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(54) METHOD FOR PRODUCING PATTERNED STRUCTURES BY PRINTING A SURFACTANT RESIST ON A SUBSTRATE FOR ELECTRODEPOSITION

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(60) Provisional application No. 60/523,498, filed on Nov. 19, 2003, provisional application No. 60/467,248, filed on May 1, 2003.

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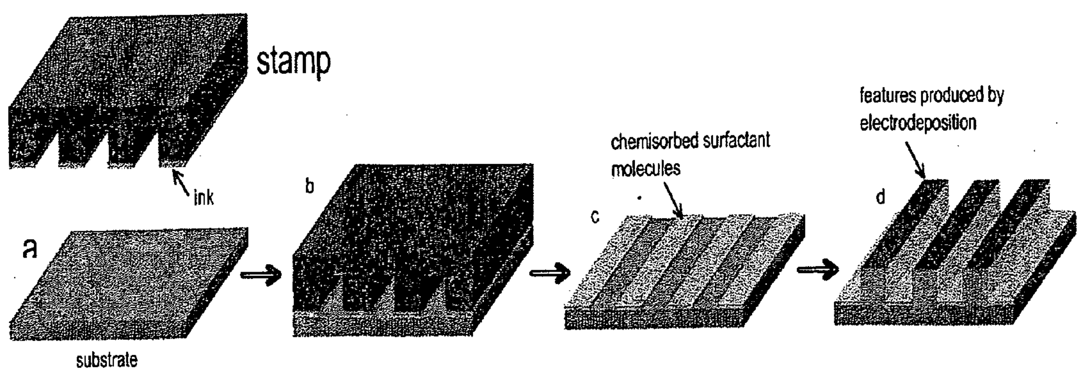
(57) **ABSTRACT**

Methods for electrodeposition of conductive material on a conductive substrate that contains a pattern of a chemisorbed surfactant formed by a stamp having a patterned surface which is pressed onto the surface of the substrate for printing the substrate. Electrodeposition occurs by immersing the patterned substrate in a plating bath upon application of deposition potential or current to the conductive substrate. In embodiment, the chemisorbed surfactant on the surface of the substrate acts as a positive resist so that electrodeposition occurs on regions of the substrate not covered with surfactant. In another embodiment, electrodeposition occurs preferentially in regions of the substrate covered with the chemisorbed surfactant.



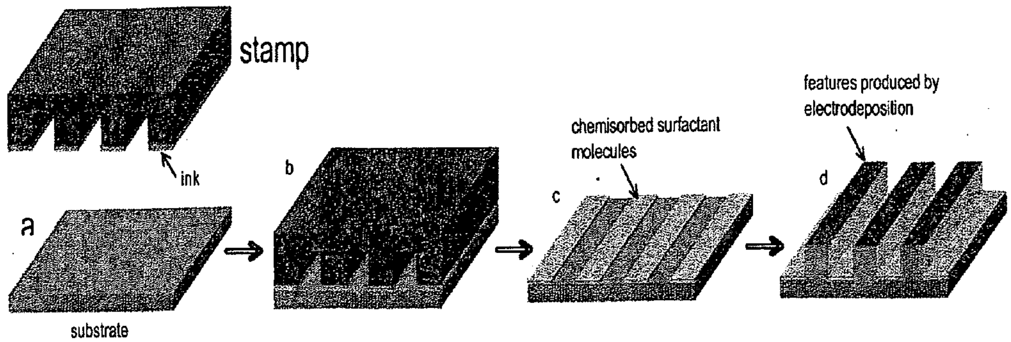


FIGURE 1

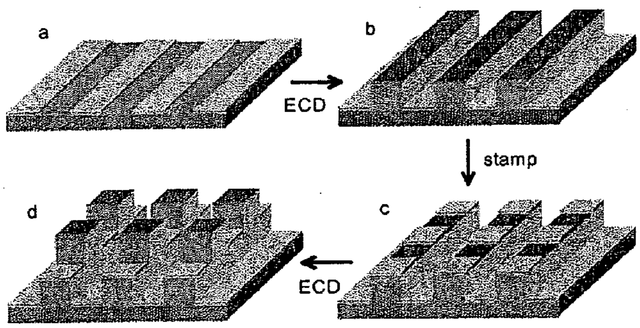


Figure 2

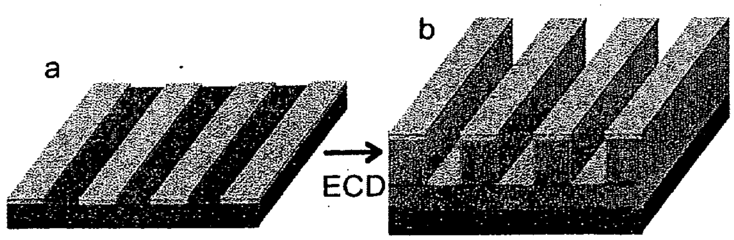


Figure 3

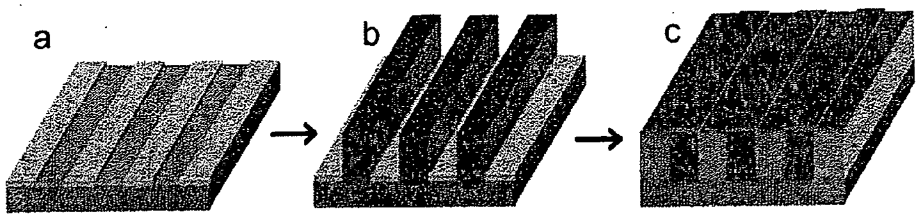


Figure 4

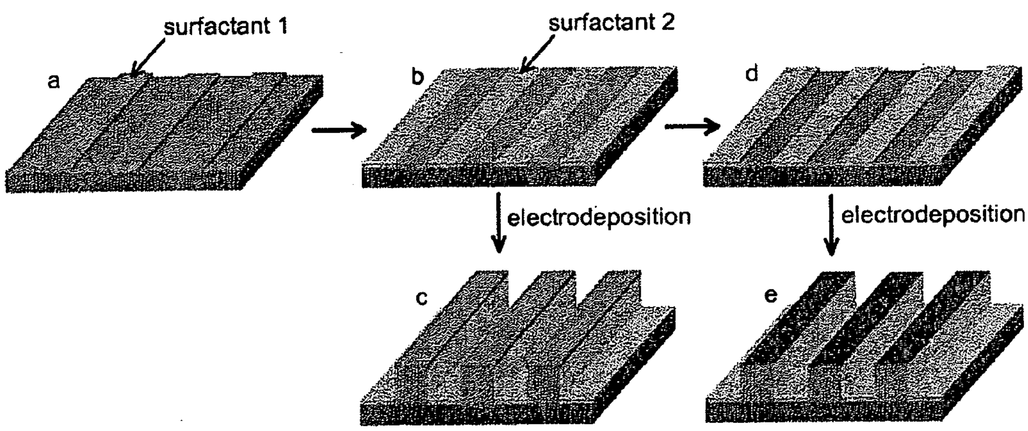


Figure 5

METHOD FOR PRODUCING PATTERNED STRUCTURES BY PRINTING A SURFACTANT RESIST ON A SUBSTRATE FOR ELECTRODEPOSITION

RELATED APPLICATIONS

[0001] This application is a continuation-in-part of U.S. application Ser. No. 11/638,137, filed Dec. 13, 2006, which is a divisional of U.S. application Ser. No. 10/836,021, filed Apr. 29, 2004, now abandoned, which claims priority to U.S. Provisional Application Nos. 60/523,498, filed Nov. 19, 2003 and 60/467,248, filed May 1, 2003, the disclosures of which are hereby incorporated by reference in their entireties.

GOVERNMENT INTEREST

[0002] This invention was made with government support under NASA Contract NGT5-50372 and NSF Grant DMR05-20491. The government has certain rights in the invention.

FIELD OF THE INVENTION

[0003] This invention relates to lithography and, in particular, to a method of high resolution lithography using a surfactant pattern to direct the electrolytic deposition of materials on a substrate surface. The process can be used to produce structures patterned in one, two and three dimensions.

BACKGROUND OF THE INVENTION

[0004] Electrodeposition of conductive materials, such as metals, onto the surface of a substrate including a patterned resist is a well-known process for producing fine metal patterns on a substrate. Electrodeposition is a process which occurs when using a conductive substrate that serves as a cathode. According to conventional methods, the cation of the metal to be deposited is reduced from a plating bath at the cathode by application of a potential or current. As such, electrodeposition occurs in the regions where the conductive substrate is in contact with the plating solution, but does not occur in regions of the substrate that are covered with the resist. Conventional methods for creating patterned resists rely on optical or electron-beam lithography to define a pattern on the substrate. These methods, however, requires expensive lithographic tools and facilities.

[0005] Another approach for producing a patterned substrate for electrodeposition is to use soft lithography (or micro-contact printing) to transfer a molecule that self-assembles on the substrate. According to this technique, a polymer stamp having a desired pattern is exposed to a solution of the surfactant molecule. The stamp is then brought into contact with the substrate, transferring the surfactant molecules from the polymer stamp to the substrate in regions defined by the pattern on the stamp. The surfactant molecules are chemisorbed to the substrate, that is, the surfactant molecules are tethered to the surface through a chemical bond.

[0006] The prior art describes methods wherein patterned self-assembled monolayers are used as resists in combination with electrodeposition. (See, e.g., Sondaghuethorst, J. A. M. et al., Generation of Electrochemically Deposited Metal Patterns by Means of Electron-Beam (Nano)Lithography of Self-Assembled Monolayer Resists, Applied Physics Letters 1994, 64, (3), pages 285-287; Felgenhauer, T. et al., Electrode modification by electron-induced patterning of aromatic self-assembled monolayers, Applied Physics Letters 2001, 79, (20), pages 3323-3325; Kaltenpoth, G. et al., Electrode modification by electron-induced patterning of self-assembled monolayers, Journal of Vacuum Science & Technology B 2002, 20, (6), pages 2734-2738; Volkel, B., et al., Electrodeposition of copper and cobalt nanostructures using self-assembled monolayer templates Surface Science (2005), 597, pages 32-41. In the examples set forth in the references identified above, the self-assembled monolayer is formed over the entire conductive surface, and the pattern is created by irradiation to selectively degrade the monolayer using an electron beam. Irradiation of thiol monolayers can result in degradation of the monolayer forming various fragments, unsaturated bonds, and sulfides. The substrates covered with the degraded fragments can be used as-is, or the fragments can be etched away to provide open regions on the conductive surface at which electrodeposition can proceed. Alternatively, irradiation may induce cross-linking in adsorbed layers that contain cross-linkable groups (e.g., 1,12-biphenyl-4-thiol), resulting in selective deposition or etching in the regions that were not irradiated, analogous to using a negative resist in conventional lithography. As mentioned above, these electron beam-based lithography processes require the use of expensive lithographic tools.

[0007] Furthermore, soft-lithography and electrodeposition techniques have not been combined into a single approach because surfactant molecules which are chemisorbed to surfaces typically form a layer only a few nanometers in height. Moreover, the surfactant molecules do not consistently prevent electrodeposition, and in many situations, the electrodeposition occurs without selectivity in both the surfactant-covered regions and the surfactant-free regions.

[0008] Accordingly, there is a need in the art for a method for patterned electrodeposition of conductive material on a conductive substrate in an efficient and cost-effective manner which overcomes the disadvantages prevalent in the conventional methods.

SUMMARY OF THE INVENTION

[0009] The present invention relates to a method for depositing patterned structures on a substrate using soft lithography (also known as microcontact printing) and electrodeposition. According to an embodiment of the present invention, the method provides for the electrodeposition of a conductive material onto a conductive substrate by bringing a stamp having a surfactant printed thereon into contact with the substrate. After removing the stamp from contact with the substrate, the surfactant is chemisorbed to the substrate in patterns dictated by the relief of the stamp. Next, the printed conductive substrate is immersed in a plating bath wherein metal ions are dissolved. Metal ions are electrochemically reduced to form metallic structures, or features, in the regions of the substrate not covered with the chemisorbed surfactant. Alternatively, metal ions are electrochemically reduced preferentially in the regions of the substrate covered with the chemisorbed surfactant to form metallic structures that are higher in these regions of the substrate.

[0010] The method has several advantages over conventional methods for producing patterned materials on substrates. First, methods such as photolithography or electron-beam lithography are considerably more costly and time consuming. Second, electrodeposition has many advantages over other deposition methods. It is low cost and can be used to deposit a wide range of materials. Furthermore, elec-

trodeposition is one of the only methods for depositing materials in a pattern formed by surfactant molecules on a substrate. Other methods that deposit material from the vapor phase, such as sputter deposition or evaporation cannot be used in conjunction with soft lithography since the depositing atoms have sufficiently high energy that they will degrade or remove the chemisorbed surfactant molecules from the substrate. Thus the combination of soft lithography and electrodeposition together provide a unique low cost, rapid method for producing patterned structures.

[0011] According to further embodiments of the present invention, the method may include multiple deposition and stamping steps to create complex, multi-layered structures.

BRIEF DESCRIPTION OF THE FIGURES

[0012] FIG. **1** illustrates a fabrication of structure by electrodeposition into surfactant-free regions of a patterned substrate.

[0013] FIG. **2** illustrates another embodiment of the present invention, in which complex topological structures can be created by sequential application of the stamping and electrodeposition processes.

[0014] FIG. **3** illustrates another embodiment of the present invention wherein deposition occurs preferentially under the surfactant layer.

[0015] FIG. **4** illustrates another embodiment of the present invention, wherein two materials are deposited in a desired pattern by sequential depositions using a single patterned surfactant layer chemisorbed to a substrate by changing the composition of the material to be deposited and/or by changing the deposition conditions.

[0016] FIG. **5** illustrates an embodiment of the fabrication process of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0017] The present invention relates to a method for electrodeposition of a conductive material, herein the "deposited material", on a substrate. Conductive materials for use in the present invention may include, e.g., gold, silver, platinum, cobalt and bismuth. The method involves the use of a structure having a patterned surface, herein referred to as a stamp, which includes a patterned microscale or nanoscale surface. The patterned surface comprises a solution which contains a surfactant material. Due to the chemisorption of the surfactant material and the substrate, the pattern of surfactant material as arranged on the stamp is transferred to the substrate. The stamp is then removed from contact from the substrate.

[0018] According to an embodiment of the present invention, the deposited material is then electrodeposited onto the surfactant-free regions of the substrate, to form features in the pattern of the relief of the stamp. In this regard, the surfactant layer serves as a resist, whereby the surfactant material binds to the substrate to form a layer that prevents electrodeposition on the one or more regions of the substrate covered by the surfactant layer. According to an embodiment of the present invention, by preventing electrodeposition of a material in a region of a substrate, the surfactant material operates in the same way as a conventional resist used in electron beam lithography or photolithography. The ability of chemisorbed surfactant molecules to serve as a resist depends on variables such as the molecular structure of the surfactant, the substrate, the chemistry, and the deposition potential or current, all of which are inter-related. The molecule chemisorbs to the substrate to form a self-assembled monolayer. The chemisorbed molecule functions as a molecular resist over a limited range of deposition potentials and metal ion concentrations. The range of deposition potentials and the concentration of metal ions that are preferable are dependent on the surfactant molecule and the substrate chosen. Thus under suitable conditions, electrodeposition may be directed to occur only in the surfactant-free regions, and not in the regions where the surfactant is chemisorbed to the surface.

[0019] For example, molecules with sulfhydryl groups will chemisorb to gold and silver surfaces. Alkanethiols ($CH_3(CH_2)_nSH$) with chain lengths greater than about 12 will form ordered self-assembled monolayers that function as resists for electrodeposition. For transition metals, such as cobalt, deposition can be performed in 50 mM Co(II) solution at −0.8 V (Ag/AgCl). The preceding examples are merely preferred embodiments, and are not meant to limit the scope of the present invention. One of skill in the art would recognize the relationship between the variables of the surfactant molecules and substrate chosen for use in the present invention.

[0020] According to an embodiment of the present invention, the surfactant may also act to promote electrodeposition to occur preferentially on the parts of the substrate covered by the surfactant layer. In this embodiment, electrodeposition of the deposited material occurs in both the surfactant-free regions and the regions covered by the surfactant molecule. In such an embodiment, the deposition rate is faster in regions covered by the surfactant molecule.

Composition of the Stamp and Related Components

[0021] In preferred embodiments, the stamp is composed of an elastomeric material, e.g., polydimethylsiloxane and polyurethane.

[0022] In preferred embodiments, the solution is ink. In even more preferred embodiments, the ink solution is an alkane thiol $R(CH_2)_nSH$ solution, where R is selected from the group consisting of hydrogen, hydroxy, branched chain or straight chain alkyl, cycloalkyl, cycloalkenyl, heterocycle, aromatic ring, and heteroaromatic ring, each of which may be optionally substituted, and n=0-6. In other embodiments, the thiol solution can also be dissolved in solvents such as hexane and chloroform.

[0023] In preferred embodiments, the surfactant material or surfactant molecule is a conductive material composed of a molecular structure which is adapted to chemisorb to the substrate to form a self-assembled monolayer (SAM).

[0024] As described above, the selection of the surfactant and the substrate is determined by the requirement that the surfactant must chemisorb onto the substrate. Accordingly, a wide range of different materials (i.e., different substrate/surfactant combinations) may be used in accordance with the present invention. For example, a surfactant material with a terminal sulfhydryl group would be a suitable combination for a substrate composed of gold or silver because sulfhydryl groups chemisorb to both gold and silver substrates. Examples of other materials suitable for deposition onto a gold or silver substrate that has been modified with a surfactant molecule that is chemisorbed to the surface include, but are not limited to gold, silver, copper, nickel, and cobalt. Other exemplary substrate/surfactant molecule combinations include, but are not limited to a surfactant molecule with an isocyanide group that chemisorbs to platinum and palladium substrates; and a surfactant molecule with a silane, carboxylic acid, phosphonic acid, hydroxamic acid that chemisorbs to the thin native oxide on many metals and alloys (e.g., transition metals and valve metals).

[0025] In preferred embodiments, the surfactant has a saturated alkane chain long enough to form strong intermolecular associations that prevent ion penetration through the monolayer. The range of potentials for which the surfactant behaves as a good resist is dependent on several factors, such as the metal ion concentration, the deposition potential, and the molecular structure of the surfactant molecule. For a given surfactant molecule, breakdown is minimized by depositing from solutions with low metal ion concentrations and at more positive deposition potentials.

[0026] It is to be appreciated by one having ordinary skill in the art that the substrate/surfactant combinations described herein are exemplary in nature, and that the scope of the invention is not limited to specific examples set forth herein.

[0027] An advantage of the process described herein is that features can be deposited to heights much greater than the height of the surfactant molecule chemisorbed to the substrate. Deposition occurs in such a way that there is no lateral growth and the features, i.e., the electrodeposited material of interest, maintain the dimensions of the pattern even at heights above the height of the surfactant layer on the substrate. This is an important difference as compared to conventional electron beam lithography or photolithography, wherein the resist is higher than the deposited feature.

[0028] As shown in FIG. **1***a*, a stamp **10** having a patterned surface **15** including one or more features **16** is inked or coated with a surfactant material **20**. The stamp **10** is then brought into contact and chemisorbs with a substrate **30**, as shown in FIG. **1***b*. Upon removing the stamp **10** from the substrate **30** (FIG. **1***c*) the surfactant material is transferred to the substrate **30** in regions where the stamp **10** contacts the surface of the substrate **30**.

[0029] Next, electrodeposition is used to deposit a conductive material (i.e., the deposited material) **40** onto the substrate, as shown in FIG. **1***d*. In this embodiment, deposition occurs only in regions of the substrate **30** where there are no chemisorbed surfactant molecules. According to this embodiment, the surfactant molecules act as a molecular resist directing deposition to occur only in regions where there are no surfactant molecules. Note that deposition of the deposited material **40** extends beyond the height of the layer of surfactant molecules **20**, which is typically less than a few nanometers, with no lateral growth. Since there is no lateral growth during deposition, the features (i.e., the deposited material) **40**, although much higher than the layer of surfactant molecules **20**, maintain the dimensions of the pattern of the substrate with high fidelity.

EXAMPLE 1

Electrodeposition of Conductive Material

[0030] In a preferred embodiment, a molecule with a sulfhydryl group at one end is used as the surfactant molecule. A stamp is used to transfer a pattern of the surfactant molecule to a gold or silver substrate. The patterned surfactant may be used to direct deposition of a material to the surfactant-free regions. The material is deposited at a potential positive to the reduction potential for the chemisorbed surfactant molecule, that is, at a potential positive to the potential where the surfactant molecule is desorbed from the substrate. In certain embodiments of the present invention, the deposited material is not applied to the regions where the substrate is covered with the surfactant molecule. The conditions under which deposition only occurs in the surfactant-free regions of the substrate and where the material is deposited with no lateral growth to heights greater than the height of the surfactant layer are dependent on the molecular structure of the surfactant molecule, the deposition potential or current, and the composition of the solution used for deposition. For example, silver from a solution containing 20 mM Ag(I) at −0.45 V (Ag/AgCl) was deposited on a gold substrate with a patterned octadecanethiol monolayer; copper from solution containing 100 mM Co(II) at −0.2 V (Ag/AgCl) was deposited on a gold substrate with a patterned octadecanethiol monolayer; and cobalt from solution containing 50 mM Co(II) at −0.8 V (Ag/AgCl) was deposited on a gold substrate with a patterned octadecanethiol monolayer.

EXAMPLE 2

Sequential Stamping

[0031] As shown in FIG. **2***a*, a substrate **230** is stamped with a surfactant material **220**, using a stamp coated or inked with surfactant molecules, thereby transferring surfactant molecules that chemisorb onto the substrate **230** in regions where the stamp contacts the surface of the substrate **230**. A conductive material **240** is deposited by electrodeposition onto the substrate to create features that grow vertically from the substrate with lateral dimensions defined by the pattern, as shown in FIG. **2***b*. Thereafter, the deposited material **240** obtained via the initial electrodeposition is stamped with a second layer of surfactant **250** that chemisorbs to that material.

[0032] The stamp orientation and pattern are selected to place the surfactant molecules in a pattern of interest on top of the layer of deposited material **240**. On removing the stamp (FIG. **2***c*) the surfactant molecule is transferred to and chemisorbs only in regions where the stamp is in contact with top of the features. Subsequently, a second conductive material **260** is electrodeposited, as shown in FIG. **2***d*. Advantageously, the electrochemical deposition of the layer of the second deposited material **60** results in the formation of vias between the features of the layer of the second deposited material.

[0033] Deposition occurs only at the top of the first layer of features where there are no chemisorbed surfactant molecules (i.e., the surfactant-free regions of the layer of the first deposited material). Since there is no lateral growth during deposition, the layer of the second layer of features grows vertically from the top of the layer of the first deposited material in a pattern defined by the surfactant distribution on those features with high fidelity. One having ordinary skill in the art will appreciate that the first deposited material **240** may be the same or different in composition from the second deposited material **260**. One having ordinary skill in the art will further appreciate that the first surfactant layer **220** may be composed of the same or different material as the second surfactant layer **250**. In addition, one having ordinary skill in the art will appreciate that the above sequential process may comprise additional stamping and depositing steps to form any number of layers of features in any desired pattern.

EXAMPLE 3

Preferential Deposition in the Regions where a Surfactant Molecule is Chemisorbed to the Surface

[0034] According to the embodiment depicted in FIG. **3**, a substrate **330** is stamped with a surfactant material **320**, using, for example, a stamp coated or inked with surfactant molecules, thereby causing the surfactant molecules **320** to chemisorb onto the substrate **330** in regions where the stamp made contact with the surface of the substrate **330**, as shown in FIG. **3***a*. Next, a conductive material **340** is deposited by electrodeposition onto the substrate, as shown in FIG. **3***b*. In this embodiment, the material of interest is deposited on both the regions of the surface covered with surfactant molecules and on the regions that are not covered with surfactant molecules. The rate of deposition in the regions covered by the surfactant molecules is faster or higher than the rate of deposition in the surfactant-free regions. As shown in FIG. **3***b*, this preferential deposition results in the deposited features growing vertically from the surface with lateral dimensions defined by the patterned surface.

[0035] According to this embodiment of the present invention, the ability of a chemisorbed surfactant to allow deposition to occur preferentially on the regions covered by the surfactant depends on the molecular structure of the surfactant, the deposition chemistry, the solution chemistry, and/or the deposition potential or current. Thus under suitable conditions, electrodeposition can be directed to occur more rapidly in the regions where the surfactant is chemisorbed to the substrate than in the surfactant-free regions.

EXAMPLE 4

Sequential Use of Deposition in Surfactant-Free Regions and Preferential Deposition in Regions Covered by the Surfactant

[0036] In the embodiment depicted in FIG. **4**, conditions are selected such that the chemisorbed surfactant **420** prevents deposition of a first deposited material **440**. According to this exemplary method, the substrate **430** is stamped with surfactant molecules **420**, using, for example, a stamp coated or inked with surfactant molecules **420**. The surfactant molecules **420** chemisorb onto the substrate in regions where the stamp made contact with the surface of the substrate **430**, as shown in FIG. **4***a*. A conductive material **40** is deposited by electrodeposition onto the substrate **430** in the surfactant-free regions to create features that grow vertically from the surface with lateral dimensions defined by the patterned substrate, as illustrated in FIG. **4***b*.

[0037] Thereafter, conditions are selected such that the chemisorbed surfactant **420** enhances the rate of deposition in the regions covered by the surfactant of the deposited material **440**. For example, when the molecular resist is an alkanethiol, deposition will occur in both surfactant covered regions as well as surfactant-free regions, however the alkanethiol will stimulate an increase in deposition rate in the surfactant covered regions.

[0038] Next, a second conductive material **450** is deposited by electrodeposition onto the substrate **440** under conditions wherein deposition is faster in the regions of the substrate **430** covered with chemisorbed surfactant **420** than on top of the features of the first deposited material **440**, resulting in the patterned structure illustrated in FIG. **4***c*.

[0039] As shown, the second deposited material **450** fills the spaces between the features of the first deposited material **440**, and is also deposited at a slower rate on top of the original features of the first deposited material **440**. Accordingly, a two-component patterned material is formed with feature lateral dimensions defined by the surfactant distribution on those features with high fidelity.

EXAMPLE 5

Stamping and Immersion to Create a Patterned Surfactant Layer on the Surface of the Substrate

[0040] According to an embodiment of the present invention, a patterned structure may be formed according to a process wherein a surfactant resist is created by sequential stamping with a surfactant ink, and immersed into a solution containing a second surfactant ink. The first surfactant ink chemisorbs to the substrate in patterns dictated by the stamp. Thereafter, the printed substrate is immersed in a solution of the second surfactant ink, which chemisorbs to the substrate in regions not occupied by the first surfactant ink. According to this embodiment, conditions may be selected such that the second surfactant is chemisorbed to the surface of the substrate and prevents electrodeposition. One having ordinary skill in the art will appreciate that the surfactant ink is a solution which contains the desired surfactant.

[0041] The fabrication process is illustrated in FIGS. **5***a*-**5***e*. As shown in FIG. **5***a*, a substrate **530** is stamped with molecules of the first surfactant **510**, thereby transferring surfactant molecules that chemisorb onto the substrate in regions where the stamp is contacted to the surface of the substrate **530**. The printed substrate is then immersed in a solution of the second surfactant **520**, which forms a chemisorbed layer in regions of the surface not covered by the first surfactant **510**, as shown in FIG. **5***b*.

[0042] In one exemplary embodiment, the first surfactant **510** is selected such that it does not prevent electrodeposition. In this example, when a conductive material **540** is deposited by electrodeposition onto the substrate in the regions covered with the first surfactant **510**, features grow vertically from the surface with lateral dimensions defined by the patterned substrate, as shown in FIG. **5***c*.

[0043] In another embodiment, the first surfactant **510** can be removed from the surface of the substrate **530** by any suitable means known to those having ordinary skill in the art, as shown in FIG. **5***d*. Next, as shown in FIG. **5***e*, electrodeposition onto the substrate in the regions not covered with the first surfactant **510** creates features that grow vertically from the surface with lateral dimensions defined by the patterned substrate **530**.

[0044] It is understood that the above-described embodiments are illustrative of only a few of the many possible specific embodiments, which can represent applications of the invention. Numerous and varied other arrangements can be made by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed:

1. A method for patterning a substrate with a conductive material, comprising the steps of:

(a) providing a substrate;

(b) contacting the substrate with a stamp comprising a surfactant layer, wherein the surfactant chemisorbs to a portion of the substrate in contact with the stamp, thereby creating a surfactant-covered region and a surfactant-free region; and

(c) removing the stamp from the substrate; and

(d) electrodepositing a conductive material onto the substrate, whereby the conductive material adheres to the surfactant-free region of the substrate.

2. The method of claim **1**, wherein the stamp comprises polydimethylsiloxane (PDMS).

3. The method of claim **1**, wherein the surfactant layer is applied to the stamp by immersing the stamp into a solution comprising the surfactant.

4. The method of claim **3**, wherein the solution comprises alkane thiol $CH_3(CH_2)_nSH$.

5. The method of claim **1**, wherein the stamp comprises a nanoscale pattern.

6. The method of claim **1**, wherein the stamp comprises microscale pattern.

7. The method of claim **1** wherein electrodeposition occurs preferentially in areas of the surfactant-covered region.

8. The method of claim **1**, wherein the method is performed a plurality of times onto the same substrate.

9. The method of claim **8**, wherein a different conductive material is electrodeposited onto the substrate each time the method is performed.

10. A method for patterning a substrate with conductive materials, comprising the steps of:

(a) providing a substrate;

(b) contacting the substrate with a first stamp comprising a layer of a first surfactant, wherein the first surfactant chemisorbs to a portion of the substrate in contact with the stamp, thereby creating a first surfactant-covered region and a first surfactant-free region;

(c) removing the first stamp from the substrate;

(d) electrodepositing a first conductive material onto the substrate, whereby the conductive material adheres to the first surfactant-free region of the substrate;

(e) contacting the portion of the substrate comprising the first conductive material with a second stamp comprising a layer of a second surfactant, wherein the second surfactant chemisorbs onto the first conductive material in contact with the second stamp, thereby creating a second surfactant covered region on the first conductive material and a second surfactant-free region on the substrate;

(f) removing the second stamp from the substrate; and

(g) electrodepositing a second conductive material onto the substrate, whereby the second conductive material adheres to the second surfactant-free region.

11. A method for patterning a conductive substrate, comprising the steps of:

(a) providing a conductive substrate;

(b) contacting the substrate with a stamp comprising a surfactant layer, wherein the surfactant chemisorbs to the portion of the substrate in contact with the stamp, thereby creating a surfactant-covered region and a surfactant-free region; and

(c) removing the stamp from the conductive substrate.

12. The method of claim **11**, further comprising electrodepositing a conductive material onto the conductive substrate, whereby the conductive material adheres to the surfactant-free region of the substrate.

13. The method of claim **11**, wherein the stamp comprises polydimethylsiloxane (PDMS).

14. The method of claim **11**, wherein the surfactant layer is applied to the stamp by immersing the stamp into a solution comprising the surfactant.

15. The method of claim **14**, wherein the solution comprises alkane thiol $CH_3(CH_2)_nSH$.

16. The method of claim **11**, wherein the stamp comprises nanoscale feature(s).

17. The method of claim **11**, wherein the stamp comprises microscale feature(s)

18. The method of claim **12** wherein electrodeposition occurs preferentially in areas of the surfactant-covered region.

19. The method of claim **12**, wherein the method is performed a plurality of times onto the same substrate.

20. The method of claim **19**, wherein a different conductive material is electrodeposited onto the substrate each time the method is performed.

21. A method for patterning a substrate with conductive materials comprising electrodepositing conductive materials onto a substrate comprising a chemisorbed surfactant.

* * * * *