

Screen-Printing Simulation Study on Solar Cell Front Side Ag Paste

Michael Neidert¹, Weiming Zhang², Dong Zhang² and Annette Kipka¹
Thick Film Materials Division

¹W.C. Heraeus GmbH, Heraeusstrasse 12-14, 63450 Hanau, Germany

²Heraeus Inc., 24 Union Hill Road, W. Conshohocken, PA 19428 USA

Abstract: The performance of solar cell front Ag paste strongly depends on the chemical composition of the ingredients and paste rheology. The correct inorganic ingredients in the paste ensure the low contact resistance and line resistance for the front fingers. On the other side, the organic ingredients combined with other ingredients provide paste rheology, which affect not only paste stability but also printability.

We discuss improvement of the printability of Heraeus front side Ag pastes in this paper. The goal of this study was to minimize time consuming printing tests by developing a screen-printing simulation program on rheology tester. We developed simulation programs that correlate paste rheology parameters to paste screen printing performance. The program focuses on simulating the screen printing process to get information on characteristics of the printed fingers like spreading and finger width uniformity, etc. The simulation response of paste SOL9848 and improved version SOL9848A was compared. A good correlation between those responses and printability was observed and discussed in this paper.

Key words: Screen printing, Ag paste, Rheology, Solar cell, Heraeus

1.0 INTRODUCTION

Screen printing technology dominates the large scale production of solar cell due to its maturity, easy of incorporation into mass production and cost effectiveness. The pastes used on solar cell, in particular Ag paste for front side contact, need to be formulated to be able to screen print at high speed ($> 8''/s$) and provide high aspect ratio and good uniformity. The performance of solar cell front Ag paste strongly depends on the chemical composition of the ingredients and paste rheology. The correct inorganic ingredients in the paste ensure the low contact resistance and line resistance for the front fingers. On the other side, the organic ingredients combined with other ingredients provide paste rheology, which affect not only paste stability but also paste printability such as printing speed, finger aspect ratio, line definition and smoothness of the printed fingers.

Paste viscosity or even rheology doesn't give too many indications on the paste printability. Evaluating a paste's printability is a time consuming process. In this paper, we discuss screen printing simulation programs we have developed which correlate paste rheology parameters to paste screen printing performance. The program focuses on simulating the screen printing process to get information on characteristics of the printed fingers like spreading and finger width uniformity etc.

2.0 EXPERIMENT AND RESULT

The basic rheology requirement for an excellence Ag front contact paste is that it can be printed easily and produces the fine and continuous fingers with a high aspect ratio. To reach these complex technical needs the paste must feature a high shear thinning behavior combined with a high elastic module to reduce spreading and slumping. In practice, easy printing can be achieved with relatively low viscosity paste, but maintaining non-spreading and slumping needs a contradictory behavior.

To monitor the different shear experiments we use the RheoStress 600 rheometer from Haake, which is equipped to do oscillation measurements to characterize the viscous and elastic behavior of our pastes. For all measurements we apply a cone – plate system with a cone diameter of 20mm and 0.5° angle at 25°C plate temperature. All programs are in the CR modus

(controlled rate i.e. stepping the shear rate), because this gives the reproducible results at high shear rates.

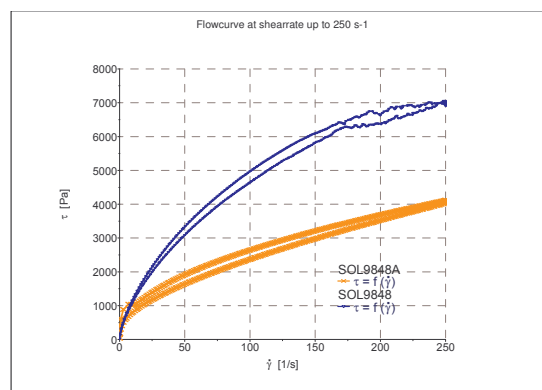


Fig. 1: Flow curves of Ag pastes

One of the key parameters of printing, the printing speed, was first examined. All flow curve programs are running with the same cycle: First ramp up the sample from a shear rate 0s^{-1} to different maximum shear rates in x minutes, holding under constant maximum shear rate for 1 minute in order to destroy the thixotropic structure, and then ramp down from maximum shear rate to 0s^{-1} in x minutes. By using different ramp rate and maximum shear rate we are able to simulate different printing speeds. Figure 1 show the flow curves, up to 250s^{-1} in 3 minutes, of paste SOL9848 in comparison to the improved version paste SOL9848A. The indication that SOL9848 may have problem at high printing speed is the unsteady course of the flow curve at a shear rate of 160s^{-1} and higher. This phenomenon is not coming from so called "Weissenberg" effect, as the paste off the gap between cone and plate has been carefully cleaned off. On the actual screen printing test, this paste (SOL9848) in deed shows necking and non uniformity fingers at printing speeds higher than $6''/s$ (figure 2), while SOL9848A, which shows a very smooth flow curve in figure 1, gives very uniform finger lines at high printing speed as high as $10''/s$ (Figure 3)

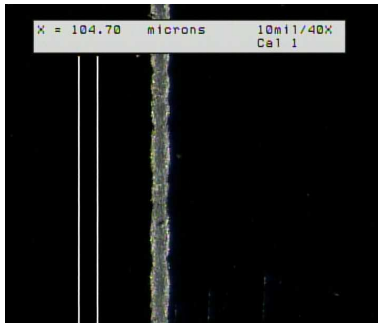


Fig. 2: Non-uniform finger line with paste SOL9848

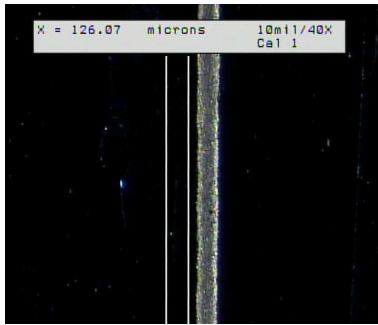


Fig. 3: Smooth finger line with paste SOL9848A

Rheological changes in the paste during printing are both time and shear dependent. Figure 4 shows the evolution of viscosity and shear rate of a typical thick film paste prior to, during and after printing with a screen. The maximum shear rate of about 1000 s^{-1} happens when the paste is forced through the screen. This 1000 s^{-1} maximum shear rate was used in the simulating program. In practice the maximum shear rate could be much higher (2000 s^{-1} to 6000 s^{-1}) depending on the printing parameters and screen.

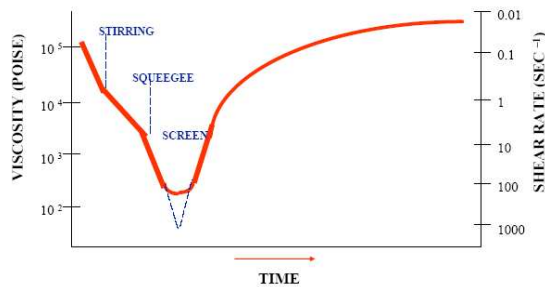


Fig. 4: Typical thick film paste viscosity change during printing.

To study the recovery time of a paste, three stages were created to simulate the paste behavior during printing: **I** – pre-print, **II**–print, **III**–post-print. The first stage represents the paste in the rest on screen, but slightly pre-stressed from stirring and flooding, in which a minor shear rate of 2 s^{-1} for 1 minute was used. In the next stage, the shear rate is 1000 s^{-1} to generate an extreme long printing step of 1 minute. Under such high shear rate the paste structure was destroyed to reach its minimum viscosity. In third stage the shear rate returns back to the initial of 2 s^{-1} for a long time period so that the paste recovers and regains its structure.

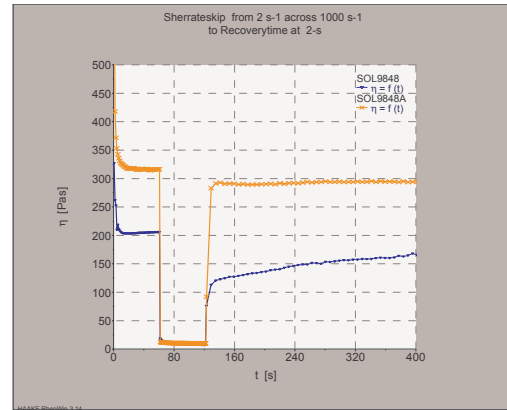


Fig. 5: Examination of a shear rate step of SOL9848 and SOL9848A

The time the paste needs to recover its initial viscosity is called recovery time. It gives us an indication how fast a paste rebuilds its complete thixotropic structure after printing. Figure 5 shows SOL9848 only recovers 60% of the initial viscosity, in contrast the improved paste SOL9848A recovers immediately 91% of the initial value. Its fast recovery helps SOL9848A to achieve better aspect ratio fingers than SOL9848 as shown in figure 6.

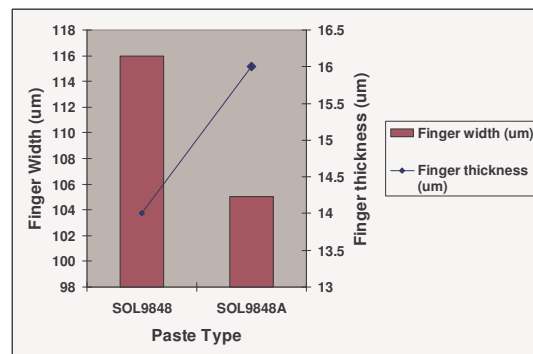


Fig. 6: Finger lines aspect ratio comparison

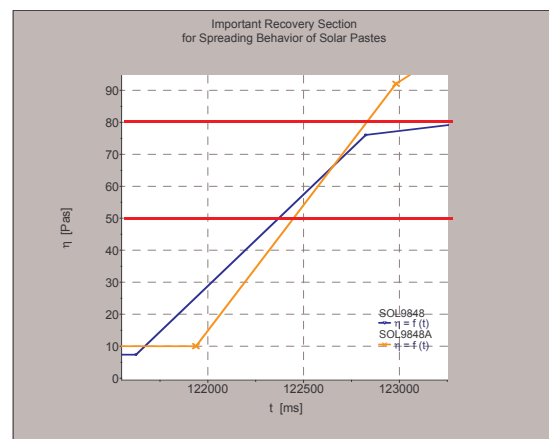


Fig. 7: Zoomed region between II print stage and III recovery stage

To get a feeling for the spreading behavior of the pastes we must zoom in the region between II print stage and III recovery stage (figure 7). In this milliseconds time period, paste is going to spread. The degree of spreading depends on how fast paste recovers its viscosity and structure in this very short time. Table I compares the

recovery time of reaching certain viscosity level say 80 Pas.

Table I: Paste recovery time comparison

Paste	Viscosity level	Recovery time
SOL9848	80 Pas	1767 ms
SOL9848A	80 Pas	879 ms

Note that the SOL9848A reaches 80 Pas viscosity level twice faster than SOL9848 does, which means the paste has only half time to spread. As confirmed from figure 6, in deed SOL9848A showed much narrower but taller fingers.

At last a screen printing simulation program was created to evaluate the paste uniformity of recovery behavior over the whole printing process (figure 8).

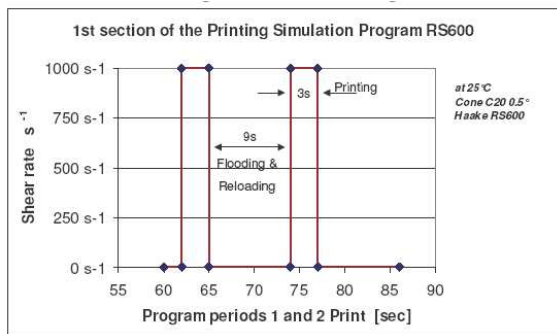


Fig. 8: Screen Printing Simulation Program

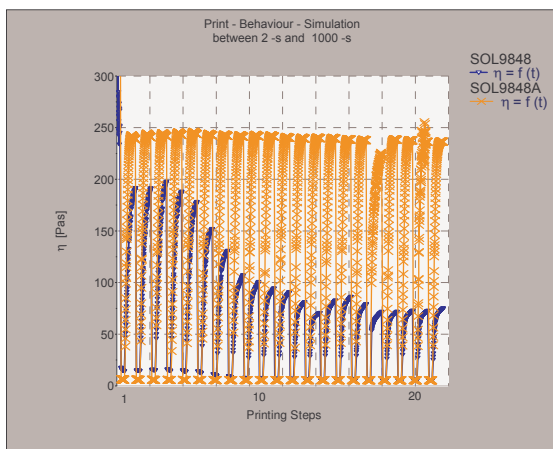


Fig. 9: Viscosity Printing Simulation measurement

The time interval between circles is set at 9 s for the flooding and loading of wafer. For the printing step the time was set at 3 s rather than milliseconds to get enough reading points for a proper evaluation.

At figure 9 we detect a very straight and uniform viscosity response from the improved paste SOL9848A at recovery stage (high viscosity level at about 240 Pas). In contrast SOL9848 shows a constant decreasing viscosity and ends at a recovery viscosity level of only 75 Pas. As mentioned before a decreasing viscosity level will generate a loss of finger height due to slumping.

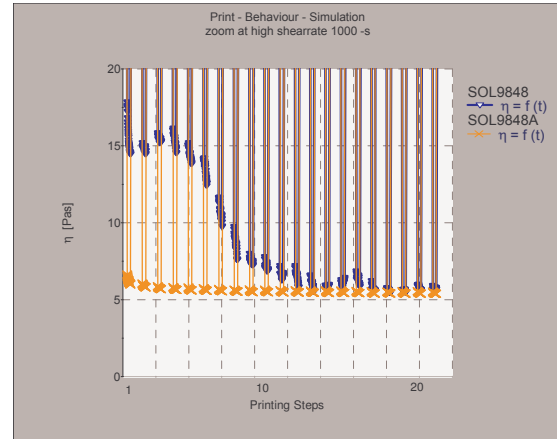


Fig. 10: Zoomed region of Printing Simulation at high shear rate of 1000 s^{-1}

From figure 10, it is clear that SOL9848 needs approximately 14 printing steps until it reaches stable viscosity at high shear stress. Which means SOL9848 needs many pre-prints before it gets a stable paste transfer and thus uniform paste deposition on wafers. The improved pastes SOL9848A however shows, even at the 1st printing step, a uniform viscosity level throughout all printing cycles. This transfers into a uniform printing result over the whole printing process as shown in figure 3.

3.0 CONCLUSION

Our approach using experimental rheology methods with the standard CR- mode of a rheometer to simulate screen printing process of front side Ag paste is quite successful. Paste responses from these printing simulation programs correlated with the in-situ screen printing result very well. We successfully improved printability of our front side Ag paste to achieve better finger line definition and higher aspect ratio. For further paste developments these simulation programs could help predict the actual paste printing performance quickly to eliminate expensive and time-consuming printing trials.

Acknowledgement:

The authors would like to acknowledge Tracy Guo for her contributions on this work.