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AME Rheology of complex fluids

Correlation between Flow Properties and Print Quality in the Front-Side Metallization of Solar Cells

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I. Motivation

- Reducing the Silver consumption is a major challenge in solar cell metallization
- Understanding paste rheology and its impact on screen-printing is essential for printing thin homogeneous lines
- The complex, multi-component nature of high-temperature metallization pastes poses a challenge for independently adjusting rheological parameters
- Capillary suspensions enable us to vary the high shear viscosity η and yield stress σ_y independently
- Capillary suspension form a percolating particle network controlled by capillary forces, induced by adding a second immiscible liquid to a regular suspension thus creating a ternary solid-liquid-liquid system [1]

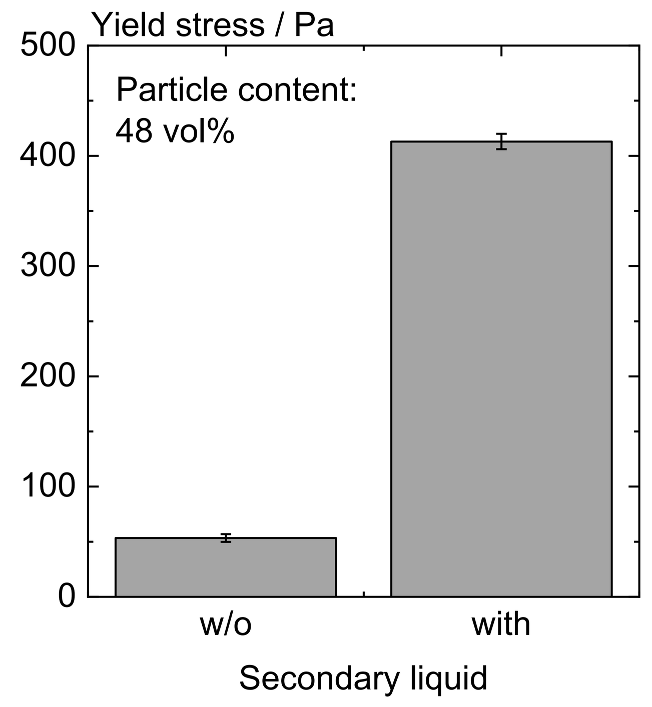
II. Materials and Methods

- The pastes contain Metalor K-7418P silver particles, Texanol as bulk and a immiscible hydrophobic liquid as second liquid
- The volume ratio between second liquid and particle fraction is kept constant at 0.1 for the capillary suspensions
- The high shear viscosity of capillary suspensions is independent of secondary liquid content [2]
- The high shear viscosity η_{hs} is calculated using the semi-empirical Maron-Pierce equation [3]

$$\eta_{hs} = \eta_{bulk}\left(1 - \frac{\phi_{particle}}{\phi_{max}}\right)^{-2}$$

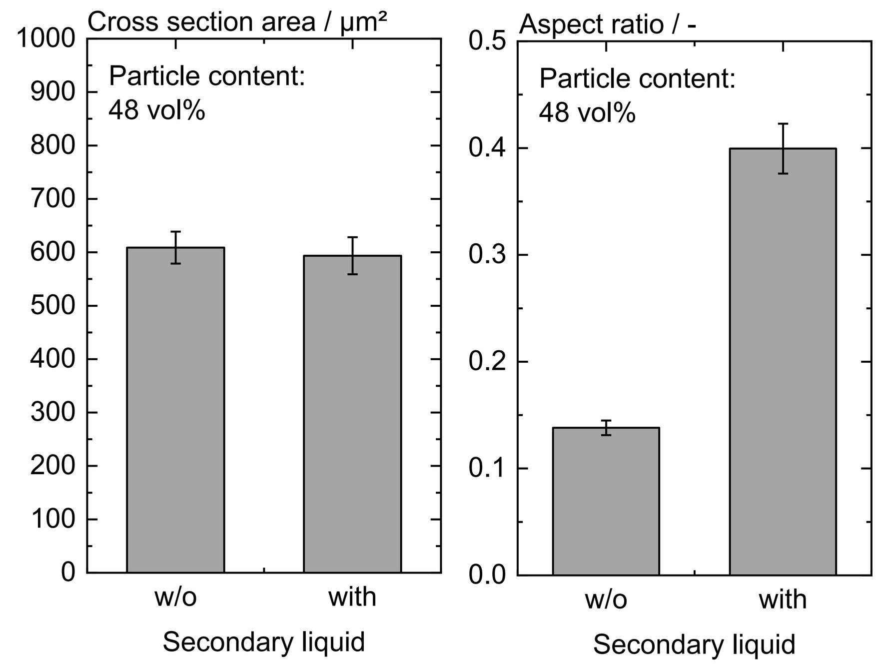
III. Influence of Second Liquid

- Comparison between a suspension with and without additional second liquid
- The yield stress increase upon addition of second liquid indicates the formation of a percolating particle network
- The high shear viscosity is constant since the particle volume fraction and bulk liquid are constant [2]



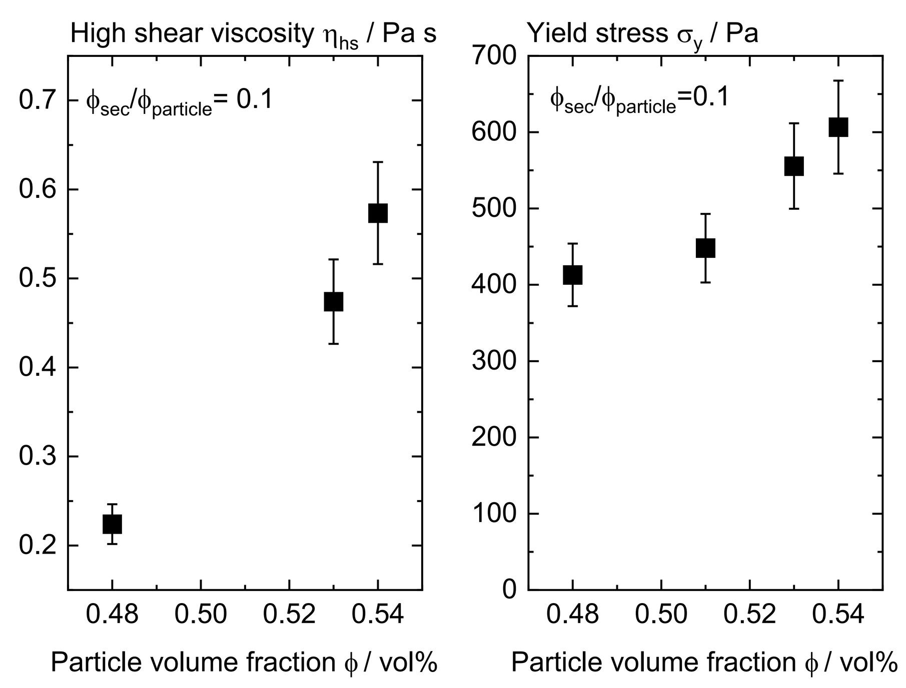
IV. Laydown at Constant Viscosity

- With constant viscosity the cross section area, and thus the paste laydown stays constant
- The increase in yield stress does not affect the paste laydown
- The aspect ratio increases with yield stress and may be caused by the formation of the capillary network



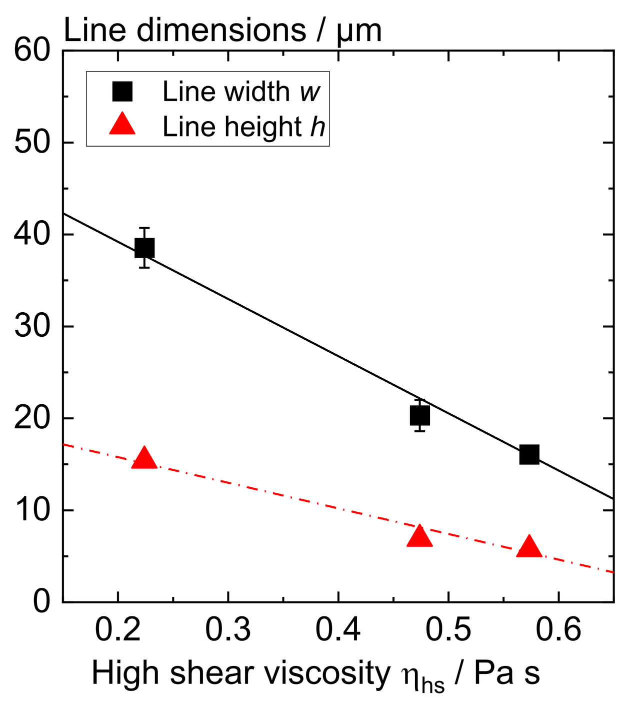
V. Particle Volume Variation

- The viscosity of the capillary suspension increases with increasing particle fraction
- The yield stress also increases with increasing particle volume
- This reflects the denser network formed with a larger number of particles



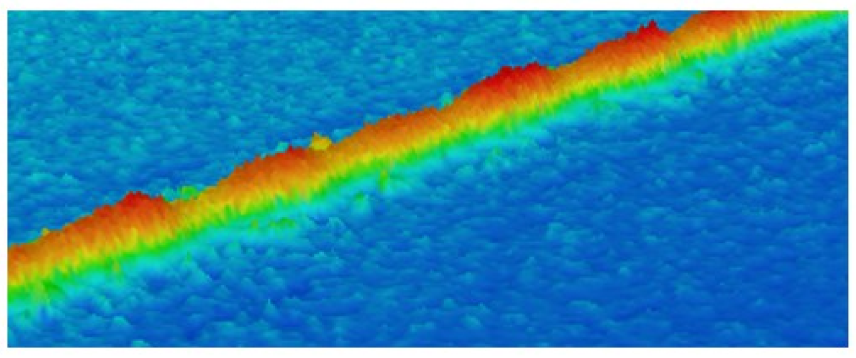
VI. Laydown with Increasing Viscosity

- The line width and height decreases with increasing viscosity leading to a reduced laydown
- As shown above, the yield stress should not affect the paste laydown
- The aspect ratio stays constant at 0.36 ± 0.06
- Higher viscosity enables the production of finer lines



VII. Optimized Paste

- Optimized paste for printing through 12 µm line openings
- Line width of 24 ± 4.1 µm
- Aspect ratio of 0.48 ± 0.12
- 16% lower laydown compared to the ITRPV 24 report
- Efficiencies of 23.53 ± 0.06% on PERC cells



Electrical data as measured at	V_{oc} / V	I_{sc} / A	FF / %	Eff / %	PL / mg
project partners site on PERC	0.69 ± 0.00	13.16 ± 0.03	85.15 ± 0.05	23.53 ± 0.06	61.85 ± 0.92

VIII. Conclusion

- The concept of capillary suspensions allows for the separation of high shear viscosity and yield stress contributions to fine line printing results
- Suspension and capillary suspension show the same paste laydown at constant high shear viscosity
- Increasing the viscosity leads to smaller line widths and heights and thus enables a reduced paste laydown
- The findings indicate that high shear viscosity plays a key role in controlling paste transfer and final line width

[1] E. Koos and N. Willenbacher (2011), Capillary Forces in Suspension Rheology, Science 331, 897.
[2] E. Koos, J. Johannsmeier, L. Schwebler, N. Willenbacher (2012), Tuning suspension rheology using capillary forces, Soft Matter 8 (24), 6620-6628.
[3] Maron, S.H., et al. (1956), Application of ree-eyring generalized flow theory to suspensions of spherical particles, J Colloid Sci 11 80–95.

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