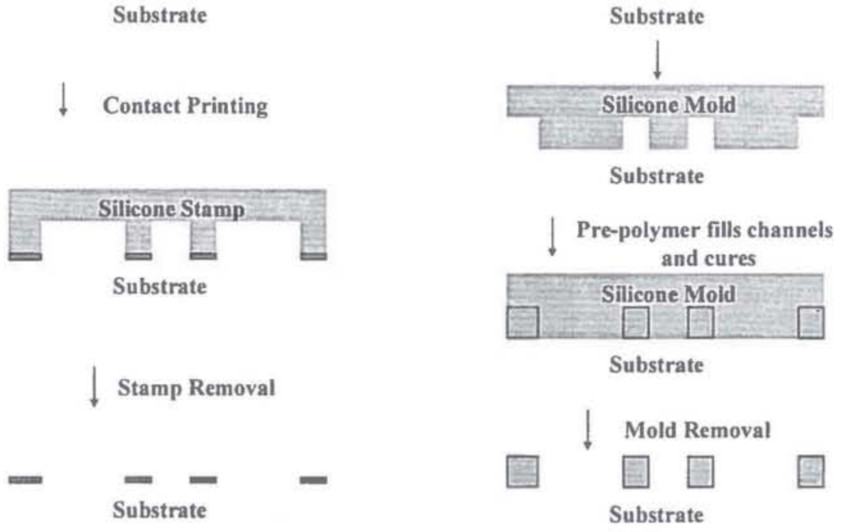
Additive Fabrication and Soft-Lithographic Patterning of Microelectronic Devices

Martin K. Erhardt Final Seminar March 20, 2001

The exponential increase in integrated circuit component density over time described by Moore's Law has been maintained since the 1960's largely because of advances made in photolithographic patterning techniques.[1] Photolithography is currently the workhorse patterning technology of the microelectronics industry, defining sub-micron scale features for metal interconnect fabrication, semiconductor doping, and oxide etching. Yet as feature sizes approach the dimensions of the light waves used in photolithography, the limitations of photolithographic patterning have become increasingly evident. Diffraction-limited resolution, the cost and complexity of the optics and light sources used for exposure, and the increasing environmental costs of solvent-intensive processing are but a few of the factors that have led scientists and engineers in the microelectronics industry to search for alternatives to photolithographic patterning.



(a) (b)

Figure 1. Schematic of two soft lithographic patterning techniques: (a) contact printing employs an elastomeric (typically silicone) patterning stamp and a molecular ink to generate patterned substrate surfaces; (b) a version of polymer molding known as micromolding in capillaries (MIMIC) uses an elastomeric (typically silicone) mold to form patterned polymer microsctructures on substrate surfaces. Once the mold contacts the substrate, a liquid pre-polymer is applied to an open edge of the mold. The pre-polymer is drawn into channels in the mold by capillary action and is cured, after which the mold is removed.

Microelectronic applications are not the only force driving the development of non-photolithographic patterning techniques. Making patterns on non-planar surfaces, over large areas, and in three dimensions is difficult or impossible by conventional photolithography. As a result, many applications ranging from microelectromechanical systems (MEMS) to bioassay sample arrays to wide field-of-view photodetector arrays are not feasible using photolithography as a patterning technique.

Numerous alternatives to photolithography have been proposed for a variety of applications, but some of the most promising recent work has been in the areas of surface modification by "soft"-lithography,[2] embossing,[3] electron beam writing,[4] and scanning probe microscopy.[5] Soft-lithography simply refers to a group of techniques that are related by their use of an elastomeric silicone mold or stamp as a patterning tool. In soft-lithography, photolithography is used only once to initially define a master mold or stamp pattern, but not repeatedly throughout the fabrication, as is the case with conventional device fabrication.

In the work described today, two soft-lithographic techniques known as microcontact printing (μCP)[6] (Figure 1(a)) and micromolding in capillaries (MIMIC)[7-8] (Figure 1(b)), were used to fabricate microelectronic devices, and thus to demonstrate the efficacy of these alternative patterning methods and their compatibility with modern device processing methods, including additive fabrication via selective chemical vapor deposition of patterned metal films.[9] Employing these techniques, the use of soft-lithographic patterning was extended to three new device arrays: platinum silicide Schottky diodes,[10] silicon metal-oxide-semiconductor field effect transistors (MOSFETs),[11] and hydrogenated amorphous silicon thin film transistors (a-Si:H TFTs).[12] These devices were fabricated not because the devices themselves were new, but rather to demonstrate the newly discovered capabilities of soft-lithographic surface patterning, and their application to devices with widespread technological utility, as summarized below.

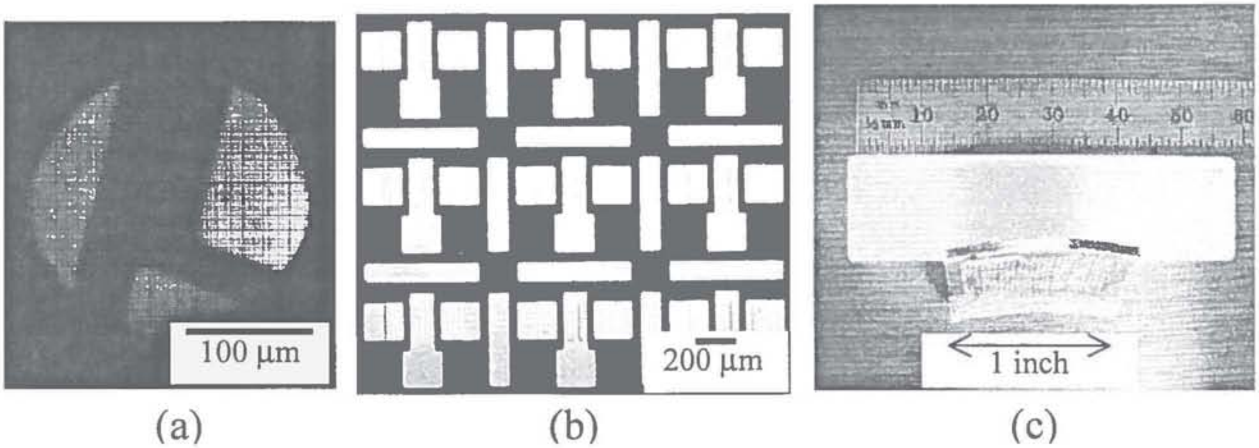


Figure 2. (a) SIMS Pt map showing evidence of selective chemical vapor deposition in a Pt/Si Schottky diode array. Areas of high platinum concentration appear bright; (b) optical micrograph of an array of p-MOSFETs fabricated by MIMIC; (c) photograph of an a-Si:H TFT array fabricated on a spherically curved glass substrate.

The fabrication of platinum silicide Schottky diodes (Figure 2(a)) demonstrated the efficacy of soft-lithographically molded polymer templates for the selective deposition of platinum by CVD and the use of this same polymer template as a resist to buffered HF/NH_4F oxide etchant. The silicon MOSFET (Figure 2(b)) fabrication demonstrated the successful use of soft-lithographic surface patterning in the fabrication of silicon devices requiring multilevel pattern registration. The fabrication of a-Si:H

TFTs (Figure 2(c)) demonstrated the use of soft-lithography to pattern micron-scale device features on a spherically curved substrate – a significant advantage over conventional photolithography. In addition to using soft-lithographic patterning to fabricate device structures, it was also shown that perfluoropolyethers (PFPEs) can be used as contact printing inks to make patterns of discrete beads with micron-scale lateral dimensions and nanoscale vertical dimensions.[13] Such patterns may be useful as nanoscale spacers to prevent contact between patterned substrates in multi-substrate vertical assemblies.

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