Picogram material dosing of microstructures

Sarah S. Bedair[1,a)] and Gary K. Fedder[2]
[1]U.S. Army Research Laboratory, Adelphi, Maryland 20783, USA
[2]Department of Electrical and Computer Engineering and The Robotics Institute, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213 USA

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A solution delivery platform comprised of a suspended microcapillary connected to a microwell enables picogram solute deposition on suspended structures. Precision material placement in the capillary from a 100 pl drop inkjetted into the well is achieved without the destruction of the microstructure and adjacent submicron electrostatic gaps. This method scales to smaller structures without the need for drop miniaturization. The theory behind the solute transfer in the system is developed. Three regions in the drying process are observed and match with the model. The "accumulation" region builds solute concentration in the capillary. The "solidification" region initiates the solidification of solute starting at the free end of the capillary. The "termination" region is characterized by a rapid increase in the solidification due to an increase in the well concentration near the end of the drop lifetime. The accumulation time and solidification rate dependence on concentration compare well with the model. © 2009 American Institute of Physics. [doi:10.1063/1.3248305]

I. INTRODUCTION

Maskless fabrication techniques have several advantages over conventional photolithographic techniques for fabrication on the micro- and nanoscales. These advantages include rapid prototypes where the need for a new mask for each design iteration is eliminated. Direct deposition is an additive process and, therefore, costly materials can be conserved. Elevated processing temperatures causing substrate distortion due to temperature coefficients of expansion mismatch can be eliminated with maskless deposition.[1] Deposition onto released cantilever structures with micron and submicron scale dimensions may only be realized with maskless techniques since photoresist deposition would lead to the destruction of the device.[2,3] Also, implementation of chemical sensor arrays, which require multimaterial deposition onto single chip surfaces, would require multiple mask steps, whereas maskless techniques such as ink-jet printing and microcapillary deposition are less costly.[2,4]

Direct material deposition and manipulation on these scales have been achieved through techniques such as atomic force microscopy (AFM), "dip pen" lithography and inkjet printing.[5] Although AFM and dip pen lithography techniques provide precise deposition on the nanoscale, both require high precision three-dimensional control of the fabrication unit and are considered slow processes.[1] Inkjet printing technology is a more rapid deposition technique. However, direct inkjet printing results in lower resolution features, where the state-of-the-art spot size is a few microns in diameter.[1,6] Nonuniform structures may result from "coffee ring" formation[7] and low viscosity fluids and inks are necessary for repeatable deposition. Direct inkjet deposition necessitates large dimensions[4] leading to, in the case of mass sensitive concentration sensors, poor mass concentration resolution detectors.[8] A more ideal deposition method would provide uniform deposition confined to only the microstructure. Miniaturizing the inkjet drop size, which proves more difficult for repeatable deposition due to issues such as jet clogging, is not necessary for micron and nanoscale material placement using the current method.

An alternative approach explored in this paper is to deposit drops into a well and have the solution wick into an adjacent suspended capillary. An example system of a capillary created on a cantilever is illustrated in Figs. 1(a)–1(c). This fabrication method alleviates some of the major problems with inkjetting and allows for picogram dosing, precise material placement with microscale resolution, and uniform deposition which is not plagued by the coffee ring phenomenon. Alignment of the deposition tool is set by the more relaxed requirement to hit the well. If the inkjet drop placement is misaligned by tens of microns, there is not a direct translation of misalignment to the deposited material, as is the case for other maskless deposition techniques such as dip pen and "fountain pen" nanolithographies.

The capillary is designed along the length of the structure to be dosed with material. We have previously shown a qualitative proof of concept utilizing this method where micron-scaled grooves and slots have been dosed with precise material amounts of 100 pg per drop resolution.[2,3] These scaled microelectromechanical system (MEMS) structures were dosed with a receptor polymer and used as a microcantilever gas vapor detector with femtogram mass resolution in air. The fabrication method demonstrated a repeatable deposition technique on sensor arrays preserving the integrity of the structure constituted by micron-scaled mechanical beam widths and submicron electrostatic gaps. Figure 1(b) shows a representative microgroove capillary device dosed with this method. The material is precisely placed in the 2 μm wide, 120 μm long suspended capillary without destruction of the

a)Electronic mail: sarahbedair@gmail.com.

