

5 **HIGH THROUGHPUT IMPRINT BASED ON
CONTACT LINE MOTION TRACKING CONTROL**

 Cross-Reference to Related Application

10 **[0001]** This application claims the benefit under 35 U.S.C. §119(e)(1) of
U.S. Provisional No. 61/005,297, filed on December 4, 2007, and U.S. Patent
Application No. 12/327,618, filed on December 3, 2008, both of which are hereby
incorporated by reference.

15 **BACKGROUND INFORMATION**

[0002] Nano-fabrication includes the fabrication of very small structures
that have features on the order of 100 nanometers or smaller. One application in
20 which nano-fabrication has had a sizeable impact is in the processing of
integrated circuits. The semiconductor processing industry continues to strive for
larger production yields while increasing the circuits per unit area formed on a
substrate, therefore nano-fabrication becomes increasingly important. Nano-
fabrication provides greater process control while allowing continued reduction of
25 the minimum feature dimensions of the structures formed. Other areas of
development in which nano-fabrication has been employed include
biotechnology, optical technology, mechanical systems, and the like.

[0003] An exemplary nano-fabrication technique in use today is commonly
referred to as imprint lithography. Exemplary imprint lithography processes are

described in detail in numerous publications, such as U.S. Patent Publication No. 2004/0065976, U.S. Patent Publication No. 2004/0065252, and U.S. Patent No. 6,936,194, all of which are hereby incorporated by reference.

[0004] An imprint lithography technique disclosed in each of the
5 aforementioned U.S. patent publications and patent includes formation of a relief
pattern in a formable layer (polymerizable) and transferring a pattern
corresponding to the relief pattern into an underlying substrate. The substrate
may be coupled to a motion stage to obtain a desired positioning to facilitate the
patterning process. The patterning process uses a template spaced apart from
10 the substrate and a formable liquid applied between the template and the
substrate. The formable liquid is solidified to form a rigid layer that has a pattern
conforming to a shape of the surface of the template that contacts the formable
liquid. After solidification, the template is separated from the rigid layer such that
the template and the substrate are spaced apart. The substrate and the
15 solidified layer are then subjected to additional processes to transfer a relief
image into the substrate that corresponds to the pattern in the solidified layer.

BRIEF DESCRIPTION OF DRAWINGS

[0005] So that the present invention may be understood in more detail, a
20 description of embodiments of the invention is provided with reference to the
embodiments illustrated in the appended drawings. It is to be noted, however,
that the appended drawings illustrate only typical embodiments of the invention,
and are therefore not to be considered limiting of the scope.

[0006] FIG. 1 illustrates a simplified side view of a lithographic system in accordance with an embodiment of the present invention.

[0007] FIG. 2 illustrates a simplified side view of the substrate shown in FIG. 1 having a patterned layer positioned thereon.

5 **[0008]** FIGS. 3A-3D illustrate simplified side views of Phases of contact between a template and a substrate.

[0009] FIG. 4 illustrates a graphical representation of contact force provided by imprint head in relation to stiffness of a template during contact between template and substrate.

10 **[00010]** FIG. 5 illustrates a graphical representation of pressure and force distribution on a template.

[00011] FIG. 6 illustrates a flow chart of an exemplary method for controlling contact transition and conforming of template to substrate.

[00012] FIG. 7 illustrates a block diagram of an exemplary control system
15 that may be used to provide controlled contact between template and substrate.

[00013] FIG. 8 illustrates a block diagram of another exemplary control system that may be used to provide controlled contact between template and substrate.

[00014] FIG. 9 illustrates a flow chart of an exemplary method for
20 determining height profile of a contact plane between template and substrate.

[00015] FIG. 10 illustrates a graphical representation of a height profile near contact plane between template and substrate.

[00016] FIG. 11 illustrates a flow chart of an exemplary method for obtaining a contact plane.

[00017] FIG. 12 illustrates a side-by-side comparison of an image of a contact plane obtained from a spread camera and an associated map of the contact plane.

[00018] FIG. 13 illustrates a simplified side view of a chuck contacting a template and defining a contact plane.

[00019] FIG. 14 illustrates another exemplary control system that may be used to provide controlled contact line motion between template and substrate in substantially real time.

DETAILED DESCRIPTION

[0001] Referring to the figures, and particularly to FIG. 1, illustrated therein is a lithographic system 10 used to form a relief pattern on substrate 12. Substrate 12 may be coupled to substrate chuck 14. As illustrated, substrate chuck 14 is a vacuum chuck. Substrate chuck 14, however, may be any chuck including, but not limited to, vacuum, pin-type, groove-type, electrostatic, electromagnetic, and/or the like. Exemplary chucks are described in U.S. Patent No. 6,873,087, which is hereby incorporated by reference.

[0002] Substrate 12 and substrate chuck 14 may be further supported by stage 16. Stage 16 may provide motion along the x-, y-, and z-axes. Stage 16, substrate 12, and substrate chuck 14 may also be positioned on a base (not shown).

[0003] Spaced-apart from substrate 12 is a template 18. Template 18 may include a mesa 20 extending therefrom towards substrate 12, mesa 20 having a patterning surface 22 thereon. Further, mesa 20 may be referred to as mold 20. Alternatively, template 18 may be formed without mesa 20.

5 **[0004]** Template 18 and/or mold 20 may be formed from such materials including, but not limited to, fused-silica, quartz, silicon, organic polymers, siloxane polymers, borosilicate glass, fluorocarbon polymers, metal, hardened sapphire, and/or the like. As illustrated, patterning surface 22 comprises features defined by a plurality of spaced-apart recesses 24 and/or protrusions 26, though
10 embodiments of the present invention are not limited to such configurations. Patterning surface 22 may define any original pattern that forms the basis of a pattern to be formed on substrate 12.

[0005] Template 18 may be coupled to chuck 28. Chuck 28 may be configured as, but not limited to, vacuum, pin-type, groove-type, electrostatic,
15 electromagnetic, and/or other similar chuck types. Exemplary chucks are further described in U.S. Patent No. 6,873,087, which is hereby incorporated by reference. Further, chuck 28 may be coupled to imprint head 30 such that chuck 28 and/or imprint head 30 may be configured to facilitate movement of template 18.

20 **[0006]** System 10 may further comprise a fluid dispense system 32. Fluid dispense system 32 may be used to deposit polymerizable material 34 on substrate 12. Polymerizable material 34 may be positioned upon substrate 12 using techniques such as drop dispense, spin-coating, dip coating, chemical

vapor deposition (CVD), physical vapor deposition (PVD), thin film deposition, thick film deposition, and/or the like. Polymerizable material 34 may be disposed upon substrate 12 before and/or after a desired volume is defined between mold 20 and substrate 12 depending on design considerations. Polymerizable
5 material 34 may comprise a monomer mixture as described in U.S. Patent No. 7,157,036 and U.S. Patent Publication No. 2005/0187339, all of which are hereby incorporated by reference.

[0007] Referring to FIGS. 1 and 2, system 10 may further comprise an energy source 38 coupled to direct energy 40 along path 42. Imprint head 30
10 and stage 16 may be configured to position template 18 and substrate 12 in superimposition with path 42. System 10 may be regulated by a processor 54 in communication with stage 16, imprint head 30, fluid dispense system 32, and/or source 38, and may operate on a computer readable program stored in memory 56.

15 **[0008]** Either imprint head 30, stage 16, or both vary a distance between mold 20 and substrate 12 to define a desired volume therebetween that is filled by polymerizable material 34. For example, imprint head 30 may apply a force to template 18 such that mold 20 contacts polymerizable material 34. After the desired volume is filled with polymerizable material 34, source 38 produces
20 energy 40, e.g., ultraviolet radiation, causing polymerizable material 34 to solidify and/or cross-link conforming to shape of a surface 44 of substrate 12 and patterning surface 22, defining a patterned layer 46 on substrate 12. Patterned layer 46 may comprise a residual layer 48 and a plurality of features shown as

protrusions 50 and recessions 52, with protrusions 50 having thickness t_1 and residual layer having a thickness t_2 .

[0009] The above-mentioned system and process may be further employed in imprint lithography processes and systems referred to in U.S. Patent
5 No. 6,932,934, U.S. Patent Publication No. 2004/0124566, U.S. Patent Publication No. 2004/0188381, and U.S. Patent Publication No. 2004/0211754, each of which is hereby incorporated by reference.

[00010] Chuck 28 and substrate chuck 14 may be used during imprinting to secure template 18 and substrate 12 respectively. Chuck 28 may be mounted on
10 imprint head 30. Imprint head 30 may be capable of controlling motion in multiple axes. For example, imprint head 30 may be a three-axis imprint head 30 capable of controlling Z, R_x and R_y motions (e.g., tip/tilt motion) by moving to independent Z_1 , Z_2 and Z_3 positions. Imprint head 30 may also provide for contact force F between template 18 and substrate 12.

15 **[00011]** Generally, there are three phases for imprint head 30 during the imprinting process. During Phase 1, as illustrated in FIG. 3A, contacting transitions and contact force of template 18 to substrate 12 may be controlled to provide a substantially stable interaction between template 18 and substrate 12 while achieving a relatively rapid response.

20 **[00012]** Imprint head 30 may provide template 18 in free space motion wherein template 18 and substrate 12 may be separated by a distance d. As template 18 moves towards substrate 12, pressure between template 18 and substrate 12 may increase as the gas flow rate may be limited by the distance

between template 18 and substrate 12. The force detected by imprint head 30 may be dependent on the pressure distribution which is a function of the velocity of imprint head 30 and the distance between template 18 and substrate 12. If the distance d between template 18 and substrate 12 is greater than approximately
5 10 μm , the resistance force generated by the air may be of a relatively low magnitude, and as such, incapable of being detected even if template 18 moves towards substrate 12 at velocities of approximately 3 mm/s.

[00013] Imprint head 30 moves template 18 at a velocity v towards substrate 12 (e.g., 3 mm/s) and decreases the distance between template 18 and
10 substrate 12 to less than approximately 10 μm . At this Phase, several Newtons of force (e.g., air resistance) may be measured. This force may be reduced by decreasing the moving velocity of imprint head 30.

[00014] During Phase 2, as illustrated in FIG. 3B, template 18 contacts substrate 12. For example, imprint head 30 may provide contact of template 18
15 to substrate 12. The Z motion of template 18 may be constrained by the stiff environment. For example, the imprint head 30 moving range may be limited by the magnitude of force F that may be possibly generated by the imprint head 30 in addition to the compliance (e.g., stiffness) of template 18 and substrate 12. As illustrated in the graph of FIG. 4, the contact force F gradually increases from
20 zero to 1 N/ μm and then quickly increases to 9 N/ μm . This contact force F may be proportional to the stiffness of template 18 and/or substrate 12.

[00015] Back pressure may be applied to template 18 and/or substrate 12. For example, as illustrated in FIGS. 3B and 3C, back pressure may be applied to

template 18 by chuck 28 and/or back pressure may be applied to substrate 12 by substrate chuck 14 respectively. As illustrated in FIG. 5, as imprint head 30 increases the magnitude of force F, back pressure provided by chuck 28 and/or chuck 14 may be reduced.

5 **[00016]** Referring to FIG. 3B, contact plane 60 is the position at which the surface of template 18 and substrate 12 conform to each other. The edge of the contact plane 60 may be defined contact line 61. For example, the contact plane 60 is the position at which mesa 20 contacts the surface of substrate 12 with the contact line 61 defining the edge of the contact plane 60. The contact
10 line 61 generally differentiates a region 63 wherein template 18 and substrate 12 are in contact with a region 65 wherein template 18 and substrate 12 are not in contact.

[00017] Referring to FIGS. 3B, a real-time multivariable tracking strategy may be used to control the velocity of the motion of the contact line 61 and a
15 height profile adjacent to the contact line 61. The height profile may be defined by the varying distance d between template 18 and substrate 12 within region 65. Generally, motion of the contact line 61 during spread of polymerizable material 34 is a non-linear function of deflection of the substrate 12 and force F provided by imprint head 30.

20 **[00018]** During imprinting, gas molecules near contact line 61 may be reduced by differential pressures generated by reducing deflection of template 18 and/or application of force F by imprint head 30. The intermolecular attractive forces may also assist in transferring energy to gas molecules in the direction of

the motion of contact line 61. For example, intermolecular attractive forces may assist in transferring energy to gas molecules in the direction of the contact line 61 when the distance is less than the radius of the molecular sphere of action (e.g., approximately 50 nm). The height profile near contact line 61 may be modeled as:

$$h(r) = h_0 + a(r - r_0)^2$$

wherein a is the coefficient of profile, h_0 is the thickness of the residual layer 48, r_0 is the radius spread area, and r is the distance from the center. Generally, the pressure along the radius direction may be governed by:

$$pdp = -\frac{6m\mu RT}{\pi m_{mol}(h_0 + a(r - r_0)^2)^3 r} dr$$

The pressure distribution p may be obtained by integrating both sides of the above equation to provide:

$$p^2 - p_0^2 = -\int_{r_0}^r \frac{6m\mu RT}{\pi m_{mol}(h_0 + a(r - r_0)^2)^3 r} dr$$

$$= -\frac{12m\mu RT}{m_{mol}\pi} \left[\frac{\ln \frac{r+r_0}{\sqrt{ar^2+h_0}} + \frac{ar_0}{\sqrt{ah_0} \operatorname{atan}\left(\frac{ar}{\sqrt{ah_0}}\right)} - \frac{1+rr_0 + \frac{ar_0 r}{h_0 \sqrt{ah_0} \operatorname{atan}\left(\frac{ar}{\sqrt{ah_0}}\right)}}{h_0^3 + 3ar_0^2 h_0^2 + 3a^2 r_0^4 h_0 + a^3 r_0^6} - \frac{2(h_0^2 + 2ar_0^2 h_0 + a^2 r_0^4)(ar^2 + h_0)}{h_0^3 + 3ar_0^2 h_0^2 + 3a^2 r_0^4 h_0 + a^3 r_0^6} \right]$$

$$+ \frac{\frac{arr_0}{h_0} - 1 - \frac{3}{2h_0^2} arr_0 - \frac{3ar_0 \operatorname{atan}\left(\frac{ar}{\sqrt{ah_0}}\right)}{8h_0^2(ar_0^2 + h_0)(ar^2 + h_0)\sqrt{h_0 a}} + \frac{a^2 r_0^4 + 4ar_0^2 h_0 + 2h_0^2 \ln \frac{r_0^2}{h_0} + 3h_0^2}{4h_0^2(ar_0^2 + h_0)^3}}{h_0^3 + 3ar_0^2 h_0^2 + 3a^2 r_0^4 h_0 + a^3 r_0^6}$$

As such, the pressure distribution may be a function of the distance d between template 18 and substrate 12 and gas flow rate (e.g., the steeper the height profile near the contact line 61, the quicker the pressure drop).

[00019] There may be a pressure gradient near the contact line 61. Molecules of gas and polymerizable material 34 may be subjected to the pressure gradient. Generally, gases have relatively low densities and viscosities, and as such, gases may be squeezed out of the gap near the contact line 61 by
5 force F and pressure gradients. Liquids, on the other hand, are generally characterized by higher densities and viscosities, and as such, the volumes tend to remain constant by self-association between droplets of polymerizable material 34. The gas pressure gradient and the intermolecular attractive forces between polymerizable material 34 and substrate 12 may drive the spread of
10 polymerizable material 34 laterally and vertically between template 18 and substrate 12 to fill features of template 18. Some of the kinematic energy from the gas molecules may transfer to molecules of polymerizable material 34 as the gas molecules are squeezed out with a high velocity.

[00020] Trapped gas molecules surrounding the polymerizable material 34
15 may have a strong influence on the spreading of droplets of polymerizable material 34 as gas exerts a high pressure on the polymerizable material 34 hindering spread if there is no adequate vent channel to expel gas molecules. This may result in longer spread time during the spreading process of polymerizable material 34.

[00021] The venting of gases may be improved by gradually conforming the
20 template 18 to the substrate 12. For example, venting action may be improved by gradually conforming template 18 to substrate 12 from the center of the contact plane 60 outward.

[00022] During Phase 3, as illustrated in FIG. 3D, the magnitude of force F provided by imprint head 30 and back pressure provided by chuck 28 and/or substrate chuck 14 may be gradually reduced. For example, the magnitude of force F provided by imprint head 30 and back pressure provided by chuck 28 and/or substrate chuck 14 may be gradually reduced to substantially zero using feedback control. By reducing the force F and back pressure, overlay distortions that may cause extra force may be minimized. For example, it has been demonstrated that a 1 Newton force F may cause 5 nm overlay distortion and 10 kPa template back pressure may cause 7 nm overlay distortion during imprinting of template 18 that are substantially thin. These overlay distortions may be minimized by reducing force F and back pressure prior to and during solidification and/or cross-linking of polymerizable material 34.

[00023] FIG. 6 illustrates a flow chart of an exemplary method 100 for controlling contact transition and conforming of template 18 to substrate 12. Generally, in a step 102, template 18 may be adjusted to a position z to provide a suitable distance d between template 18 and substrate 12 having polymerizable material 34 on the surface 46 thereof. In a step 104, a pre-determined amount of force and pressure applied to template 18 providing contact between template 18 and substrate 12 may be determined. In a step 106, the pre-determined amount of force and pressure may be applied to template 18 to provide contact between template 18 with substrate 12. In a step 108, the pre-determined amount of force and pressure applied to template 18 may be adjusted to provide an adjusted amount of force and pressure. The adjusted amount of force and

pressure may provide suitable contact line velocity and/or suitable height profile.

In a step 110, orientation of template 18 may be adjusted such that forces applied by imprint head 30 are within a pre-determined error window. In a step

112, the adjusted amount of force and pressure may be reduced. For example,

5 the adjusted amount of force and pressure may be reduced to zero. In a step

114, polymerizable material 34 may be solidified and/or cross-linked. The

following provides a more detailed explanation of the steps described above.

ADJUSTING IMPRINT HEAD

10 **[00024]** Referring to FIG. 3A, the distance between template 18 and substrate 12 may be adjusted such that template 18 is moved to a position z to provide a suitable distance d between template 18 and substrate 12. Position z is generally higher than the contact plane 60 and provides for little or no contact between template 18 and substrate 12. Position z may be calculated as:

15
$$z = z_{CONTACT} - \Delta z_p - \Delta z$$

wherein Δz is the error window of the contact plane 60, Δz_p is the estimated deflection, and $z_{CONTACT}$ is the estimated contact plane 60.

[00025] The error window Δz of the contact plane 60 may be determined by estimating the accuracy of the contact plane 60. The estimated accuracy of the contact plane 60 is generally the estimated accuracy of the combined variation in
20 template 18 and substrate 12 thickness. Generally, the error window Δz of contact plane 60 may be large enough to avoid any contact when the template 18 is moved adjacent to the substrate 12 under position control of the imprint

head 30. It should be noted, however, that contact transition may be increased if there is a large separation distance when template 18 stops movement towards substrate 12.

[00026] The estimated deflection Δz_p may be based on the applied back pressure to the template 18. For example, the Δz_p may be based on the applied back pressure to the template 18 using a calibrated template deflection model.

[00027] The estimated contact plane $z_{CONTACT}$ may be first determined by using mechanical dimensions of mechanism design. A more accurate estimate may then be made by gradually reducing the gap between template 18 and substrate 12 until interference fringes are observed by a spread camera 70. For example, when illuminated with energy (e.g., white light), fringes generally are not observed until the separation distance is less than the interference length of the energy (e.g., $< 1 \mu\text{m}$). The contact plane $z_{CONTACT}$ may be measured by recording the position z while maintaining the desired amount of contact force during contact transition.

CONTROL SYSTEM

[00028] FIG. 7 illustrates a block diagram of a control system 72 that may be used to decrease the moving velocity of the imprint head 30 to provide controlled contact between template 18 and substrate 12. Mapping between contact force F and length of contact line 61 may be calibrated using spread camera 70 to provide contact force trajectory. Generally, by tracking the profile of the contacting force, a substantially constant velocity of contact line 61 may be

maintained providing a smooth transition as template 18 contacts substrate 12. This may void latency that can affect uniformity of the residual layer 48 (shown in FIG. 2).

[00029] Generally, the control system 72 may provide contact of template 18 with substrate 12 by gradual reduction of the gap between template 18 and substrate. Control system 72 may include force sensors 74 capable of measuring the contact force F applied by imprint head 30 at different locations. Force sensors 74 may be in communication with controller 78 and provide a first signal (input signal) to controller 78. Controller 78 receives the first signal providing information regarding the force and pressure applied to template 18 and uses this information to provide a second signal (output signal) having an adjusted force and pressure to position actuators 76 of imprint head 30.

[00030] A combination of integral action and feedback control may be used to provide the adjusted force and pressure to position actuators 76. Generally, the state of the contact line 61 may be estimated based on a mechanical dimensions of mechanism design in addition to the measured position of the imprint head 30 and contact force F and pressure. Variations of the contact plane 60 may be canceled by the integral action. The error of the contact force F , therefore, may be substantially equal to the set-point force reduced by the measured force as the contact forces may be approaching zero prior to contact of template 18 with substrate 12. The contact force F may be integrated and the actuating signal may be proportional to the integral of the error. This signal may continue to accumulate as the imprint head 30 progresses toward the substrate

12. As template 18 contacts substrate 12, as illustrated in FIG. 3B, the contact force F may converge to a setpoint value such that the contact force F may cancel the error of the contact line 61 estimate.

[00031] FIG. 8 illustrates a block diagram of another exemplary control system 72a. Moving velocity of the contact line 61 and the height profile near contact line 61 may be controlled by adjusting magnitude of force F of imprint head 30 and/or pressure provided by chuck 28 and/or substrate chuck 14. The magnitude of force F and/or pressure provided by imprint head 30 and chuck 28 respectively may be based on a physical model related to the spread of polymerizable material 34. Controller 78 may evaluate applied force F and/or pressure based on the physical model to provide the adjusted magnitude of force F and pressure. The adjusted magnitude of force F and/or pressure may be provided to actuators 76 and/or chuck 28. For example, control of force F may be implemented by adjusting position of imprint head 30 using a cascaded control scheme.

[00032] The contact line 61 and the height profile near the contact plane 60 may be measured using spread camera 70. For example, contact line 61 during fluid spread of polymerizable material 34 may be measured using white light interferometry. The white light may contain all visible wavelengths, $\lambda = 400 \text{ nm} - 700 \text{ nm}$, from an LED array that illuminated substrate 12 through template 18. Some incident beams may reflect and/or deflect from substrate 12 off of template 18. These reflected beams may interfere and the resulting beam interference pattern may be provided in an image (e.g., an image on a CCD screen). The

light intensity of the image may vary following coherence function of the light source. This observed light intensity may vary as a function of the distance d (also herein referred to as gap height) between template 18 and substrate 12 as described by:

$$I(h) = I_o \left(1 + e^{-\left(\frac{h}{l_c}\right)^2} \cos\left(\frac{4\pi h}{\lambda_c}\right) \right)$$

wherein I is the light intensity on the CCD, h is the gap height between template 18 and substrate 12, λ_c is the central wavelength of white light (e.g., 0.5 μm), and l_c is the coherence length of white light (e.g., 1.2 μm).

[00033] FIG. 9 illustrates a flow chart of an exemplary method 200 for determining height profile near the contact line 61 using the image provided by the spread camera 70. In a step 202, high frequency noise of observed light intensity may be removed using a low pass filter. In a step 204, the DC value of light intensity I_o may be evaluated. For example, the DC value of light intensity I_o may be evaluated by averaging observed light intensity $I(h)$. In a step 206, the maximum value and minimum value of intensity modulation may be determined (e.g., peak and valley). In a step 208, modulation $e^{-\left(\frac{h}{l_c}\right)^2}$ may be evaluated using the maximum value and minimum value of intensity modulation. In a step 210, the height difference between the maximum value and minimum value of intensity modulation may be determined. In a step 212, the height variation (or phase change) between adjacent maximum value and minimum value of intensity modulation may be evaluated. FIG. 10 illustrates a graphical representation of an exemplary height profile near contact line 61.

[00034] FIG. 11 illustrates a flow chart of an exemplary method 300 for obtaining a map of contact line 61 using the image provided by spread camera 70. In a step 302, center of contact line 61 may be estimated. In a step 304, if needed, light intensity profile obtained by spread camera 70 may be transformed from Cartesian to polar coordinates. In a step 306, high frequency noise of observed light intensity may be removed. For example, high frequency noise of observed light intensity may be removed by using a low pass filter. In a step 308, at least one edge of contact line 61 may be determined by locating the position of maximum and minimum light intensity. In a step 310, the diameter of the contact line 61 may be estimated. In a step 312, if needed, position of contact line 61 may be transformed from polar to Cartesian coordinates. In a step 314, the center of contact line 61 may be estimated. In a step 316, map of contact line 61 obtained by image provided by spread camera may be provided. A side-by-side comparison of an exemplary image of contact line 61 obtained from spread camera 70 and the associated map of the contact line 61 is illustrated in FIG. 12.

[00035] FIG. 14 illustrates another exemplary embodiment of a control system 72c. Generally, spread camera 70 may provide at least one image. Image may undergo image processing to determine velocity of the contact line 61 between template 18 and substrate 12 and height profile near contact line 61. For example, velocity of contact line 61 and height profile may be determined using white light interferometry. The velocity of the contact line 61 between template 18 and substrate 12 and height profile near contact line 61 may be used

by controller 78 to adjust imprint head 30, chuck 28, and/or substrate chuck 14 to provide controlled contact between template 18 and substrate 12.

ORIENTATION OF TEMPLATE

5 **[00036]** Referring to FIGS. 7 and 8, after template 18 contacts substrate 12, orientation of template 18 may be adjusted such that forces applied by imprint head 30 to template 18 are within a pre-determined error window. Generally, contact forces observed from force sensors 74 may be combined with distances between sensing locations and a central contact point to determine orientation of
10 template 18 at the initial set point. For example, controller 78 may be used to adjust the orientation of the template 18 by adjusting three axis z positions until the difference among the forces is within a pre-determined error window. Additionally, template 18 may be adjusted such that template 18 and substrate 12 are substantially co-planar and template 18 is substantially parallel to
15 substrate 12. This may be further verified by observation with spread camera 70.

SOLIDIFICATION/CROSS-LINKING OF POLYMERIZABLE MATERIAL

[00037] After template 18 and substrate 12 conform, the magnitude of force and pressure applied to template 18 may be gradually reduced. For example,
20 the magnitude of force and pressure applied to template 18 may be gradually reduced to zero. Reduction of the magnitude of force and pressure may be based on information provided by control system 72.

[00038] With the magnitude of force and pressure reduced, polymerizable material 34 on the surface 46 of substrate 12 may then be solidified and/or cross-linked. As previously discussed, the reduction in force and pressure may reduce overlay distortions.

5

TEMPLATE LOADING

[00039] It should be noted that systems and methods described herein may be applied to the loading of templates 18. Variations in the parallelism errors between chuck 28 and template 18 may be minimized using closed loop control
10 during loading of template 18. The low contact force may prevent potential damage of template 18. For example, as illustrated in FIG. 13, the vacuum land surface 120 of chuck 28 may be moved to a position close to the surface 122 of template 18. The contact plane may be detected and orientation of imprint head 30 may be adjusted to make vacuum land surface 120 of chuck 28 conform to
15 surface 122 of template 18 with minimum contact force. Template 18 may then be transferred and secured by chuck 28 by turning on vacuum of chuck 28.

[00040] In using the systems and methods described herein in the loading of template 18, generally, the position z , R_x and R_y may not need to be accurately registered. For example, low contact forces, limited by force
20 measurement accuracy, may be sufficient to automatically detect where and when the template 18 contacts an object. As such, the reliability in loading template 18 may be increased.

WHAT IS CLAIMED IS:

1. A control system for controlling velocity of a contact line and height profile between a template and a substrate during imprinting of polymerizable material

5 on the substrate, the control system comprising:

an imprint head having a plurality of actuators capable of providing a pre-determined amount of force to template;

a chuck positioned adjacent to template and capable of providing a pre-determined amount of pressure to template, the pre-determined
10 amount of force and pre-determined amount of pressure providing an applied force and an applied pressure on template resulting in a first velocity of the contact line between template and substrate and a first height profile between template and substrate;

at least one force sensor positioned between template and substrate and
15 capable of providing a first signal of applied force and applied pressure on template; and,

a controller in communication with the force sensor, actuators, and chuck, the controller capable of receiving the first signal from the force sensor and evaluating the first signal to provide a second signal to
20 actuators and chuck, the second signal having an adjusted force and an adjusted pressure to provide a second velocity of the contact line between template and substrate and a second height profile between template and substrate.

2. The control system of claim 1 further comprising a spread camera in communication with the controller, the spread camera providing at least one image of the first contact line to the controller, the controller capable of evaluating the image and the first signal to provide the adjusted force and the adjusted pressure.

3. The control system of claim 1 wherein the spread camera includes an LED array in superimposition with template to illuminate substrate through template.

4. The control system of claim 3 wherein the spread camera includes a charge-coupled device (CCD) providing the image.

5. The control system of claim 2 wherein the controller is capable of evaluating the image to provide the second velocity of contact line between template and substrate.

6. The control system of claim 2 wherein the controller is capable of evaluating the image to provide the second height profile between template and substrate.

7. A method for controlling contact transition and conformation between a template and substrate during imprinting of polymerizable material on a surface of substrate, the method comprising:

providing a distance between template and substrate;

5 applying, by an imprint head, a pre-determined amount of force to template, the pre-determined amount of force determined to provide a first velocity of a contact line between template and substrate and a first height profile between template and substrate;

determining, by at least one force sensor, applied force to template;

10 providing, by force sensor, a first signal containing the applied force to template;

receiving, by a controller, the first signal containing the applied force to template;

determining, by controller, an adjusted force to provide a second contact
15 line velocity and second height profile between template and substrate;

providing, by controller, a second signal containing the adjusted force;

receiving, by imprint head, the second signal containing the adjusted
force;

20 applying, by imprint head, the adjusted force to template.

8. The method of claim 8 further comprising:

applying, by a chuck, a pre-determined amount of pressure to template,
the pre-determined amount of pressure determined to provide, with
the pre-determined amount of force, the first velocity of a contact
line between template and substrate and the first height profile
5 between template and substrate;

determining, by at least one force sensor, applied pressure to template;
providing, by force sensor, a third signal containing the applied pressure
to template;

receiving, by a controller, the third signal containing the applied pressure
10 to template;

determining, by controller, an adjusted pressure to provide, with the
adjusted force, the second contact line velocity and the second
height profile between template and substrate;

providing, by controller, a fourth signal containing the adjusted pressure;

15 receiving, by chuck, the fourth signal containing the adjusted pressure;
and,

applying, by chuck, the adjusted pressure to template.

9. The method of claim 8 wherein the applied force and the applied pressure
20 are provided in the same signal.

10. The method of claim 8 wherein the adjusted force and the adjusted
pressure are provided in the same signal.

11. The method of claim 7 wherein the applied force and pressure is determined using force sensors positioned at a plurality of locations between template and substrate.

5

12. The method of claim 8 further comprising:

providing, by a spread camera, at least one image of the first contact line between template and substrate; and,

receiving, by controller, the image of the first contact line between template and substrate

10

wherein determining the second height profile between template and substrate includes evaluating the image provided by spread camera.

15 13. The method of claim 12 wherein evaluating the image provided by spread camera comprises:

removing high frequency noise of light intensity from the image;

evaluating the DC value of light intensity;

determining maximum and minimum intensity modulation; and,

20 evaluating maximum and minimum intensity modulation to determine phase change;

14. The method of claim 12 wherein determining the second velocity of the contact line between template and substrate includes evaluating the image provided by spread camera.

5 15. The method of claim 14 wherein evaluating the image provided by spread camera comprises:

determining an estimated center of contact line;

removing high frequency noise of observed light intensity from the image;

locating maximum and minimum light intensities in the image to provide

10 the location of edge of contact line;

determining an estimated diameter of contact line based on location of the edge of contact line; and,

providing map of contact line based on estimated center of contact line and estimated diameter of contact line.

15

16. The method of claim 8 further comprising adjusting orientation of template such that adjusted force and pressure applied to template is within a pre-determined error window.

20 17. The method of claim 8 further comprising solidifying polymerizable material.

18. The method of claim 17 further comprising reducing adjusted force and pressure applied by imprint head and chuck.

19. The method of claim 18 wherein the adjusted force and pressure is
5 reduced to substantially zero.

20. The method of claim 19 wherein the adjusted force and pressure is reduced prior to solidifying polymerizable material.

10 21. The method of claim 7 wherein the contact transition and conformation between a template and substrate is performed directly in substantially real time.

22. A method for controlling contact transition and conformation between a chuck and a template during loading of template within a lithographic system, the
15 method comprising:

providing a distance between chuck and template;

applying, by an imprint head, a pre-determined amount of force to chuck,

the pre-determined amount of force determined to provide a first
velocity of a contact line between chuck and template and a first

20 height profile between chuck and template;

determining, by at least one force sensor, applied amount of force to
chuck;

- providing, by force sensor, a first signal containing the applied force
amount of force to chuck;
- receiving, by a controller, the first signal containing the applied force to
chuck;
- 5 determining, by controller, an adjusted force to provide a second contact
line velocity and second height profile between chuck and template;
- providing, by controller, a second signal containing the adjusted force;
- receiving, by imprint head, the second signal containing the adjusted
force;
- 10 applying, by imprint head, the adjusted force to chuck.