Paper Patterning Techniques for Microfluidics

Photolithography	**Description:** Patterned using chromatography paper soaked in SU-8 photo resist polymer solution before being selectively exposed to ultraviolet (UV) radiation using a patterned mask to shield desired pathways. Shielded regions remain hydrophilic and the unreacted SU-8 is washed away. Unshielded regions become hydrophobic after undergoing polymerization. **Advantages:** Convenient, useful; **Disadvantages:** Expensive chemicals and equipment, multiple steps, time consuming, reduced paper flexibility; **Examples:** Martinez, A.W., et al., *Patterned Paper as a Platform for Inexpensive, Low- Volume, Portable Bioassays.* Angewandte Chemie International Edition, 2007. **46**(8): p. 1318–1320. Martinez, A.W., et al., *FLASH: A rapid method for prototyping paper- based microfluidic devices.* Lab on a Chip, 2008. **8**(12): p. 2146–2150.
"FLASH" printing	**Description:** Fast Lithographic Activation of Sheets (FLASH); Much like photolithography, except the paper is laminated between a transparent film and a black paper sheet. A standard ink-jet printer is then used to print a black ink mask onto the film. After polymerization the black paper and film is removed. **Advantages:** Faster, customized masks; **Disadvantages:** Expensive, multiple steps, reduced paper flexibility; **Examples:** Martinez, A.W., et al., *FLASH: A rapid method for prototyping paper- based microfluidic devices.* Lab on a Chip, 2008. **8**(12): p. 2146–2150.
Etch Printing	**Description:** Completely hydrophobised paper, using a polystyrene toluene solution, is "etched" using a toluene solvent printed on the surface which dissolves the solution to allow for the hydrophilic channels to form. **Advantages:** Custom designs, faster; **Disadvantages:** Corrosive/flammable, chemicals; **Examples:** Abe, K., K. Suzuki, and D. Citterio, *Inkjet- Printed Microfluidic Multianalyte Chemical Sensing Paper.* Analytical Chemistry, 2008. **80**(18): p. 6928–6934.
PDMS Printing	**Description:** PDMS is dissolved in hexane and printed onto filter paper using a modified x-y plotter. To form the hydrophobic barriers, the PDMS solution penetrates through the paper thickness. **Advantages:** Enhanced flexibility; **Disadvantages:** Reduced channel resolution due to "creeping" solution; **Examples:** Bruzewicz, D.A., M. Reches, and G.M. Whitesides, *Low-Cost Printing of Poly(dimethylsiloxane) Barriers To Define Microchannels in Paper.* Analytical Chemistry, 2008. **80**(9): p. 3387–3392.
Plasma Printing	**Description:** Paper previously hydrophobised using the cellulose reactive compound, alkyl-ketene-dimer (AKD) is patterned using metal masks that are clamped to the paper before being placed in a plasma asher. The AKD hydrocarbon chains are then oxidized by the plasma, leaving the hydrophilic channels. **Advantages:** Flexible; **Disadvantages:** Expensive, slow manufacturing rate; **Examples:** Li, X., et al., *Fabrication of paper- based microfluidic sensors by printing.* Colloids and Surfaces B: Biointerfaces, 2010. **76**(2): p. 564–570. Li, X., et al., *Paper- Based Microfluidic Devices by Plasma Treatment.* Analytical Chemistry, 2008. **80**(23): p. 9131–9134. Li, X., J. Tian, and W. Shen, *Quantitative biomarker assay with microfluidic paperbased analytical devices.* Analytical and Bioanalytical Chemistry, 2010. **396**(1): p. 495–501.

Paper Patterning Techniques for Microfluidics

Wax Printing	**Description:** Multiple techniques. The simplest involves pattering both sides of filter paper with a wax crayon before heating it. He was then melts into the substrate to form hydrophobic barriers. Also can be extended to inkjet printing for more complicated designs with higher resolution, but at an increased cost. **Advantages:** Good in resource limited settings; **Disadvantages:** Low resolution; **Examples:** Lu, Y., et al., *Fabrication and Characterization of Paper- Based Microfluidics Prepared in Nitrocellulose Membrane By Wax Printing.* Analytical Chemistry, 2009. **82**(1): p. 329–335. Carrilho, E., A.W. Martinez, and G.M. Whitesides, *Understanding Wax Printing: A Simple Micropatterning Process for Paper- Based Microfluidics.* Analytical Chemistry, 2009. **81**(16): p. 7091–7095.
Laser Cutting	**Description:** Uses a computer- controlled x- y knife plotter to cut the paper into the desired design with very high detail. Does not utilize imbibing techniques. **Advantages:** Cheaper fabrication costs, detailed design, clear labeling, can be fully or partially enclosed; **Disadvantages:** experimental technique, heating; **Examples:** Fenton, E.M., et al., *Multiplex Lateral-Flow Test Strips Fabricated by Two-Dimensional Shaping.* ACS Applied Materials & Interfaces, 2008. **1**(1): p. 124–129.
Inkjet	**Description:** Office or specialized inkjet printer receive hydrophobic and bioactive ink cartridges. Resolution of 20 μm or better determined by the diameter of the ink droplet. **Advantages**: low cost and flexibility of digital printing, established technology. **Disadvantages**: interaction ink-paper critical, plugging of nozzles. **Examples:** Li, X., et al., *Fabrication of paper- based microfluidic sensors by printing.* Colloids and Surfaces B: Biointerfaces, 2010. **76**(2): p. 564–570.
Lithography, Flexography, Silk Screening	**Description:** contact printing techniques. **Advantages:** fast, cheap, established technology. **Disadvantages**: require a mold, blanket or negative