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(54) **RESIDUAL LAYER THICKNESS MEASUREMENT AND CORRECTION**

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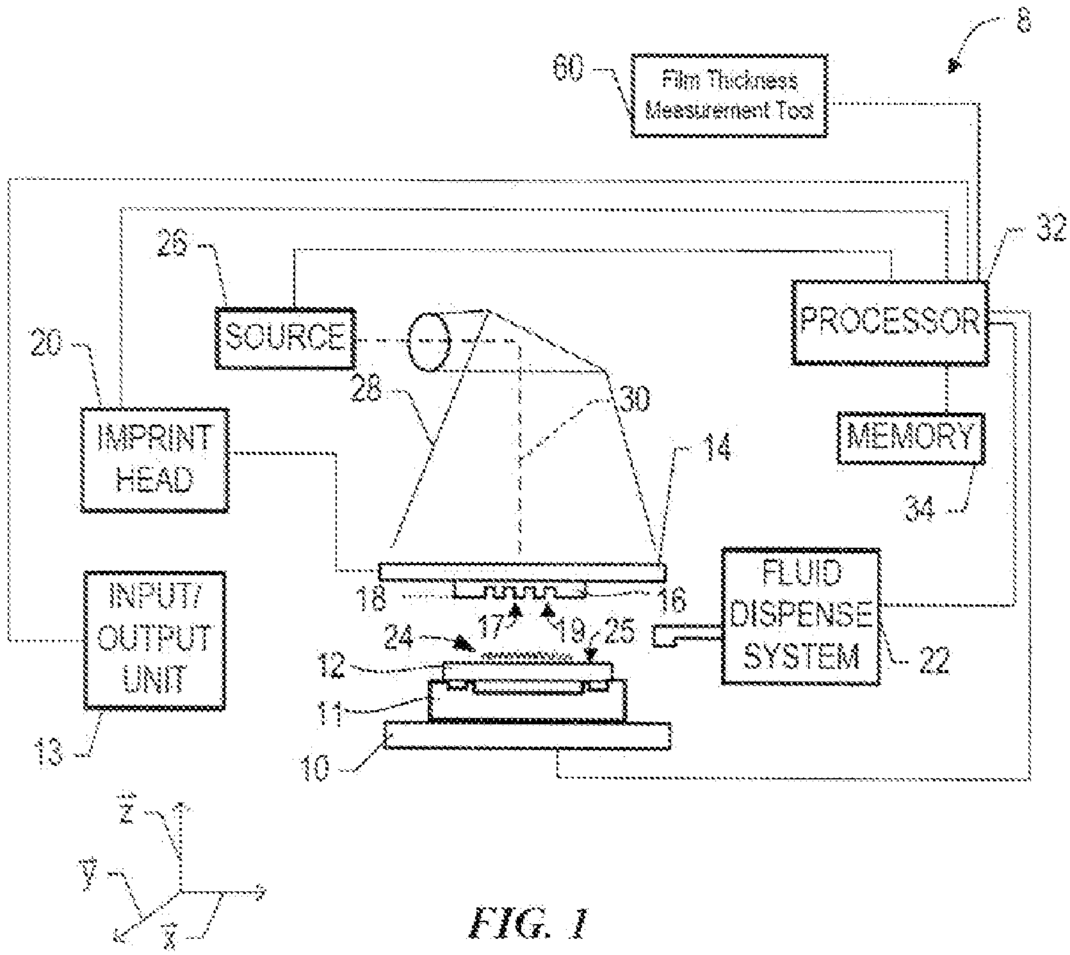
(52) **U.S. Cl.** **264/40.4**; 264/319; 425/385; 425/375; 425/141

(57) **ABSTRACT**

In nano-imprint lithography it is important to detect thickness non-uniformity of a residual layer formed on a substrate. Such non-uniformity is compensated such that a uniform residual layer may be formed. Compensation is performed by calculating a corrected fluid drop pattern.


8
60
Film Thickness Measurement Tool
32
26
SOURCE
PROCESSOR
20
28
30
MEMORY
IMPRINT HEAD
14
34
18
16
FLUID DISPENSE SYSTEM
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19
25
24
INPUT/ OUTPUT UNIT
12
22
11
13
10
z
y
x

FIG. 1

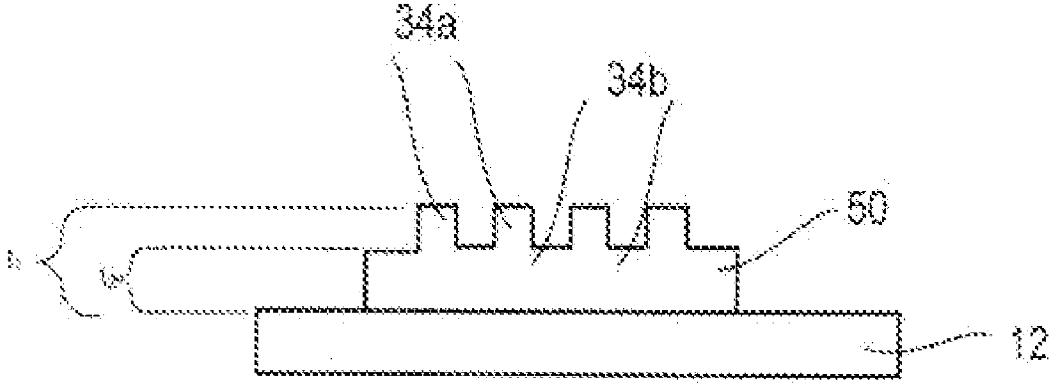


FIG. 2

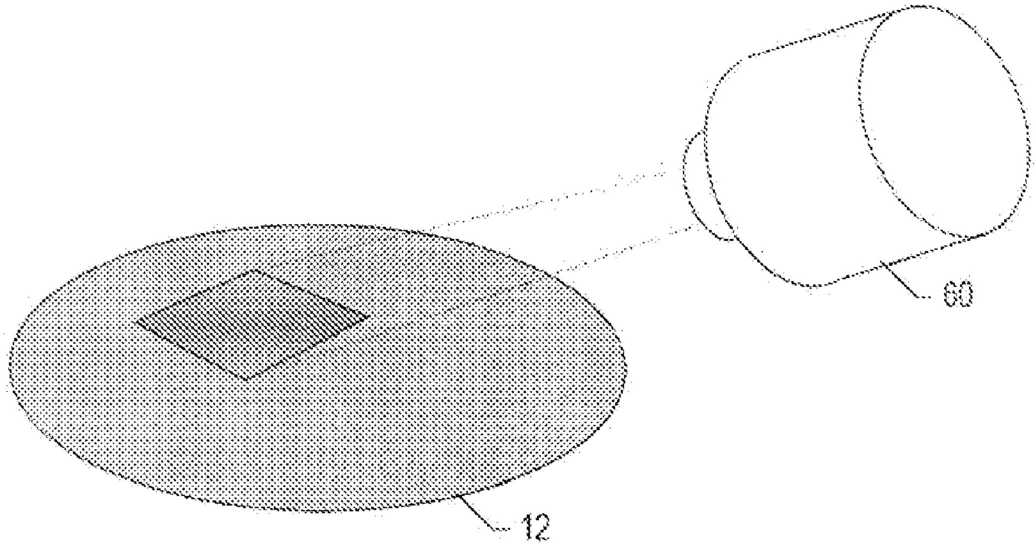


FIG. 3

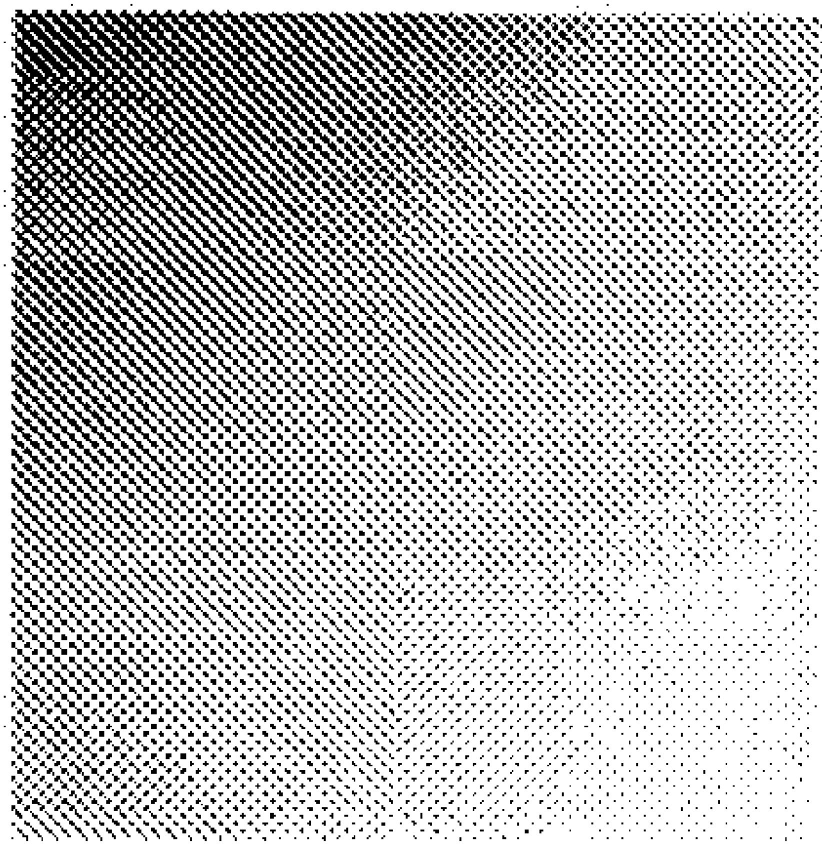


FIG. 4

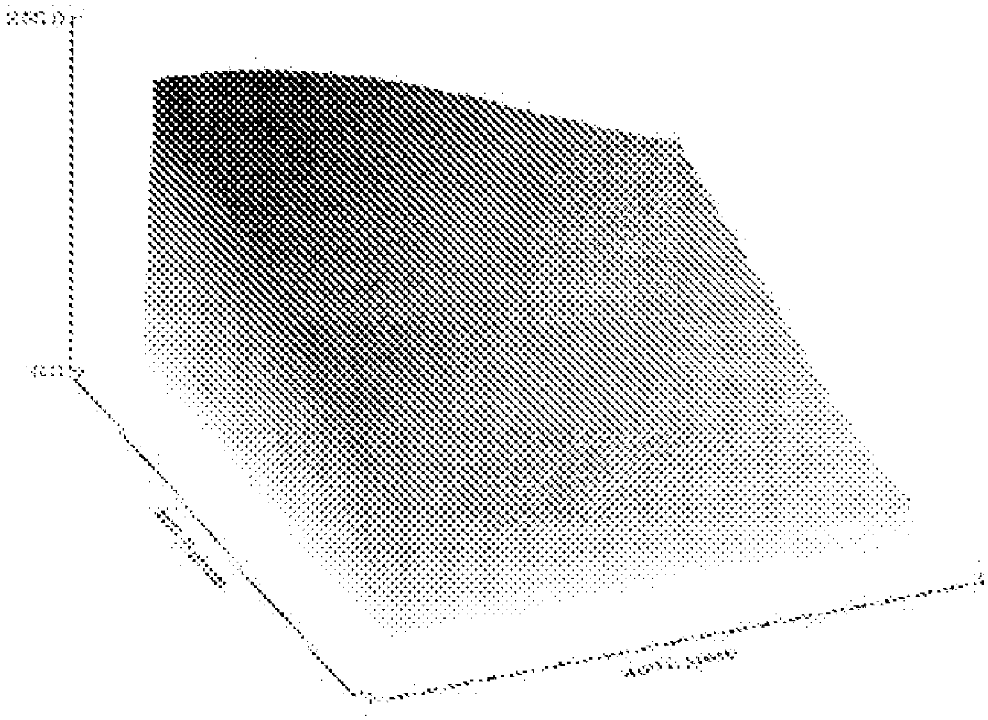
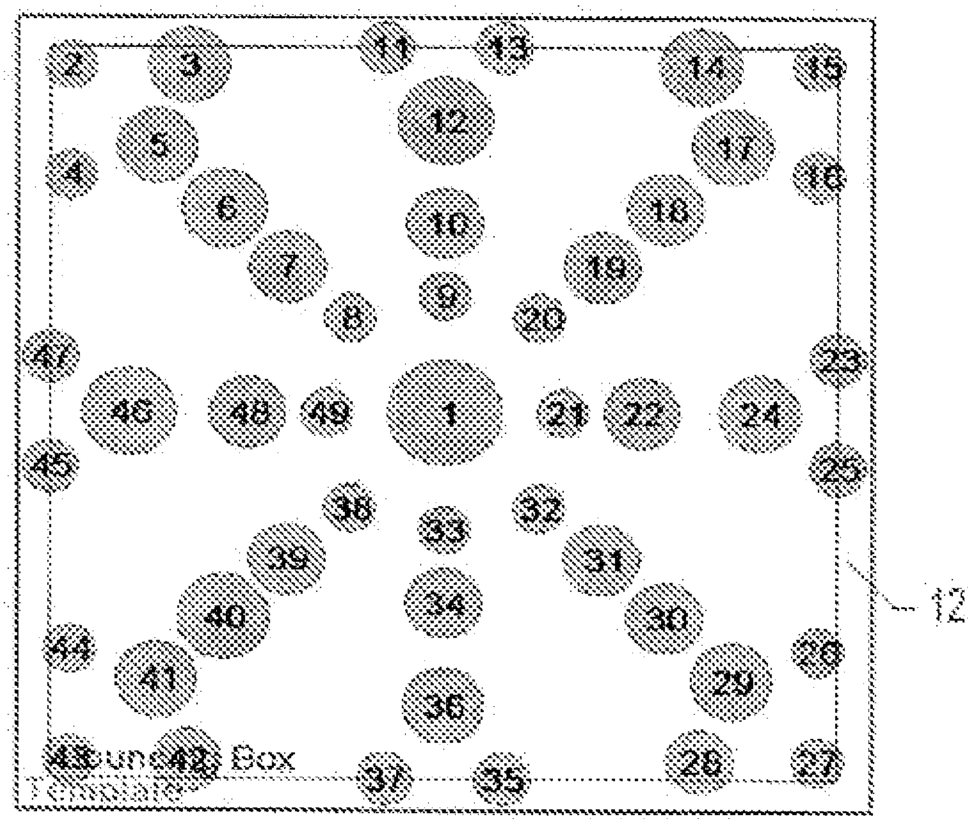


FIG. 5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32
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42
43
44
45
46
47
48
49
Box
Template
12

FIG. 6

FIG. 7A

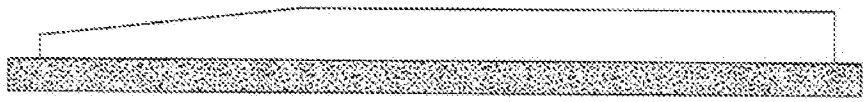


FIG. 7B

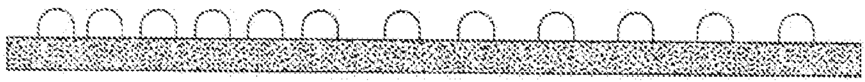


FIG. 7C

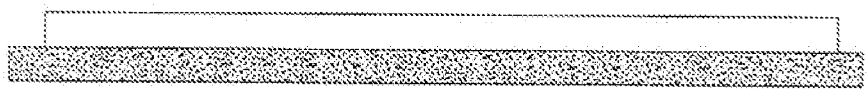
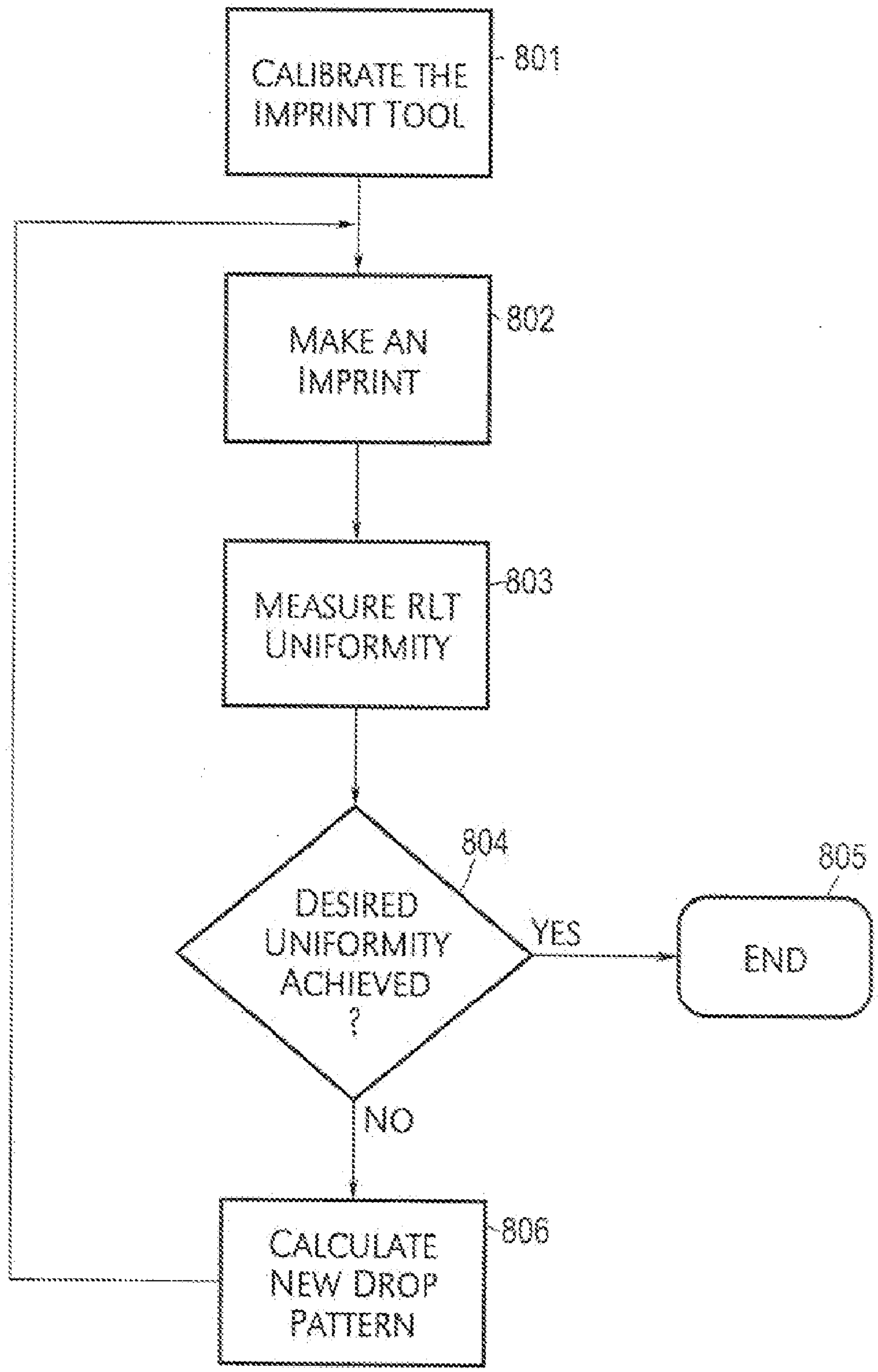


FIG. 7D



CALIBRATE THE IMPRINT TOOL
801
MAKE AN IMPRINT
802
MEASURE RLT UNIFORMITY
803
DESIRED UNIFORMITY ACHIEVED ?
804
YES
END
805
NO
CALCULATE NEW DROP PATTERN
806

FIG. 8

RESIDUAL LAYER THICKNESS MEASUREMENT AND CORRECTION

[0001] This application for patent claims priority to U.S. Provisional Patent Application Ser. No. 60/788,808, which is hereby incorporated by reference herein.

BACKGROUND

[0002] Nano-fabrication involves the fabrication of very small structures, e.g., having features on the order of nanometers or smaller. One area in which nano-fabrication has had a sizeable impact is in the processing of integrated circuits. As the semiconductor processing industry continues to strive for larger production yields while increasing the circuits per unit area formed on a substrate, nano-fabrication becomes increasingly important. Nano-fabrication provides greater process control while allowing increased reduction of the minimum feature dimension 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 is commonly referred to as imprint lithography. Exemplary imprint lithography processes are described in detail in numerous publications, such as United States patent application publication 2004/0065976 filed as U.S. patent application Ser. No. 10/264,960, entitled, "Method and a Mold to Arrange Features on a Substrate to Replicate Features having Minimal Dimensional Variability"; United States patent application publication 2004/0065252 filed as U.S. patent application Ser. No. 10/264,926, entitled "Method of Forming a Layer on a Substrate to Facilitate Fabrication of Metrology Standards"; and U.S. Pat. No. 6,936,194, entitled "Functional Patterning Material for Imprint Lithography Processes," all of which are assigned to the assignee of the present invention.

[0004] Imprint lithography disclosed in each of the aforementioned United States patent application publications and United States patent includes formation of a relief pattern in a polymerizable layer and transferring a pattern corresponding to the relief pattern into an underlying substrate. The substrate may be positioned upon a motion stage to obtain a desired position to facilitate patterning thereof. To that end, a template is employed spaced-apart from the substrate with a formable liquid present between the template and the substrate. The liquid is solidified to form a solidified layer that has a pattern recorded therein that is conforming to a shape of the surface of the template in contact with the liquid. The template is then separated from the solidified layer such that the template and the substrate are spaced-apart. The substrate and the solidified layer are then subjected to processes to transfer, into the substrate, a relief image that corresponds to the pattern in the solidified layer.

[0005] The solidified layer may comprise a residual layer of material, i.e., a contiguous layer. Residual layer thickness (RLT) and residual layer thickness uniformity are key metrics for evaluating the quality of imprinted wafers. For many applications, a plasma etch step directly follows imprinting. Film thickness uniformity requirements for plasma etching are well known in the field. RLT uniformity determines the film thickness uniformity of imprinted samples to be etched. Presently, residual layer thickness uniformity is evaluated using the unaided eye to look at fringe patterns. To that end, there is no quantitative feedback to improve the residual layer uniformity once the liquid is positioned between the template and the substrate.

BRIEF DESCRIPTION OF DRAWINGS

[0006] FIG. **1** is a simplified side view of a lithographic system having a template spaced-apart from a substrate;

[0007] FIG. **2** illustrates a residual layer;

[0008] FIG. **3** is a simplified elevation view of a film thickness measurement tool proximate the substrate, shown in FIG. **1**;

[0009] FIG. **4** illustrates an image taken by the thickness measurement tool, shown in FIG. **3**;

[0010] FIG. **5** is simplified three dimensional representation of the image, shown in FIG. **4**;

[0011] FIG. **6** is a top down view of the substrate having a drop pattern positioned thereon;

[0012] FIGS. **7**A-**7**D illustrate exemplary steps for addressing a non-uniform residual layer; and

[0013] FIG. **8** illustrates a process for compensating for a non-uniform residual layer.

DETAILED DESCRIPTION

[0014] Referring to FIG. **1**, a system **8** to form a relief pattern on a substrate **12** includes a stage **10** upon which substrate **12** is supported and a template **14**, having a patterning surface **18** thereon. In a further embodiment, substrate **12** may be coupled to a substrate chuck (not shown), the substrate chuck (not shown) being any chuck including, but not limited to, vacuum and electromagnetic.

[0015] Template **14** and/or mold **16** may be formed from such materials including but not limited to, fused-silica, quartz, silicon, organic polymers, siloxane polymers, borosilicate glass, fluorocarbon polymers, metal, and hardened sapphire. As shown, patterning surface **18** comprises features defined by a plurality of spaced-apart recesses **17** and protrusions **19**. However, in a further embodiment, patterning surface **18** may be substantially smooth and/or planar. Patterning surface **18** may define an original pattern that forms the basis of a pattern to be formed on substrate **12**.

[0016] Template **14** may be coupled to an imprint head **20** to facilitate movement of template **14**, and therefore, mold **16**. In a further embodiment, template **14** may be coupled to a template chuck (not shown), the template chuck (not shown) being any chuck including, but not limited to, vacuum and electromagnetic. A fluid dispense system **22** is coupled to be selectively placed in fluid communication with substrate **12** so as to deposit polymeric material **24** thereon. It should be understood that polymeric material **24** may be deposited using any known technique, e.g., drop dispense, spin-coating, dip coating, chemical vapor deposition (CVD), physical vapor deposition (PVD), and the like.

[0017] A source **26** of energy **28** is coupled to direct energy **28** along a path **30**. Imprint head **20** and stage **10** are configured to arrange mold **16** and substrate **12**, respectively, to be in superimposition and disposed in path **30**. Either imprint head **20**, stage **10**, or both vary a distance between mold **16** and substrate **12** to define a desired volume therebetween that is filled by polymeric material **24**.

[**0018**] Referring to FIGS. **1** and **2**, typically, polymeric material **24** is disposed upon substrate **12** before the desired volume is defined between mold **16** and substrate **12**. However, polymeric material **24** may fill the volume after the desired volume has been obtained. After the desired volume is filled with polymeric material **24**, source **26** produces energy **28**, e.g., broadband energy that causes polymeric material **24** to solidify and/or cross-link conforming to the shape of a surface **25** of substrate **12** and patterning surface **18**, defining a patterned layer **50** on substrate **12** having a contiguous formation of polymeric material **24** over surface **25**. More specifically, patterned layer **50** comprises sub-portions **34***a* and **34***b*, with sub-portions **34***b* being in superimposition with protrusions **19**, with sub-portions **34***a* having a thickness t**1** and sub-portions **34***b* having a thickness t**2**, with sub-portions **34***b* commonly referred to as the residual layer. Thicknesses t**1** and t**2** may be any thickness desired, dependent upon the application.

[**0019**] Referring to FIGS. **1**, **2**, and **3**, the broadband energy may comprise an actinic component including, but not limited to, ultraviolet wavelengths, thermal energy, electromagnetic energy, visible light and the like. The actinic component employed is known to one skilled in the art and typically depends on the material from which imprinting layer **12** is formed. Control of this process is regulated by a processor **32** that is in data communication with stage **10**, imprint head **20**, fluid dispense system **22**, source **26**, operating on a computer readable program stored in memory **34**. System **8** may further include a film thickness measurement tool **60** coupled with the substrate chuck (not shown), described further below. Film thickness measurement tool **60** may comprise an optical detection system, and further may be in data communication with processor **32**. Film thickness measurement tool **60** may be a stand alone tool commonly used in semiconductor fabrication. Such tools are commercially available from Metrosol, Inc., Filmetrics, Rudolph Technologies, and J. A. Woolam.

[**0020**] Patterned layer **50** may have variations among thicknesses t**2**, which may be undesirable. More specifically, minimizing, if not preventing, variations among sub-portions **34***b*, and thus, the residual layer may result in improved control of the critical dimension of pattered layer **50**, which may be desired. In an example, it may be desirable to reduce variations among sub-portions **34***b* below the approximately 30 nm level seen in typical imprints in order to minimize, if not prevent, the impact to etched feature critical dimension.

[**0021**] To that end, variations in thicknesses t**2** of sub-portions **34***b* may be measured generating measured data, with the measured data facilitating a design in positioning of polymeric material **24** upon substrate **12**. In the present embodiment, polymeric material **24** is positioned as a plurality of droplets upon substrate **12**, and thus, the measured data facilitates a design in the drop pattern of polymeric material **24**. As a result, uniformity in thicknesses t**2** of the sub-portions **34***b* may be achieved.

[**0022**] The variations in thicknesses t**2** of sub-portions **34***b* may be measured at a plurality of points employing film thickness measurement tool **60**, with the optical detection system digitizing imprinted fields, i.e., patterned layer **50**, and subsequently employing processor **32** operating on a computer readable program stored in memory **34** to analyze said imprinted fields to construct a map of the thickness t**2** of sub-portions **34***b* across patterned layer **50**. To that end, the drop pattern of polymeric material **24** may be varied, i.e., droplets may be added or subtracted, the drop offset may be varied, individual drop volumes of the plurality of drops, based upon the variations in thickness t**2** of sub-portions **34***b* to generate a drop pattern that may facilitate patterned layer **50** comprising sub-portions **34***b* having a desired thickness uniformity.

[**0023**] Referring to FIGS. **1** and **3**, to that end, film thickness measurement tool **60** may be positioned at a fixed angle and distance from substrate **12**, with the distance from the imprint field, i.e., patterned layer **50**, to film thickness measurement tool **60** being calculated. A calibration process may be required to obtain accurate dimensions of the imprint field. An alternative method for measuring the residual layer thickness measures the optical properties of the film, such as reflected intensity versus wavelength or circular versus elliptical polarization of light reflected from the field. These spectroscopic measurements are then fit to a model of the film stack to determine parameters of interest such as film thickness. Such a process can be implemented using the commercially available film thickness measurement tools noted above.

[**0024**] Referring to FIGS. **1** and **4**, after an image of the imprint field is taken by film thickness measurement tool **60**, processor **32** operating on a computer readable program stored in memory **34** may employ an algorithm to convert the image into a square (or, rectangle, circular, etc.) imprint area. Subsequently, processor **32** may convert differences in color and shade grades into a Z-height profile of the imprint field. FIG. **5** shows an example of a three-dimensional representation of the field shown in FIG. **4**. Furthermore, the computer readable program stored in memory **34** may comprise a program entitled ImageJ available from http://rsb.info.nih.gov/ij/.

[**0025**] Further analysis of the imprinted filed is performed to map surface **25** of substrate **12** with a polynomial two-dimensional function, f(x,y). In this way, we can assign a specific thickness to each (x,y) point. Further, an average g(x,y) may be calculated, as well as deviation from this average: $w(x,y)=g(x,y)-f(x,y)$.

[**0026**] The slope g(x,y) will be used to calculate the offsets in X and Y directions of the drop pattern. Deviation function w(x,y) will be used to control local unit fluid volume; number of drops, position of drops and drop volume itself.

[**0027**] FIG. **6** shows an exemplary drop pattern of polymeric material **24** used for imprinting that produced a desired thickness profile shown on FIG. **5**. Using a multi-nozzle dispensing unit, various drop patterns can be generated on the substrate, such as a uniform grid superimposed with localized compensating drops.

[**0028**] Furthermore, the drop pattern on FIG. **6** corresponds to the following drop matrix, M(x,y):

[**0029**] 1: (0,0) 3.3113E-4 uL (microliters)×29 drops (0,0) refers to the center of the template

[**0030**] 2: (−0.95, 0.95) 3.3113E-4 uL×6

[**0031**] 3: (−0.65, 0.95) 3.3113E-4 uL×15

[0032] 4: (−0.95, 0.65) 3.3113E-4 uL×6

[0033] 5: (−0.73, 0.73) 3.3113E-4 uL×15

[0034] 6: (−0.56, 0.56) 3.3113E-4 uL×16

[0035] 7: (−0.4, 0.4) 3.3113E-4 uL×13

[0036] 8: (−0.24, 0.26) 3.3113E-4 uL×6

[0037] 9: (0, 0.32) 3.3113E-4 uL×6

[0038] 10: (0, 0.52) 3.3113E-4 uL×13

[0039] 11: (−0.15, 1) 3.3113E-4 uL×7

[0040] 12: (0, 0.8) 3.3113E-4 uL×20

[0041] 13: (0.15, 1) 3.3113E-4 uL×7

[0042] 14: (0.65, 0.95) 3.3113E-4 uL×15

[0043] 15: (0.95, 0.95) 3.3113E-4 uL×6

[0044] 16: (0.95, 0.65) 3.3113E-4 uL×6

[0045] 17: (0.73, 0.73) 3.3113E-4 uL×15

[0046] 18: (0.56, 0.56) 3.3113E-4 uL×13

[0047] 19: (0.4, 0.4) 3.3113E-4 uL×13

[0048] 20: (0.24, 0.26) 3.3113E-4 uL×6

[0049] 21: (0.3, 0) 3.3113E-4 uL×6

[0050] 22: (0.5, 0) 3.3113E-4 uL×13

[0051] 23: (1, 0.15) 3.3113E-4 uL×7

[0052] 24: (0.8, 0) 3.3113E-4 uL×15

[0053] 25: (1, −0.15) 3.3113E-4 uL×7

[0054] 26: (0.95, −0.65) 3.3113E-4 uL×6

[0055] 27: (0.95, −0.95) 3.3113E-4 uL×6

[0056] 28: (0.65, −0.95) 3.3113E-4 uL×10

[0057] 29: (0.73, −0.73) 3.3113E-4 uL×15

[0058] 30: (0.56, −0.56) 3.3113E-4 uL×13

[0059] 31: (0.4, −0.4) 3.3113E-4 uL×13

[0060] 32: (0.24, −0.26) 3.3113E-4 uL×6

[0061] 33: (0, −0.32) 3.3113E-4 uL×6

[0062] 34: (0, −0.52) 3.3113E-4 uL×13

[0063] 35: (0.15, −1) 3.3113E-4 uL×7

[0064] 36: (0, −0.8) 3.3113E-4 uL×15

[0065] 37: (−0.15, −1) 3.3113E-4 uL×7

[0066] 38: (−0.24, −0.26) 3.3113E-4 uL×6

[0067] 39: (−0.4, −0.4) 3.3113E-4 uL×13

[0068] 40: (−0.56, −0.56) 3.3113E-4 uL×19

[0069] 41: (−0.73, −0.73) 3.3113E-4 uL×15

[0070] 42: (−0.65, −0.95) 3.3113E-4 uL×10

[0071] 43: (−0.95, −0.95) 3.3113E-4 uL×6

[0072] 44: (−0.95, −0.65) 3.3113E-4 uL×6

[0073] 45: (−1, −0.15) 3.3113E-4 uL×7

[0074] 46: (−0.8, 0) 3.3113E-4 uL×20

[0075] 47: (−1, 0.15) 3.3113E-4 uL×7

[0076] 48: (−0.5, 0) 3.3113E-4 uL×13

[0077] 49: (−0.3, 0) 3.3113E-4 uL×6

[0078] To that end, to compensate for variations among thicknesses t**2** of sub-portions **34***b*, the following may be employed:

[0079] 1. Use function g(x,y) to calculate drop pattern offset represented as a vector S:

$$S-A\,\mathrm{grad}(g(x,y))i-B\,\mathrm{grad}(g(x,y))j,$$

[0080] where i and j are the unit vectors along X and Y axes. A, B are the proportionality coefficients that need to be determined experimentally, for instance, using a blank mesa template. Imprint new field and measure g(x,y) again. Verify that the slope in X and Y is near zero.

[0081] 2. After gradient of function g(x,y) is minimized, individual drop volumes are addressed. Multiply the drop pattern matrix M(x,y) by function w'(x,y), where:

$$w'(x,y)=w(x,y)/(\max(w(x,y))-\min(w(x,y)))$$

[0082] So new drop pattern M'(x,y) will be:

$$M'(x,y)=M(x,y)*w'(x,y)$$

[0083] 3. Verify that the new imprint has uniform thickness by measuring the slope of g(x,y) and minimizing function w(x,y).

[0084] A process for obtaining a uniform residual layer thickness (RLT) is illustrated in FIGS. **7**A-**7**D and **8**. In step **801**, the imprint tool is calibrated to determine how much fluid to dispense to make an imprint with a desired thickness. In step **802**, a uniform distribution of fluid is deposited on the substrate as illustrated in FIG. **7**A. An imprint is performed. Evaporation and other non-uniformities may cause the RLT to be non-uniform. In step **803**, RLT uniformity is measured across a dense array of points in the imprinted field using the film thickness measurement tool **60**. In step **804**, if a desired uniformity is achieved, then the process may end in step **805**. If not (see FIG. **7**B), then the process proceeds to step **806**, where one of the above algorithms is employed, such as in software running in processor **32**, to calculate a new corrected drop pattern, which will add drops, or increase drop size, to thin areas and/or remove drops, or decrease drop size, from thick areas to achieve improved RLT uniformity. The process then returns to step **802** to make a new imprint using the corrected drop pattern (see FIG. **7**C), and steps **803** and **804** are performed again. This process may be repeated as needed until a desired uniformity RLT is achieved, as illustrated in FIG. **7**D.

[0085] This above-mentioned method may be employed to obtain a desired volume of polymeric fluid **24** positioned upon substrate **12** to the volume of features (protrusions **17** and recesses **19**) in mold **16**. In a further embodiment, the above-mentioned method may be employed to compensate for evaporation in the plurality of droplets of polymeric material **24** after positioning the same upon substrate **12** and prior to contact with mold **16**. In both cases, matching a volume of polymeric material **24** upon substrate **12** to the volume of features in mold **16** result in improved residual layer uniformity, i.e., variations among thicknesses t**2** of sub-portions **34***b*. This improved residual layer uniformity enables better control of feature CDs across imprinted and etched wafers. Furthermore, the above-mentioned may also minimize, if not reduce, and impact of faceting during a breakthrough etch of the residual layer.

[0086] The embodiments of the present invention described above are exemplary. Many changes and modifications may be made to the disclosure recited above, while remaining within the scope of the invention. Therefore, the scope of the invention should not be limited by the above description, but instead should be determined with reference to the appended claims along with their full scope of equivalents.

1. In an imprint lithography system, a method comprising:

a) depositing a plurality of drops of imprint fluid on a substrate, the plurality of drops having a drop pattern in which each of the plurality of drops has an assigned size and position on the substrate;

b) performing an imprint of the plurality of drops of imprint fluid by patterning the imprint fluid between a mold and the substrate resulting in an imprinted layer;

c) measuring a thickness of a residual layer of the imprinted layer;

d) calculating a new drop pattern that compensates for nonuniformities in the thickness of the residual layer by adjusting the assigned size and position of certain ones of the plurality of drops; and

e) repeating step b).

2. The method as recited in claim 1, further comprising repeating step c) after step e).

3. The method as recited in claim 2, wherein steps b), c), and d) are repeated until a desired uniformity of the thickness of the residual layer is achieved.

4. An imprint lithography system, comprising:

a fluid dispense system for depositing a plurality of drops of imprint fluid on a substrate, the plurality of drops having a drop pattern in which each of the plurality of drops has an assigned size and position on the substrate;

an imprint mold for performing an imprint of the plurality of drops of imprint fluid by patterning the imprint fluid between the imprint mold and the substrate resulting in an imprinted layer;

a film thickness measurement tool for measuring a thickness of a residual layer of the imprinted layer;

circuitry for calculating a new drop pattern that compensates for nonuniformities in the thickness of the residual layer by adjusting the assigned size and position of certain ones of the plurality of drops.

* * * * *