarity between all varnishes, which reached a fraction of defect area of less than 0.06% is a high amount (70.4 wt %) of oligomer in the varnish.

Electron beam varnishes with smoothing release web

There is a lot of dust in an industrial surrounding. If a roll to roll coater is placed there, defects on the varnish surface can appear. A possible approach to minimize the influence of defects through particles, is a coater, which laminates a smoothing release web onto the wet varnish layer.



1) substrate
2) wet varnish
3) smoothing-release web
   → protects wet varnish of atmospheric dirt
4) linear Electron Beam system
5) EB curing area
6) Cured varnish film with smoothing-release web
   → protects cured varnish film of atmospheric dirt

Figure 8: scheme of laminating process with smoothing release web

The requirements for those smoothing release webs are:

- a low / no adhesion to the varnish (surfaces with low surface energy needed)
- a smooth, defect free surface
- a high electron beam stability to ensure multiple utilization

Selected webs:

- commercially available release webs for smooth surfaces (siliconized PET webs)
- polymer webs with low surface energy (e.g. fluoropolymers, polypropylene)
- coated polymer webs
  - o metallic
  - o oxidic

	S_a	D_f
web type	of varnish layer	
commercially available release webs	9 nm - 140 nm	5% - 35%
polymer webs	8 nm - 30 nm	8% - 24%
metallic coated PET (Al)	~ 5 nm	0,2% - 0,4 %
oxidic coated PET, PC, PEN	**5** nm - 9 nm	**0,05%** - 12%

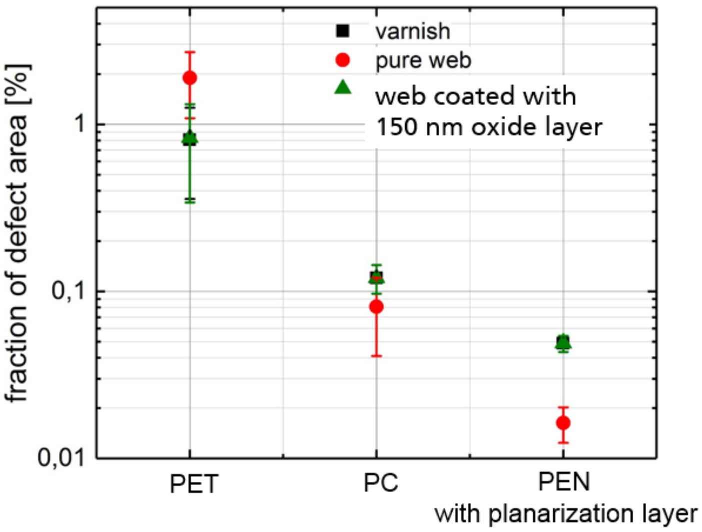


Figure 9: fraction of defect area of different polymer webs, oxide coated polymer webs and the resulting varnish surface

The lowest fraction of defect area can be reached by using an oxide coated polymer web, which has a smooth and defect free surface.

Conclusions

Electron beam cured varnishes

To get a smooth surface with less defects:

- fraction of monomer ↓
- molar mass ↑
- content of oligomers in varnish ↑
- add surface additives ↑

Electron beam varnishes with smoothing release web

- lowest fraction of defect area
  by using oxide coated polymer webs
  - surface quality of oxide surface
    depending on substrate surface quality

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