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~~disclosure 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~~disclosure employ a sacrificial layer or film.

[0005a] In one aspect, there is provided a method for fabricating free-standing multilayer structures, the method comprising:

pressing a planarized sacrificial film onto a polymer-coated silicon mold;

separating said planarized sacrificial film from said polymer-coated silicon mold resulting in a pattern transfer from said mold to said planarized sacrificial film;

pressing said patterned sacrificial film onto another patterned sacrificial film; and

removing said patterned sacrificial films thereby producing a free-standing multilayer structure.

[0005b] In one aspect, there is provided 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 (Tg) 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 Tg of the polymer so as to form an assembly;

(d) separating the sacrificial film from the assembly at a temperature below the Tg 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;

(e) pressing the patterned polymeric thin film onto another patterned sacrificial film; and

(f) removing the sacrificial films to yield a free-standing multilayer structure.

[0005c] In one aspect, there is provided a method for producing a free-standing multilayer structure, the method comprising:

treating a patterned silicon mold with silane;

spin-coating a polymer solution onto said patterned silicon mold thereby forming a planarized thin film;

pressing a substrate into said planarized thin film above a glass transition temperature of said polymer solution;

separating said substrate from said planarized thin film below said glass transition temperature of said polymer solution after a period of time following said pressing of said substrate into said planarized thin film;

pressing a sacrificial film onto a recoated polymer-coated silicon mold at a temperature above said glass transition temperature of said polymer solution;

separating said sacrificial film from said polymer-coated silicon mold at a temperature below said glass transition temperature of said polymer solution resulting in a pattern transfer from said mold to said sacrificial film;

pressing said patterned sacrificial film onto another patterned sacrificial film; and

removing said patterned sacrificial films thereby producing said free-standing multilayer structure.

[0006] In some embodiments, the present ~~invention~~disclosure 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 used 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~~disclosure, 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~~disclosure 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~~disclosure in order that the detailed description of the ~~invention~~disclosure that follows may be better understood. Additional features and advantages of the ~~invention~~disclosure will be described hereinafter which form the subject of the claims ~~of the invention~~.

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.

CLAIMS

1. A method for fabricating free-standing multilayer structures, the method comprising:

   pressing a planarized sacrificial film onto a polymer-coated silicon mold;

   separating said planarized sacrificial film from said polymer-coated silicon mold resulting in a pattern transfer from said mold to said planarized sacrificial film;

   pressing said patterned sacrificial film onto another patterned sacrificial film; and

   removing said patterned sacrificial films thereby producing a free-standing multilayer structure.

2. The method of claim 1, wherein the sacrificial film comprises material selected from the group consisting of organic materials, inorganic materials, and combinations thereof.

3. The method of claim 1, wherein the sacrificial film is a thin film of material selected from the group consisting of Al, Zn, Fe, Cu, and combinations thereof.

4. The method of claim 1, wherein the sacrificial film is a water soluble polymer used to imprint non-water soluble material.

5. The method of claim 2, wherein the inorganic materials are selected from the group consisting of ceramics, aluminum, copper, zinc, steel, and combinations thereof.

6. 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 (Tg) 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 Tg of the polymer so as to form an assembly;

(d) separating the sacrificial film from the assembly at a temperature below the Tg 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;

(e) pressing the patterned polymeric thin film onto another patterned sacrificial film; and

(f) removing the sacrificial films to yield a free-standing multilayer structure.

7. The method of claim 6, further comprising a step of transferring the patterned polymeric thin film to a substrate.

8. The method of claim 7, further comprising a step of etching polymer residue from the polymeric thin film to yield discrete polymeric structures patterned on a surface.

9. The method of claim 8, wherein the polymeric structures comprise sub-micron dimensions.

10. The method of claim 6, wherein the sacrificial films are removed with an acid.

11. A method for producing a free-standing multilayer structure, the method comprising:

treating a patterned silicon mold with silane;

spin-coating a polymer solution onto said patterned silicon mold thereby forming a planarized thin film;

pressing a substrate into said planarized thin film above a glass transition temperature of said polymer solution;

separating said substrate from said planarized thin film below said glass transition temperature of said polymer solution after a period of time following said pressing of said substrate into said planarized thin film;

pressing a sacrificial film onto a recoated polymer-coated silicon mold at a temperature above said glass transition temperature of said polymer solution;

separating said sacrificial film from said polymer-coated silicon mold at a temperature below said glass transition temperature of said polymer solution resulting in a pattern transfer from said mold to said sacrificial film;

pressing said patterned sacrificial film onto another patterned sacrificial film; and

removing said patterned sacrificial films thereby producing said free-standing multilayer structure.

12. The method as recited in claim 11, wherein a polymer film of said polymer-coated silicon mold adheres to said sacrificial film.

13. The method as recited in claim 12, wherein said sacrificial film has a higher surface energy than said mold.

14. The method as recited in claim 12 further comprising:

removing a residual layer of said polymer film using oxygen plasma etching.

15. The method as recited in claim 11, wherein said substrate comprises a wafer.

16. The method as recited in claim 11, wherein said substrate comprises glass.