pattern **225**). As shown by the inset cross-section, the channel **254** goes from a larger diameter to a smaller diameter. The minimum spacing between patterns necessary to generate such stepped flat surfaces is also the area required as a transition between steps, and can be calculated with the sidewall angle and the height difference between steps. A sidewall angle of approximately 85 degrees is created from medium-low grayscale tones. Grayscale tones close to the homogenization threshold generate surfaces with lower sidewall angles that may vary depending on the pattern.

[0078] FIG. **20** shows a pattern **205** that may be used to create such a channel **254**. FIG. **21** shows a detail of an 8×4 swatch **206***a* (10%) and a 5×1 swatch **206***b* (60%) used to make such a pattern master **205**. As mentioned, once the method of the present invention has created a three dimensional microfluidic device, the device may be used to create libraries of liquid plugs with arbitrary concentrations of chemicals, cells, etc.

[0079] The homogenization phenomenon is further enhanced by designing a mask with an array of circles filled with different patterns to fabricate a combinatorial set of polymerized structures. Each circle in the mask may be tiled with a different 8×4 swatch (swatch formed by 8×4 pixels), that differ in either average "grayscale tone" (the ratio of transparent to opaque pixels where 0% is completely transparent and 100% completely opaque) or in pixel size. Again as shown in FIG. **1**, it was discovered that there is a transition where binary patterns on the mask are transferred to the photoresist as homogeneous polymerized patterns, or discrete polymerized patterns where the pixel geometry is apparent (e.g., one post per pixel). Interestingly, this transition does not depend on pixel density but instead is found to occur for a critical value of the product of n×a, where n is the number of transparent pixels per unit area, and a is the side length of the pixel.

[0080] Specifically, if n×a>5500 μm per unit of patterned area (in mm^2), the pattern is transferred as a homogeneous smooth surface (this condition may be referred to as the "grayscale homogenization threshold"). Further, if n×a<3000 $\mu m/mm^2$, it is transferred as a collection of discrete pixelated patterns (FIG. **2**). Thus, while the relation between grayscale tone and polymerized feature height is reproducible, it may be complex to predict. Nevertheless, as shown in FIG. **34** a simple calibration method may be used to empirically determine this relation for a set of swatches and design microfluidic devices a posteriori. For example, each swatch produces a specific photopolymerized structure of a distinct height, and, therefore, they may be used as building blocks in a hierarchical design approach for the creation of complex polymerized patterns within the device. In this way, multilevel flat features can be easily fabricated by designing adjacent large areas with swatches of different grayscale tones.

[0081] FIGS. **22-24**, show how another embodiment of the present invention may be formed utilizing hierarchical patterning. FIG. **22** shows a compound of concentric circles **209** of different grayscale tones in pattern **205**. The 8×4 swatches **206** below from left to right correspond to a 35%, 45%, 60%, and 65% grayscale tone. FIG. **23** shows a mask design **207** pixilated using first-level 8×4 swatches **206**. First, a horn **210** is constructed from concentric circles **209** patterned with different tonalities of first-level grayscale 8×4 swatches. Such a single horn **210** is shown in FIG. **24**. In any event, the circles **209** vary monotonically from black in the outer circle (1 mm outer diameter) to white in the inner circle (50 μm diameter), as shown in FIG. **22**. Next, this design is used to define a second-level swatch, and apply it to pattern a large rectangle with the same repetitive motif as shown in FIG. **25**A to create a master. Additional first-level swatches may be added to the design to generate multilevel micro channels or other curved surfaces. Alternatively, the master horn pattern **256** may be used to construct microfluidic ejectors **270**, shown in FIG. **27**A.

[0082] Fabrication of the ejectors **270** is as follows: an adhesive **262** is poured over the master **256**, next a glass slide **264** with a thick membrane of polydimethylsiloxan (PDMS) **266** is pressed against the master **256** and the adhesive **262** is exposed to a UV light **261**. When both sides are pressed together, the tips of the horns are inserted into the soft PDMS layer **266** to form an ejector plate **272**. Thus, the horn cavities **269** created on one side of the sandwiched membrane end up in orifices that surface on the other side of the membrane. Next the completed membrane or ejector plate **272** is released from the master. The membrane with the horn cavities **269** connecting both sides is used as an ejector plate.

[0083] A prototype of an atomizer **274** with an ejector plate **272** is shown in FIG. **26**. The plate **272** is mounted over a PDMS gasket **282** and piezoelectric actuator **284**. These are then assembled between pieces of aluminum and polycarbonate to form a sandwich structure **286** around a fluid cavity, as shown in FIG. **26**.

[0084] To operate the ejector, the fluid cavity is primed with water. A sinusoidal AC voltage signal is then generated by a function generator provided by Stanford Research Systems DS345 and an RF amplifier provided by T&C Power Conversion AG1020. When it is operated at a specific frequency (e.g. from 0.8 to 1.1 MHz), the piezoelectric transducer **276** produces standing acoustic waves that are focused by geometrical reflections within the horns, creating a pressure gradient that can be used for fluid jet ejection. The resulting micro fluidic device **274** may be used to eject liquids, such as water, through the thiolene nozzle orifices at ≈5 ml/min flow rate (see, e.g., FIGS. **27**A and **27**B). Moreover, the diameter of the nozzle orifices (40 μm) is well suited to cell manipulation via focused mechanical forces to enable various biophysical effects such as the uptake of small molecules and gene delivery and transfection. Additionally, the grayscale mask here may be designed to create nozzle orifices of different sizes for application to areas as diverse as mass spectrometry, fuel processing, manufacture of multilayer parts and circuits, and photoresist deposition without spinning.

[0085] FIG. **25**A illustrates the result when the design of a single horn shown in FIG. **24** is used as a second-level swatch to pattern a large rectangular area (20×20 mm^2). After fabrication, this swatch pattern may be used to generate an array of thiolene horns. As shown in FIG. **25**B, these horns then may be used as a template to replicate repetitive cavities and form an ejector plate (see, e.g., FIG. **26**).

[0086] FIG. **26** shows a microfluidic device including the ejector formed from the array of horns. FIG. **27**A shows a schematic illustrating the operation of an ultrasonic atomizer created using a method of the present invention. Here fluid enters the chamber through a capillary. When the piezoelectric transducer is driven at a resonant frequency of the chamber, pressure wave focusing leads to ejection of jets of liquid. FIGS. **27**A and **27**B both show a demonstration of jet ejection with a microfluidic.

[0087] As shown in FIGS. **28** and **29**, various pixels of varying sizes may be used to create a wide variety of swatches