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(54) **METHODS FOR FABRICATING PATTERNED FEATURES UTILIZING IMPRINT LITHOGRAPHY**

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(51) **Int. Cl.**
H01L 21/302 (2006.01)
H01L 21/461 (2006.01)

(52) **U.S. Cl.** **438/738**; 438/712; 438/725; 438/799; 438/737; 264/293; 427/198

(58) **Field of Classification Search** 438/712, 438/725, 733, 737, 738; 264/293; 427/198
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,810,874 A 5/1974 Mitsch et al.
4,267,212 A 5/1981 Sakawaki
4,440,804 A 4/1984 Milgram
4,451,507 A 5/1984 Beltz et al.
4,512,848 A 4/1985 Deckman et al.
4,614,667 A 9/1986 Larson et al.
4,617,238 A 10/1986 Crivello et al.
4,731,155 A 3/1988 Napoli et al.
4,826,943 A 5/1989 Ito et al.
4,931,351 A 6/1990 McColgin et al.
5,028,366 A 7/1991 Harakal et al.
5,169,494 A 12/1992 Hashimoto et al.
5,259,926 A 11/1993 Kuwabara et al.

(Continued)

FOREIGN PATENT DOCUMENTS

DE 2800476 7/1978

(Continued)

OTHER PUBLICATIONS

Wolf and Tauber; Silicon Processing for the VLSI Era vol. 1: Process Technology; 1986; Lattice Press, Sunset Bech, CA; pp. 541, 542, 544, 564 and 565.*

(Continued)

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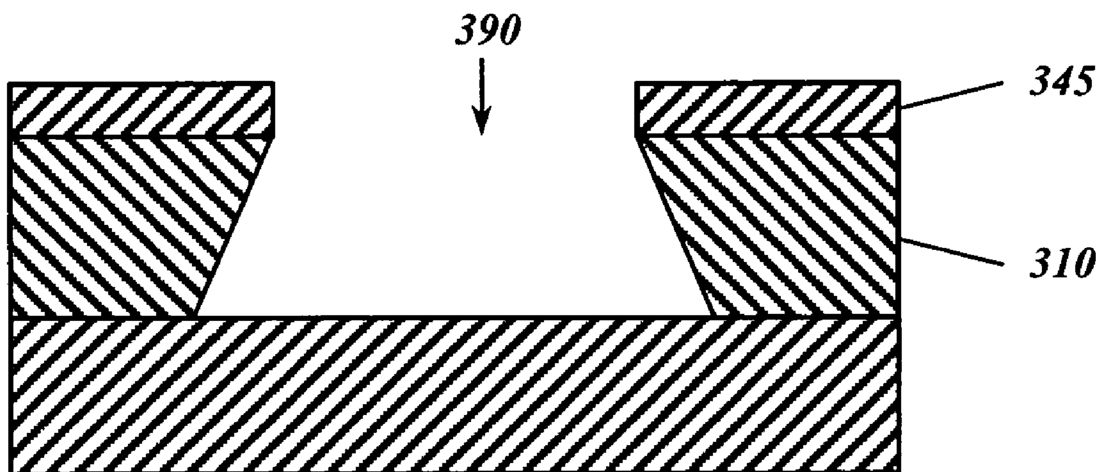
(57) **ABSTRACT**

One embodiment of the present invention is a method for generating patterned features on a substrate that includes: (a) forming a first layer on at least a portion of a surface of the substrate, the first layer comprising at least one layer of a first material, which one layer abuts the surface of the substrate; (b) forming a second layer of a second material on at least a portion of the first layer, which second layer is imprinted with the patterned features; (c) removing at least portions of the second layer to extend the patterned features to the first layer; and (d) removing at least portions of the first layer to extend the patterned features to the substrate; wherein the first layer and the second layer may be exposed to an etching process that undercuts the patterned features, and the first material may be lifted-off.

31 Claims, 5 Drawing Sheets



U.S. PATENT DOCUMENTS

5,331,020 A 7/1994 Brown et al.
5,369,722 A 11/1994 Heming et al.
5,389,696 A 2/1995 Dempsey et al.
5,425,848 A 6/1995 Haisma et al.
5,480,047 A 1/1996 Tanigawa et al.
5,542,978 A 8/1996 Kindt-Larsen et al.
5,594,042 A 1/1997 Glover et al.
5,601,641 A 2/1997 Stephens
5,629,095 A 5/1997 Bujanowski et al.
5,772,905 A 6/1998 Chou
5,776,748 A 7/1998 Singhvi et al.
5,837,314 A 11/1998 Beaton et al.
5,849,209 A 12/1998 Kindt-Larsen et al.
5,849,222 A 12/1998 Jen et al.
5,861,467 A 1/1999 Bujanowski et al.
5,900,160 A 5/1999 Whitesides et al.
5,948,470 A 9/1999 Harrison et al.
6,039,897 A 3/2000 Lochhead et al.
6,132,632 A 10/2000 Haney et al.
6,204,343 B1 3/2001 Barucha et al.
6,309,580 B1 10/2001 Chou
6,316,290 B1 11/2001 Wensel
6,334,960 B1 1/2002 Willson et al.
6,337,262 B1 1/2002 Pradeep et al.
6,344,105 B1 2/2002 Daugherty et al.
6,391,217 B1 5/2002 Schaffer et al.
6,468,642 B1 10/2002 Bray et al.
6,475,704 B1 11/2002 Iwasaki et al.
6,482,742 B1 11/2002 Chou
6,503,829 B1 * 1/2003 Kim et al. 438/637
6,503,914 B1 1/2003 Benish et al.
6,517,995 B1 2/2003 Jacobenson et al.
6,518,189 B1 2/2003 Chou
6,544,594 B1 4/2003 Linford et al.
6,565,778 B1 5/2003 Li et al.
6,580,172 B1 6/2003 Mancini et al.
6,646,662 B1 11/2003 Nebashi et al.
6,649,272 B1 11/2003 Moore et al.
6,664,306 B1 12/2003 Gaddam et al.
6,696,220 B1 2/2004 Bailey et al.
6,713,238 B1 3/2004 Chou et al.
6,721,529 B1 4/2004 Chen et al.
6,737,489 B1 5/2004 Linert et al.
6,774,183 B1 8/2004 Palumbo et al.
6,776,094 B1 8/2004 Whitesides et al.
6,790,905 B1 9/2004 Fitzgerald et al.
6,802,870 B1 10/2004 Chang et al.
6,809,356 B1 10/2004 Chou
6,828,244 B1 12/2004 Chou
6,830,819 B1 12/2004 Kaplan et al.
7,037,639 B1 * 5/2006 Voisin 430/316
2001/0044075 A1 11/2001 Nishimura et al.
2002/0042027 A1 4/2002 Chou et al.
2002/0093122 A1 7/2002 Choi et al.
2002/0094496 A1 7/2002 Choi et al.
2002/0098426 A1 7/2002 Sreenivasan et al.
2002/0132482 A1 9/2002 Chou
2002/0167117 A1 11/2002 Chou
2002/0177319 A1 11/2002 Chou
2003/0034329 A1 2/2003 Chou
2003/0080471 A1 5/2003 Chou
2003/0080472 A1 5/2003 Chou
2003/0235787 A1 12/2003 Watts et al.
2004/0007799 A1 1/2004 Choi et al.
2004/0008334 A1 1/2004 Sreenivasan et al.
2004/0009673 A1 1/2004 Sreenivasan et al.
2004/0010341 A1 1/2004 Watts et al.
2004/0021254 A1 2/2004 Sreenivasan et al.
2004/0021866 A1 2/2004 Watts et al.
2004/0022888 A1 2/2004 Sreenivasan et al.
2004/0036201 A1 2/2004 Chou et al.
2004/0038552 A1 2/2004 Watts et al.
2004/0046271 A1 3/2004 Watts
2004/0046288 A1 3/2004 Chou
2004/0065252 A1 4/2004 Sreenivasan et al.
2004/0110856 A1 6/2004 Young et al.
2004/0118809 A1 6/2004 Chou et al.
2004/0124566 A1 7/2004 Sreenivasan et al.
2004/0131718 A1 7/2004 Chou et al.
2004/0137734 A1 7/2004 Chou et al.
2004/0156108 A1 8/2004 Chou et al.
2004/0170770 A1 9/2004 Nguyen et al.
2004/0192041 A1 9/2004 Jeong et al.
2004/0197843 A1 10/2004 Chou et al.
2004/0256764 A1 * 12/2004 Choi et al. 264/293
2005/0118749 A1 * 6/2005 Sakamoto et al. 438/107

FOREIGN PATENT DOCUMENTS

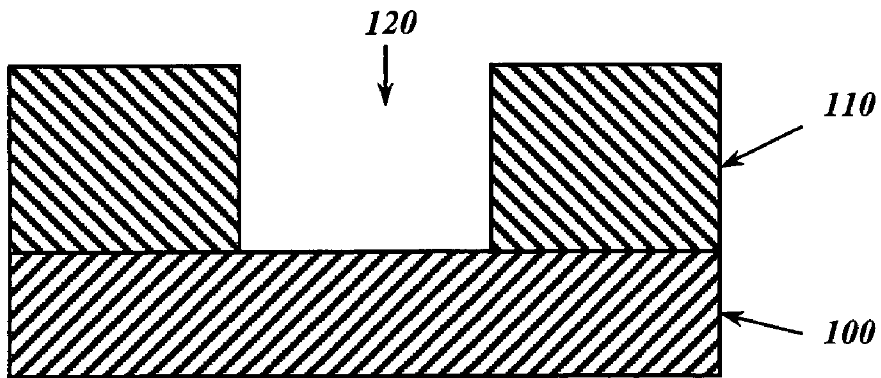
JP 1-196749 8/1989
JP 02-24848 1/1990
JP 02-92603 4/1990
WO WO 99/05724 2/1999
WO WO 00/21689 4/2000
WO WO 01/47003 6/2001
WO WO 01/69317 9/2001
WO WO 01/90816 11/2001
WO WO 02/07199 1/2002
WO WO 02/22916 3/2002
WO WO 03/010289 2/2003
WO WO 03/079416 9/2003
WO WO 03/099536 12/2003
WO WO 2004/114016 12/2004

OTHER PUBLICATIONS

Krauss et al., “Fabrication of Nanodevices Using Sub-25nm Imprint Lithography,” Appl. Phys. Lett 67(21), 3114-3116, 1995.
Chou et al., “Imprint of Sub-25 nm Vias and Trenches in Polymers,” Applied Physics Letters, Nov. 20, 1995, pp. 3114-3116, vol. 67(21).
Chou et al., “Imprint Lithography with 25-Nanometer Resolution,” Science, Apr. 5, 1996, pp. 85-87, vol. 272.
Haisma et al., “Mold-Assisted Nanolithography: A Process for Reliable Pattern Replication,” Journal of Vacuum Science and Technology, Nov./Dec. 1996, pp. 4124-4128, vol. B 14(6).
Chou et al., “Imprint Lithography with Sub-10nm Feature Size and High Throughput,” Microelectronic Engineering, 1997, pp. 237-240, vol. 35.
Xia et al., “Soft Lithography,” Annu. Rev. Mater. Sci., 1998, pp. 153-184, vol. 28.
Xia et al., “Soft Lithography,” Agnew. Chem. Int. Ed., 1998, pp. 550-575, vol. 37.
Wu et al., “Large Area High Density Quantized Magnetic Disks Fabricated Using Nanoimprint Lithography,” Journal of Vacuum Science and Technology, Nov./Dec. 1998, pp. 3825-3829, vol. B 16(6).
Colburn. et al., “Step and Flash Imprint Lithography: A New Approach to High-Resolution Patterning”, Proc. of SPIE, 1999, pp. 379-389, vol. 3676.
Chou et al., “Lithographically-Induced Self Assembly of Periodic Polymer Micropillar Arrays,” Journal of Vacuum Science and Technology, Nov./Dec. 1999, pp. 3197-3202, vol. B 17(6).
Ruchhoeft et al., “Patterning Curved Surfaces: Template Generation by Ion Beam Proximity Lithography and Relief Transfer by Step and Flash Imprint Lithography,” Journal of Vacuum Science and Technology, 1999, pp. 2965-2982, vol. 17.
Chou, “Nanoimprint Lithography and Lithography Induced Self-Assembly,” MRS Bulletin, Jul. 2001, pp. 512-517.
Mirkin et al., “Emerging Methods for Micro-and Nanofabrication,” MRS Bulletin, Jul. 2001, pp. 506-509.
Choi et al., “High Precision Orientation Alignment and Gap Control Stages for Imprint Lithography Processes,” U.S. Appl. No. 09/698,317, filed Oct. 27, 2000.

Bender M. et al., "Fabrication of Nanostructures using a UV-based Imprint Technique," Microelectronic Engineering, pp. 223-236, 2000.
Nguyen, A. Q., "Asymmetric Fluid-Structure Dynamics in Nanoscale Imprint Lithography," University of Texas at Austin, Aug. 2001.
Sreenivasan et al., "A Method of Forming A Layer on A Substrate To Facilitate Fabrication Of Metrology Standards," U.S. Appl. No. 10/264,926, filed Oct. 4, 2002.
Sreenivasan, "Postive Tone Bi-Layer Imprint Lithography Method," U.S. Appl. No. 10/396,615, filed Mar. 25, 2003.
Sreenivasan, "A Method Of Forming Stepped Structures Employing Imprint Lithography," U.S. Appl. No. 10/423,642, filed Apr. 25, 2003.
Choi et al., "Method To Reduce Adhesion Between A Conformable Region And A Pattern Of A Mold," U.S. Appl. No. 10/463,396, filed Jul. 17, 2003.
U.S. Appl. No. 10/687,519, filed Oct. 16, 2003, Nguyen et al.
U.S. Appl. No. 11/027,473, filed Dec. 30, 2004, Bailey et al.
U.S. Appl. No. 10/948,511, filed Sep. 23, 2004, Xu et al.
U.S. Appl. No. 10/967,740, filed Oct. 18, 2004, Xu et al.
U.S. Appl. No. 10/919,224, filed Aug. 16, 2004, Xu et al.
U.S. Appl. No. 11/026,821, filed Dec. 30, 2004, Willson et al.
U.S. Appl. No. 11/062,420, filed Feb. 22, 2005, Willson et al.
U.S. Appl. No. 11/068,397, filed Feb. 28, 2005, Xu et al.
U.S. Appl. No. 11/068,174, filed Feb. 28, 2005, Xu et al.
Choi et al., Design of Orientation Stages for Step and Flash Imprint Lithography, Precision Engineering, pp. 192-199, Jan. 1, 2001.
Colburn et al., Step and Flash Imprint Lithography for sub-100 nm Patterning, Proceedings of SPIE vol. 3997, pp. 453-457, Jan. 1, 2000.
Johnson et al., Advances in Step and Flash Imprint Lithography, SPIE Microlithography Conference, Feb. 23, 2003.
Heidari, Nanoimprint Lithography at the 6 in. Wafer Scale, J. Vac. Sci. Technol. B 18(6), pp. 3557-3560, Nov. 1, 2000.
Translation of Japanese Patent 02-92603.
Translation of Japanese Patent 02-24848.
Hirai et al., Mold Surface Treatment for Imprint Lithography, Journal of Photopolymer Science and Technology, vol. 14, No. 3, pp. 457-462, Aug. 1, 2001.
Roos et al., Nanoimprint Lithography with a Commercial 4 Inch Bond System for Hot embossing, Proceedings of SPIE vol. 4343, pp. 427-435, Oct. 1, 2001.
Chou et al., Ultrafast and Direct Imprint of Nanostructures in Silicon, Nature, Col. 417, (Jun. 2002), pp. 835-837, Jun. 1, 2002.
Chou et al., Nanoimprint Lithography, Journal of Vacuum Science Technolgoy B 14(16), pp. 4129-4133, Nov. 1, 1996.
Colburn et al., Development and Advantages of Step-and-Flash Lithography, Solid State Technology, Jul. 1, 2001.
Colburn et al., Characterization and Modeling of Volumetric and Mechanical Properties for Step and Flash Imprint Lithography Photopolymers, Journal of Vacuum Science Technology, vol. b. 19(6), Nov. 1, 2001.
Yu et al., Properties of Fluorinated Amorphous Diamond Like Carbon Films by PECVD, Applied Surface Science 219 (3-4); pp. 228-237, Dec. 1, 2003.
Compon et al., Electroanalysis at Diamond-Like and Doped-Diamond Electrodes, Electroanalysis 15(17); pp. 1349-1363, Sep. 1, 2003.
Mansano et al., Protective Carbon Layer for Chemical Corrosion of Stainless Steel, Diamond and Related Materials 12 (3-7); pp. 749-752, Mar. 1, 2003.
Butter et al., Production and Wetting Properties of Fluorinated Diamond-Like Carbon Coatings, Thin Solid Films, 311(1-2); pp. 107-113, Dec. 31, 1997.
Hakovirta et al., Heat Resistance of Fluorinated Diamond-Like Carbon Films, Diamond and Related Materiasl 10(8); pp. 1486-1490, Aug. 1, 2001.
Zhu et al., The Improvement of the Oxidation Resistance of TiAl Alloys by Fluorine Plasma-Based Ion Implantation, Surface and Coatings Technology 158; pp. 502-507, Sep. 1, 2002.
Yao et al., Structural, Mechanical and Hydrophobic Properties of Fluorine-Doped Diamond-Like Carbon Films Synthesized by Plasma Immersion Ion Implantation and Deposition (PIII-D), Applied Surface Science 230; pp. 172-178, Apr. 17, 2004.
Bailey et al., Step and Flash Imprint Lithography: Defect Analysis, Journal of Vacuum Science, B 19(6), pp. 2806-2810, Nov. 1, 2001.
Bailey et al., Step and Flash Imprint Lithography: Template Surface Treatment and Defect Analysis, Journal of Vacuum Science, B 18(6), pp. 3572-3577, Nov. 1, 2000.
Schneider et al., Stripes of Partially Fluorinated Alkyl Chains: Dipolar Langmuir Monolayers.
Golden et al., Designing Porous Low-k Dielectrics, www.reed-electronics.com/semiconductor/index.asp?layout=articlePrint &articleID=CA82824, Apr. 6, 2005.
Padovani et al., Chemically Bonded Porogens in Methylsilsesquioxane: I. Structure and Bonding, Journal of the Electrochemical Society, 149(12) F161-F170, Oct. 16, 2002.
Wolf et al., Silicion Processing for the VLSI Era, vol. 1—Process Technology, pp. 407-413, Jan. 1, 1986.

* cited by examiner



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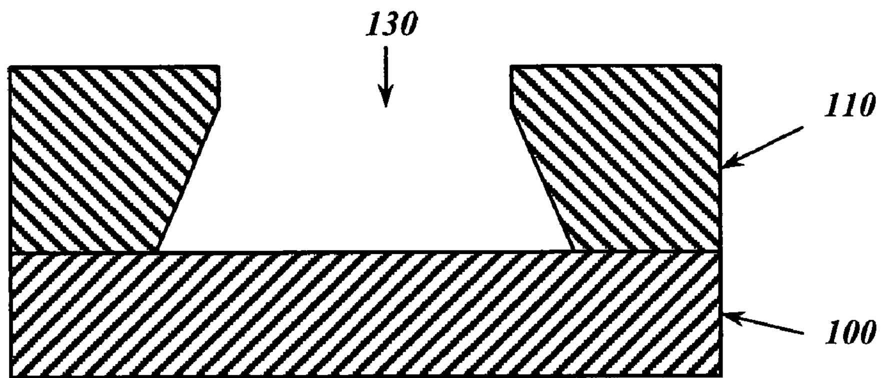
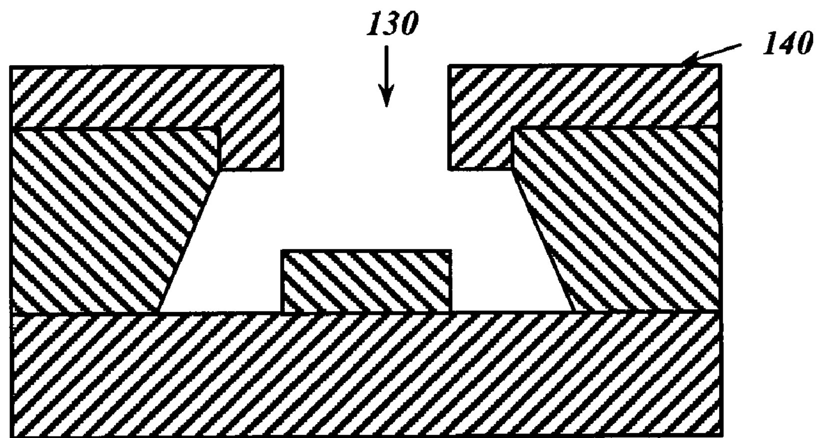


Fig. 1B



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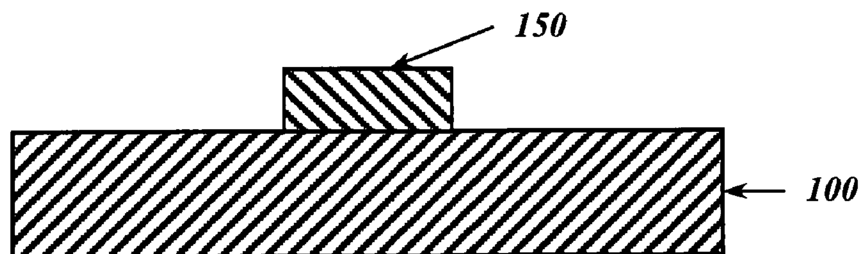

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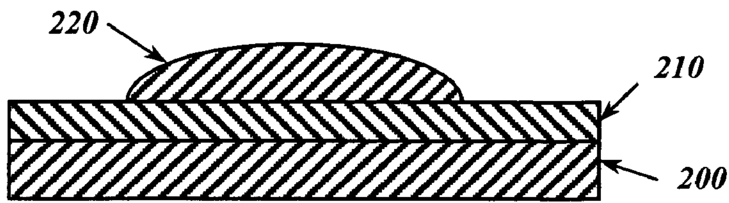

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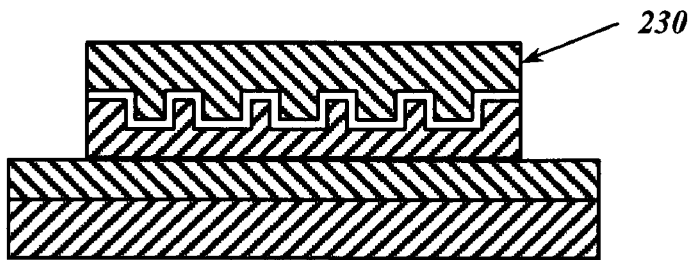

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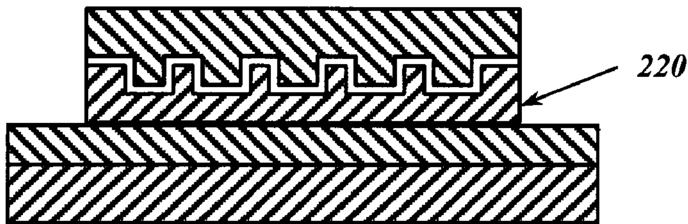

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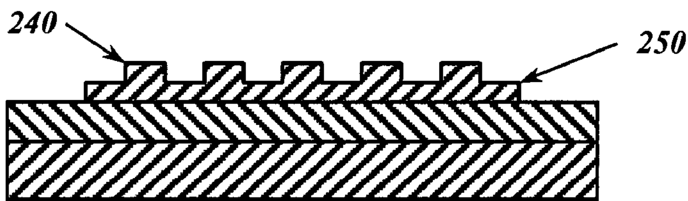

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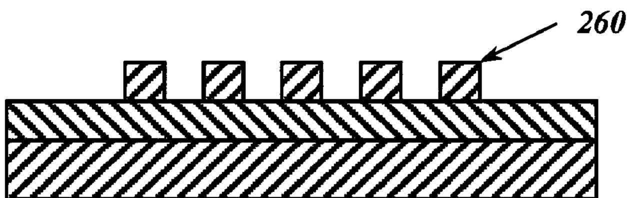

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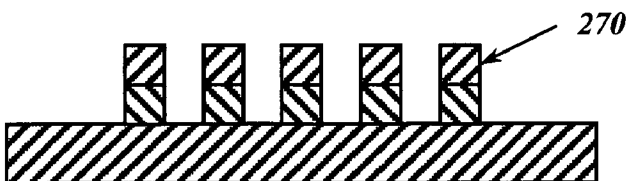

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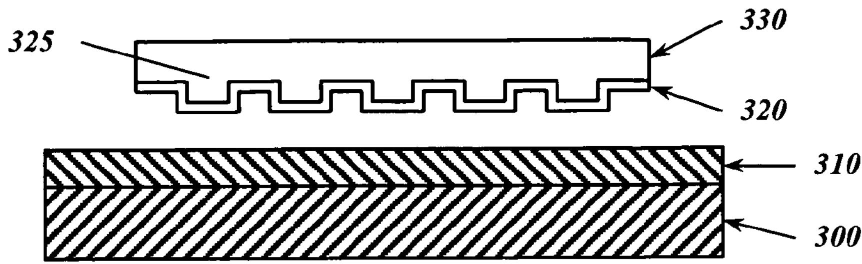

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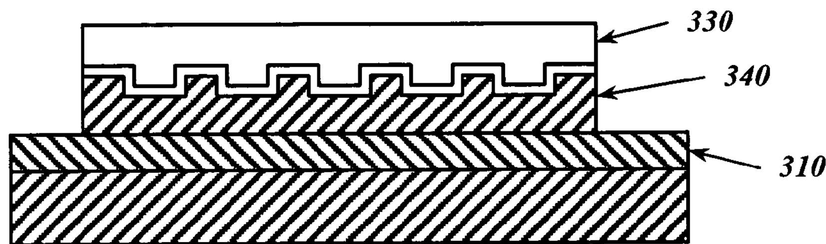

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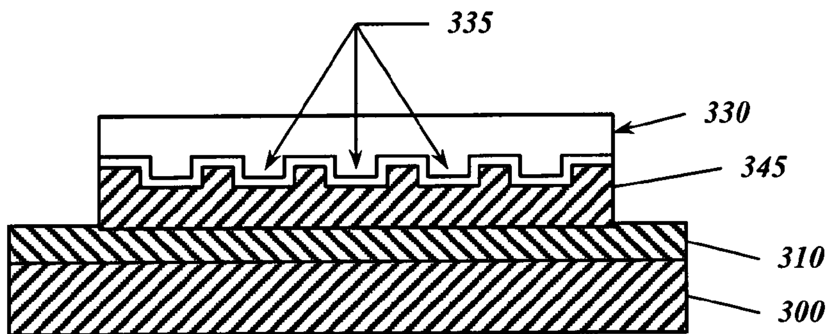

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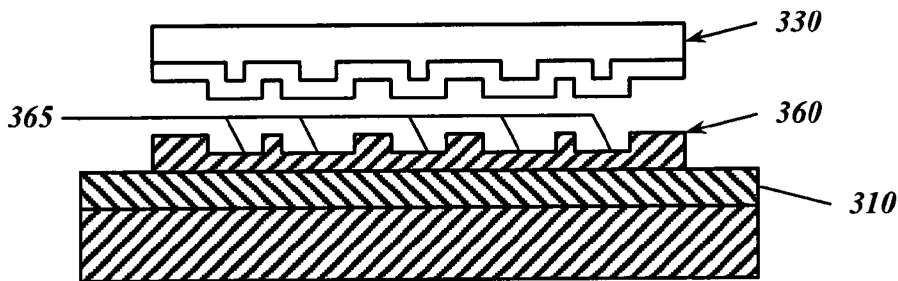

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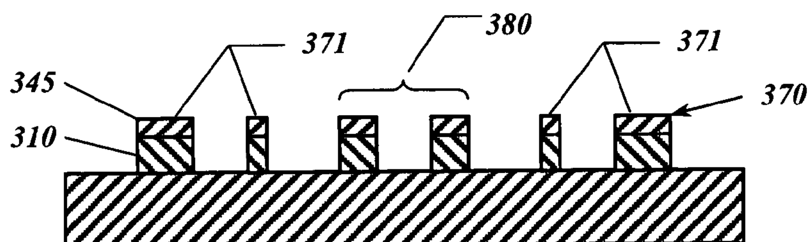

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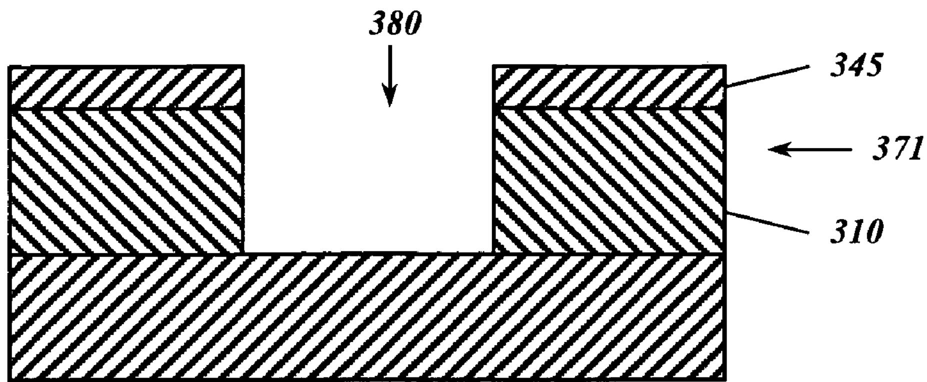

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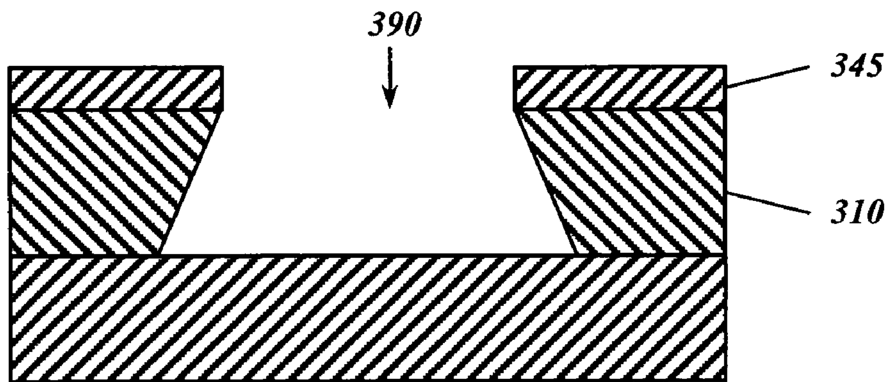

Fig. 3G

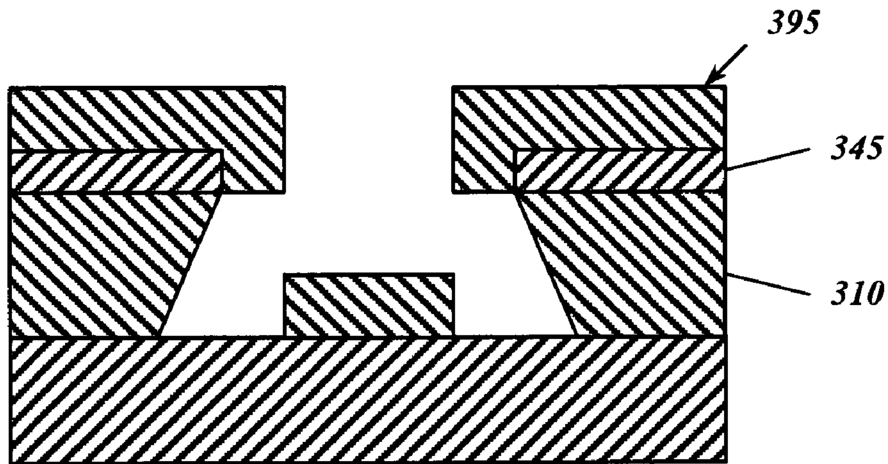

Fig. 3H

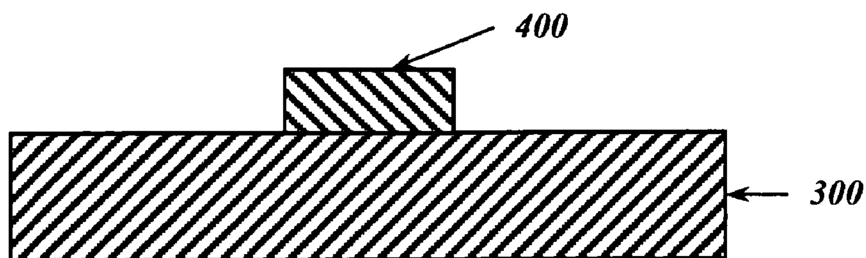

Fig. 3I

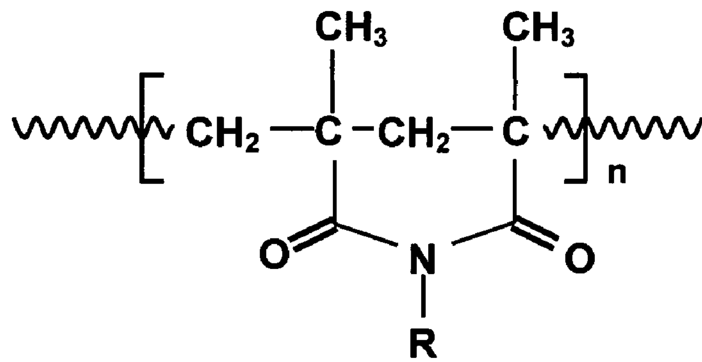

Fig. 4

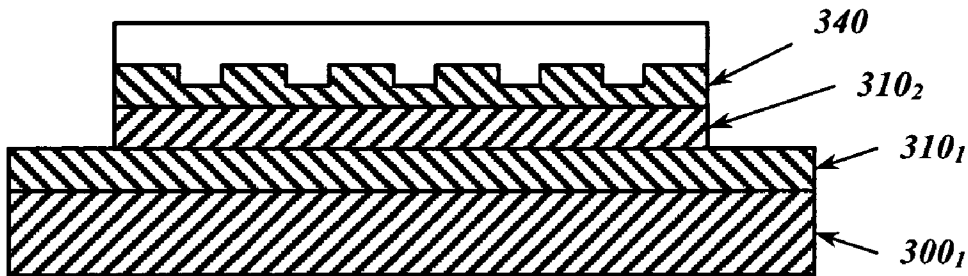

Fig. 5

METHODS FOR FABRICATING PATTERNED FEATURES UTILIZING IMPRINT LITHOGRAPHY

BACKGROUND OF THE INVENTION

One or more embodiments of the present invention relate generally to methods for fabricating patterned features utilizing imprint lithography.

There is currently a strong trend, for example and without limitation, in the semiconductor manufacturing industry, toward micro-fabrication, i.e., fabricating small structures and downsizing existing structures. For example, micro-fabrication typically involves fabricating structures having features on the order of micro-meters or smaller.

One area in which micro-fabrication has had a sizeable impact is in microelectronics. In particular, downsizing microelectronic structures has generally enabled such microelectronic structures to be less expensive, have higher performance, exhibit reduced power consumption, and contain more components for a given dimension relative to conventional electronic devices. Although micro-fabrication has been utilized widely in the electronics industry, it has also been utilized in other applications such as biotechnology, optics, mechanical systems, sensing devices, and reactors.

As is well known, methods for fabricating patterned features are an important part of micro-fabrication. In the art of micro-fabrication of, for example and without limitation, semiconductor devices, "lift-off" is a well known method for fabricating patterned metal features such as, for example and without limitation, lines on a substrate or wafer. FIGS. **1**A–**1**D illustrate a well known process for fabricating patterned metal features in which a photoresist mask is undercut by a developer prior to metal deposition. As shown in FIG. **1**A, substrate **100** has been coated with photoresist layer **110** in accordance with any one of a number of methods that are well known to those of ordinary skill in the art, and photoresist mask layer **110** has been patterned in accordance with any one of a number of methods that are well known to those of ordinary skill in the art to provide aperture **120** having relatively straight side walls. For example, in accordance with one such lithography technique, photoresist **110** was exposed to a beam of electrons, photons, or ions by either passing a flood beam through a mask or scanning a focused beam. The beam changed the chemical structure of an exposed area of photoresist layer **110** so that, when immersed in a developer, either the exposed area or an unexposed area of photoresist layer **110** (depending on the type of photoresist used) was removed to recreate a pattern, or its obverse, of the mask or the scanning. Next, as shown in FIG. **1**B, aperture **120** has been undercut in accordance with any one of a number of methods that are well known to those of ordinary skill in the art to form aperture **130** in photoresist mask layer **110**. Next, as shown in FIG. **1**C, a relatively thin metal layer has been blanket-deposited over the structure shown in FIG. **1**B. As is well known, metal thin film deposition techniques such as, for example and without limitation, physical vapor deposition ("PVD") or sputtering (and excepting conformal deposition techniques such as, for example and without limitation, chemical vapor deposition ("CVD") and electroplating) provide limited step coverage. As a result, metal deposited using such techniques does not coat steep or undercut steps. Thus, as shown in FIG. **1**C, after blank metal deposition, the undercut side walls of aperture **130** are not coated. In other words, the use of undercut aperture **130** in photoresist mask layer **110** avoids side wall metal deposition, and provides discontinuous metal regions on substrate **100** and photoresist mask layer **110**. Lastly, as shown in FIG. **1**D, a photoresist lift-off process has been carried out in accordance with any one of a number of methods that are well known to those of ordinary skill in the art to provide patterned metal feature **150** on substrate **100**. As is well known, during the lift-off process, photoresist material under metal film **140** is removed using, for example and without limitation, a solvent or a photoresist stripper. As a result, metal film **140** is removed, and patterned metal feature **150** that was deposited directly on substrate **100** remains.

Lithography is an important technique or process in micro-fabrication that is used to fabricate semiconductor integrated electrical circuits, integrated optical, magnetic, mechanical circuits and microdevices, and the like. As is well known, and as was discussed above, lithography may be used to create a pattern in a thin film carried on a substrate or wafer so that, in subsequent processing steps, the pattern can be replicated in the substrate or in another material that is deposited on the substrate. An imprint lithography technology for producing nanostructures with 10 nm feature sizes has been discussed in the literature. One embodiment of imprint lithography—referred to in the art as Step and Flash Imprint Lithography ("SFIL")—is disclosed in an article by B. J. Smith, N. A. Stacey, J. P. Donnelly, D. M. Onsongo, T. C. Bailey, C. J. Mackay, D. J. Resnick, W. J. Dauksher, D. Mancini, K. J. Nordquist, S. V. Sreenivasan, S. K. Banerjee, J. G. Ekerdt, and C. G. Willson entitled "Employing Step and Flash Imprint Lithography for Gate Level Patterning of a MOSFET Device" *SPIE Microlithography Conference, February* 2003, which article is available on the Internet at www.molecularimprints.com, and which article is incorporated by reference herein. SFIL is a lithography technique that enables patterning of sub-100 nm features at a cost that has the potential to be substantially lower than either conventional projection lithography or proposed next generation lithography techniques. As described in the article, SFIL is a molding process that transfers the topography of a rigid transparent template using a low-viscosity, UV-curable organosilicon solution at room temperature with low pressure mechanical processes.

One such SFIL process is illustrated in conjunction with FIGS. **2**A–**2**F. As shown in FIG. **2**A, thinorganic layer **210** (referred to as a transfer layer) has been spin-coated on silicon substrate **200**. Next, a small amount of low viscosity, photopolymerizable, organosilicon solution **220** is dispensed over transfer layer **210** in an area to be imprinted (solution **220** is sometimes referred to as an "imprinting material"). The viscosity of solution **220** is sufficiently low so that minimal pressure (for example and without limitation, a pressure of about 2–4 psi) and no additional heating is necessary to move the liquid into an imprint template. For example, solution **220** may be a solution of an organic monomer, a silylated monomer, and a dimethyl siloxane oligomer ("DMS") and a multifunctional cross-linker. Each component plays a role in the imaging process. For example: (a) the free radical generator initiates polymerization upon exposure to actinic (typically UV) radiation; (b) the organic monomer ensures adequate solubility of the free radical generator, desirable cohesive strength of cured imprinting material and adhesion to underlying organic transfer layer **210**; (c) and the silylated monomers and the DMS provide silicon required to provide high-oxygen etch resistance (useful in subsequent processing steps described below); and (d) multi-functional crosslinker provides chemical crosslinking. In addition, these monomer types help main-

tain a low viscosity that is useful during imprinting. In further addition, the silylated monomer and the DMS derivative also lower the surface energy of solution **220**, thereby enhancing a separation process (described below). Advantageously, the organic monomer polymerizes in a fraction of a second using low cost, broadband light sources. For example, as described in the article, solution **220** consisted of 15% (w/w) ethylene glycol diacrylate (obtained from Aldrich Chemical Company of Milwaukee, Wis.), 44% (3-acryloxypropyl)tris(trimethylsiloxy)silane (obtained under the trade name SIA0210.0 from Gelest, Inc. of Morrisville, Pa.), 37% t-butyl acrylate (obtained from Lancaster Synthesis Inc. of Windham, N.H.), and 4% 2-hydrozy-2-methyl-1-phenyl-propan-1-one (obtained under the trade name Darocur 1173 from CIBA® of Tarrytown, N.Y.).

Next, as shown in FIG. **2**B, template **230**—bearing patterned relief structures (for example and without limitation, a circuit pattern) and whose surface was treated with a fluorocarbon release film—was aligned over dispensed solution **220** and moved to decrease a gap between template **230** and substrate **200**. This displaced solution **220**, and filled the patterned relief structures on template **230**. Suitable release layers are described in an article by D. J. Resnick, D. P. Mancini, S. V. Sreenivasan, and C. G. Willson entitled "Release Layers for Contact and Imprint Lithography" *Semiconductor International*, June 2002, pp. 71–80, which article is incorporated by reference herein. As is known, it is desired that a template release layer has a low enough surface energy to enable template/substrate separation, and also is reasonably durably bonded to the template surface to remain functional after a number of imprints. Alkyltrichlorosilanes form strong covalent bonds with a surface of fused silica, or SiO_2. In addition, in the presence of surface water, they react to form silanol intermediates which undergo a condensation reaction with surface hydroxyl groups and adjacent silanols to form a networked siloxane monolayer. When this functional group is synthetically attached to a long fluorinated aliphatic chain, a bifunctional molecule suitable as a template release film may be created. The silane-terminated end bonds itself to a template's surface, providing durability useful for repeated imprints. The fluorinated chain, with its tendency to orient itself away from the surface, forms a tightly packed comb-like structure, and provides a low-energy release surface. Annealing further enhances the condensation, thereby creating a highly networked, durable, low surface energy coating.

Next, as shown in FIG. **2**C, once filling has occurred, the area is irradiated with broadband UV ultraviolet light (for example and without limitation, a 500 W Hg arc lamp) through a back side of template **230**, and cross-linking of solution **220** occurs.

Next, as shown in FIG. **2**D, template **230** and substrate **200** are mechanically separated to expose cured, organosilicon relief pattern **240** (an imprinted version of the relief pattern in template **230**) that is disposed on residual layer **250** (a residue of cross-linked solution **220**). The SFIL steps illustrated in FIGS. **2**A–**2**D may be carried out in a tool described by I. McMackin, P. Schumaker, D. Babbs, J. Choi, W. Collison, S. V. Sreenivasan, N. Schumaker, M. Watts, and R. Voisin in an article entitled "Design and Performance of a Step and Repeat Imprinting Machine" *SPIE Microlithography Conference*, February 2003, which article is available on the Internet at www.molecularimprints.com, and which article is incorporated by reference herein.

Next, etching is performed in a two-step process. S. C. Johnson, T. C. Bailey, M. D. Dickey, B. J. Smith, E. K. Kim, A. T. Jamieson, N. A. Stacey, J. G. Ekerdt, and C. G. Willson describe suitable etch processes in an article entitled "Advances in Step and Flash Imprint Lithography" *SPIE Microlithography Conference*, February 2003, which article is available on the Internet at www.molecularimprints.com, and which article is incorporated by reference herein. As set forth in the article, the first etch step, referred to as a "break-through etch," anisotropically removes residual cross-linked layer **250** to break through to underlying transfer later **210**. The second etch step, referred to as a "transfer etch," uses the remaining cross-linked relief pattern **240** as an etch mask to transfer the pattern into underlying transfer layer **210**. In one embodiment of SFIL, silicon in polymerized solution **220**, and lack of silicon in transfer layer **210**, provides etch selectivity between polymerized solution **220** and transfer layer **210**. In such an embodiment, the etching may be done in a LAM Research 9400SE obtained from Lam Research, Inc. of Fremont, Calif.

As shown in FIG. **2**E, a halogen "breakthrough etch" was performed. For example and without limitation, the halogen etch described in the article was an anisotropic halogen reactive ion etch ("RIE") rich in fluorine, i.e., wherein at least one of the precursors was a fluorine-containing material (for example and without limitation a combination of CHF_3 and O_2, where the organosilicon nature of solution **220** called for the use of a halogen gas). Other suitable halogen compounds include, for example and without limitation, CF_4. This etch is similar to a standard SiO_2 etch performed in modern integrated circuit processing. Lastly, as shown in FIG. **2**F, an anisotropic oxygen reactive ion etch was used to transfer features **260** to underlying substrate **200**. The remaining silicon containing features **260** served as an etch mask to transfer the pattern to underlying substrate **200**. The "transfer etch" was achieved with a standard, anisotropic, oxygen RIE processing tool.

In order to imprint sub-100 nm features, it is useful to avoid intermixing between an imprinting material and a transfer layer. Intermixing may cause problems such as, for example and without limitation, distortion of features when an imprint template is separated from a substrate after exposure to polymerizing radiation. This can be particularly problematic when feature thicknesses are as small as 50 to 100 nm. In addition, intermixing may be particularly problematic when using an imprinting material comprised of low viscosity acrylate components because such components have solvency toward many polymers. Because of this, some have used a cross-linked BARC material (BARC or "bottom antireflective coating" is an organic antireflective coating that is typically produced by a spin-on process) as a transfer layer. However, because BARC is cross-linked, it cannot be undercut by conventional wet developers and removed by organic photostrippers. As a result, the above described method for fabricating patterned metal features using lift-off cannot be used.

In light of the above, there is a need for methods for fabricating patterned features utilizing imprint lithography that overcome one or more of the above-identified problems.

SUMMARY OF THE INVENTION

One or more embodiments of the present invention satisfy one or more of the above-identified needs in the art. In particular, one embodiment of the present invention is a method for generating patterned features on a substrate that includes: (a) forming a first layer on at least a portion of a surface of the substrate, the first layer comprising at least one layer of a first material, which one layer abuts the surface of the substrate; (b) forming a second layer of a

second material on at least a portion of the first layer, which second layer is imprinted with the patterned features; (c) removing at least portions of the second layer to extend the patterned features to the first layer; and (d) removing at least portions of the first layer to extend the patterned features to the substrate; wherein the first layer and the second layer may be exposed to an etching process that undercuts the patterned features, and the first material may be lifted-off.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A–**1**D illustrate a well known process for fabricating patterned metal features in which a photoresist mask is undercut by a developer prior to metal deposition;

FIGS. **2**A–**2**F illustrate a step-by-step sequence for carrying out one example of one type of imprint lithography process, a Step and Flash Imprint Lithography ("SFIL") process;

FIGS. **3**A–**3**I illustrate a step-by-step sequence for fabricating patterned features in accordance with one or more embodiments of the present invention utilizing imprint lithography;

FIG. **4** shows a portion of a structure of a chemical used to fabricate a planarization and transfer layer in accordance with one or more embodiments of the present invention; and

FIG. **5** illustrates an alternative step for that illustrated in FIG. **3**B.

DETAILED DESCRIPTION OF THE INVENTION

FIGS. **3**A–**3**I illustrate a step-by-step sequence for fabricating patterned features in accordance with one or more embodiments of the present invention utilizing imprint lithography. Imprint lithography steps may be carried using a tool described by I. McMackin et al. in an article entitled "Design and Performance of a Step and Repeat Imprinting Machine" *SPIE Microlithography Conference*, February 2003, which article is cited in the Background of the Invention, and which article is incorporated by reference herein.

As shown in FIG. **3**A, planarization and transfer layer **310** has been formed on substrate or wafer **300** using any one of a number of methods that are well known to those of ordinary skill in the art such as, for example and without limitation, by spin-coating to provide a substantially continuous, planar surface over substrate **300**. In accordance with one or more embodiments of the present invention, an inventive planarization and transfer layer is a polymer containing a poly(dimethylglutarimide) ("PMGI") structure. FIG. **4** shows the structure of PMGI used to form the polymer of inventive planarization and transfer layer. Advantageously, in accordance with one or more embodiments of the present invention, a planarization and transfer layer based on PMGI has the following beneficial properties that solve one or more of the problems identified in the Background of the Invention: (a) little, if any, interfacial mixing with acrylic-based imprinting fluids; (b) such a planarization and transfer layer is removable in developer(s)/stripper(s), for example and without limitation, wet developer(s)/stripper(s) (it is believed that this is because such a planarization and transfer layer is not cross-linked by exposure to the UV radiation used to polymerize the imprinting fluid); and (c) such a planarization and transfer layer does not cross-link in response to UV radiation.

A polymer containing a PMGI structure that is suitable for use in carrying out one or more embodiments of the present invention may be obtained under the trade name SF7S ("PMGI SF7S") from MicroChem Corp. of Newton, Mass. Other polymers containing a PMGI structure that are also suitable for use in carrying out one or more embodiments of the present invention may be obtained under the trade names LOL1000 and LOL2000 from Shipley Company, L.L.C. of Marlborough, Mass. In accordance with one embodiment of the present invention, PMGI SF7S was spin coated on a silicon wafer at about 3,000 rpm (conventional spin-coaters may rotate at speeds from about 500 to about 6000 rpm). The wafer was soft baked at about 180° C. for about 5 min, and a thickness of the PMGI layer was about 500 nm. Advantageously further embodiments of the present invention may be fabricated readily by one of ordinary skill in the art without undue experimentation since the developmental characteristics of a polymer containing a PMGI structure may be controlled by bake time and bake temperature.

As further indicated in FIG. **3**A, feature pattern **325** has been fabricated on imprint template **330** using any one of a number of methods that are well known to those of ordinary skill in the art. In accordance with one or more embodiments of this imprint lithography process, imprint template **330** may have a nanoscale relief structure formed therein having an aspect ratio ranging, for example and without limitation, from about 1×10^{-5} to about 10. Specifically, the relief structures in imprint template **330** may have a width that ranges, for example and without limitation, from about 10 nm to about 5000 μm, and the relief structures may be separated from each other by a distance that ranges, for example and without limitation, from about 10 nm to about 5000 μm. In accordance with one or more embodiments of the present invention, imprint template **330** may be comprised of material that is transparent, at least to a desired extent, to radiation utilized to cross-link an imprint fluid. Such material may be, for example and without limitation, SiO_2, in the form of quartz, fused-silica, sapphire and the like.

In accordance with one or more embodiments of the present invention, a surface of imprint template **330** may be treated with a surface modifying agent such as a fluorocarbon silylating agent to promote release of imprint template **330** after transfer of feature pattern **325**. In addition, in accordance with one or more embodiments of this imprint lithography process, the step of treating the surface of imprint template **330** may be carried out utilizing a technique such as, for example and without limitation, a plasma technique, a chemical vapor deposition technique, a solution treatment technique, and combinations thereof. In accordance with one or more further embodiments of the present invention, the release properties of imprint template **330** may be improved by conditioning feature pattern **325** of imprint template **330** by exposing it to a conditioning mixture including an additive that will remain on imprint template **330** to reduce the surface energy of its surface. An exemplary additive is a surfactant such as, for example and without limitation, a mixture that includes approximately 0.1% or more of a surfactant available under the trade name ZONYL® FSO-100 from DUPONT™ having a general structure of R_1R_2 where R_1=$F(CF_2\,{}_{CF2})_Y$, with y being in a range of 1 to 7, inclusive and R_2=$CH_2\,{}_{CH2}O(CH_2CH_2O)_XH$, where X is in a range of 0 to 15, inclusive—with the remainder comprising isopropyl alcohol ("IPA") Exposure of feature pattern **325** may be achieved by virtually any manner known in the art, including dipping feature pattern **325** into a volume of the conditioning mixture, wiping the

pattern with a cloth saturated with the conditioning mixture and spraying a stream of the conditioning mixture onto the surface. The IPA in the conditioning mixture is allowed to evaporate before using imprint template **330**. In this manner, the IPA facilitates removing, from the pattern, undesired contaminants while leaving the additive, thereby conditioning the surface of the pattern. In accordance with one or more still further embodiments of the present invention, the feature pattern of imprint template **330** may be conditioned by pattern priming. Pattern priming is achieved by selectively contacting the imprint fluid (to be described below) with the pattern a sufficient number of times to accurately reproduce a pattern complementary to the initial pattern. Specifically, by repeatedly contacting the imprint fluid, the complementary pattern formed improves with each successive imprint. After a sufficient number of imprints, an accurate complementary reproduction of the pattern in imprint template **330** is formed.

In addition, in accordance with one or more embodiments of the present invention, and has been indicated in FIG. **3**A, release layer **320** has been deposited on imprint template **330**. An important factor in accurately forming feature pattern **325** is to reduce, if not prevent, adhesion of polymerized imprint fluid to imprint template **330'**. A release layer is typically hydrophobic and/or has low surface energy. Providing polymerized imprint fluid with improved release characteristics minimizes distortions in feature pattern **325** recorded into the polymerized imprint fluid upon template separation. This type of release layer may be referred to as an a priori release layer, i.e., a release layer that is solidified to the mold. Suitable release layers are described in an article by D. J. Resnick, D. P. Mancini, S. V. Sreenivasan, and C. G. Willson entitled “Release Layers for Contact and Imprint Lithography” *Semiconductor International*, June 2002, pp. 71–80, which article is cited in the Background of the Invention, and which article is incorporated by reference herein.

As further indicated in FIG. **3**A, imprint template **330** is aligned over and spaced apart from planarization and transfer layer **310**.

Next, as shown in FIG. **3**B, polymerizable fluid **340** (also referred to as an “imprint fluid” or “imprint material”) has been dispensed over planarization and transfer layer **310** using any one of a number of methods that are well known to those of ordinary skill in the art such as, for example and without limitation, by dispensing as a plurality of fluid beads or droplets. As further shown in FIG. **3**B, imprint template **330** has been brought close enough to polymerizable fluid **340** so that the features in feature pattern **325** of imprint template **330** have been filled with polymerizable fluid **340**. Note that polymerizable fluid **340** has a viscosity sufficiently low that it may rapidly and evenly spread and fill the features in an efficient manner, for example and without limitation, a viscosity in a range from about 0.01 cps to about 100 cps measured at 25° C. In addition, polymerizable fluid **340** has an ability to wet the surface of planarization and transfer layer **310** and imprint template **330**, and to avoid subsequent pit or hole formation after polymerization.

The constituent components that form polymerizable fluid **340** to provide the aforementioned characteristics may differ. This results from substrate **300** being formed from a number of different materials. As a result, the chemical composition of planarization and transfer layer **310** varies dependent upon the material from which substrate **300** is formed. For example, and without limitation, substrate **300** may be formed from silicon, plastics, gallium arsenide, mercury telluride, and composites thereof. Additionally, substrate **300** may include one or more layers, for example and without limitation, dielectric layers, metal layers, semiconductor layers, and the like.

In accordance with one or more such embodiments of the present invention, polymerizable fluid **340** comprises further constituents that provide its low viscosity, selectable etchability with respect to planarization and transfer layer **310** (to be described in detail below). In accordance with one or more such embodiments of the present invention, polymerizable fluid **340** is comprised of a silicon-containing material such as, for example and without limitation, an organosilane.

An exemplary composition for the silicon-containing material includes: (a) isobornyl acrylate (obtained from Aldrich Chemical Company of Milwaukee, Wis.); (b) acryloxymethyltrimethylsilane (obtained under the trade name XG-1039 from Gelest, Inc. of Morrisville, Pa.); (c) (3-acryloxypropyltristrimethylsiloxy)silane (obtained under the trade name SIA0210.0 from Gelest, Inc. of Morrisville, Pa.); (d) a fluorinated surfactant (obtained under the trade name FC4432 from 3M Company St. Paul, Minn.); (e) ethylene glycol diacrylate (obtained under the trade name EGDA from Aldrich Chemical Company of Milwaukee, Wis.); and (f) UV photoinitiator (for example and without limitation, 2-hydroxy-2-methyl-1-phenyl-propan-1-one) (obtained under the trade name Darocur 1173 from CIBA® of Tarrytown, N.Y.). In an exemplary such composition, isobornyl acrylate comprises approximately 30% by weight of the composition, acryloxymethyltrimethylsilane comprises approximately 40% by weight of the composition, (3-acryloxypropyltristrimethylsiloxy)silane comprises approximately 10% by weight of the composition, the fluorinated surfactant comprises approximately 0.5% by weight of the composition, ethylene glycol diacrylate comprises approximately 20% by weight of the composition, and the UV photoinitiator comprises approximately 3% by weight of the composition. Further useful compositions using the above-described materials may be determined readily by one of ordinary skill in the art without undue experimentation. Advantageously, little or no interfacial mixing occurs between polymerizable fluid **340** and planarization and transfer layer **310** for these above-described embodiments.

In accordance with one or more alternative embodiments of the present invention, polymerizable fluid **340** may comprise a nonsilicon-containing material such as, for example and without limitation, (a) isobornyl acrylate; (b) n-hexyl acrylate; (c) ethylene glycol diacrylate; and (d) 2-hydroxy-2-methyl-1-phenyl-propan-1-one. In one such exemplary composition, isobornyl acrylate comprises approximately 55% of the composition, n-hexyl acrylate comprises approximately 27% of the composition, ethylene glycol diacrylate comprises approximately 15% of the composition, and the UV initiator, for example and without limitation, 2-hydroxy-2-methyl-1-phenyl-propan-1-one, comprises approximately 3% of the composition. The above-identified composition may also include stabilizers that are well known in the chemical art to increase the operational life of the composition. Further useful compositions using the above-described materials may be determined readily by one of ordinary skill in the art without undue experimentation.

To improve the release properties of imprint template **330** and polymerized layer **345** and to ensure that polymerized layer **345** does not adhere to imprint template **330**, the composition from which polymerizable fluid layer **340** is formed may include an additive that reduces the surface tension thereof. To that end, polymerizable fluid layer **340** may include, as an additive, a surfactant. For purposes of

this patent application, a surfactant is defined as any molecule, one tail of which is hydrophobic. Surfactants may be either fluorine containing, e.g., including a fluorine chain, or may not include any fluorine in the surfactant molecule structure.

An exemplary surfactant is available under the trade name ZONYL® FSO-100 from DUPONT™ that has a general structure of R_1R_2 where $R_1{=}F(CF_2CF_2)_Y$, with y being in a range of 1 to 7, inclusive and $R_2{=}CH_2\ _{CH2}O(CH_2CH_2O)_XH$, where X is in a range of 0 to 15, inclusive. This provides one or more embodiments of polymerizable fluid **340** with the following composition: (a) isobornyl acrylate; (b) n-hexyl acrylate; (c) ethylene glycol diacrylate; (d) 2-hydroxy-2-methyl-1-phenyl-propan-1-one; and (e) $R_fCH_2CH_2O(CH_2CH_2O)_XH$. In accordance with one or more such embodiments, the ZONYL® FSO-100 additive comprises less than 1% of the composition, with the relative amounts of the remaining components being as discussed above. However, the percentage of ZONYL®FSO-100 may be greater than 1%. An advantage provided by the latter composition is that it may abrogate the need for an a priori release layer, i.e., a separate hydrophobic and/or low surface energy release layer disposed on imprint template **330**. Specifically, the latter composition provides desirable release properties to imprint template **330** and polymerizable fluid **340** so that polymerized layer **345** (described below) does not adhere to imprint template **330** with sufficient force to distort a feature pattern recorded therein.

FIG. **5** illustrates an alternative step for that illustrated in FIG. **3**B. As shown in FIG. **5**, instead of using planarization and transfer layer **310**, substrate **300** has been covered using any one of a number of methods that are well known to those of ordinary skill in the art with two layers, i.e., planarization and transfer layer $\mathbf{310}_1$ and planarization and transfer layer $\mathbf{310}_2$. In accordance with one or more embodiments of the present invention, planarization and transfer layer $\mathbf{310}_1$ is a polymer containing a PMGI structure, and planarization and transfer layer $\mathbf{310}_2$ is a DUV30J-6 BARC layer that is spin coated on top of planarization and transfer layer $\mathbf{310}_1$. In accordance with one such embodiment, (a) the polymer containing a PMGI was formed as was described above; (b) the BARC layer was cured at about 180° C. for about 60 sec; and (c) polymerizable fluid **340** was a silicon containing fluid that was formed as was described above. Advantageously, little or no interfacial mixing occurs between polymerizable fluid **340** and planarization and transfer layers $\mathbf{310}_1$ and $\mathbf{310}_2$ for such alternative embodiments.

Next, as shown in FIG. **3**C, the structure shown in FIG. **3**B is exposed to blanket actinic radiation such as, for example and without limitation, UV radiation **335**, through imprint template **330** to cross-link a substantial portion of polymerizable fluid **340** and to convert it into polymerized layer **345**. For example and without limitation, polymerizable fluid **340** was exposed for about 30 sec to UV radiation (having a wavelength of about 365 nm and having an intensity of about 15 mW/cm^2). It should be understood that the particular radiation employed to initiate the polymerization of polymerizable fluid **340** may be determined by one of ordinary skill in the art depending on a specific application which is desired.

Next, as shown in FIGS. **3**D and **3**E, imprint template **330** is withdrawn to provide high resolution, low aspect ratio relief pattern **360** that defines a residual layer **365** in polymerized layer **345**. Also note residual material **365** that may be in the form of: (1) a portion of polymerizable fluid, (2) a portion of polymerized fluid, or (3) combinations of (1) and (2). Thereafter, relief pattern **360** is anisotropically etched to remove residual layer **365** using any one of a number of methods that are well known to those of ordinary skill in the art. A selective etch is then employed to etch both polymerized layer **345** and planarization and transfer layer **310**. In accordance with one or more embodiments of the present invention, the etching selectivity of planarization and transfer layer **310** relative to polymerized layer **345** may range, for example and without limitation, from about 1.5:1 to about 100:1. Further, in accordance with one or more further embodiments of the present invention, the selective etching may be carried out by a halogen-rich (for example and without limitation, fluorine rich) reactive ion etch process. Such halogen-rich etch processes may utilize precursors such as, for example and without limitation, CHF_3 and CF_4. In addition, planarization and transfer layer **310** has been selectively etched to substrate **300** using any one of a number of methods that are well known to those of ordinary skill in the art to provide high resolution, high aspect ratio feature pattern **370**, with the features there comprising a stacked structure **371** that includes portions of polymerized layer **345** and planarization layer **310**. In accordance with one or more further embodiments of the present invention, the selective etching may be carried out by an oxygen plasma etch process. As is well known, such etching processes may be carried out in any one of a number of apparatus that are commercially available from suppliers such as, for example and without limitation, Lam Research, Inc. of Fremont, Calif.

Next, FIG. **3**F shows aperture **380** that is a portion of high resolution, high aspect ratio feature pattern **370** illustrated in FIG. **3**E.

Next, as shown in FIGS. **3**H and **3**G, the sidewalls of aperture **380** have been undercut by immersion in a developer/stripper, which developer/stripper etches the sidewalls (selectively with respect to cross-linked polymerized layer **345**) to form stacked structure **371** with an aperture **390** having a re-entrant shape. For example, a polymer containing a PMGI structure can be developed/stripped in tetramethylammonium hydroxide (TMAH) that may be obtained under the trade name CD26 from Shipley Company, L.L.C. of Marlborough, Mass. In accordance with one such embodiment of the present invention, 0.26N TMAH (i.e., 0.26 normal concentration of TMAH, where 0.26N is an industry-accepted standard concentration for TMAH developer/stripper) was used. Advantageously, in accordance with one or more embodiments, polymerized fluid **345** does not etch (i.e., dissolve) in 0.26N TMAH while a polymer containing a PMGI structure etches (i.e., dissolves) slowly therein to provide undercutting. In accordance with one or more further embodiments of the present invention, polymerized fluid **345** may also be etched in a developer/stripper used to etch planarization and transfer layer **310**. However, it is believed that better undercutting is provided when the material forming polymerized fluid **345** etches only very slowly or at a slower rate than that of the material forming planarization and transfer layer **310**.

Next, as shown in FIG. **3**H, a relatively thin metal layer **395** has been blanket-deposited over the structure shown in FIG. **5**G utilizing a reasonably directional deposition technique such as, for example and without limitation, physical vapor deposition ("PVD") or sputtering.

Next, as shown in FIG. **3**I, a lift-off process has been carried out to provide patterned metal feature **400** on substrate **300**. For example and without limitation, a polymer containing a PMGI structure can be lifted off using an N-methylpyrrolidinone ("NMP") based stripper such as, for example and without limitation, a stripper obtained under

the trade name Remover **1165** from Shipley Company, L.L.C. of Marlborough, Mass. In addition, in accordance with one such embodiment, the substrate may be processed by ultrasonic immersion in Remover **1165** at, for example and without limitation, about 50° C.

Lastly, an optional final cleaning step may be performed by rinsing the wafer in IPA and blowing it dry. Optionally, this step may be followed by an oxygen plasma etching step.

Although various embodiments that incorporate the teachings of the present invention have been shown and described in detail herein, those skilled in the art can readily devise many other varied embodiments that still incorporate these teachings. For example and without limitation, further embodiments of the present invention exist wherein the planarization and transfer layer described above may be a high molecular weight (Mn>50,000) polyhydroxystyrene. However, for such embodiments, although such a planarization and transfer layer may slightly intermix with an acrylic-based polymerizable fluid, the combination may be suitable for certain applications. In addition, although the polymerizable fluid, as described above, is an acrylic-based composition, other embodiments exist wherein this is not the case.

What is claimed is:

1. A method for generating patterned features on a substrate that comprises:

forming a first layer on at least a portion of a surface of the substrate, the first layer comprising at least one layer of a first material, which one layer abuts the surface of the substrate;

forming a second layer of a second material on at least a portion of the first layer, which second layer is imprinted with the patterned features;

removing at least portions of the second layer to extend the patterned features to the first layer; and

removing at least portions of the first layer to extend the patterned features to the substrate;

wherein the first layer and the second layer may be exposed to an etching process that undercuts the patterned features, and the first material may be lifted-off.

2. The method of claim **1** wherein the etching process causes etching of the first material and no etching of the second material.

3. The method of claim **1** method wherein the etching process causes etching of the first material and etching of the second material at a slower rate than a rate at which the first material is etched.

4. The method of claim **1** wherein the second layer does not intermix with the first layer.

5. The method of claim **1** wherein the step of removing at least portions of the second layer comprises dry etching.

6. The method of claim **1** wherein the step of removing at least portions of the first layer to extend the patterned features to the substrate does not remove second material.

7. The method of claim **1** wherein the first layer and the second layer are selectively etchable.

8. The method of claim **7** wherein the second layer comprises a silicon-containing material and the first layer comprises a non-silicon containing material.

9. The method of claim **8** wherein the step of removing at least portions of the second layer to extend the patterned features to the first layer comprises an anisotropic halogen etch.

10. The method of claim **9** wherein the anisotropic halogen etch is an anisotropic halogen reactive ion etch comprising a fluorine-containing precursor.

11. The method of claim **8** wherein the step of removing at least portions of the first layer to extend the patterned features to the substrate comprises an oxygen plasma etch.

12. The method of claim **1** wherein step of forming the second layer comprises dispensing an acrylic-based polymerizable fluid.

13. The method of claim **12** wherein the acrylic-based polymerizable fluid includes (a) isobomyl acrylate; (b) n-hexyl acrylate; (c) ethylene glycol diacrylate; and (d) 2-hydroxy-2-methyl-1-phenyl-propan-1-one.

14. The method of claim **13** wherein the acrylic-based polymerizable fluid further includes a surfactant.

15. The method of claim **12** wherein the acrylic-based polymerizable fluid includes (a) isobomyl acrylate; (b) acryloxymethyltrimethylsilane; (c) (3-acryloxypropyltristrimethylsiloxy)silane; (d) ethylene glycol diacrylate; and (f) a UV photoinitiator.

16. The method of claim **15** wherein the acrylic-based polymerizable fluid further includes a surfactant.

17. The method of claim **15** wherein the UV initiator comprises 2-hydroxy-2-methyt-1-phenyl-propan-1-one.

18. The method of claim **1** wherein the step of forming the first layer comprises coating a polymer containing a poly (dimethylglutarimide) ("PMGI") structure.

19. The method of claim **18** wherein coating comprises spin coating.

20. The method of claim **1** wherein the step of forming the first layer comprises coating a high molecular weight polyhydroxystyrene.

21. The method of claim **1** wherein the first layer comprises the one layer and another layer of another material disposed on the one layer, and the second layer does not intermix with the another layer.

22. The method of claim **21** wherein the etching process causes etching of the first material and no etching of the another material.

23. The method of claim **21** method wherein the etching process causes etching of the first material and etching of the another material at a slower rate than a rate at which the first material is etched.

24. The method of claim **21** wherein the another layer is a BARC layer.

25. The method of claim **1** further comprising:

exposing the first layer and the second layer to an etching process that undercuts the patterned features.

26. The method of claim **25** wherein the step of forming the first layer comprises coating a polymer containing a poly(dimethylglutarimide) ("PMGI") structure.

27. The method of claim **26** wherein the step of exposing comprises exposing the first and second layer to tetramethylammonium hydroxide.

28. A method for generating patterned features on a substrate that comprises:

forming a first layer on at least a portion of a surface of the substrate, the first layer comprising at least one layer of a first material, which one layer abuts the surface of the substrate, with forming the first layer comprising coating a polymer containing a poly(dimethylglutarimide) ("PMGI") structure;

forming a second layer of a second material on at least a portion of the first layer, which second layer is imprinted with the patterned features;

removing at least portions of the second layer to extend the patterned features to the first layer; and

removing at least portions of the first layer to extend the patterned features to the substrate;

wherein the first layer and the second layer may be exposed to an etching process that undercuts the patterned features, and the first material may be lifted-off.

29. The method of claim **28** wherein coating comprises spin coating.

30. A method for generating patterned features on a substrate that comprises:

forming a first layer on at least a portion of a surface of the substrate, the first layer comprising at least one layer of a first material, which one layer abuts the surface of the substrate, with forming the first layer comprising coating a high molecular weight polyhydroxystyrene;

forming a second layer of a second material on at least a portion of the first layer, which second layer is imprinted with the patterned features;

removing at least portions of the second layer to extend the patterned features to the first layer; and

removing at least portions of the first layer to extend the patterned features to the substrate;

wherein the first layer and the second layer may be exposed to an etching process that undercuts the patterned features, and the first material may be lifted-off.

31. A method for generating patterned features on a substrate that comprises:

forming a first layer on at least a portion of a surface of the substrate, the first layer comprising at least one layer of a first material, which one layer abuts the surface of the substrate, with forming the first layer comprising coating a polymer containing a poly(dimethylglutarimide) ("PMGI") structure;

forming a second layer of a second material on at least a portion of the first layer, which second layer is imprinted with the patterned features;

removing at least portions of the second layer to extend the patterned features to the first layer;

removing at least portions of the first layer to extend the patterned features to the substrate; and

exposing the first layer and the second layer to tetramethylammonium hydroxide that undercuts the patterned features, and the first material may be lifted off.

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