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Rheological control of the coffee stain effect for inkjet printing of ceramics

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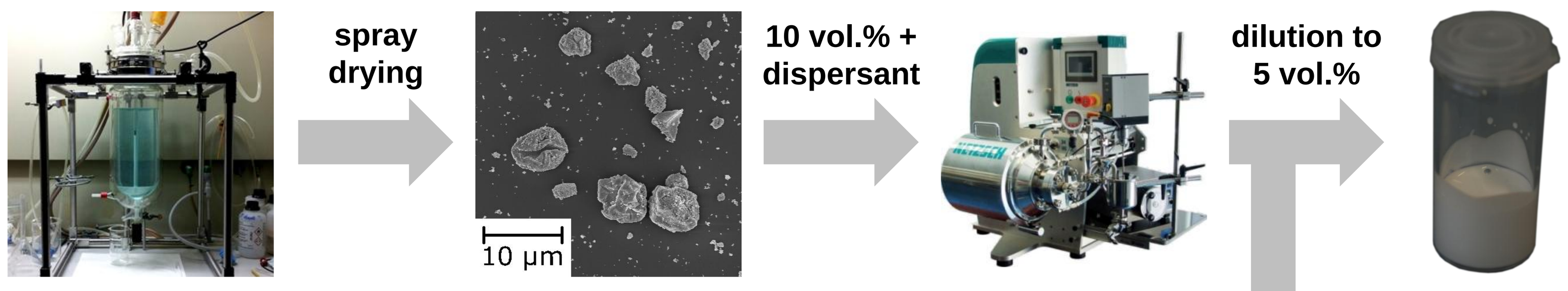
Introduction

Coffee staining is a general problem of inkjet printing ceramic suspensions. It is caused by a flow of liquid from the centre to the edge of a drying drop and leads to a non-uniform deposition of particles. Conventional thick-film preparation methods such as screen printing do not show coffee staining due to the high viscosity of the printing medium.

The approaches to prevent coffee staining that are reported in the literature make use of various physical phenomena such as the Marangoni flow or electro-wetting to obtain homogeneous films.

We present a new approach, which follows a simple consideration: Coffee staining can be suppressed by a sufficiently fast increase of viscosity after deposition. However, the ink viscosity during printing is usually restricted to very low values due to the small diameter of the print-head nozzles. Hence, inks with tailored viscosity need to be developed.

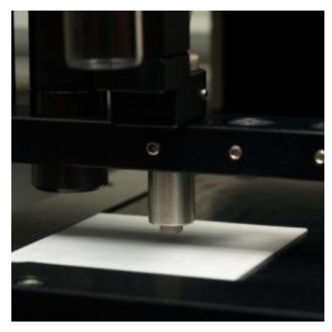
Ink preparation and ink properties



Material: $Ba_{0.6}Sr_{0.4}TiO_3$
Solvent: butyl diglycol

+ 0–1.25 vol.% ethyl cellulose (EC)
+ 0–50 vol.% isopropy alcohol (IPA)

printing + drying

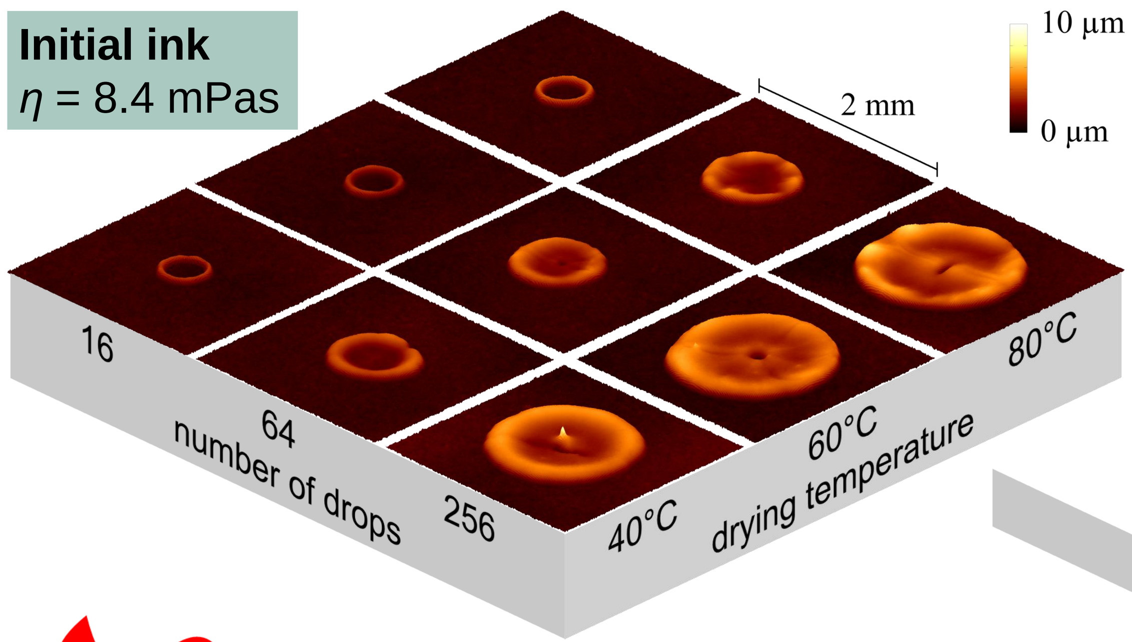


Ink properties:

- → Long time stable ✓ (no sedimentation observable)
- → Particle size: $d_{50} \approx 150$ nm, $d_{100} < 1$ µm
- → Surface tension: $\gamma = 24–30$ mN/m
- → Viscosity: $\eta = 5–43$ mPa·s
- → $0.09 < Oh < 0.71$ → **all inks well printable**

Characterisation of dried structures

Initial ink
η = 8.4 mPas

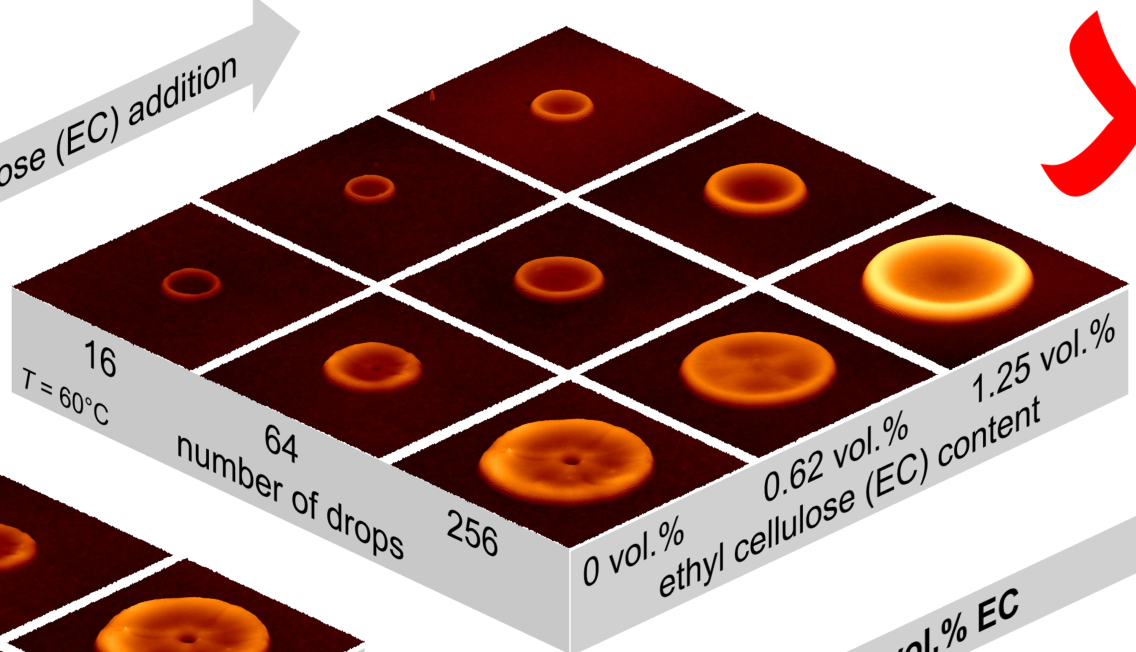


Figures:
Surface topography measurements of drops printed with different inks and dried at different substrate temperatures.

Severe coffee staining for all drop sizes and drying temperatures

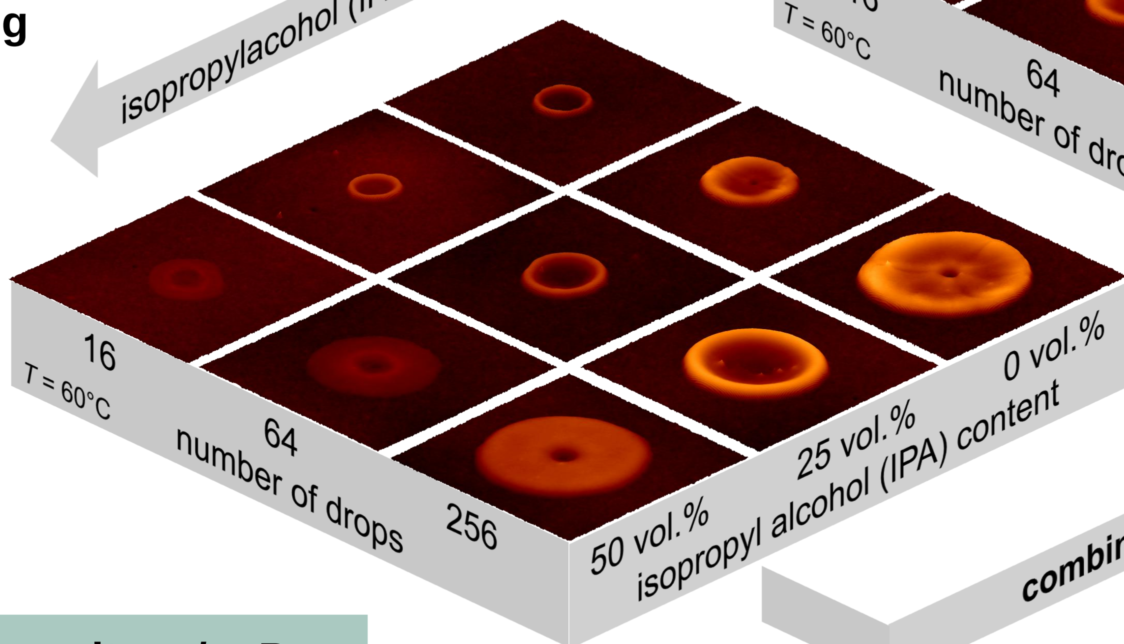
ethyl cellulose (EC) addition

Ethyl cellulose (EC) content			
0 vol.%	0.62 vol.%	1.25 vol.%	
8.4	21.6	42.6	**Viscosity η / mPas**
100%	100%	100%	**Drying time t / t_0**



An increase of viscosity within the boundaries of printability is not suitable to prevent coffee staining

isopropylacohol (IPA) addition

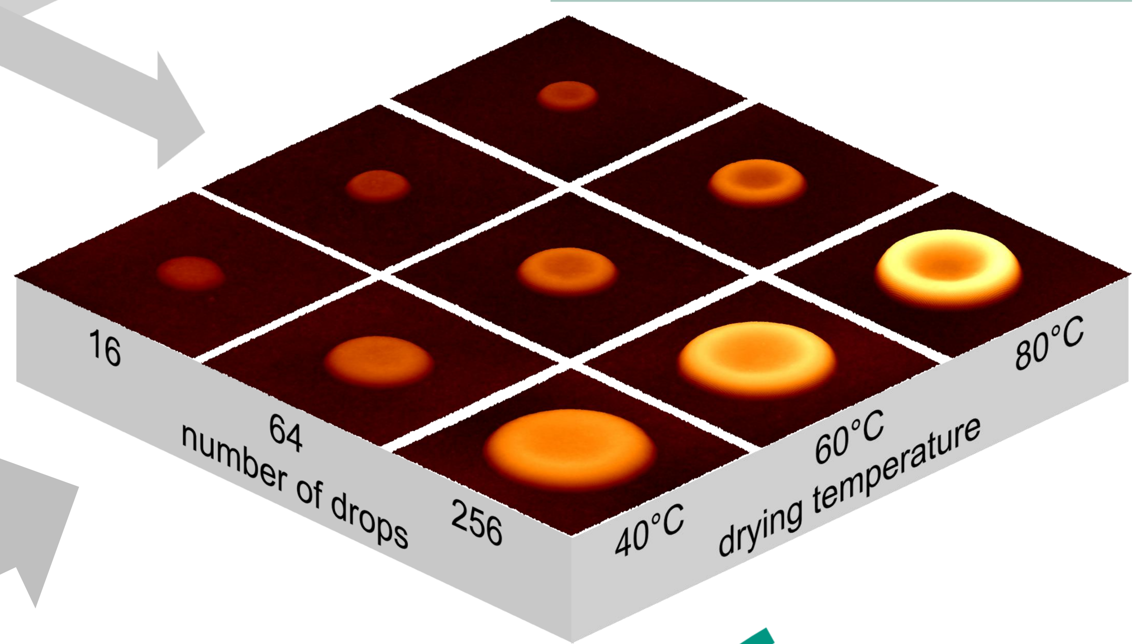


Isopropyl alcohol (IPA) content			
0 vol.%	25 vol.%	50 vol.%	
8.4	5.9	4.6	**Viscosity η / mPas**
100%	80%	55%	**Drying time t / t_0**

A decrease of drying time is not suitable to prevent coffee staining, if the viscosity is also lowered.

combination of 49 vol.% IPA and 1 vol.% EC

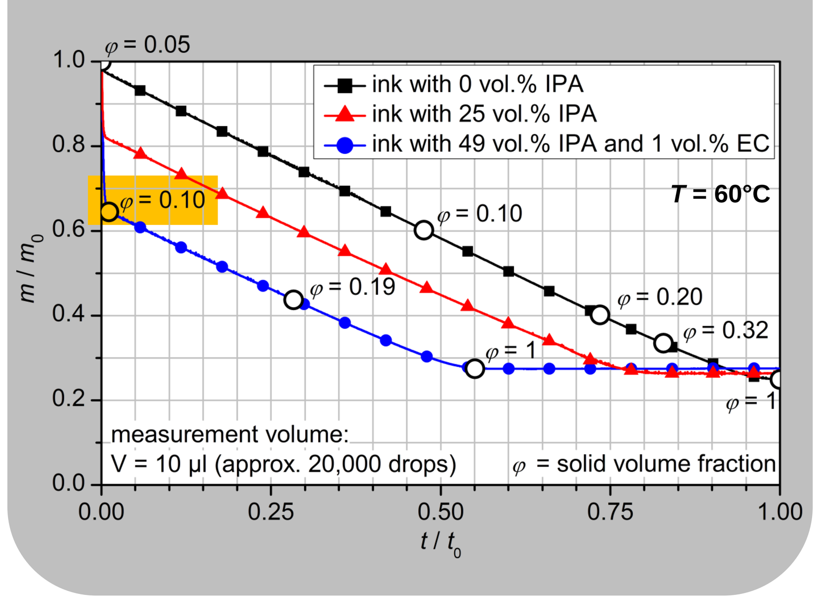
Combination of IPA and EC:
Viscosity: η = 22.7 mPas
Drying time: t / t_0= 55%



The fast evaporation of the IPA leads to a rapid increase of viscosity after deposition and prevents coffee staining at low drying temperatures ✓

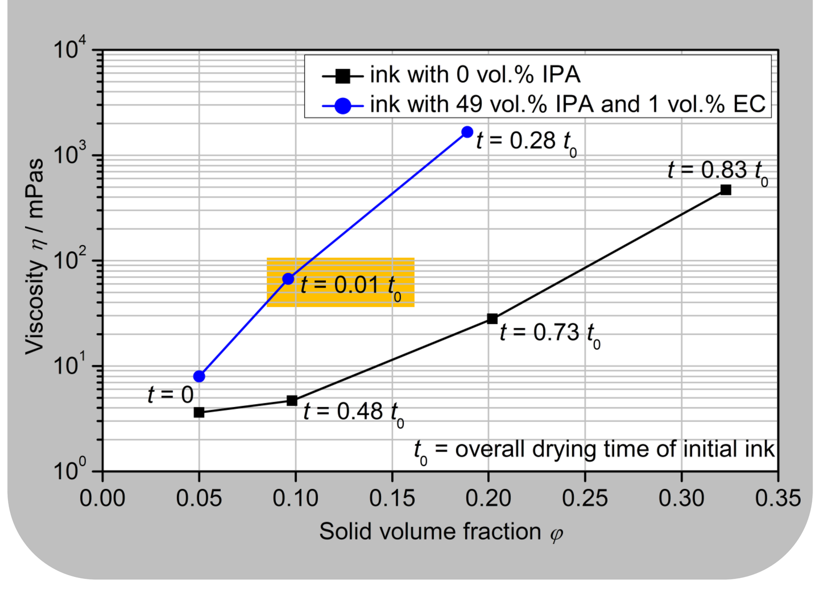
Thermogravimetric experiment:

IPA evaporates approximately 50 times faster than the residual solvent



Rheology measurements:

The viscosity of the ink with EC and IPA rises about 1 order of magnitude in a very short time span



Conclusion

The investigations show that the use of a fast drying solvent in the inks is not suitable to prevent coffee staining, if the viscosity is also lowered. When adding a binder to the inks, the viscosity exceeds the boundaries for printing before it is high enough to prevent coffee staining.

However, a combination of binder and fast drying solvent is suitable to prevent coffee staining. This is due to a sufficiently low viscosity during printing and a rapid increase of viscosity after deposition, which leads to a considerable improvement in film topography.