

METHOD OF LOW TEMPERATURE IMPRINTING PROCESS WITH HIGH PATTERN TRANSFER YIELD

TECHNICAL FIELD

[0001] The present invention relates generally to micro- and nano-imprinting lithography techniques, and specifically to the use of sacrificial layers to form 3-dimensional and multi-layer structures using such techniques.

BACKGROUND INFORMATION

[0002] While X-ray, ion beam, and e-beam lithography have all been demonstrated as viable next generation lithography techniques, they are, however, slow and expensive (M. Geissler, Y. Xia, *Adv. Mater.* 16(15), p. 1249, 2004). Nano-imprinting lithography (NIL) offers a very attractive alternative to the fabrication of sub-micron (i.e., nanometer-scale) features, largely due to the process being simple, fast, and inexpensive, thus making it a potential technique for replacing photolithography in mass production. Although a relatively high yield has been demonstrated, the yield of imprinting relies heavily on a proper tuning of surface energy among the components, i.e., the substrate, the mold, and the polymer. An anti-adhesion layer is almost a prerequisite in NIL processes to ensure that the polymer remains on the substrate during de-molding steps. Accordingly, non-uniformity in the anti-adhesion treatment often results in poor yield (R.W. Jaszcwiski, H. Schiff, B. Schnyder, A. Schneuwly and P. Groning, *Appl. Sur. Sci.* 143, pp. 301-308, 1999; S. Park, C. Padeste, H. Schiff and J. Gobrecht, *Microelectronic Eng.* 67-68, pp. 252-258, 2003).

[0003] Although NIL techniques have successfully demonstrated an ability to fabricate multilayer structures (L.R. Bao, X. Cheng, X.D. Huang, L.J. Guo, S.W. Pang, and A.F. Yee, *J. Vac. Sci. Technol. B* 20, pp. 2881-2886, 2002; X.D. Huang, L.R. Bao, X. Cheng, L.J. Guo, S.W. Pang, and A.F. Yee, *J. Vac. Sci. Technol. B* 20(6), pp. 2872-2876, 2002; X. Sun, L. Zhuang, W. Zhang and S.Y. Chou, *J. Vac. Sci. Technol. B* 16(6), pp. 3922-3925, 1998; B. Faircloth, H. Rohrs, R. Ruogg, R.R. Krchnavek, *J. Vac. Sci. Technol. B* 18(4), pp. 1866-1873, 2000), there are some limitations on the type of structures

patternable by these techniques. For instance, it is quite challenging to fabricate such a multilayer structure using NIL, due to difficulties such as: (a) solvent intermixing between layers; (b) deformation of the underlying layer during the imprinting of the top layer due to relatively high temperature and pressure; (c) a requirement that the subsequent layer have a lower T_g than the underlaying layer, in the case of polymeric materials; and (d) limited choice of materials that are imprintable, for instance, in one example, a bilayer or tri-layer resist with different properties are required; in another example, a crosslinked polymer is required to be the underlying layer (Z. Yu, H. Gao, W. Wu, H. Ge and S.Y. Chou, J. Vac. Sci. Technol. B 21(6), pp. 2874-2877, 2003).

[0004] While multilayer structures have been demonstrated, as a result of the above-described limitations, the yield is typically very low and the types of polymer used in the layers is quite limited. Accordingly, an improved method of NIL capable of making multi-layer structures in high yield, and with minimal material restrictions, would be highly desirable.

BRIEF DESCRIPTION OF THE INVENTION

[0005] In some embodiments, the present invention is directed to novel methods of imprinting substrate-supported or freestanding structures at low cost, with high pattern transfer yield, and using low processing temperature. Such methods overcome many of the above-described limitations of the prior art. Generally, such methods of the present invention employ a sacrificial layer or film.

[0006] In some embodiments, the present invention is directed to the use of sacrificial films in duo-mold imprinting, hot-embossing lithography (HEL) or nano-imprinting lithography (NIL), and mold-assisted lithography (MAL) or step-and-flash imprint lithography (SFIL). The combined use of sacrificial films with these techniques serves to improve these techniques in a novel and non-obvious manner.

[0007] In accordance with some embodiments of the present invention, utilization of a sacrificial film is illustrated by the following steps: (a) treating a patterned silicon mold, the mold comprising patterned trenches, with a low surface energy silane; (b) depositing polymer having a glass transition temperature (T_g) into the mold such that it fills in the trenches and forms a patterned (structured) polymeric thin film in the patterned silicon

mold, wherein the patterned polymeric thin film comprises a planarized top surface and a patterned bottom surface that adopts a patterned imprint structure where it conformally contacts the mold; (c) providing a sacrificial film having a surface energy higher than that of the patterned silicon mold and pressing the sacrificial film into the planarized top surface of the polymeric thin film at a temperature above the T_g of the polymer so as to form an assembly; and (d) separating the sacrificial film from the assembly at a temperature below the T_g of the polymer such that the patterned polymeric thin film adheres to the sacrificial film on separation and forms a sacrificial film-supported patterned polymeric thin film. The sacrificial film-supported patterned polymeric thin film can then be transferred to a substrate and the sacrificial film and/or residual polymer between the structures of the patterned polymeric thin film can be removed so as to yield discrete polymeric structures. Using such methods, 3-dimensional and multi-layer structures can be fabricated.

[0008] By utilizing a sacrificial film, the present invention offers a number of advantages. First, the pattern transfer yield during the demolding process is significantly improved. The entire pattern, supported on the sacrificial film, can be transferred to a target substrate with subsequent removal of the sacrificial film. This provides a near 100% pattern transfer yield. Second, the pattern transfer from the sacrificial film can be carried out at milder temperatures and pressures, assisted by the conformal nature of the sacrificial film. This advantage enables the imprinting of a multilayer structure comprising a single type of material, thereby broadening the choice of polymers for multilayer structures and allowing for easy preparation of freestanding 3-D structures. Third, this technique is applicable to either or both conventional and reverse imprinting methods by using a sacrificial film such as aluminum foil. The sacrificial film is typically inexpensive, thus adding to the benefit of a low cost nanofabrication process for mass production.

[0009] The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

[0011] FIGURE 1 is a schematic illustrating an imprinting process, according to an embodiment of the present invention, where the process uses a sacrificial substrate;

[0012] FIGURE 2 is an SEM image of a bi-layer PMMA structure with 500 nm wide grating structures on both the top and bottom layer;

[0013] FIGURE 3 schematically illustrates fabrication of a freestanding single layer, in accordance with an embodiment of the present invention;

[0014] FIGURE 4 schematically illustrates fabrication of a sacrificial film-supported or freestanding triple-layer structure, in accordance with an embodiment of the present invention;

[0015] FIGURE 5 schematically illustrates the use of a sacrificial film in a duo-mold process to yield a sacrificial film-supported or freestanding 3-D structure, in accordance with an embodiment of the present invention;

[0016] FIGURE 6 schematically illustrates the use of a sacrificial film in a HEL or NIL process to yield either a sacrificial layer supported structure or a freestanding structure, in accordance with an embodiment of the present invention;

[0017] FIGURE 7 schematically illustrates the use of a sacrificial film in a MAL or SFIL process to yield either a sacrificial layer supported structure or a freestanding structure, in accordance with an embodiment of the present invention;

[0018] FIGURES 8A and 8B are SEM images depicting samples of 500 nm gratings imprinted by HEL or NIL processes in combination with a sacrificial layer and in accordance with an embodiment of the present invention;

[0019] FIGURE 9 is an SEM image of a single layer PMMA structure supported on an aluminum foil substrate imprinted by a silicon mold with 75 nm gratings, in accordance with some embodiments of the present invention; and

[0020] FIGURE 10 is an SEM image of a two-layer PMMA scaffold structure supported on aluminum foil imprinted by a silicon mold with 75 nm gratings, in accordance with some embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0021] In the following description, specific details are set forth such as specific quantities, sizes, etc. to provide a thorough understanding of the present invention. However, it will be obvious to those skilled in the art that the present invention may be practiced without such specific details. In many cases, details concerning such considerations and the like have been omitted inasmuch as such details are not necessary to obtain a complete understanding of the present invention and are within the skills of persons of ordinary skill in the relevant art.

[0022] In some embodiments, the present invention is directed to a method of low temperature imprinting using a sacrificial film, the method having high transfer yield. This sacrificial film can be inorganic or organic material that can easily be removed by simple wet etching techniques. By using such a sacrificial film, a near 100% imprinting transfer yield can be achieved, and freestanding structures can easily be obtained, even at low process temperatures.

[0023] An imprinting process in accordance with some embodiments of the present invention is shown schematically in FIGURE 1. Referring to FIGURE 1, a patterned silicon (Si) mold is treated with a low surface energy silane, for example: 1H,1H,2H,2H-perfluorodecyltrichlorosilane (FDTS), octadecyltrichlorosilane (OTS), or octadecylmethyldichlorosilane (ODS). A polymer solution, for example poly(methyl methacrylate) (PMMA) in, e.g., toluene, is then spin-coated onto the mold such that it fills up the trenches and forms a planarized thin film (FIGURES 1a3 and 1a4). A wafer or glass substrate with high surface energy (FIGURE 1a1) can be pressed into the planarized thin film above the glass transition temperature (T_g) of the polymer of which the planarized thin film is comprised (FIGURE 1b1) and, after a predetermined

imprinting time, the wafer or glass substrate can be separated below the T_g of the polymer (FIGURE 1c1) and optionally subjected to oxygen (O_2) plasma etching to remove residual layer and yield a patterned polymeric film on a wafer or glass substrate (FIGURE 1d1). Additionally or alternatively, a sacrificial film or substrate (FIGURE 1a2), for instance aluminium foil, is treated with an oxygen plasma to impart it with a high surface energy. This sacrificial film is then pressed, at a suitable pressure, onto the polymer-coated Si mold at a temperature above the T_g of the polymer (FIGURE 1b2). After a predetermined imprinting time, the sacrificial film is then separated below the T_g of the polymer, resulting in a pattern transfer from the mold to the sacrificial film (FIGURE 1c2). This transfer occurs because of the difference in the surface energies between the mold and the sacrificial film. Since the sacrificial film has a higher surface energy than that of the mold, the polymer film preferentially adheres to the sacrificial film and thus results in the transfer of the polymer film. An O_2 plasma etching may then be carried out to remove the residue (residual) layer of the polymer film. This results in residual layer-free pattern on the sacrificial film (FIGURE 1d2). With the polymer pattern on the sacrificial substrate, it is possible to carry out the following two processes:

- 1) The patterned sacrificial film can be pressed at a suitable pressure onto a pre-patterned polymer on a substrate (FIGURE 1e1). By removing the sacrificial film, a bilayer structure (FIGURE 1f1) can be obtained. This imprinting process can be carried out at an ambient temperature with near 100% yield.
- 2) Alternatively, the patterned sacrificial film can be pressed at a suitable pressure onto another patterned sacrificial film (FIGURE 1e2). A freestanding bilayer structure (FIGURE 1f2) is then obtained after removing the sacrificial films. This step can also be carried out at an ambient condition (i.e., temperature), as described above.

[0024] The sacrificial film described herein can give a near 100% imprinting yield in nano-imprinting lithography (NIL) processes such that the entire pattern on the sacrificial substrate can be transferred to a target substrate. Low imprinting temperatures can be used in multilayer fabrication process since the sacrificial film can be removed by dissolving in a suitable solution rather than mechanical demolding. In NIL processes, demolding steps generally require a good anti-adhesion property, otherwise low

imprinting transfer yields will result. Using a sacrificial film, a freestanding structure can easily be obtained by removing the sacrificial film. Additionally, the same kind of polymer material can be used to fabricate a multilayer structure, since the imprinting temperature can be low and the sacrificial substrate is removed by dissolving instead of demolding.

[0025] FIGURE 3 schematically illustrates the fabrication of a single-layer freestanding structure, according to an embodiment of the present invention. Referring to FIGURE 3, polymer is coated onto a silane-treated mold and a sacrificial substrate with high surface energy is brought into close proximity (Step (a)). The sacrificial substrate is then pressed onto the polymer at a temperature above the T_g of the polymer (Step (b)). Next, the polymer is separated from the mold at a temperature below T_g , as shown in Steps (c) and (d). After separation from the mold, the sacrificial substrate 301 can be removed, and this results in a single-layer freestanding structure 305 (Step (e)). The sacrificial film materials can be polymer materials, ceramics and metals. The structure size can also be controlled from the sub-micron level down to nanometers in scale.

[0026] In some embodiments, it is also possible to design micro- or nanometer-scale structures that assemble with a three layer structure, as shown in FIGURE 4. Referring to FIGURE 4, polymer 402 is coated onto a silane-treated mold 403 and a sacrificial substrate 401 is brought into close proximity and then pressed onto the polymer at a temperature above T_g for the polymer (Step (a)). Next, the polymer is separated from the mold at a temperature below T_g , as shown in Steps (b) and (c). One such fabricated polymer structure is then O_2 -plasma etched to remove the residual layer (Step (d)) and form structure 405a. Another such polymer structure (405b) has residual layer without plasma etching. The two structures (405a and 405b), as formed in Step (d), are then brought together and pressed at low temperature (Step (e)). One sacrificial substrate is then selectively removed (Step (f)) without destroying the other sacrificial layer to yield structure 406. The residual layer can be removed by plasma etching and another layer is added (this can be done multiple times), as shown in Step (g). Finally, all sacrificial substrates are removed (Step (h)). The resulting three-layer structure 407 can be fabricated by the same type of material, and this also allows the three-layer structure to be substrate supported or freestanding. It should be recognized by persons of skill in the art

that the methods of the present invention can also fabricate more complex structures having more than three layers.

[0027] In some embodiments, a sacrificial layer is used in combination with a duo-mold imprinting method (United States Patent Application Serial No. 10/852,448, filed May 24, 2004). Referring to FIGURE 5, polymer 501 is spin-coated onto a first mold 502 having low surface energy (e.g., silane-treated), as shown in Step (a). A second mold 503 having medium surface energy is then pressed into the polymer layer above the T_g of the polymer (Step (b)). The molds are then separated at a temperature below T_g and the polymer preferentially adheres to the second mold (Step (c)). The polymer is then pressed and released onto a sacrificial substrate layer 504 (Steps (d) and (e)) to yield sacrificial substrate-supported 3-D structure 505. Finally, if desired, the sacrificial substrate layer 504 can be removed to yield a freestanding 3-D structure 506, as shown in Step (f).

[0028] In some embodiments, a sacrificial layer is used in combination with hot-embossing lithography (HEL) or nano-imprinting lithography (NIL). Referring to FIGURE 6, an adhesion layer 602 is placed between sacrificial layer 603 and support substrate 601. Polymer 604 is then spin-coated onto sacrificial layer 603, as shown in Step (a). In Step (b), silane treated stamp 605 is pressed into polymer layer 604 at a suitable temperature. Mold 605 is then separated at low temperature (Step (c)) to yield substrate supported structure 606. Support substrate 601 can then be removed to yield a sacrificial layer supported structure 607a (Step (d1)), or the sacrificial layer can be removed to yield a freestanding structure 607b (Step (d2)). FIGURES 8A and 8B illustrate examples of samples imprinted with HEL or NIL used in combination with a sacrificial layer (aluminum), wherein the SEM images depict 500 nm gratings on aluminum.

[0029] In some embodiments, a sacrificial layer is used in combination with mold-assisted lithography (MAL) or step-and-flash imprint lithography (SFIL). Referring to FIGURE 7, a cavity is formed between transparent stamp 704 and sacrificial layer 703. Adhesion layer 702 is used to adhere sacrificial layer 703 to support substrate 701. The cavity is then filled with monomer dispenser (Step (a)) and the cavity gap closed (Step (b)). Local curing is done through the transparent stamp 704 by irradiating with

ultraviolet light, as shown in Step (c). Stamp 704 is then removed to reveal a patterned polymer structure 705 (Step (d)). Finally, support substrate 701 can be removed to yield a sacrificial layer supported structure 706a (Step (e1)), and sacrificial layer 703 can be removed to yield a freestanding polymer structure 706b (Step (e2)).

[0030] It should be mentioned that while aluminum (Al) foil is described herein as a suitable sacrificial substrate, the process and principle described herein can also be applied by using other commercially available materials, such as water soluble polymer sheets, thin ceramic films, and metals such as Zn, Fe or Cu. Likewise, while PMMA has been described as a suitable polymeric material for use in invention embodiments, those of skill in the art will recognize that many other polymeric materials are also suitable. Such suitable polymers include, but are not limited to, poly(lactic acid) (PLA), poly(caprolactone) (PCL), and poly(ethylene terephthalate) (PET).

[0031] As noted throughout, a key feature of the present invention is the use of a mechanically conformable and chemically etchable film as a sacrificial component in nanoimprinting and lithographic processes. This sacrificial feature provides an easy, low cost method for increasing the yield of nanopatterning in NIL. Cost and yield are two very important criteria for mass production. Additionally, the present invention fills the need for a NIL process utilizing milder temperatures and pressures.

[0032] Potential applications for the structures made by the methods of the present invention include, but are not limited to, micro- and nano-electrical-mechanical systems (MEMS and NEMS devices; e.g., fluidics, actuators, lenses, resonators), sensors, integrated circuit (IC) devices and photonic band gap structures (waveguides).

[0033] The following examples are included to demonstrate particular embodiments of the present invention. It should be appreciated by those of skill in the art that the methods disclosed in the examples that follow merely represent exemplary embodiments of the present invention. However, those of skill in the art should, in light of the present disclosure, appreciate that many changes can be made in the specific embodiments described and still obtain a like or similar result without departing from the spirit and scope of the present invention.

EXAMPLE 1

[0034] This Example illustrates the use of a sacrificial layer in an imprinting process, in accordance with an embodiment of the present invention. The various steps described below are correlated with those shown in FIGURE 1.

[0035] A 7 wt.% PMMA (average $M_w \approx 120k$, Aldrich) in toluene solution is spin-coated at 3000 rpm for 20 seconds onto a Si mold to obtain a planarized coating of around 800 nm in thickness (FIGURE 1a4). The PMMA-coated mold is then baked at 80°C for 5 minutes to remove any remaining solvent in the film. The polished side of a piece of aluminum foil (Diamond Company) (FIGURE 1a2) is treated by oxygen plasma at a power of 100 W, a base pressure of 50 mtorr, and a working pressure of 250 mtorr, for 1 minute. The oxygen plasma-treated aluminum foil is then pressed onto the PMMA-coated mold (FIGURE 1b2) with a pressure of 40 bars at 150°C for 5 minutes. The mold is then cooled down to 70°C and separated. This results in the transfer of the patterned PMMA film from the mold to the aluminium foil (FIGURE 1c2). The PMMA-patterned aluminium foil is then treated with an oxygen plasma at a power of 80 W, a base pressure of 35 mtorr, and a working pressure of 150 mtorr, for around 20 seconds, to remove the residual layer (FIGURE 1d2).

[0036] Separately, a glass substrate is treated with oxygen plasma at a power of 100 W, a base pressure of 50 mtorr, and a working pressure of 250 mtorr, for 5 minutes. The glass substrate is then pressed onto a PMMA-coated mold (FIGURE 1a3) with a pressure of 40 bars at 150°C for 5 minutes. The glass substrate is then cooled and separated, followed by oxygen plasma to remove the residual layer. This results in 500 nm PMMA gratings supported on glass substrate (FIGURE 1d1).

[0037] Both the glass and aluminium foil supported gratings are brought together perpendicularly, and are pressed with a pressure of 20 bars at 80°C for 5 minutes, then the substrates are cooled down to 40°C and separated. The structure is then immersed in a 0.5 M HCl solution for 30 minutes to selectively remove the aluminium foil. This results in a PMMA bilayer scaffold structure on a glass substrate (FIGURE 1f1).

EXAMPLE 2

[0038] This Example illustrates, in a visual manner, a two-layer PMMA scaffold structure fabricated in accordance with some embodiments of the present invention.

[0039] FIGURE 2 is a scanning electron micrograph (SEM) image of a two-layer PMMA scaffold structure supported on a glass substrate comprising 500 nm-wide gratings on both the bottom and the top, wherein this structure was fabricated using a method of the present invention. Compared to demonstrated multilayer structures (L.R. Bao, X. Cheng, X.D. Huang, L.J. Guo, S.W. Pang, and A.F. Yee, *J. Vac. Sci. Technol. B* 20, pp. 2881-2886, 2002; X.D. Huang, L.R. Bao, X. Cheng, L.J. Guo, S.W. Pang, and A.F. Yee, *J. Vac. Sci. Technol. B* 20(6), pp. 2872-2876, 2002), the top surface of the protrusion of this scaffold is rough. This is due to the rough surface of the sacrificial aluminum film used; dissolving of the sacrificial film will result in a surface with a roughness similar to that of the aluminum foil. However, this rough protrusion surface can be optimized and smoothed by using a well-polished aluminum foil or other sacrificial films and should not be construed as a limitation of this technique.

EXAMPLE 3

[0040] This Example illustrates the fabrication of PMMA structures in accordance with invention embodiments. Such structures are similar to those described in EXAMPLE 2 and shown in FIGURE 2, but comprise smaller dimensions.

[0041] FIGURE 9 is an SEM image of a single layer PMMA grating structure on aluminum foil, the layer fabricated using a silicon mold with 75 nm gratings, in accordance with invention embodiments. Once the Al foil is etched, the 75 nm grating will be a free-standing film. To use the sacrificial film method on conventional NIL, an additional support substrate is used. By extension, scaffold structures with high fidelity have been obtained. FIGURE 10 is an SEM image of a scaffold structure with 75 nm gratings. It is worth noting that this scaffold structure with exceedingly small features is

fabricated with PMMA, a material that is difficult to structure with other lithographic techniques.

[0042] All patents and publications referenced herein are hereby incorporated by reference to the extent not inconsistent herewith. It will be understood that certain of the above-described structures, functions, and operations of the above-described embodiments are not necessary to practice the present invention and are included in the description simply for completeness of an exemplary embodiment or embodiments. In addition, it will be understood that specific structures, functions, and operations set forth in the above-described referenced patents and publications can be practiced in conjunction with the present invention, but they are not essential to its practice. It is therefore to be understood that the invention may be practiced otherwise than as specifically described without actually departing from the spirit and scope of the present invention as defined by the appended claims.

CLAIMS

1. A method for fabricating structures, the method combining the use of a sacrificial film with a nanoimprinting technique selected from the group consisting of reversal nanoimprinting, duo-mold imprinting, conventional nanoimprinting, mold-assisted lithography, and combinations thereof.
2. The method of claim 1, wherein the nanoimprinting technique comprises reversal nanoimprinting, and wherein the use of a sacrificial film provides for a low temperature imprinting process with high pattern transfer yield.
3. The method of claim 2, wherein the reversal nanoimprinting is operable for the fabrication of a single-layer structure.
4. The method of claim 3, wherein the single-layer structure is made of a polymeric material selected from the group consisting of poly(methyl methacrylate) (PMMA), poly(lactic acid) (PLA), poly(caprolactone) (PCL), poly(ethylene terephthalate) (PET), and combinations thereof.
5. The method of claim 3 or claim 4, wherein the single-layer structure exists in a manner selected from the group consisting of substrate-supported, freestanding, and combinations thereof.
6. The method of any one of claims 2 to 5, wherein the reversal nanoimprinting is operable for the fabrication of multilayer structures.
7. The method of claim 6, wherein the multilayer structures comprise a single type of material.
8. The method of claim 6, wherein the multilayer structures comprise different types of materials.
9. The method of claim 8, wherein the materials are polymeric.
10. The method of claim 6, wherein the multilayer structures exist in a manner selected from the group consisting of substrate-supported, freestanding, and combinations thereof.

11. The method of any one of claims 2 to 10, wherein use of the sacrificial film allows for low processing temperatures.
12. The method of claim 11, wherein the low processing temperatures are between about room temperature and about 100°C.
13. The method of any one of claims 2 to 12, wherein the high pattern transfer yield results from complete pattern layer transfer from the sacrificial film to a substrate.
14. The method of any one of the preceding claims, wherein the sacrificial film comprises material selected from the group consisting of organic materials, inorganic materials, and combinations thereof.
15. The method of any one of the preceding claims, wherein the sacrificial film is a thin film of material selected from the group consisting of Al, Zn, Fe, Cu, and combinations thereof
16. The method of any one of claims 1 to 14, wherein the sacrificial film is a water soluble polymer used to imprint non-water soluble material.
17. The method of claim 14, wherein the inorganic materials are selected from the group consisting of ceramics, aluminum, copper, zinc, steel, and combinations thereof.
18. The method of claim 15, wherein the sacrificial film is a hard substrate.
19. The method of claim 15, wherein the sacrificial film is a flexible substrate.
20. The method of claim 3, wherein the structure comprises sub-micron dimensions.
21. The method of claim 6, wherein the structures comprise sub-micron dimensions.
22. The method of any one of the preceding claims, wherein duo-mold imprinting is used to fabricate 3-D structures that exist in a manner selected from the group consisting of sacrificial film-supported, freestanding, and combinations thereof.
23. The method of claim 22, wherein the structures comprise sub-micron dimensions.

24. The method of any one of claims 1 to 21, wherein conventional nanoimprinting is used to fabricate 3-D structures that exist in a manner selected from the group consisting of sacrificial film-supported, freestanding, and combinations thereof.
25. The method of claim 24, wherein the structures comprise sub-micron dimensions.
26. The method of any one of claims 1 to 21, wherein mold-assisted lithography is used to fabricate 3-D structures that exist in a manner selected from the group consisting of sacrificial film-supported, freestanding, and combinations thereof.
27. The method of claim 26, wherein the structures comprise sub-micron dimensions.
28. The method of claim 1, wherein the mold-assisted lithography comprises step-and-flash imprinting lithography.
29. A method comprising the steps of:
- a) treating a patterned silicon mold, the mold comprising patterned trenches, with a low surface energy silane;
 - b) depositing polymer having a glass transition temperature (T_g) into the mold such that it fills in the trenches and forms a patterned polymeric thin film in the patterned silicon mold, wherein the patterned polymeric thin film comprises a planarized top surface and a patterned bottom surface that adopts a patterned imprint structure where it conformally contacts the mold;
 - c) providing a sacrificial film having a surface energy higher than that of the patterned silicon mold and pressing the sacrificial film into the planarized top surface of the polymeric thin film at a temperature above the T_g of the polymer so as to form an assembly; and
 - d) separating the sacrificial film from the assembly at a temperature below the T_g of the polymer such that the patterned polymeric thin film adheres to the sacrificial film on separation and forms a sacrificial film-supported patterned polymeric thin film.

30. The method of claim 29, further comprising a step of removing the sacrificial film to yield a patterned polymeric thin film.
31. The method of claim 30, further comprising a step of transferring the patterned polymeric thin film to a substrate.
32. The method of claim 31, further comprising a step of etching polymer residue from the polymeric thin film to yield discrete polymeric structures patterned on a surface.
33. The method of claim 32, wherein the polymeric structures comprise sub-micron dimensions.
34. The method of any one of claims 29 to 33, wherein the patterned trenches comprise sub-micron dimensions.
35. The method of any one of claims 29 to 34, wherein the low surface energy silane is selected from the group consisting of 1H,1H,2H,2H-perfluorodecyltrichlorosilane (FDTS), octadecyltrichlorosilane (OTS), octadecylmethyldichlorosilane (ODS), and combinations thereof.
36. The method of any one of claims 29 to 35, wherein the polymer is selected from the group consisting of poly(methyl methacrylate) (PMMA), poly(lactic acid) (PLA), poly(caprolactone) (PCL), poly(ethylene terephthalate) (PET), and combinations thereof.
37. The method of any one of claims 29 to 36, wherein the polymer is deposited from solution.
38. The method of any one of claims 29 to 37, wherein the sacrificial film comprises material selected from the group consisting of Al, Zn, Fe, Cu, and combinations thereof.
39. The method of any one of claims 30 to 38, wherein the sacrificial film is removed with an acid.
40. The method of any one of claims 29 to 39, wherein the method is used in combination with a technique selected from the group consisting of reversal nanoimprinting, duo-mold imprinting, conventional nanoimprinting, mold-assisted lithography, and combinations thereof.