A DISPENSING SYSTEM FOR SEDIMENTING METAL MICROPARTICLE SOLUTIONS BASED ON A CIRCULATION MIXER METHOD

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ABSTRACT

We present a novel method for the ejection of sedimenting microparticle solutions by a non-contact drop-on-demand dispensing system with integrated mixing technology. The system enables the generation of single liquid droplets in the nanoliter range containing similar amounts of solids. The system is evaluated for a process time of more than 4 h and is applied to produce particle layers with homogeneous layer thicknesses in the micrometer range.

KEYWORDS

sedimenting microparticle solution, mixing, contact-free micro dispensing

INTRODUCTION

A specific application for the use of homogeneous metal particle layers is the production of electrical connections by printing and subsequent laser sintering for high performance electronics and small footprint PCBs. Thereby, the layer thickness needs to be in the high micrometer range (>= 20 µm) thus enabling a feasible conductance for high currents. This largely exceeds the thickness typically achievable by inkjet printers with nanoparticle inks in printed electronics [1,2] without executing 100+ printing cycles. Also, the reduction of costs per sample due to the use of microparticles instead of nanoparticles is a non-negligible issue. The handling of metal microparticle solutions is however critical due to sedimentation issues as stabilizing a dispersion based on high specific gravity microparticles poses a significant challenge. Additionally, dispensing systems which are capable to handle microparticle solutions can hardly be found on the market. An applicable dispensing technology is the PipeJet [3] dispenser from BioFluidix [4]. In contrast to standard dispensing valves, the open, direct volume displacement method is resistant against deposition of particles at the wall inside of the system. However, sedimentation of microparticles inside the nozzle implies clogging after a few minutes. Also, concentration gradients appear which lead to unreproducible and inhomogeneous layers. Therefore, a circular mixing procedure not only in the reservoir but also in close proximity to the nozzle is required, keeping the particles continuously in movement, without changing the pressure boundary inside the nozzle.

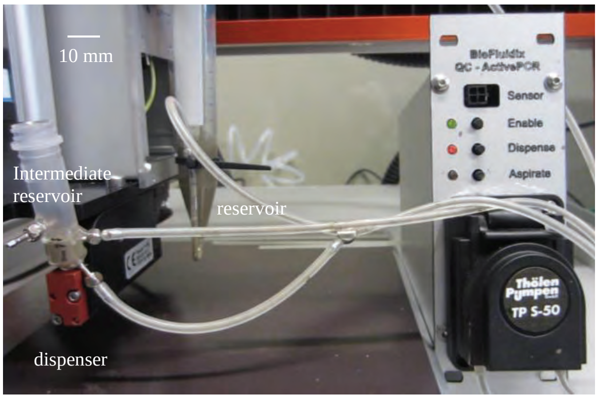

Figure 1: Experimental setup to demonstrate functionality of the circulation mixer. It comprises a PipeJet P9 dispenser (left) mounted on a XYZ stage (BioSpot BT600, BioFluidix, Germany), a first prototype of the intermediate reservoir, the main reservoir containing the dispersion as well as a peristaltic pump (right) to circulate the liquid.

The presented circular mixing method is based on the continuous circulation of the particle solution by a standard peristaltic pump, c.f. figure 1. The entire system consist of a main reservoir, containing the particle solution, a roller pump with disposable pump chamber, a PipeJet P9 dispenser and the intermediate reservoir, which is the integral part, keeping the solution in a homogeneous mixing state. All components are connected by the fluidic pathway (silicone tubes) as shown in fig. 1.

WORKING PRINCIPLE

The intermediate reservoir provides an inlet and outlet connection for the circulation system, as well as a connector to the dispenser nozzle, refer to figure 2. The open concept prevents pressure changes inside the system rendering it highly suitable for the PipeJet technology.

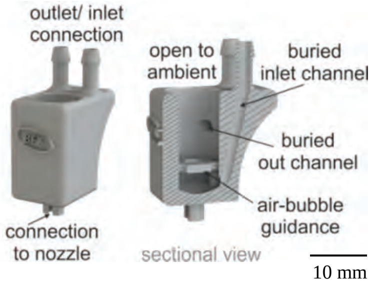

Figure 2: Design of the intermediate reservoir (second prototype). The outlet and inlet connections are guided by buried channels to the reservoir inside to enable a small mounting size. The air-bubble guidance prevents the nozzle inlet from clogging by air.

The working principle of the circulation mixer can be explained *via* the schematic in figure 3. Due to the continuous circulation of the solution, the filling level in the intermediate reservoir and thus the hydrostatic pressure at the nozzle stays constant. Surplus liquid is sucked in at 5 and mixed with small air-bubbles. These bubbles additionally lead to a mixing effect even while the liquid is transported through the fluid path. Ejected liquid out of the nozzle is refilled from the main reservoir continuously. This self-sustaining process is guaranteed due to the well adapted fluidic resistance ratio in the tubing system, connected at 3 and 4. The supply of solution including small air-bubbles, entering into the intermediate reservoir at the bottom side and passing the air-bubble guidance delivers the required mixing effect.

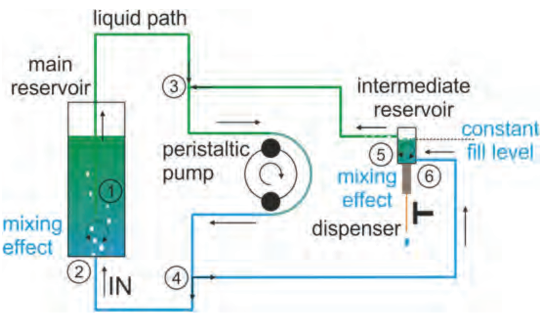

Figure 3: Principle schematic of the circulation method and the liquid pathway. The size of the main reservoir is independent whereas the filling height of the intermediate reservoir must not surpass a certain height (depending on surface tension of the sample).

EXPERIMENTAL CHARACTERIZATION

To evaluate the system performance we used Ag dispersion as listed in table 1.

Table 1: Applied Ag microparticle dispersion

solution	KTD 6078, FEW Chemicals, Germany
particle size	d= 0.5 - 1 µm
concentration	20 wt% Ag
contents	polymer stabilizer
(full) sedimentation time	1 hour

Applying the presented method kept the system operational for over 4 hours without any clogging effect. As circulation flow rate, a setting of 10 µL/s was chosen however operation could be demonstrated for lower and higher flow rates, too. We took several samples at identical dispensing parameters to evaluate the constancy of the particle concentration over time, c.f. figure 4. The method was further applied to produce Ag layers as shown in figure 5. For that instance, droplet patterns comprising 50 dispenses (5X * 10Y) of 50 nL droplets arrayed with a 1 mm pitch were printed. This procedure was repeated up to three times with a variable delay to allow for partial or complete drying. The printing of a layer based on the current process parameters and a single dispenser nozzle took about 15 s.

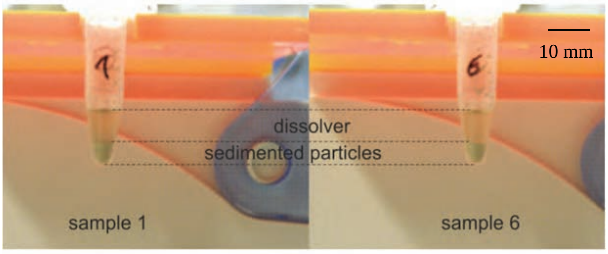

Figure 4: Evaluation of the concentration homogeneity over time. Several samples were taken from the running system by dispensing a constant number of droplets into the test vessel. The pictures are taken after a sedimentation time of 1h. A comparable amount of solids is found in the test vessel.

The patterns were then evaluated with an optical microsocope (Zeiss Axioplan 2 Light / Fluorescence Microscope, Zeiss, Germany) and e.g. a thickness of 23 µm and a deviation of +/- 2 µm was measured for the dual-layer coating. The illustration shows two batches of printed dual-layers with a downtime of 2 hours in between.

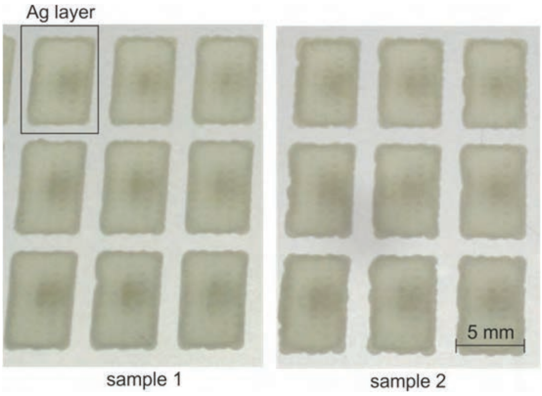

Figure 5: Ag microlayers fabricated by the presented circulation mixer dispensing system. For all layers, similar process parameters were applied. The nine patterns on the right side were printed 2 hours after the patterns on the left side. All layers feature an average thickness of 23 µm +/- 2 µm. The limited edge quality is correlated to the low-pinning substrate surface.

SUMMARY

In summary we presented a novel dispenser/mixer hybrid system for the handling of sedimenting media. The concept was successfully implemented on a dispensing process for the fabrication of homogeneous micro layers using sedimenting silver microparticle solutions. Future work will focus on the printing process optimization and the production of electrical conductors based on Ag and Cu dispersions. Additionally, different particle dispersions with varying fluidic properties will be tested to assess the performance of the circulation mixed in other application scenarios.

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