GESIM

# Nano-Plotter Application Note

## Ink-Jet Printing of PDMS Solutions Using GeSiM Piezo Tips

### Introduction

Polydimethylsiloxane (PDMS) is a widely used silicone elastomer with interesting properties such as low cost, biocompatibility and optical transparency.

Ink-jet printing technology can be used for additive manufacturing, as it allows the deposition of small amounts of material at specified positions anywhere on a substrate. Dispensing several layers on top of each other eventually results in complex 3D structures.

Whether polymers can be printed using piezoelectric dispensers depends on properties of the material such as viscosity and surface tension. The permissible viscosity of piezo dispensers is often limited to a few tens of mPa · s or less, depending on the dispenser design. Heating would reduce sample viscosity, but is often undesired. It has been shown recently (see ref.) that dilution with octyl acetate (OA) can lower the viscosity of the PDMS to such an extent that it can be printed at room temperature using standard ink-jet dispensers.

Here we show how GeSiM's piezoelectric tips can be used to dispense PDMS inks.

### Materials and methods

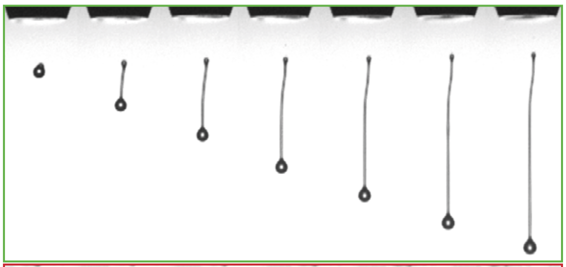
The PDMS was Sylgard 184 (Dow) and was mixed at a ratio of 10:1 (v/v) with curing agent before printing. Octyl acetate (octyl ethanoate, Sigma-Aldrich) was used to dilute this PDMS mixture.

A GeSiM microarrayer, Nano-Plotter NP2.1/E, was equipped with different types of GeSiM piezo tips. Tips were connected to a PTFE tubing system containing a syringe pump with 3-way valve (diluter). PDMS ink was aspirated from a micro-well plate, and the solution was separated from the system liquid (= de-ionized water) by using an air gap and a buffer of extra solvent. Droplet volumes were measured with the GeSiM flow sensor while dispensing was controlled with a stroboscope.

PDMS arrays were dispensed using rectangular voltage pulses onto standard 1×3 inch ((25.4×76) mm$^2$) glass slides whose surface had been modified by exposure to silane vapour. The contact angle of water after this treatment is usually 90°. PDMS spots were dried and cured in an oven at 120 °C for 30 minutes and the resulting spot diameters measured in a calibrated microscope.

### Experimental results

A



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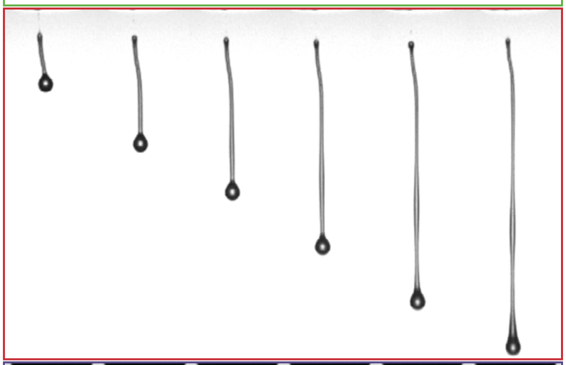

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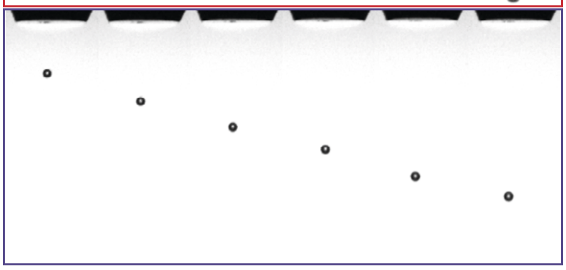

**Fig. 1:** *Droplet shapes, measured 250 µs after triggering of the piezo, for different dispensers. (A) Nano-Tip A for a PDMS:OA ratio of 1:3 and piezo voltages between 60 and 120 V, (B) Nano-Tip HV for a 1:3 PDMS–OA solution and voltages between 60 and 120 V and (C) Pico-Tip for a 1:3 PDMS-OA solution and voltages between 60 and 85 V.*

**Nano-Tip A**

Two dilutions of PDMS in octyl acetate where tested (PDMS:OA = 1:3 and 1:4 v/v). Both could be dispensed; droplets were somewhat distorted (Fig. 1A).

*Droplet volume*: At a 1:4 ratio of PDMS:OA, the dispensed volume for the 1:4 PDMS-OA solution was 200 – 420 pl (Fig. 2A, green line). Shorter actuation pulses were used for the 1:3 solution, resulting in droplet volumes between 130 and 300 pl (not shown).

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**Nano-Tip HV**
The Nano-Tip HV is designed to dispense liquids of higher viscosity as compared to the other tips. Two dilutions of PDMS in octyl acetate were tested (PDMS:OA = 1:2 and 1:3 v/v); both were dosable, with droplet shapes similar to the Nano-Tip A (Fig. 1B).

*Droplet volume*: For the 1:3 PDMS–OA solution, droplets of approx. 200–700 pl were generated at voltages between 40 and 100 V (Fig. 2A). The more viscous PDMS ink (PDMS:OA 1:2) showed a smaller range of droplet volumes, approx. 300–600 pl (not shown).

*Spot diameter*: Fig. 2B shows the spot diameters for dispensed volumes (red line) and Fig. 3A photographs of the spots.

**Pico-Tip**
Due to the different design of the Pico-Tip (smaller orifice), the viscosity of the ink has a higher effect on the dispensing behaviour. Therefore a higher PDMS dilution (PDMS:OA 1:5 v/v) was used. Droplet shapes appeared to be normal (Fig. 1C).

*Droplet volume*: The 1:5 PDMS–OA solution resulted in droplets of about 65–95 pl at voltages between 60 and 85 V (Fig. 2A).

*Spot diameter*: Again arrays were printed onto silane-modified glass slides, see Figs. 2B (blue line) and 3B.

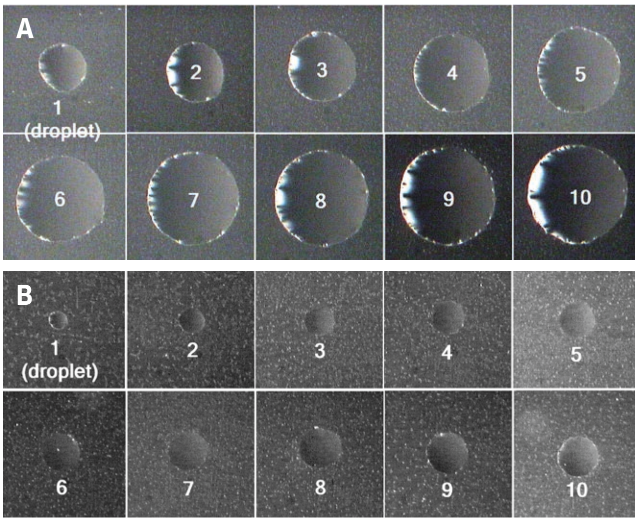


**Fig. 3:** *Dried/hardened spots of PDMS ink on hydrophobic glass slides for different dispensed volumes (corresponding to droplets per spot). (A) Nano-Tip HV, PDMS:OA 1:3; (B) Pico-Tip, PDMS:OA 1:5.*

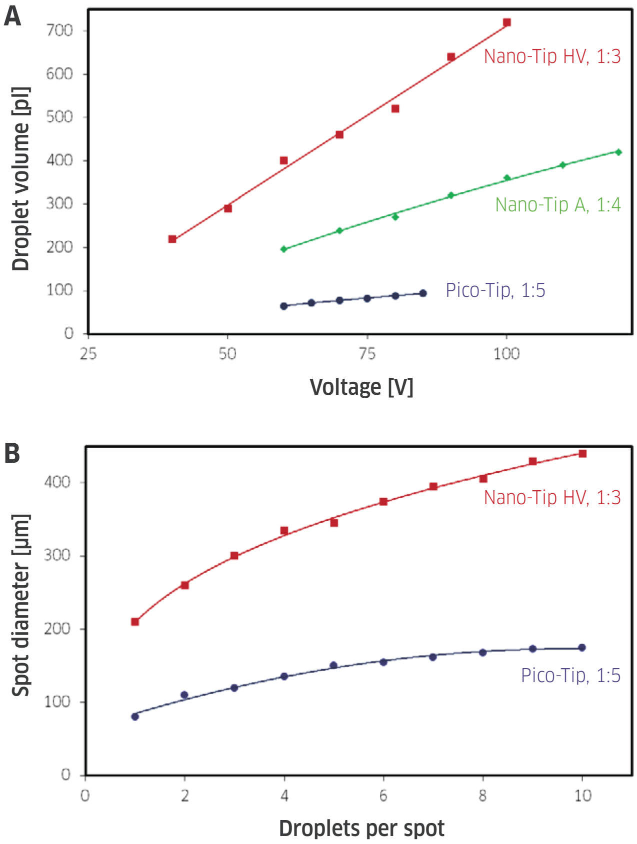


**Fig. 2:** *(A) Droplet volumes for three GesiM piezo tips at different actuation voltages; (B) spot diameters of PDMS inks on hydrophobic glass slides for different dispensed volumes (corresponding to droplets per spot). The ratio PDMS to octyl acetate (v/v) is indicated.*

## Reference

Mikkonen, R., Puistola, P., Jönkkäri, I., Mäntysalo, M.: Inkjet printable polydimethylsiloxane for all-inkjet-printed multilayered soft electrical applications. ACS Appl. Mater. Interfaces 2020, 12, 11990–11997

## Note

As the same dispensers can be built into GeSiM's 3D bioprinters (BioScaffolder), this information holds also true for this system..

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