Design and Nanofabrication of New Heated Atomic Force Microscope (AFM) Cantilever for Nanolithography Applications

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Thermal dip pen nanolithography (t-DPN) is a maskless top-down nanofabrication technique which is based on atomic force microscope (AFM). In t-DPN, a nanoscale (diameter of 10-100 nm) sharp AFM tip is coated with polymer, placed in contact with surface and heated above the glass transition temperature of polymer for patterning nanostructures. Here, we present the design and fabrication process of a new generation heated AFM cantilever with two embedded joule heaters (tip and reservoir heater) connected via a microchannel (Fig. 1a). The joule heaters are formed by selective doping, where the low doped parts act as the joule heaters and the highly doped silicon legs pass electric current. The reservoir heater can store about 40 ng of solid polymer making it able to write polymer nanostructures with about 40 fg/s mass flow control which is many order of magnitude larger than current available heated AFM cantilevers. The molten polymer imbibes the microchannel as a result of capillary action. Moreover, temperature gradient between the heaters provides thermocapillary stress on the molten polymer causing the fluid to flow from hot to cold reservoir (Fig. 1b). Fig. 2 shows the fabrication process of the designed cantilevers. Silicon-on-insulator (SOI) with 9 μm silicon device layer is used for the process. Fabrication begins with formation of bases, guards and partial formation of tip by selective etching of silicon with inductively coupled plasma Reactive Ion Etching (ICP-RIE) (Fig. 2a). Then, the channel and final form of the tip is defined by wet etching of silicon (Fig. 2b). Cantilever legs are fabrication by etching the rest of the silicon device layer of SOI (Fig. 2c). The entire cantilever except the channel is low doped with phosphorous (Fig. 2d) and subsequently, by masking the reservoirs and the channel, the entire cantilever, including legs and base, are high doped with phosphorous (Fig. 2e). After coating the entire cantilever with silicon oxide, an insulator layer, vias on the highly doped silicon bases are formed by etching the oxide layer with RIE (Fig. 2f) and aluminum traces are deposited with electron Beam (E-beam) Evaporation for providing electrical contact between the doped silicon and the aluminum (Fig. 2g). Finally, by through etching of 500 μm handling layer of the SOI and removing the buried silicon oxide layer with HF the heated AFM cantilever is released (Fig 2h). Figure 3.a shows Scanning Electron Microscope (SEM) image of the sharp tip fabricated after wet etching of the silicon fabricated. Figures 3.b-c show the fabricated cantilevers with short and long channel, respectively.

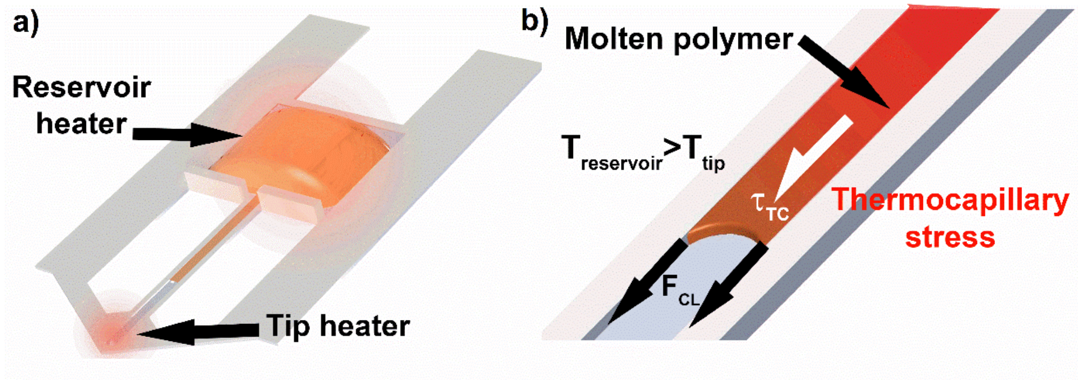

Figure 1: a) Schematic of the cantilever design with embedded tip and reservoir heater. b) Effect of thermocapillary stress on flow of polymer.

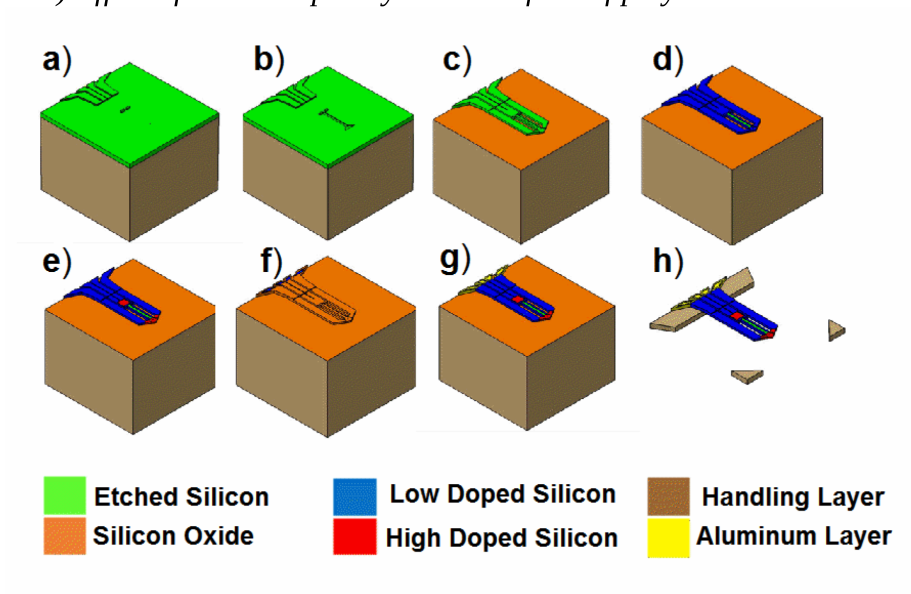

Figure 2: Schematic of microfabrication process flow of the heated AFM cantilever.

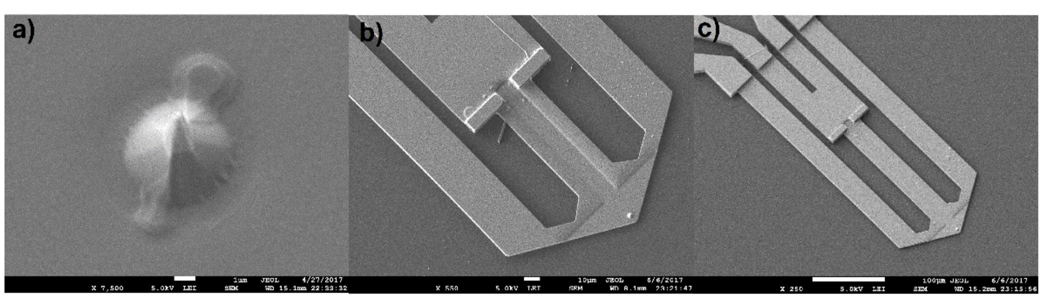

Figure 3: SEM images of a) cantilever tip. b) Cantilever with short channel. c) Cantilever with long channel.