Inkjet Printing of Functional Ceramics

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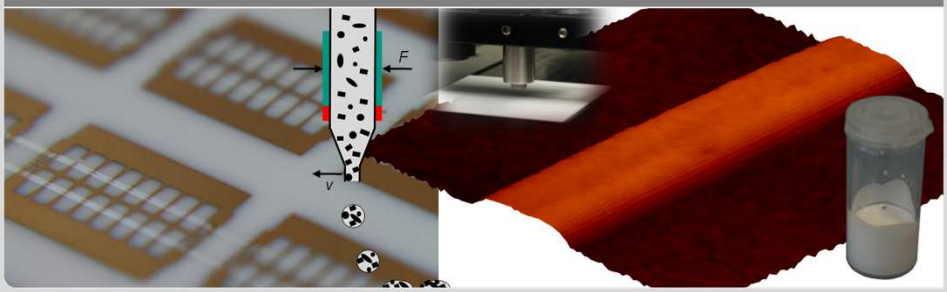
INSTITUTE FOR APPLIED MATERIALS (IAM-KWT)



KIT – University of the State of Baden-Wuerttemberg and
National Research Center of the Helmholtz Association

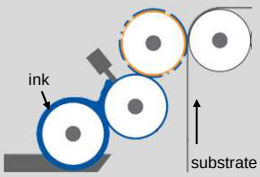
www.kit.edu

Print Technologies

Conventional

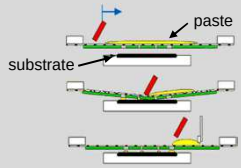
- gravure printing
- relief / flexo printing
- flat printing / offset printing

Roll-to-Roll Processing



http://www.americanlabel.com/

- screen printing



http://www.idd.tu-darmstadt.de/

- Other printing technologies

Digital

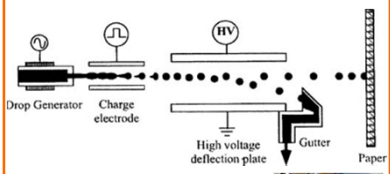
- laser printing
- inkjet printing
  - continuous
  - Drop-on-Demand (DoD)
- thermoprinting
- Other printing technologies

B. Derby,
Annu. Rev. Mater. Res. 40 (2010)

Overview: Inkjet Printing

Inkjet Printing

continuous

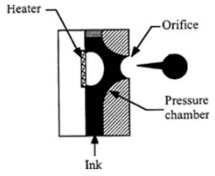


Application: **Industrial printer for labeling (e.g. expiry date)**

http://www.packaging-int.com

‚Drop-on-Demand' (DoD)

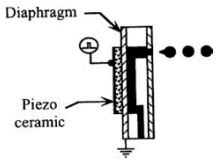
thermic



Example: HP-Printer

http://www.hp.com

piezoelectric



Example: Epson-Printer

http://www.epson.com

H.P.Le, Progress and Trends in Ink-jet Printing Technology, *J. Imaging Sci. Techn. 42: 49–62 (1998)*

Overview: Inkjet Printing

Inkjet Printing

‚Drop-on-Demand' (DoD)

But: High requirements to the used inks

(1) Particle size and ink stability	(2) Fluid mechanics	(3) Drying properties

speed	< 5 m/s
materials	**multi material printing**
substrate	**user-defined**

Example: Epson-Printer

http://www.epson.com

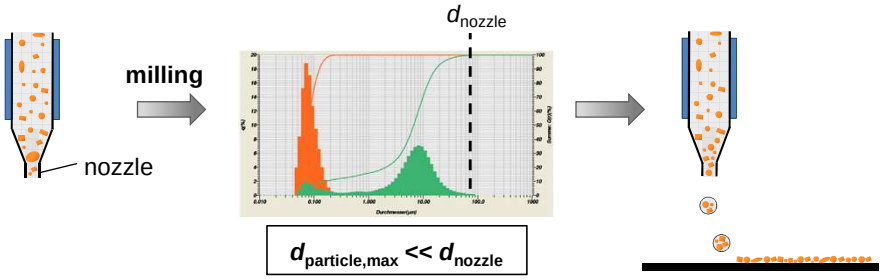
H.P.Le, Progress and Trends in Ink-jet Printing Technology, *J. Imaging Sci. Techn. 42: 49–62 (1998)*

(1) Particle Size and Ink Stability

Particle Size

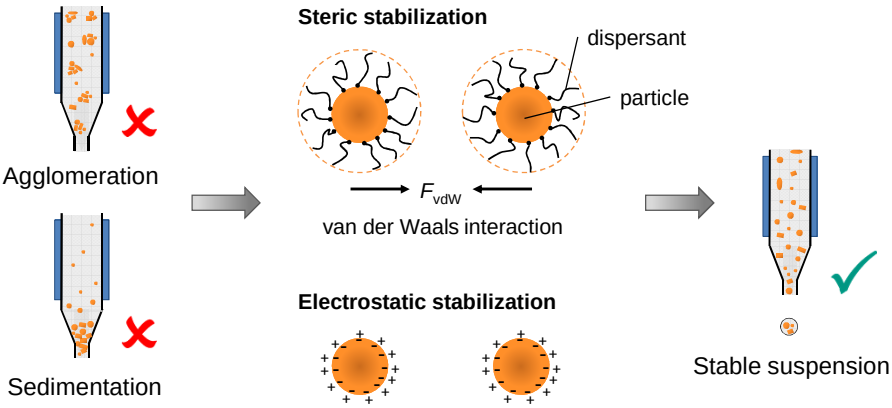
- Nozzle diameter: 10-100 µm
- Rule of thumb: $d_{100} \approx 0.01\text{-}0.05 \cdot d_{nozzle}$

- Synthesis of ceramic particles with corresponding sizes
- Milling of the ceramic powder or screening of particles



(1) Particle Size and Ink Stability

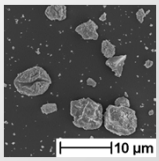
- Particle size influences the stability of ceramic inks



- Stable inks by careful choice of constituents (solvent, dispersant, etc.)

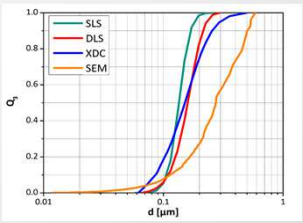
Development of $(Ba,Sr)TiO_3$ Inks

Synthesized BST powder

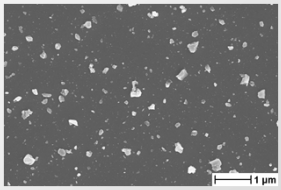


Milling & dispersing

Particle size distribution

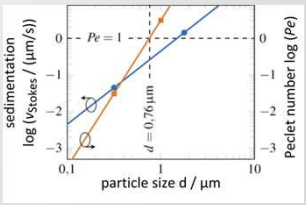


SEM image



d_{50} ≈ 140 nm
d_{max} ≈ 600 nm

Stability of suspension



A. Friederich et al., *J. Am. Ceram. Soc.* 96 (2013) 2093-2099

(2) Fluid Mechanics

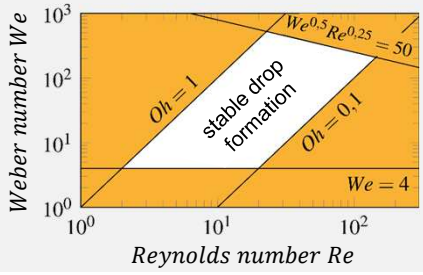
- Characteristic values of inks
  - density ρ
  - viscosity η
  - surface tension σ
- Important dimensionless quantity to describe the fluid properties and to predict a stable drop formation
  - Reynolds number: $Re = \frac{v\rho a}{\eta}$ → „fluid flow in the capillary"
  - Weber number: $We = \frac{v^2\rho a}{\sigma}$ → „atomization behavior"
  - Ohnesorge number: $Oh = \frac{\sqrt{We}}{Re}$ → „printability of an ink"

velocity of the droplet: v = 1-10 m/s characteristic length: a = 20-100 µm

(2) Fluid Mechanics

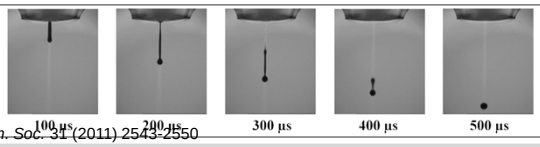
$We^{0,5}Re^{0,25} \geq 50$
onset of splashing

***Oh* > 1**:
Ink too viscous



***Oh* < 0.1**:
Ink to thin

0.1 ≤ Oh ≤ 1



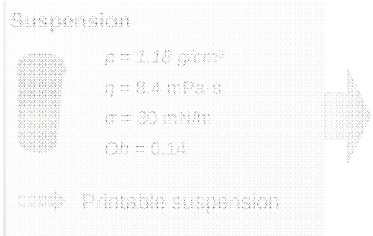
✓

B. Derby, *J. Eur. Ceram. Soc.* 31 (2011) 2543-2550

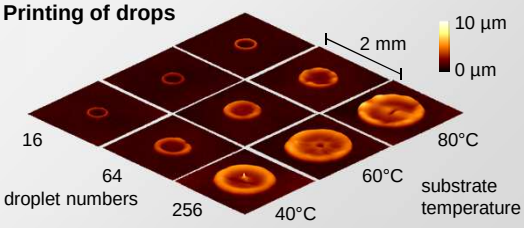
Development of $(Ba,Sr)TiO_3$ Inks

✓ **Printability** is given

✗ **Drying behavior** is not optimized



Printing of drops

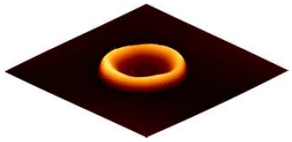


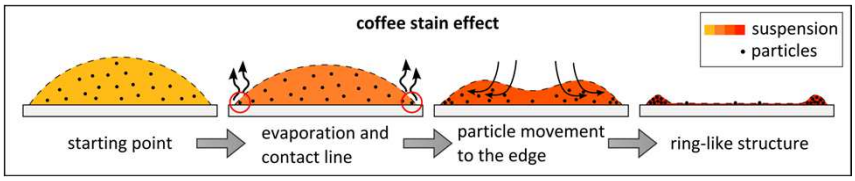
[4] A. Hasenkox et al., J. Am. Ceram. Soc. 95 (2012) 2055-2059

(3) Drying Properties

Preconditions for coffee staining

1. Contact angle > 0
2. Pinned contact line
3. Drying through evaporation





(1) Starting point: homogenous droplet on the substrate

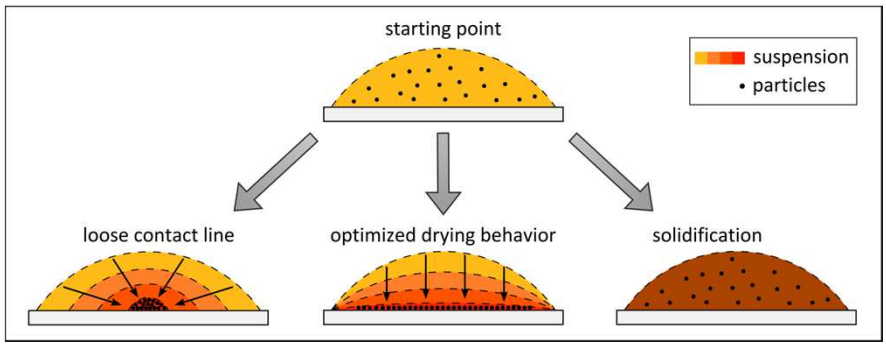
(2) Evaporation of the solvent, particle at the edge caused *contact line pinning*

(3) Faster evaporation at the edge → liquid flow from the center to the edge

(4) Particle movement to the edge and a ring-like structure is formed

(3) Drying Properties

Approaches to prevent coffee stain effect



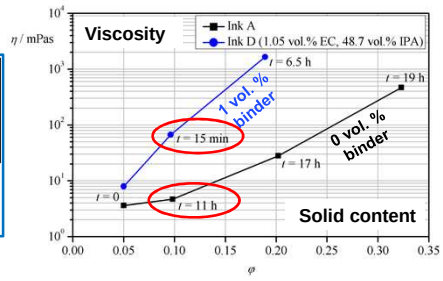
KIT approach: Particle movement during drying is prevent by rapid increase in viscosity after deposition

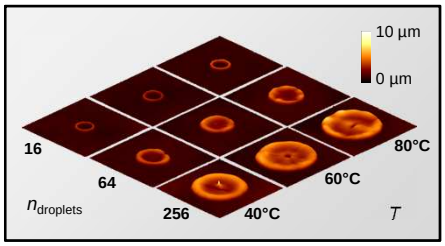
⇨ well suited for inkjet printing of ceramics

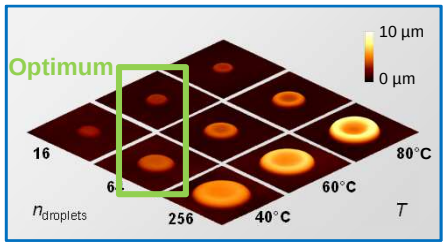
Development of $(Ba,Sr)TiO_3$ inks

KIT approach: Ink composition

Ceramic powder:	BST
Dispersant:	Dolacol D1001
1st solvent :	butyl diglycol
2nd solvent:	isopropyl alcohol
Binder:	ethyl cellulose







A. Friederich et al., *J. Am. Ceram. Soc.* 96 (2013) 2093-2099

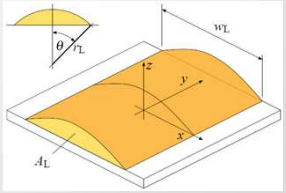
(3) Drying Properties

Resolution of the line width

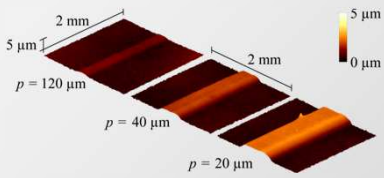
- Roughness of the substrate
- Droplet diameter d_0
- Contact angle of the ink Θ
- Drop distance p

→ Calculation of the line width w_L

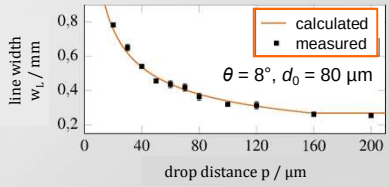
$$w_L = d_0 \sqrt{\frac{2\pi d_0}{3p(\theta/sin^2\,\theta - 1/\tan\theta)}}$$



Example: Printing of lines

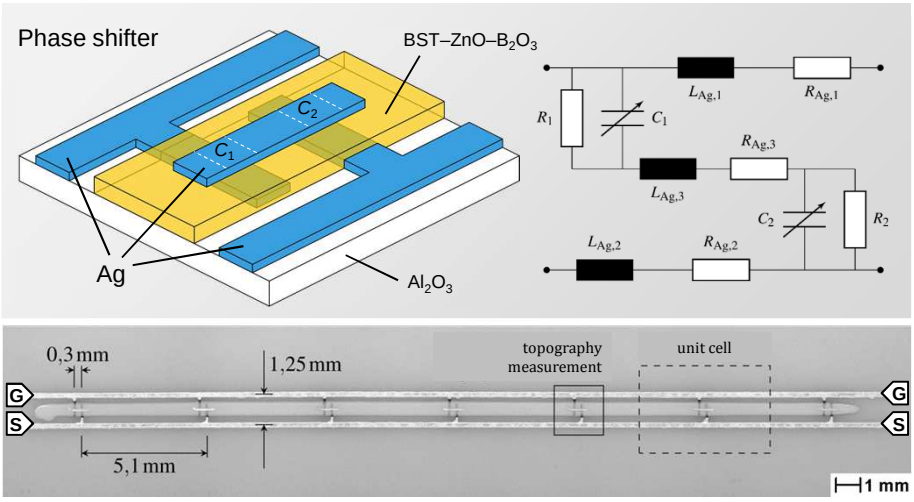


Comparison: calculated and printed lines



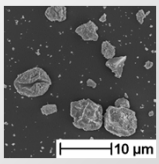
Applications of Inkjet-printed $(Ba,Sr)TiO_3$

Metal-insulator-metal capacitors for tunable microwave applications



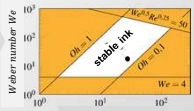
Summary and Outlook

Synthesized BST powder

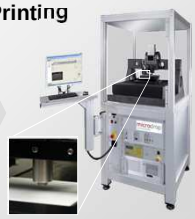


Milling & dispersing

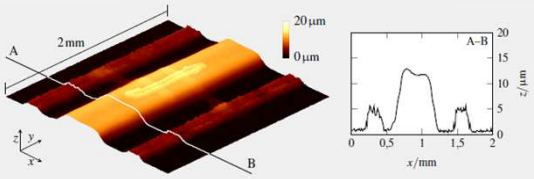
BST ink



Printing



Inkjet-printed devices for microwave applications



Flexible passive elements