Electron Beam Curable Varnishes – Rapid Processing of Planarization Layers

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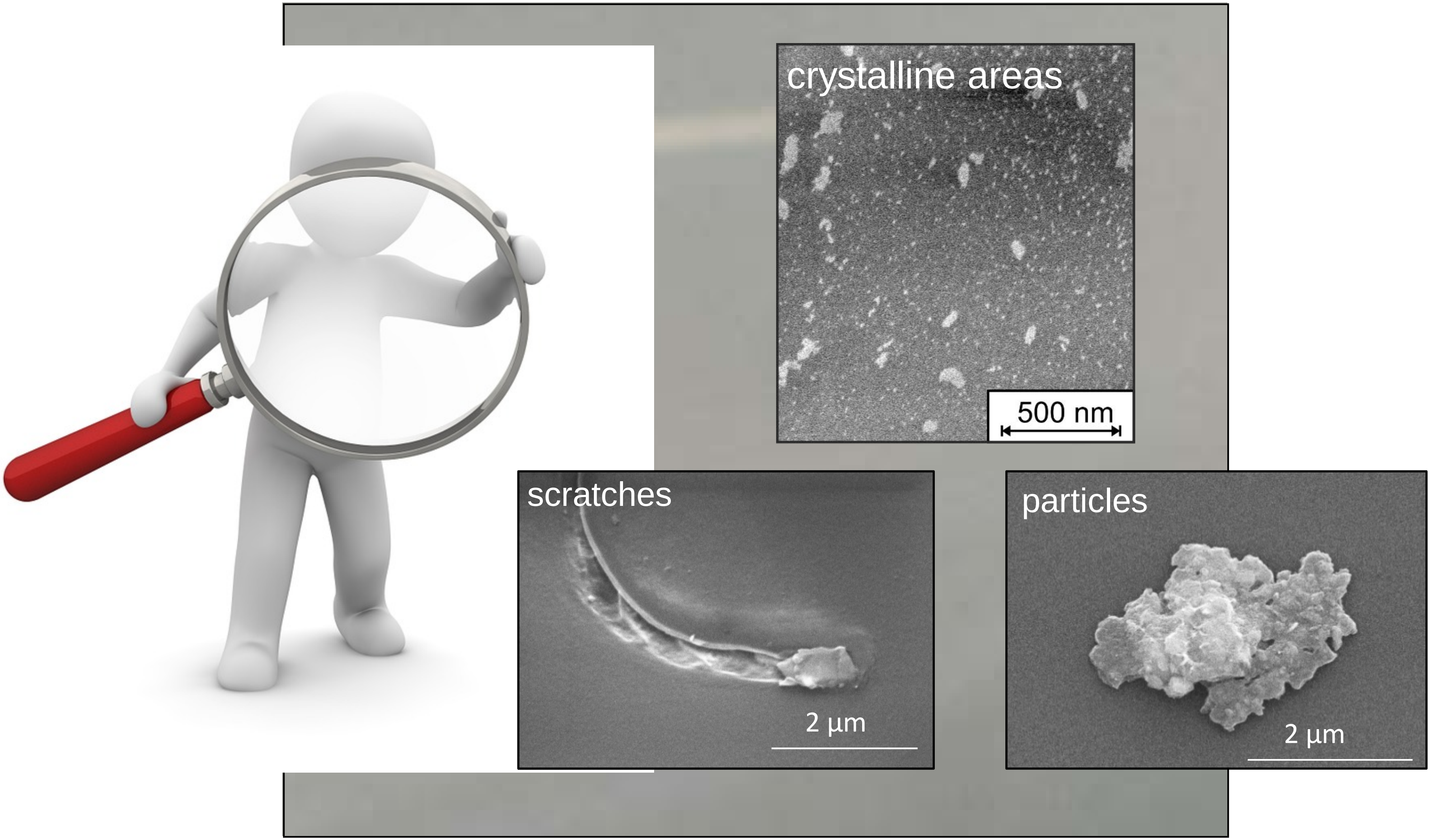
What is a Plane Surface?



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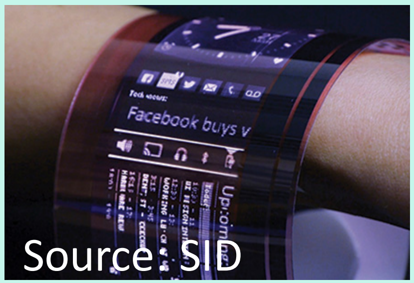
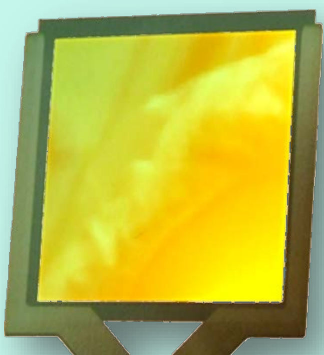
Motivation – Applications of Planarization Layers

flexible electronics

flexible OTFT display

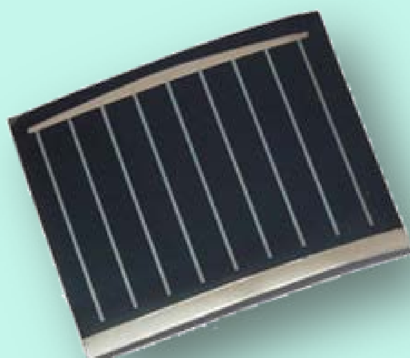


Source: SID



flexible OLED
for lightning

flexible solar cell



antimicrobial surfaces

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FEP Approaches for a Plane, Defect Free Surface

➡ Electron beam (EB) curable varnishes

➡ EB curable varnishes + Smoothing – Release web

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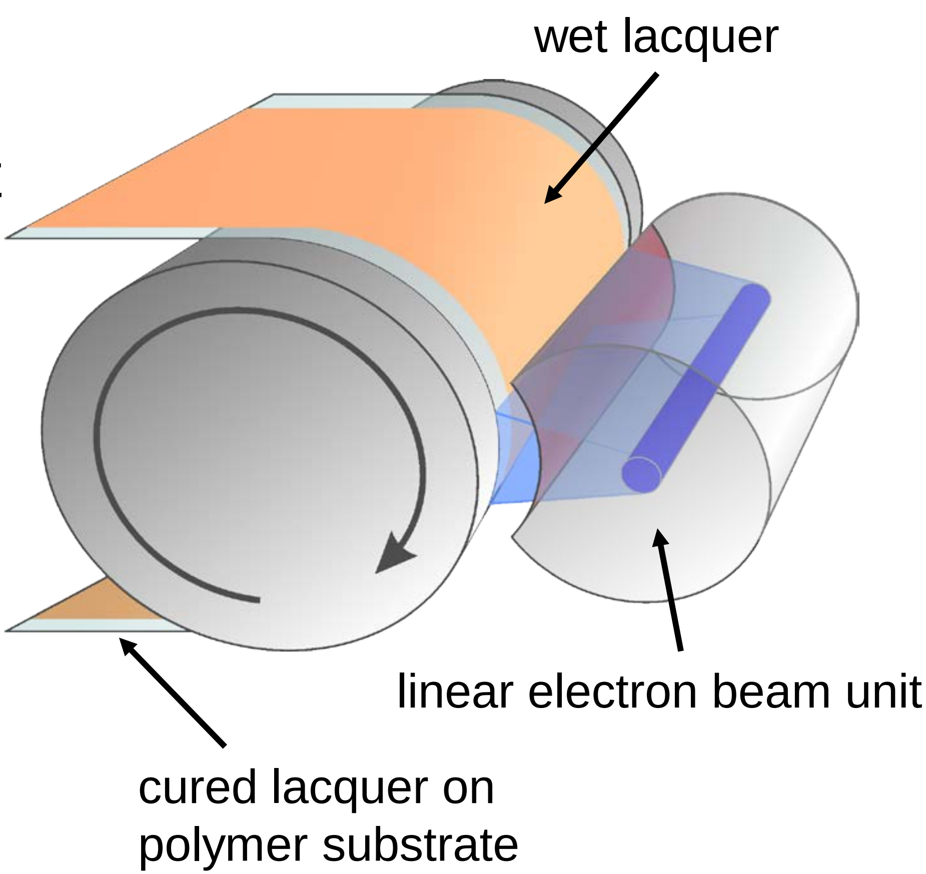
Electron Beam Curing

Technical benefits:

- high production speed
- compact, robust equipment
- low temperature impact
- no photoinitiators needed
- no solvents in the varnish needed
- high conversion levels



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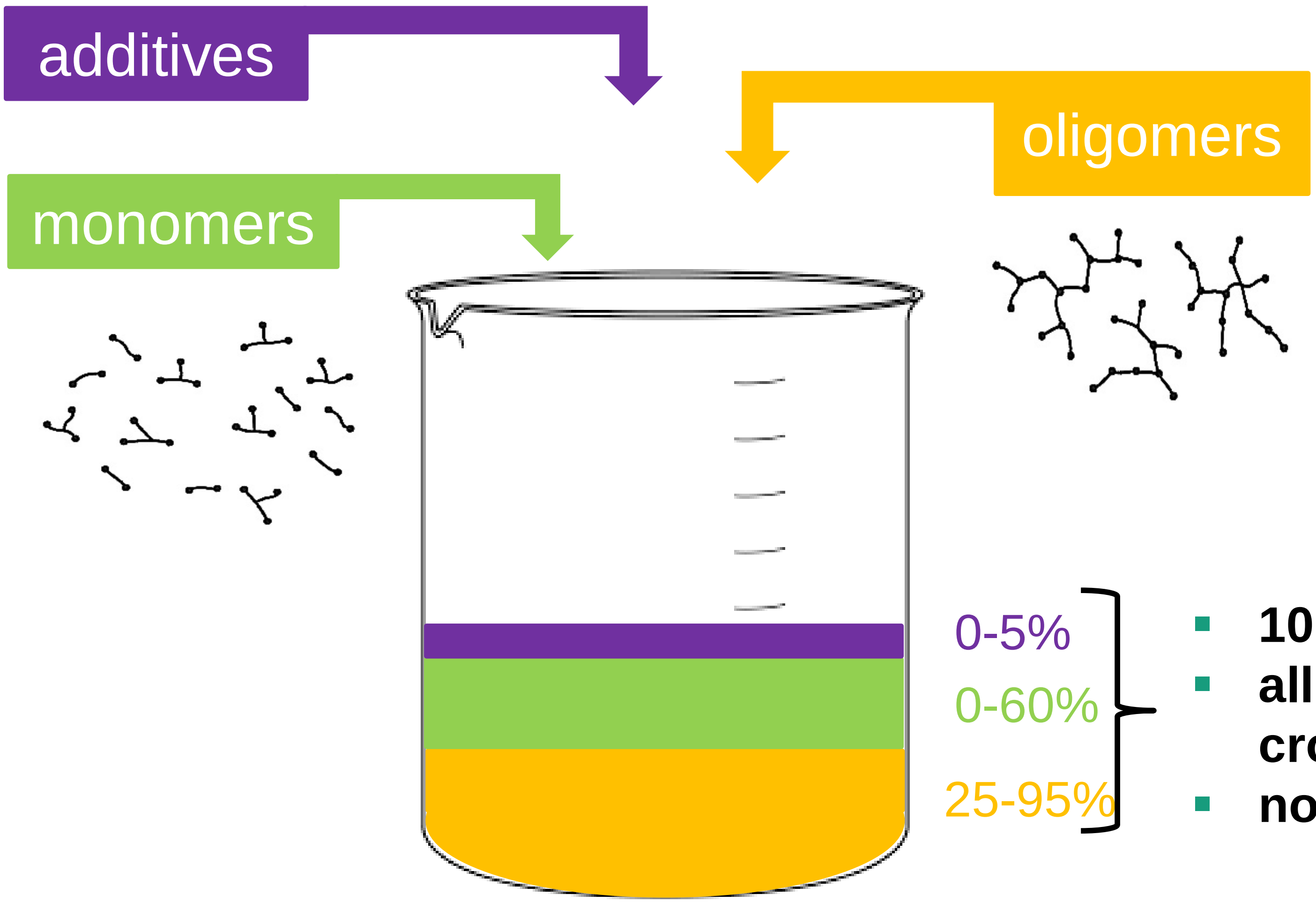
Composition of EB Curable Varnishes



- **100% systems**
- **all components crosslink**
- **no solvents!**

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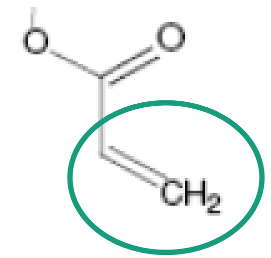
EB Curable Varnishes

- all used components are reactive
  → contain carbon-carbon double bonds



- oligomers and monomers influence:
  - reactivity
  - viscosity
  - flexibility/ hardness
  - chemical and weathering stability
  - scratch resistance

  → by variation of:
  - resin chemistry (e.g. epoxy, urethane, polyester/-ether)
  - molar mass
  - functionality

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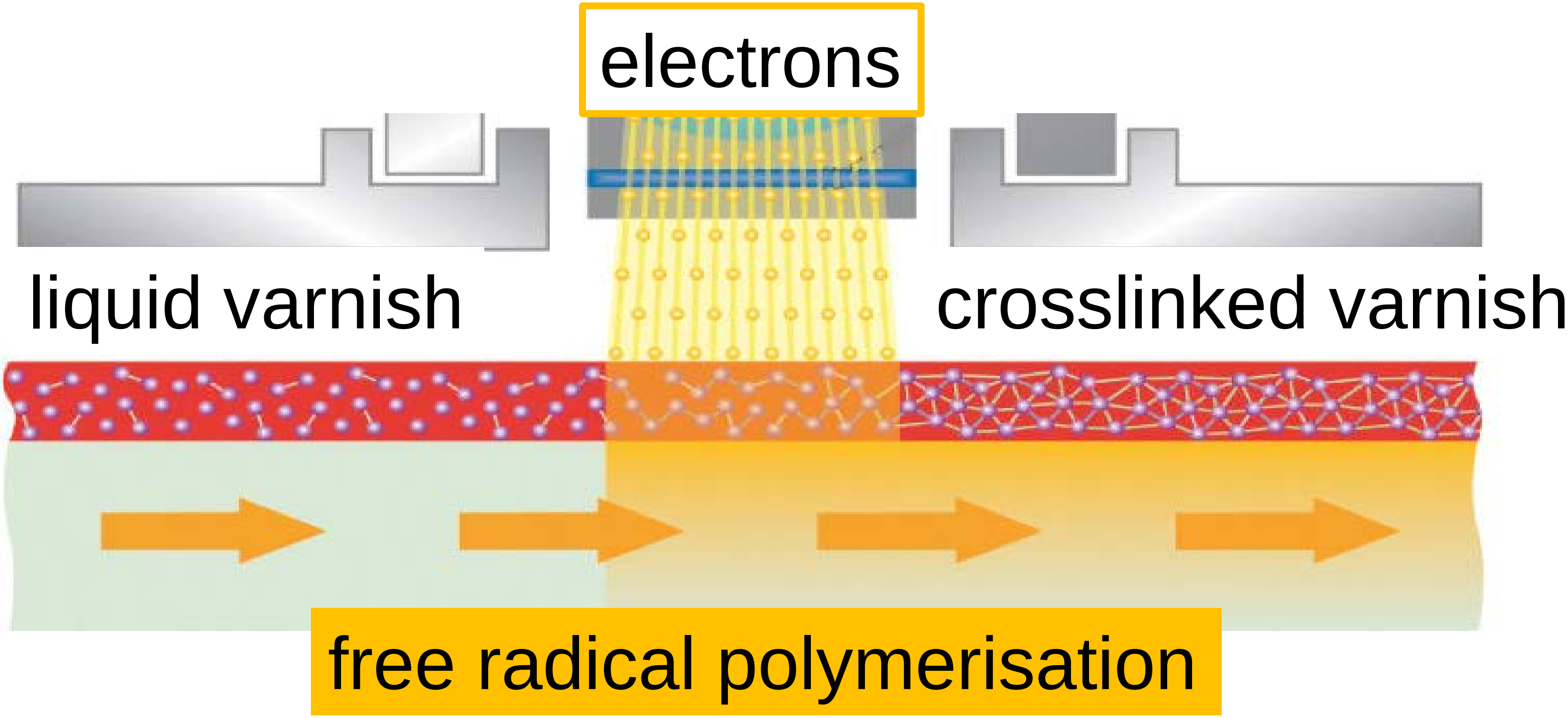
EB Curable Varnishes – Film Formation



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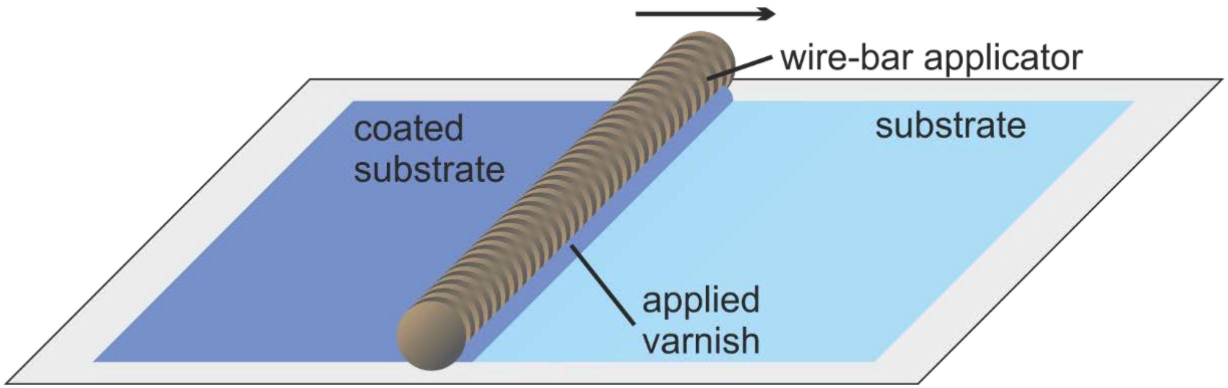
Varnish Layer Manufacturing



- substrate: PET web (75 µm)
- layer thickness: 20 µm
- EB dose: 45 kGy
- EB acceleration voltage: 150 kV
- EB current: 6 mA
- motion speed: 266 mm/s

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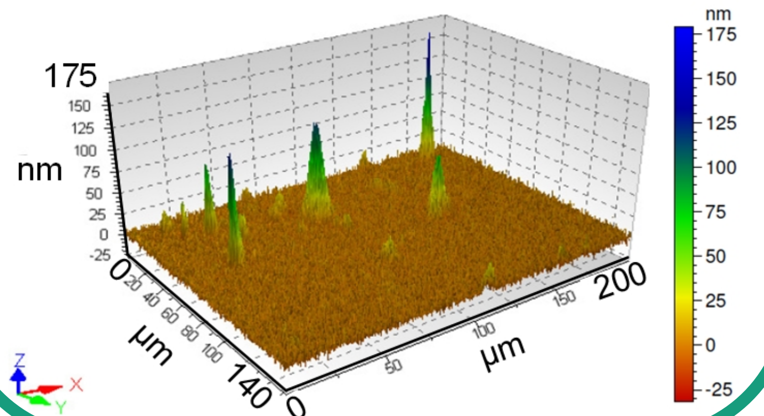
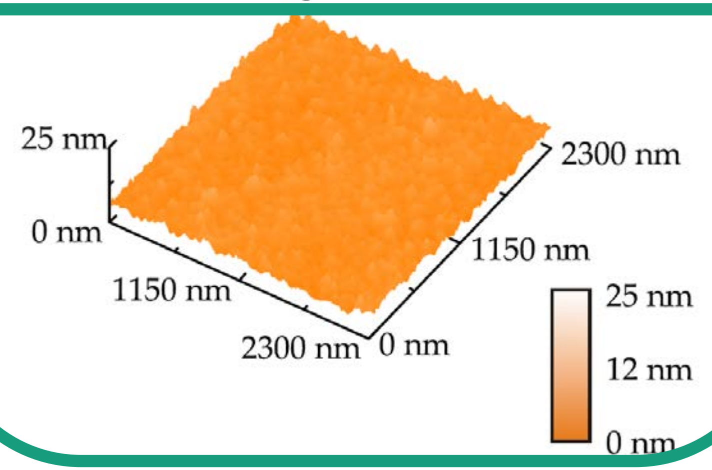
Characterization Methods

WLI white light interferometer	AFM atomic force microscope
z- resolution	
0.3 nm	< 0.1 nm
x-y- resolution	
0.2 µm	5 nm





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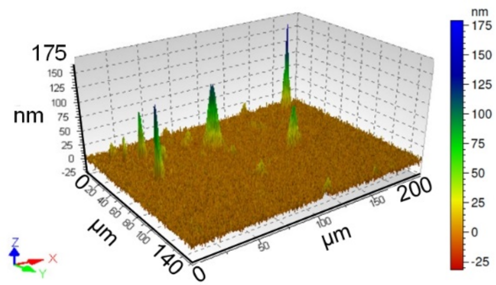
Characterization Methods

WLI

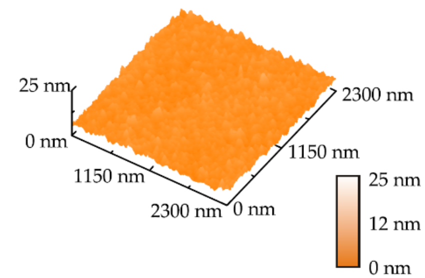


$$S_a = \frac{1}{A}\int_A |z(x,y)|\,dxdy$$

fraction of defect area D_f [%]:

defect = area > 0.4 µm^2 + pokes out of S_a

AFM



$$R_a = \frac{1}{l}\int_0^l |z(x)|\,dx$$

R_t= maximum distance between highest and lowest point

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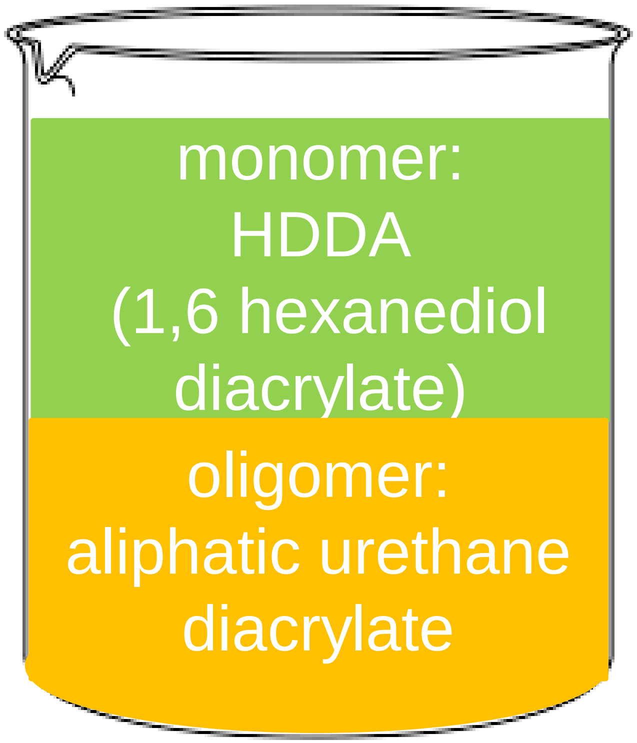
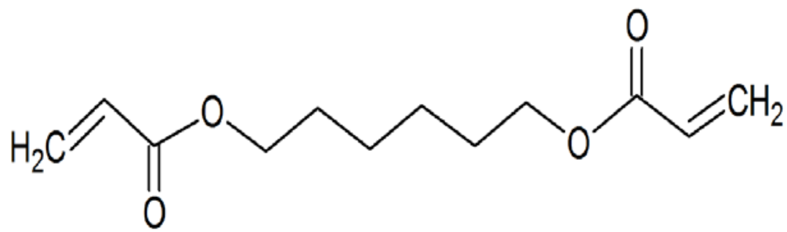
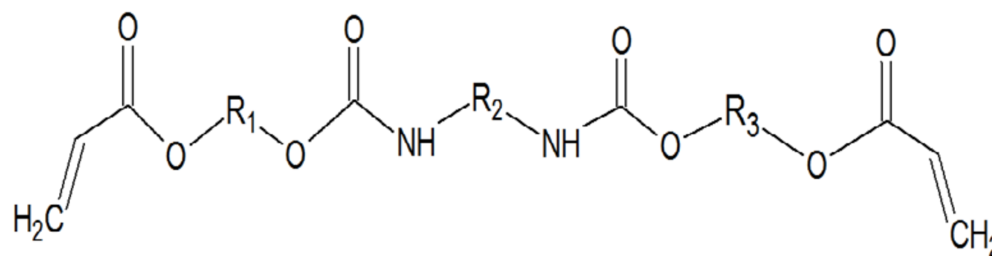
Studied Varnishes – Start System







→ variation of concentration of monomers/oligomers

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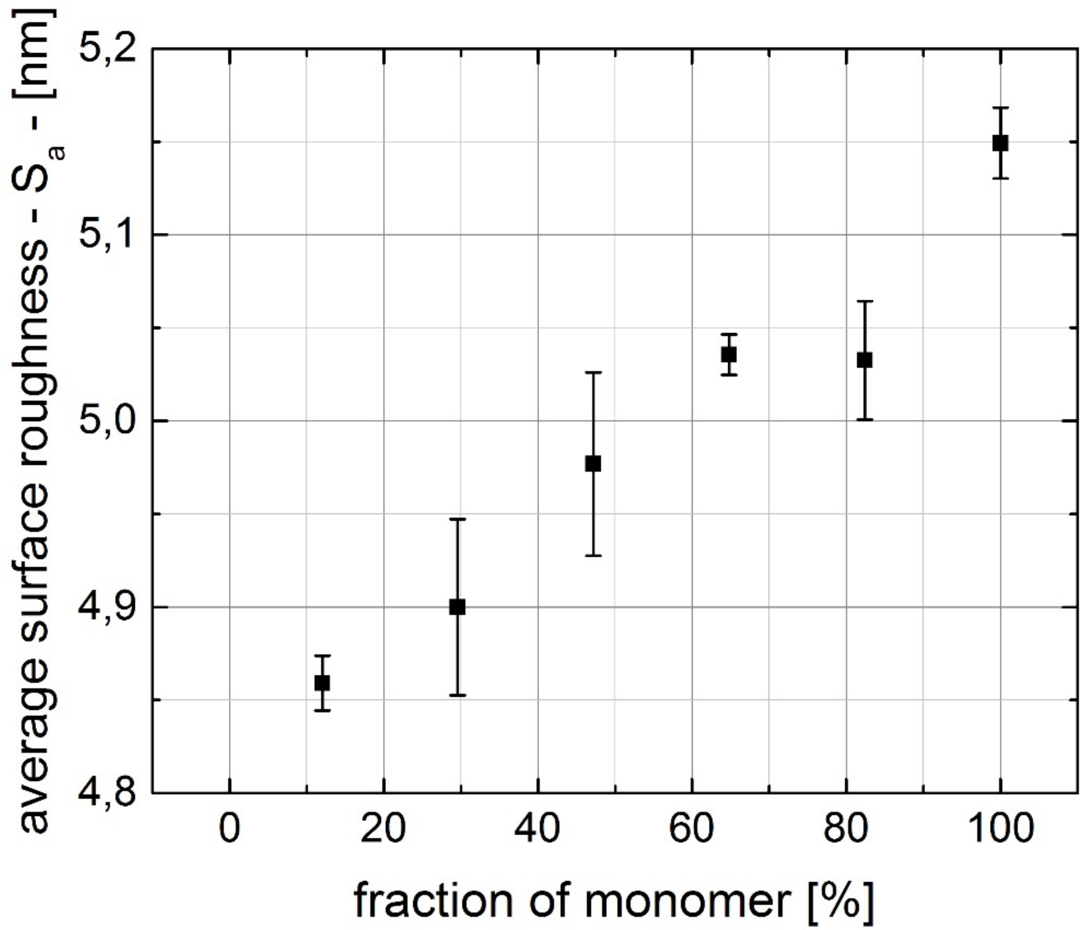
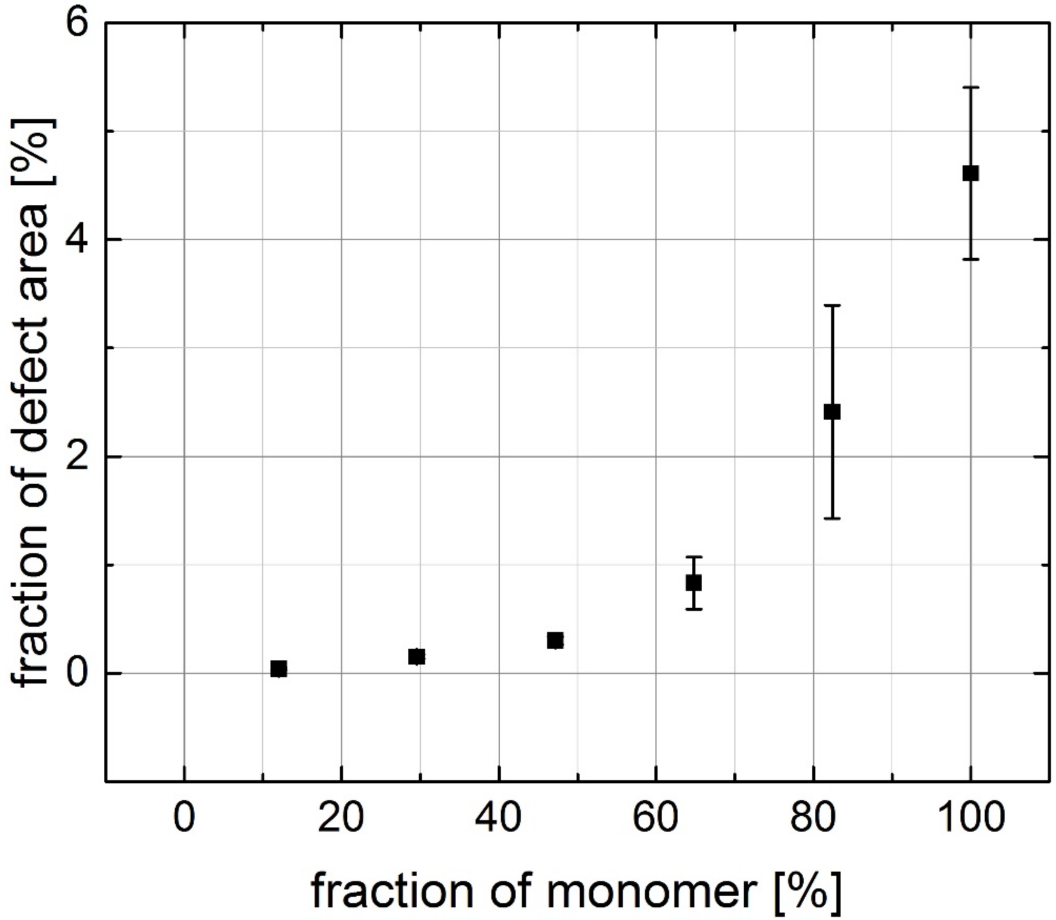
Studied Varnishes – Start System



fraction of monomer ⬆ → S_a ⬆

S_a: arithmetic average of the surface roughness

Studied Varnishes – Start System



fraction of monomer ⬆ → fraction of defect area ⬆

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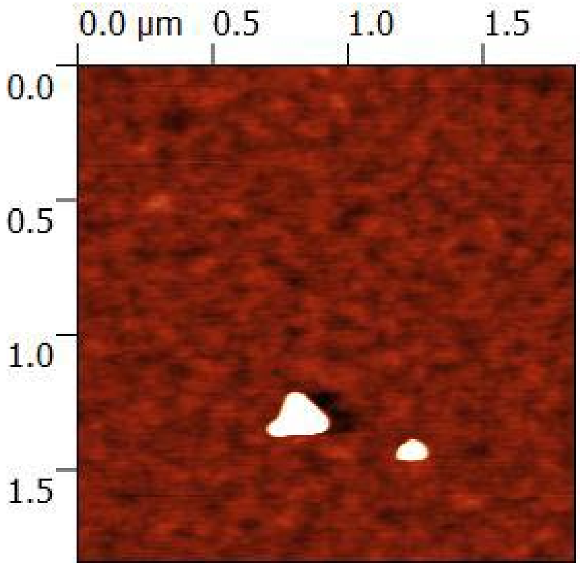
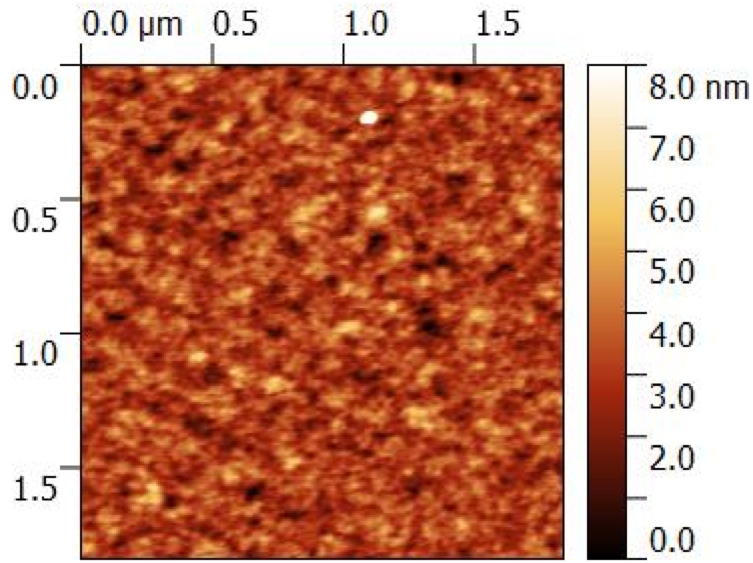
Defect Characterization - AFM



12 % monomer



100 % monomer

fraction of monomer	R_a [nm]
100 %	1,5
82,4 %	0,9
49,8 %	0,7
12 %	0,4

- fraction of monomer ⬆ → R_a ⬆
  - molecular weight ⬇ → more starting points for radical polymerization →more secondary reactions (e.g. cyclizations)

R_a: arithmetic average of the roughness profile

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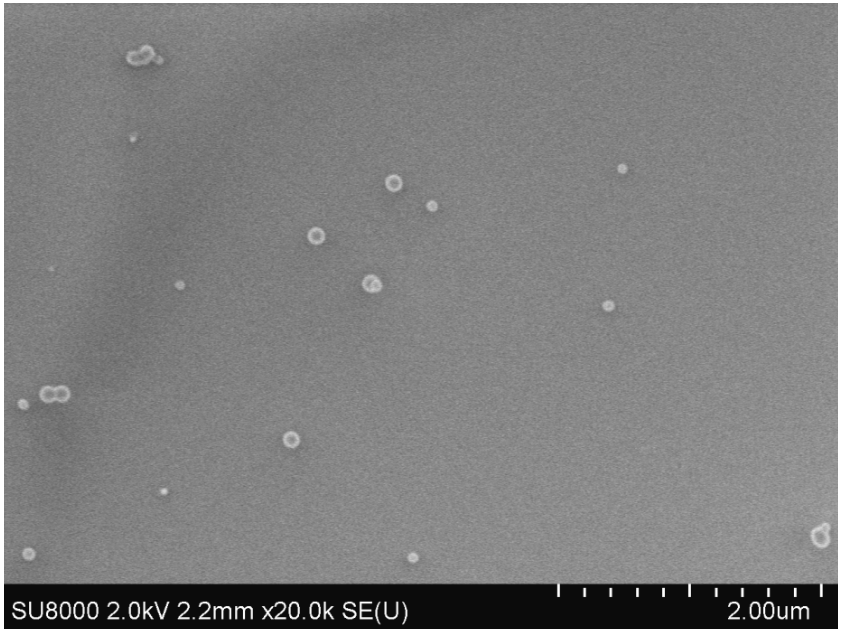
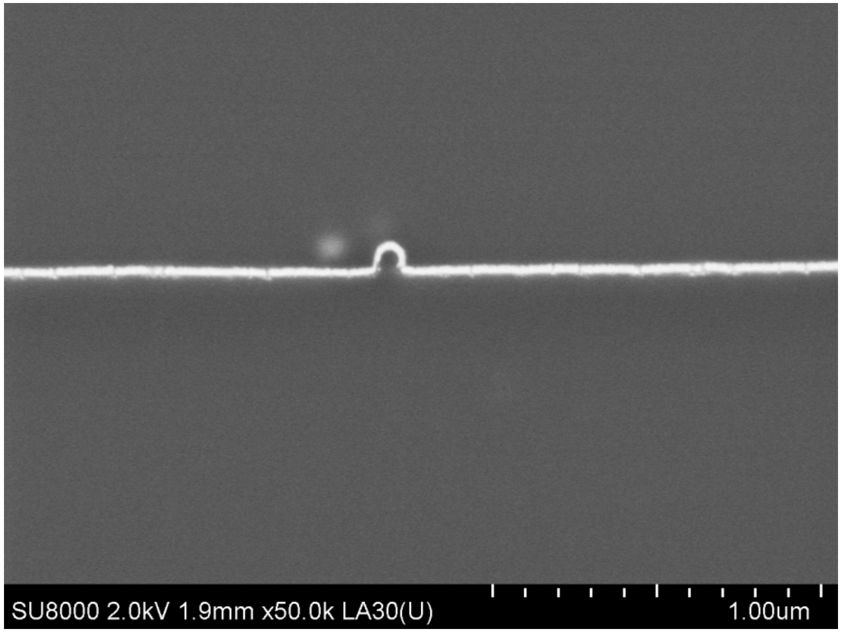
Defect Characterization - SEM





- circular, polymeric defects in the range of 20 to 200 nm

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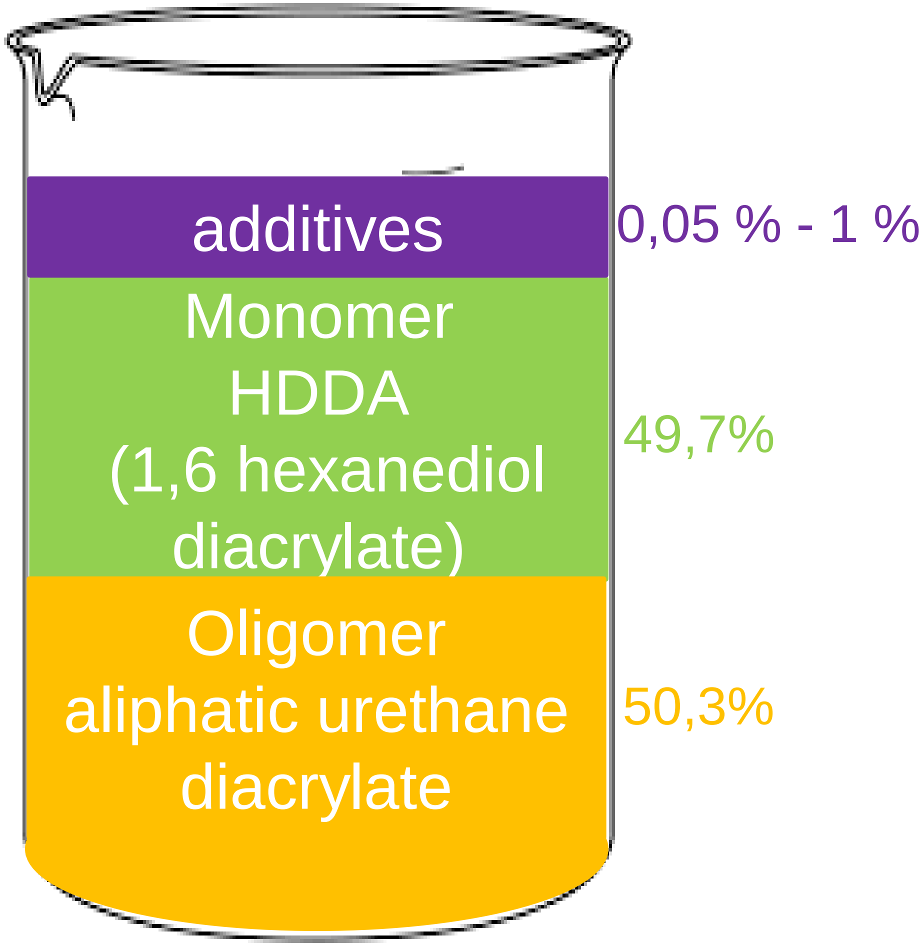
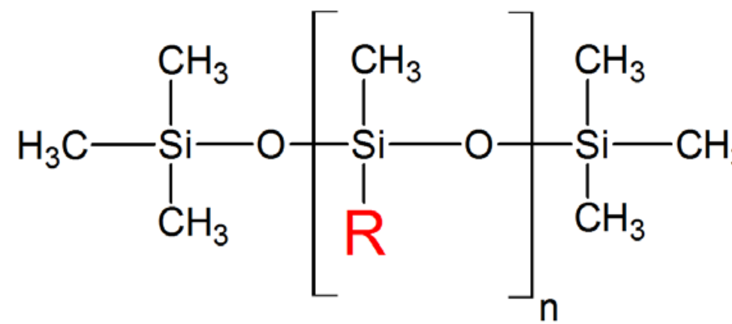
Studied Varnishes – Start System - Additives



surface additives

→ leveling agents

- polydimethylsiloxane



- acrylate copolymer

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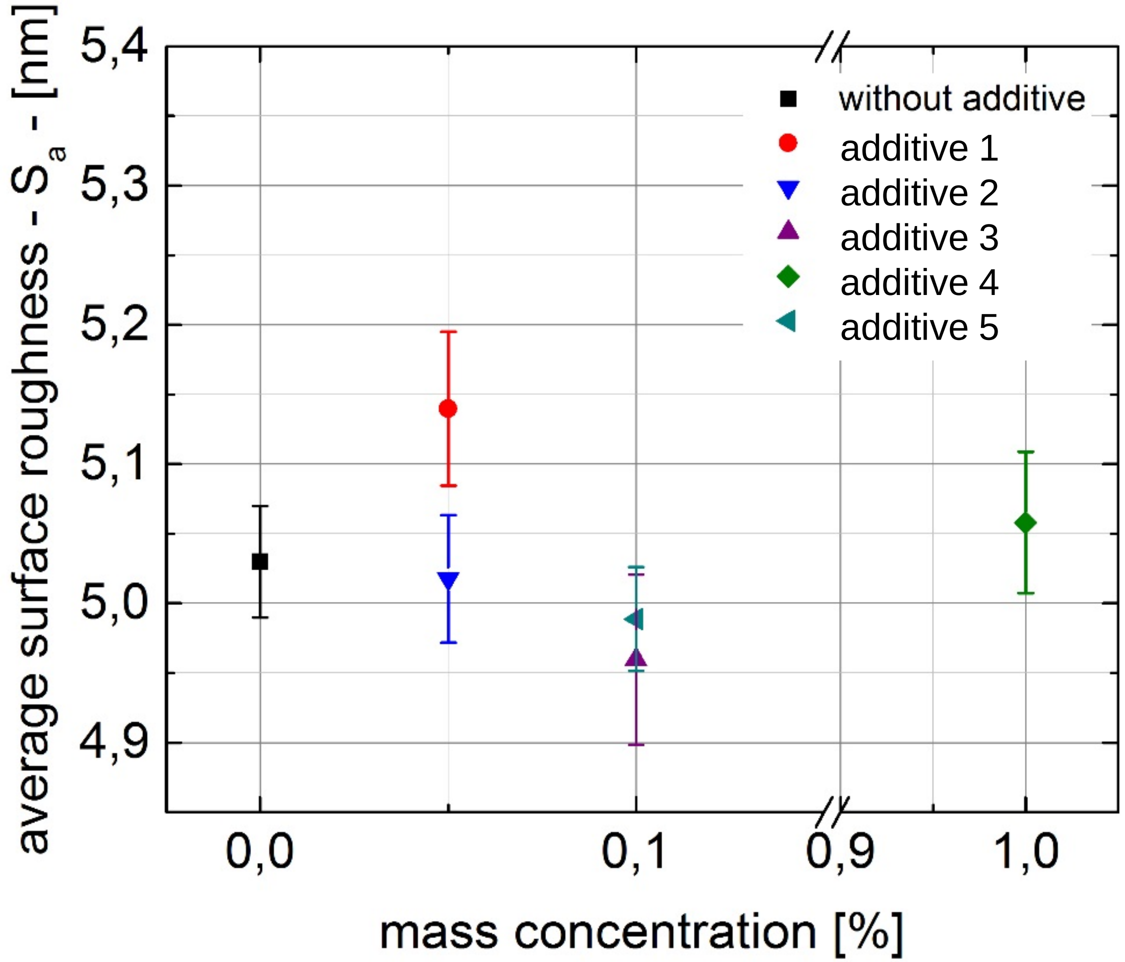
Influence of Additives



just minor differences in S_a

S_a: arithmetic average of the surface roughness

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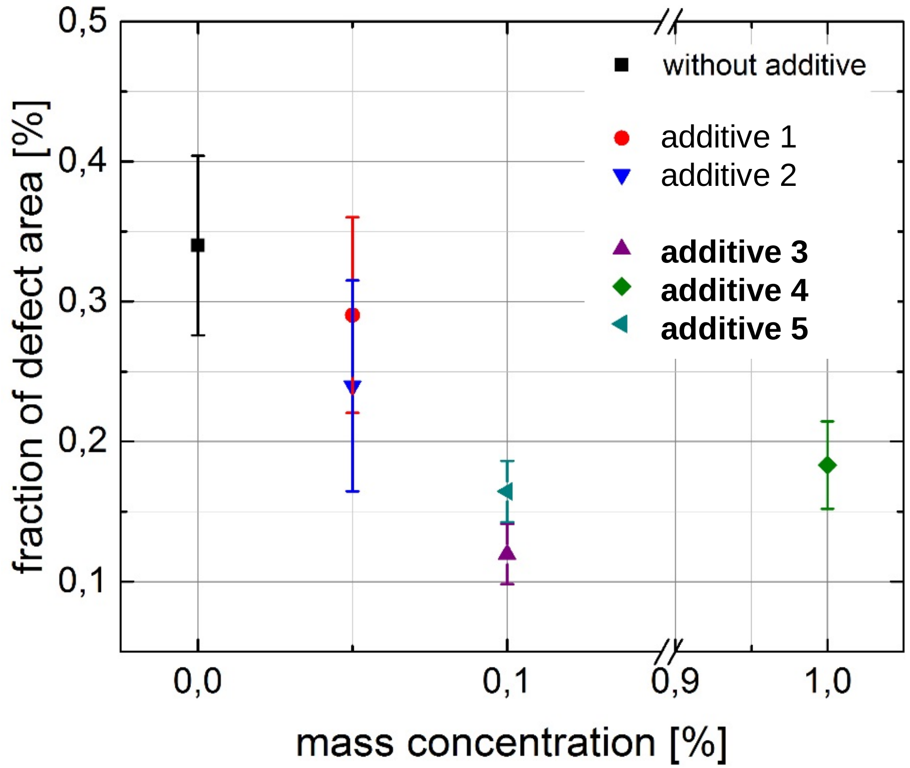
Influence of Additives



- significant reducing of defect area by adding:
  - additives 3, 5 (polydimethylsiloxane)
  - additive 4 (acrylate copolymer)

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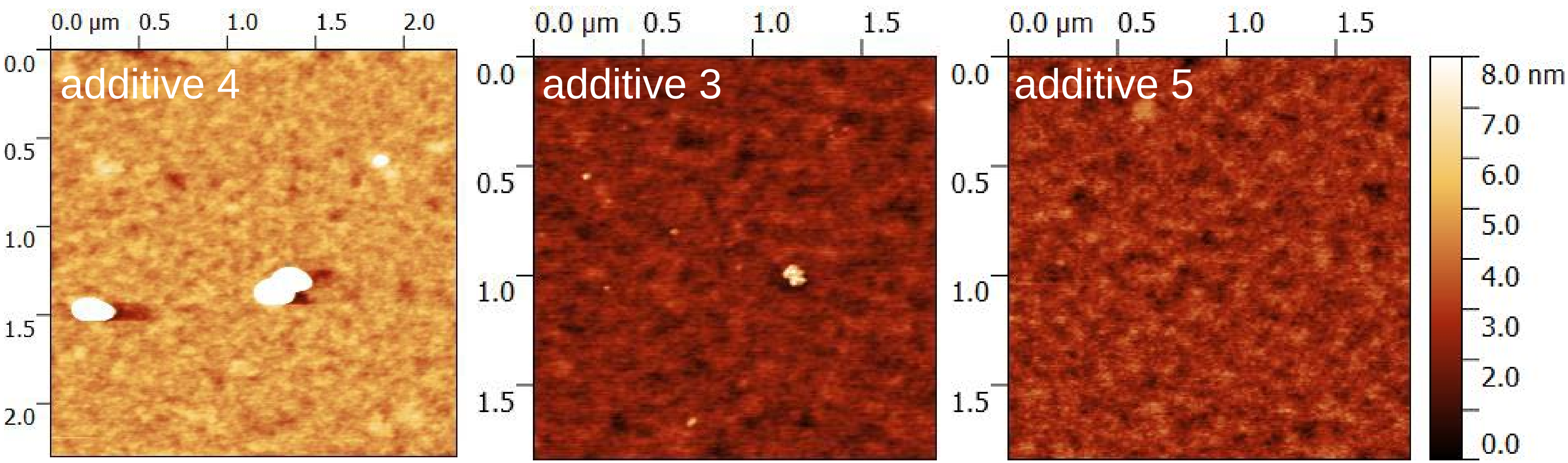
Influence of Additives



additive	R_a [nm]	R_t [nm]
additive 4	1,2	100
additive 3	0,7	20
additive 5	0,7	6

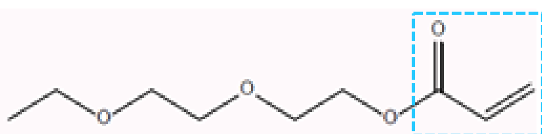
} reduced defect heights

R_a: arithmetic average of the roughness profile
R_t: maximum distance between highest and lowest point

Studied Varnishes – Component Screening

	monomers	oligomers
	acrylates	aliphatic urethane acrylates
attribute	molar mass	
	functionality	
	structure	

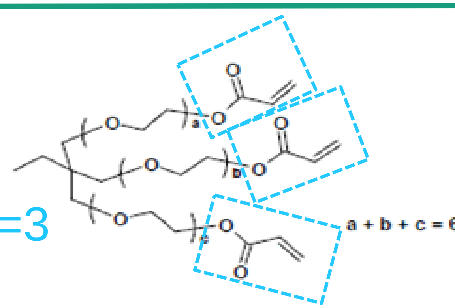
linear	branched	cyclic

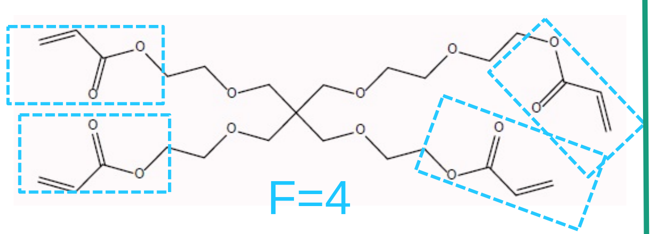


F=1

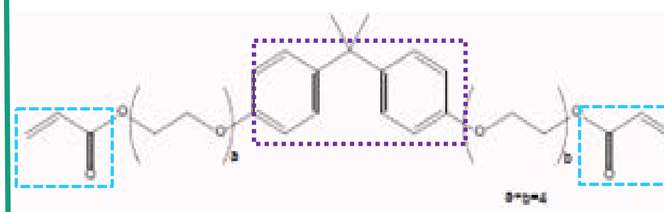
F=2

F=3

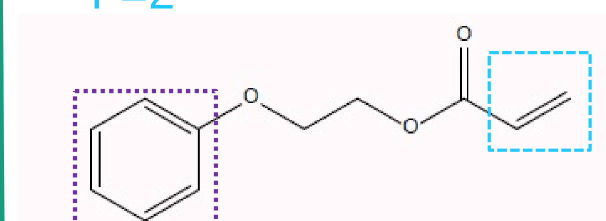




F=4



F=2



F=1

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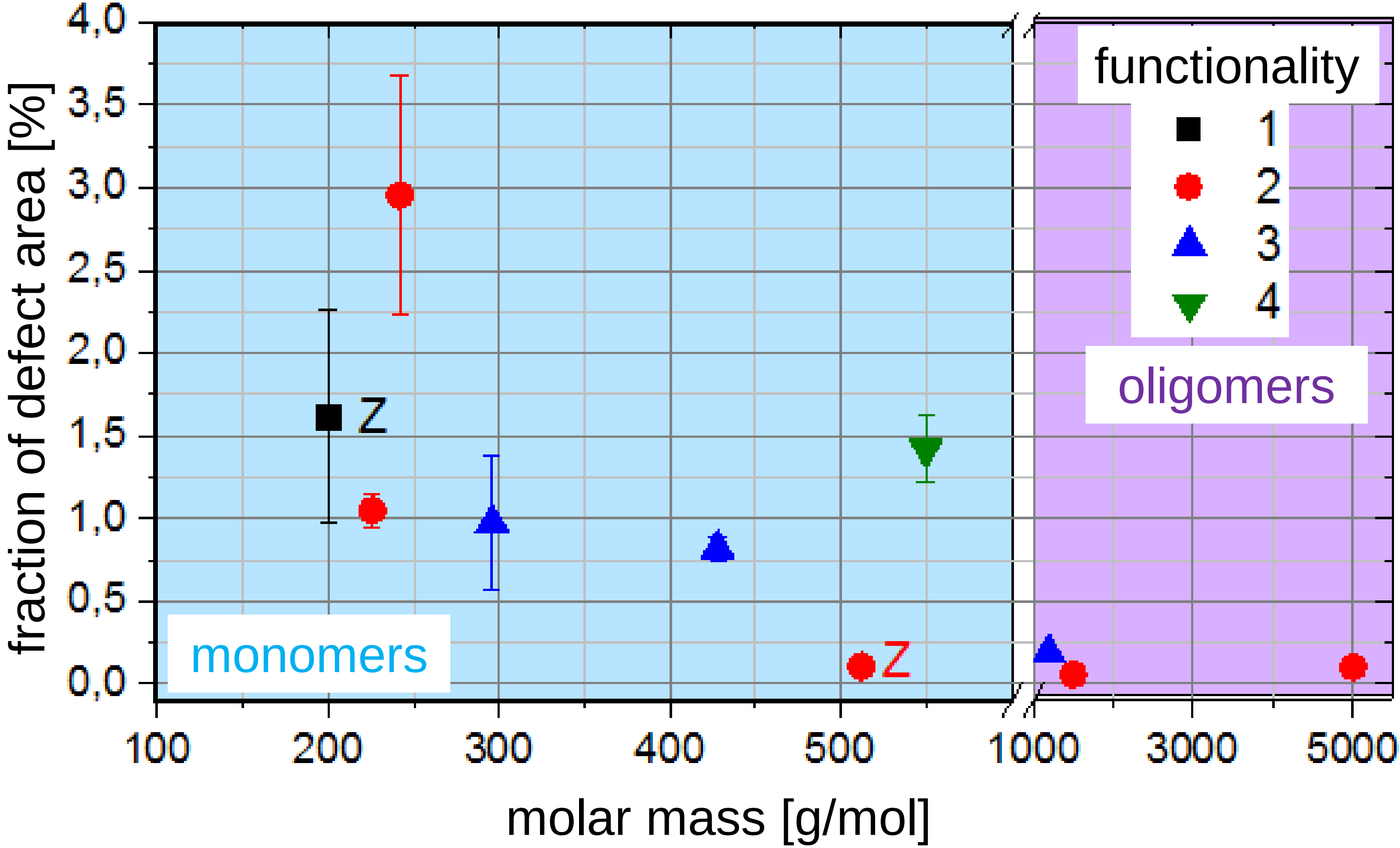
Fraction of Defect Area D_f - Pure Components



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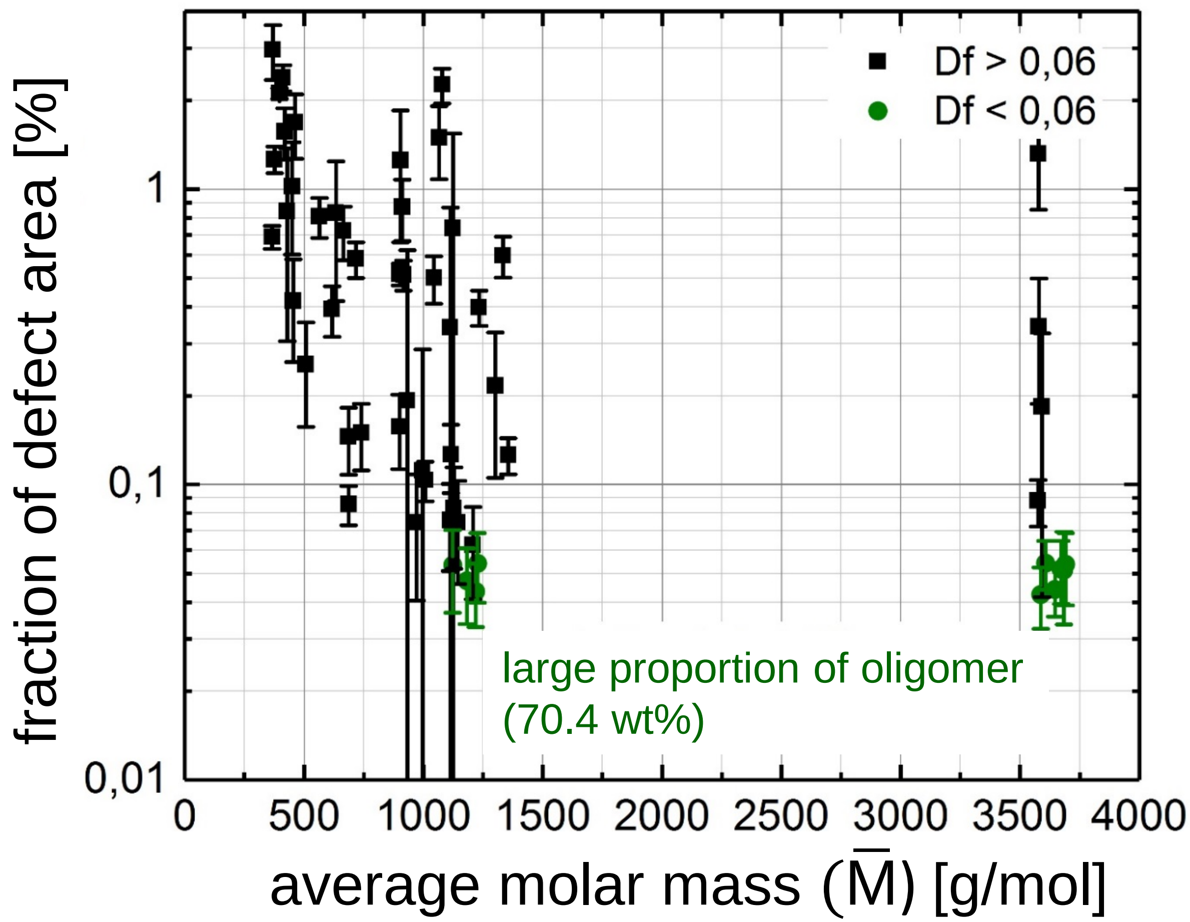
Fraction of Defect Area D_f – Varnishes



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

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Conclusion – EB Varnishes

To get a plane surface with less defects:

- fraction of monomer ⬇
- molar mass ⬆
- content of oligomers in varnish ⬆
- add leveling additives ⬆

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FEP Approaches for Plane, Defect Free Surfaces

Electron beam (EB) curable varnishes

EB curable varnishes + Smoothing – Release web

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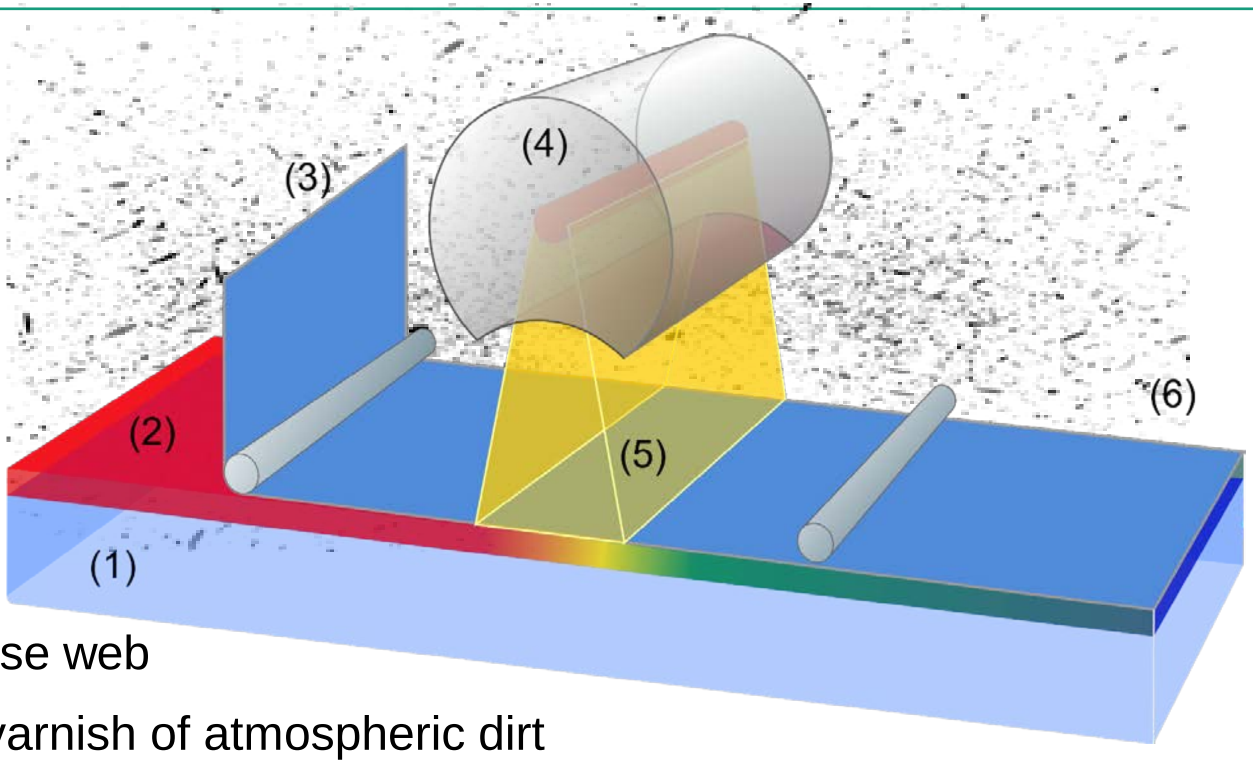
Smoothing Release Web - Scheme



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

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Smoothing Release Webs – Varnish Surface

Characterization of varnish surface (after removement of release web):

- arithmetic average surface roughness (S_a)
  - comparative value (varnish): ~5 nm
- fraction of defect area (D_f)
  - comparative value (varnish): 0,04 ± 0,01 %

	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%

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Thank you for your interest !!

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EFRE

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Smoothing Release Web - Requirements

requirements for smoothing-release webs:

- low/no adhesion to the varnish

  → surfaces with low surface energy

- smooth, defect free surface
- high electron beam stability → 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
    - metallic/oxidic

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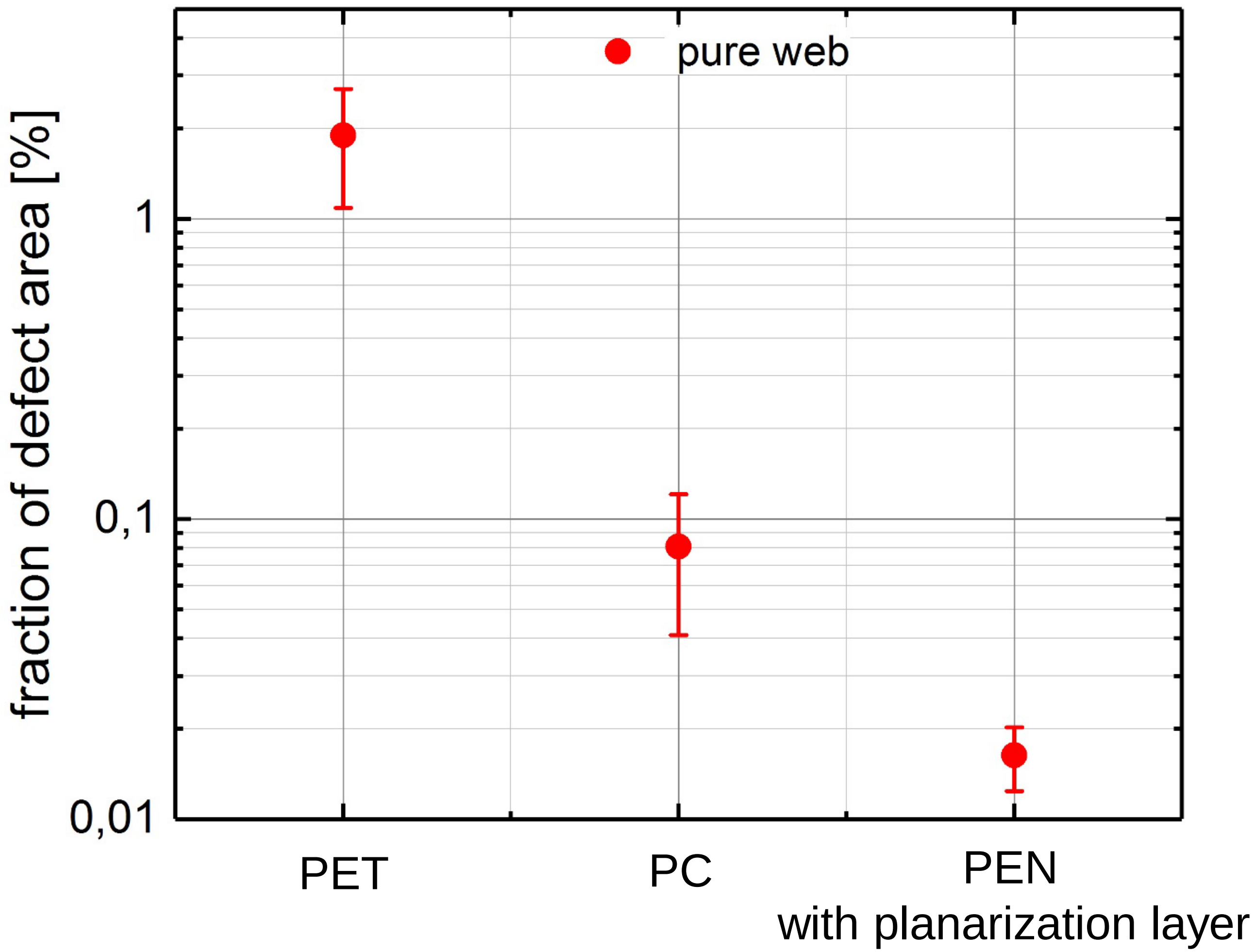
Smoothing Release Webs – Pure Polymer Web



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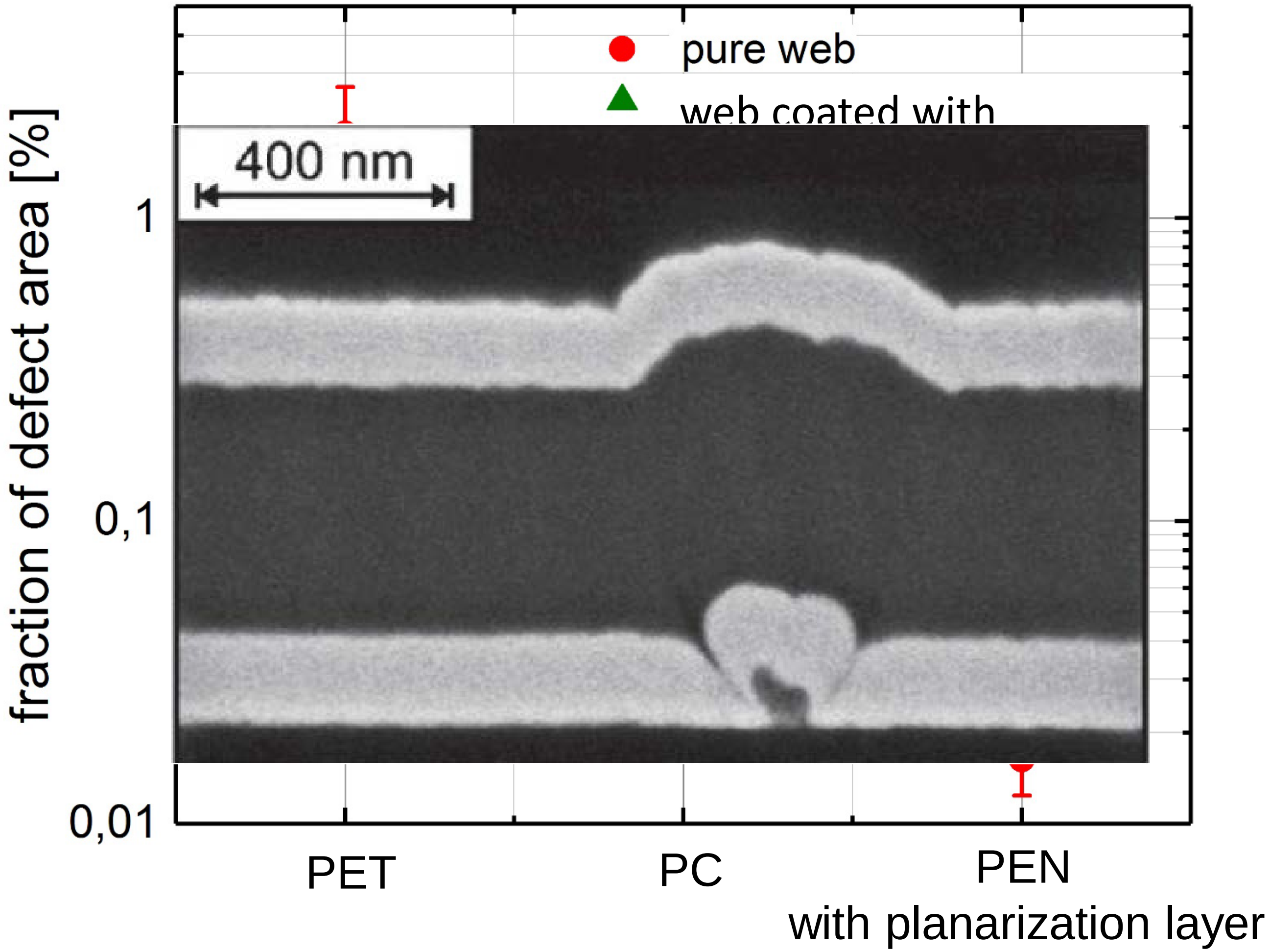
Smoothing Release Webs – Oxide Coated Polymers



→ surface quality of oxide layers depends on surface quality of the web

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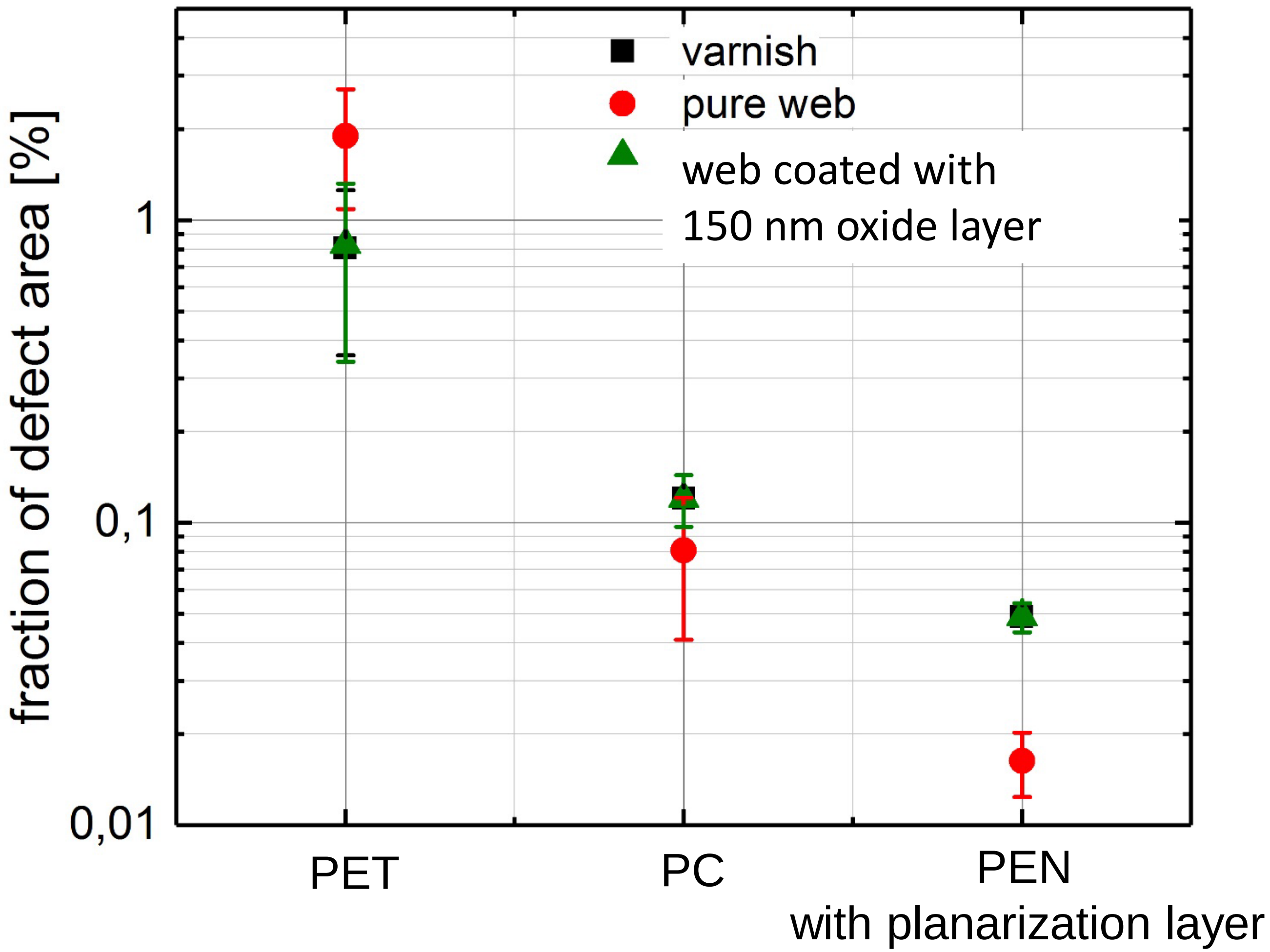
Smoothing Release Webs – Varnish Surface



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Conclusion – Smoothing Release Webs

- 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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