A Novel Micromachined Inking Chip for Scanning Probe Nanolithography Using Local Vapor Inking Method

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Summary: For Scanning Probe Nanolithography (SPN), chemicals (inks) must first be deposited on scanning probe tips for subsequent writing onto a substrate. This process is called inking and is a very critical and challenging step. Ideally, the inking procedure should be fast, efficient, reproducible, and allows high-density, multiplexed ink transfer onto an array of SPN probes. We report a new method for inking scanning probes, including the design, fabrication, and testing of the new chip and the validation of performance. The new method, based on local thermal evaporative inking transfer, results in low loss, high density, and rapid inking action (minutes). Microfluid channels deliver inks to multiple, closely spaced ink sites that provides local, on-demand vaporization and ink transfer to arrayed scanning probes.

Background: Existing methods of inking face severe limitations. The liquid phase dip inking is simple and popular, but it provides non-uniform, uncontrollable inking. It also suffers from high rate of evaporative ink loss from reservoirs and cross-contamination [1]. Ink-pad based probe inking method is proposed to overcome this issue. It employs a porous membrane (e.g., PDMS) for containing/capping the inking solution. However, it takes long time (> 6 hours) for thiol molecules to diffuse through the thin membrane from ink-delivery channels [2].

Principle: Vapor-phase inking is uniform, reliable, and much faster than liquid phase inking [3]. Traditionally, vapor phase inking is conducted by placing probes in a container filled with liquid chemical solutions or crystallized chemical compounds. Unfortunately, this method does not support multi-probe and multi-ink delivery. In this work, we combined microfluid ink delivery technology and on-demand thermal evaporative ink transfer from a limited reservoir volume. This novel inking chip consists of two parts: Polydimethylsiloxane (PDMS) fluidic network and silicon inking reservoirs (Figure1a). Inks are transported to reservoirs by capillary force to the reservoirs, located at the end of each channel. A resistive heater is associated with each reservoir for providing local heating to initiate vaporization of inks. Natural vaporization is limited due to limited aperture opening.

Each ink reservoir is designed to accommodate a single SPN probe. Positioning probes over reservoirs, the temperature of the reservoir is locally increased (to 60°C or above) by applying a current to the underneath thin film heater. The thiol molecules are evaporated and uniformly coated on the surface of SPN probe inside ink reservoir with several minutes (Figure 1b). Also, due to special design of ink reservoir, each SPN probe is tightly sealed inside individual reservoir so the ink cross contamination is limited.

Chip preparation: The ink loading channels are made inside PDMS layer using soft lithography. The inking channels are made of hydrophilic silicon nitride using standard micromachining techniques. Also, in order to keep ink solution from overflowing the reservoirs, a 2μm thick highly hydrophobic Paryline layer is deposited on the top of silicon nitride layer. Au thin film heater is fabricated underneath the silicon chip to locally heat up thiol molecules inside reservoirs. Figure 2 is the detail fabrication processes.

Application: 1mM 16-Mercaptohexadecanoic acid (MHA) in the ethanol solution is used to characterize this inking chip. After 2-min heating followed by 2-min cooling (the temperature profile, confirmed with IR microscope, is shown in Figure 3), inked scanning probes are loaded on scanning probe lithography instruments (Nscriptor, Nanoink Inc, Chicago, USA). MHA patterns are successfully written on the fresh gold-coated silicon substrate (Au/Cr = 30nm/5nm) at 25°C room temperature and 30% relative humidity environment (Figure 4a, 4b and 4c). The minimum feature is less than 60nm. Moreover, the different ink channels can be loaded different inks so this chip has multiple inking capabilities.

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Figure 1. (a) Schematic of local vapor inking based inking chip for SPN (b) Mechanism of local vapor inking for SPN.

Figure 2. Silicon chip fabrication flow: 1. Au thin film heater fabrication on oxide wafer; 2. Flat bottom cavity array EDP etching; 3. Scarification layer ZnO deposition and patterning and function layers PECVD nitride / Parylene deposition, then RIE etching windows; 4. Hydrochloride acid solution chip releasing; 5. Silicon mold DRIE etching; 6. PDMS layer molding; 7. Loading hole punching and cutting; 8. PDMS layer alignment with silicon chip.
Figure 3. (a) Transient temperature measurement during local vapor inking using IR microscope (b) Radian image for transient temperature measurement.

Figure 4. Characterization of local vapor inking chip (a) dots array writing (3.58μm by 3.58μm scanning size) and (b) lines writing (3.3μm by 3.3μm scanning size) at 25% and 30% relative humidity.

References