may be applied at an angular acceleration of 8,000 revolutions per minute and then baked at around 95° C. for about 2 minutes. The resulting photoresist thickness may be about 1070±10 nanometers.

[0014] Turning first to the exposure step **22**, a user of the nanofabrication process **20** exposes the photoresist to a grayscale radiation pattern of varied intensity. The term "grayscale" refers to a controlled radiation intensity over some area of the pattern. As an example, lower intensity radiation does not penetrate as deeply into the photoresist as higher intensity radiation. Thus, the pattern can be designed to imprint a complex three dimensional topography (e.g., a surface pattern) into the photoresist from the "top down."

[0015] In a further example of forming a grayscale radiation pattern, a photomask having a diffractive pattern may be used. For instance, the photomask may be formed on a transparent substrate using known techniques. The substrate includes a pattern of opaque areas, such as squares, disposed thereon such that the photomask reduces incident radiation into a grayscale pattern.

[0016] In one specific example, a chromium-on-quartz photomask may be used in conjunction with a reduction stepper as a diffraction or spatial frequency filter. The photomask may be patterned with a diffractive array of chromium squares of size s on a square lattice of pitch p. The reduction stepper illuminates the photomask with light of wavelength λ_s and partial coherence parameter σ_s, and a lithographic lens projects the pattern onto the photoresist with a reduction factor of $1/M_s$. With appropriate selection of s and p, diffractive orders other than zero are rejected by the lens aperture. As the zeroth diffractive order determines only the amplitude of the image intensity, individual elements within the diffractive arrays are not resolved, and a grayscale of uniform intensity results. The stepper resolution determines the critical aerial pitch per Equation (1) below, while the diagonal spacing between adjacent elements in the diffractive arrays on the photomask determines the critical square size per Equation (2) below. Diffractive array pitches larger than p_c or squares smaller than s_c will result in fluctuations in aerial intensity as diffractive elements begin to resolve. When Equations (1) and (2) are satisfied, the aerial image intensity of a grayscale is represented per Equation (3) below, where I_0 is the incident illumination intensity.

$$p'_c = \frac{1}{1+\sigma_s}\frac{\lambda_s}{NA_s} \tag{1}$$

$$s_c = p - \sqrt{\frac{p_c^2}{2}} \tag{2}$$

$$I'_{GS} = I_0\left(1-\left(\frac{s^2}{p^2}\right)\right)^2 \tag{3}$$

[0017] In one example, a staircase function grayscale aerial intensity pattern may be rendered with diffractive arrays of chromium squares varying in size from s=1.37 to 2.24 micrometers on a fixed pitch p=4.00 micrometers. The photomask may have a critical dimension tolerance of 15 nanometers (absolute error), critical dimension uniformity of 15 nanometers (maximum range) and an address unit of 5 nanometers. In this case, the photomask creates thirty different grayscale depths having an aerial width of 4.00 micrometers defined by diffractive arrays five square elements wide. The aerial grayscale intensity I_{GS} normalized by the incident illumination intensity I_0 is a function of square size s. Many more grayscales depths can be rendered by varying the diffractive array lattice structure, pitch, or element shape, or by specifying a photomask with improved critical dimension tolerance and uniformity. Non-planar nanofluidic structures with submicrometer lateral dimensions could also be fabricated by reducing the width of the diffractive arrays to one diffractive element per unit pitch.

[0018] A calibration photomask may be used to characterize the response of a particular type of photoresist to grayscale exposure. For instance, the incident illumination intensity I_0 is the dose required to fully clear the photoresist during development. In one example, an approximately linear response may occur over a usefully large range and may simplify subsequent nanofabrication process design.

[0019] After exposure, the substrate and the irradiated photoresist are developed in the developer step **24**. The type of developer used may depend, for example, on the type of photoresist selected for use. In this case, the developer removes the irradiated portions and partially irradiated portions of the photoresist (i.e., a positive photoresist). The non-irradiated portions are insoluble in the developer and remain on the substrate. The developer thereby forms a patterned topography in the photoresist. The patterned topography corresponds to the pattern imprinted by the grayscale radiation pattern and includes a plurality of nanoscale critical dimensions. That is, the grayscale radiation pattern may be designed to create a desired patterned topography in the photoresist, with features having critical dimensions of nanoscale size. The physical structure of a "critical dimension" may depend on the type of feature but may include dimensions such as photoresist film thicknesses, feature heights or depths, steps in photoresist film thickness or feature height or depth, gradients of smooth surfaces which are sloped or curved, and the like. Generally, the critical dimension can be regarded as the smallest geometrical dimension which can be formed.

[0020] Turning now to the transfer step **26**, the plurality of nanoscale critical dimensions of the patterned topography is then transferred from the photoresist to the substrate. One premise of this disclosure is that the nanofabrication process **20** provides the ability to form a plurality of nanoscale critical dimensions that comprise a complex three dimensional topography, in a substrate in a single pattern transfer process without the need for multiple patterning and etching cycles or alignment of photomasks as in standard photolithography.

[0021] As illustrated in the progressive views of FIG. **2**, the photoresist **40** initially includes a patterned topography **41** having the plurality of nanoscale critical dimensions **44** (steps in this example). In this case, the plurality of critical dimensions **44** includes seven steps having nanoscale heights and arranged as a stepped gradient from a shallowest depth to a deepest depth. A depth **46**, for instance, is less than the next, deeper depth **48** and so on and so forth. In other examples, the patterned topography **41** may include fewer nanoscale critical dimensions **44** or more nanoscale critical dimensions, or the topography may have a pattern that is not a staircase structure. The depths from the surface of the photoresist **40** may be nanoscale (in which case this is considered to be a critical dimension) or submicrometer scale, and the height or step size may also be nanoscale (in which case the step size is considered to be a critical dimension).

[0022] The photoresist **40** and the substrate **42** are selectively etched to transfer the plurality of nanoscale critical