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(54) Title: MOLD AND SUBSTRATE SEPARATION FOR IMPRINT LITHOGRAPHY

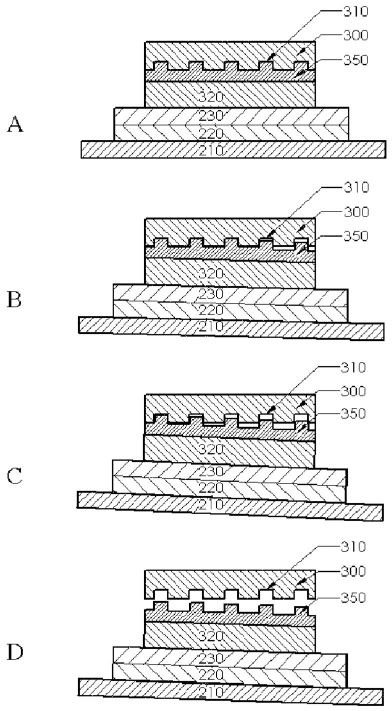

FIG. 1

(57) Abstract: A nanoimprint system and methods for separating imprinted substrates with nano-scale patterns from mold for manufacturing. Generally, the system includes means to create, monitor, and control relative movement between the mold and substrate for separation. It is capable of controlling where and when the separation happens and finishes. The relative movement may be generated by motion stages, springs, stage driven flexures, inflatable O-rings, gas flow, and other mechanical means. It may be monitored by separation force, overhead camera, and vacuum/pressures in different area of the system. The relative movement may be any combination of stages movements and movement sequences. The separation speed, direction, and force can be well controlled in the system to achieve fast and reliable separation between mold and substrate, and at the same time maintain the pattern shape and details on the consolidated imprint resist.

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— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US14/30655

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B29C 39/08, 43/04, 43/10 (2014.1)
USPC - 425/405.2, 440; 264/293;
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8): B28B 7/06, 11/08, 11/10; B29C 33/20, 33/30, 35/08, 39/08, 39/36, 41/52, 43/04, 43/10, 43/56, 59/00, 59/02, 59/16; H01L 21/027, 21/302 (2014.1) USPC: 264/293, 481; 425/112, 174.4, 385, 388, 405.2, 440; 438/690, 945; CPC: B29C 39/405, 43/184

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC: B29C 39/405, 43/184, 2043/562, 2043/025, 2043/142, 2059/023

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
MicroPatent (US-G, US-A, EP-A, EP-B, WO, JP-bib, DE-C,B, DE-A, DE-T, DE-U, GB-A, FR-A); Google Scholar; ProQuest; IP.com; antireflection, axis, axes, chuck, contact, deform, demold, effector, force, imprint lithography, mask, mold, motion, nanoimprint lithography, peel, pitch, roll, robot, sensor, separate, substrate, template, tilt, tip, window, yaw

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2009/0140445 A1 (LU, X et al.) 04 June 2009; title; figures 1, 3B-C; paragraphs [0002]-[0004], [0020]-[0021], [0029], [0034], [0042], [0058]	1-2, 6, 11 --------------------- 3-5, 7-10, 12-14
Y	US 2010/0201042 A1 (SREENIVASAN, SV et al.) 12 August 2010; figures 33A-C; paragraphs [0003], [0051], [0090]-[0091], [0112], [0150]-[0152], [0168]-[0172], [0181]	3-5, 7-10, 13-14
Y	US 2011/0180965 A1 (ZHANG, W et al.) 28 July 2011; figures 1, 2a-d, 3; paragraphs [0017]-[0019], [0022]	12-14
A	US 2010/ 0173032 A1 (SUEHIRA, N et al.) 08 July 2010; entire document	1-14
A	US 2006/0172549 A1 (CHOI, BJ et al.) 03 August 2006; entire document	1-14
A	US 2004/0251775 A1 (CHOI, BJ et al.) 16 December 2004; entire document	1-14

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

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Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I: Claims 1-14 are directed toward a method and systems of separating a mold and an imprinted substrate in imprint lithography.

Group II: Claims 15-29 are directed toward methods and systems of patterning substrates and roller molds with microstructure and nanostructure patterns in roller imprint lithograph.

Group III: Claims 30-51 are directed toward a method and system for patterning substrate surfaces with microstructure and nanostructure patterns in step and repeat imprint lithography.

-***-Continued Within the Next Supplemental Page-***-

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-14

Remark on Protest
☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
☒ No protest accompanied the payment of additional search fees.

-***-Continued from Box No. III: Observations where unity of invention is lacking-***-

The inventions listed as Groups I-III do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the special technical features of Group I include a mold holding fixture for holding a mold having a mold surface with nanostructures; a substrate holding fixture for holding a substrate having a molding surface; a stage assembly having three axis movement, an overhead camera for observation of separation boundary; and means to divide the chamber into two fluidly separate sub-chambers, each sub-chamber being configured for a separate controlled sub-chamber environment including a separate pressure and/or vacuum, a separate gas content, and a separate gas flow rate into and out thereof, which are not present in Groups II-III; the special technical features of Group II include roller imprint lithography, at least one of the moldable or the molding surfaces is part of a roller, or at least one backside of the mold and the substrate is contacting a roller; a ACP head enabling the applying of a pressure on the output of the head; moldable material bath in contact with at least a section of the substrate, or a roller in contact with the substrate and moldable material; a vapor treatment chamber to coat vapor of chemicals on a section of the mold or the substrate; rollers to move at least one of substrate and mold; and means to control the thickness of the moldable materials by contacting and taking away extra materials; coating roller mold with surfactant coating; roll the mold on the substrate patterned surface with a controlled pressure, so the pattern on the substrate is transferred to the mold surface; removing the surfactant coating exposed in the air; plating the roller mold with metal; rotating the roller mold to polish its surface so that the patterns are exposed in the air and the metal surface is smooth; and removing the remaining surfactant and patterns transferred initially from the substrate; coating the roller surface with photoresist; using projection optics with UV light and photomask to exposure a line of the resist on the surface of the roller; rotating the roller to next field and run exposure again; keeping rotating and exposure each time until all required areas on the roller surface are exposed; placing roller into a developer to remove unwanted resists; and etching the pattern into the roller using a wet etching or a dry etching; and coating the roller surface, the back surface of the substrate, or both with either glue or a magnetic material, which are not present in Groups I and III; the special technical features of Group III include step and repeat imprint lithography; a gantry for holding mold holder; a multi-axis stages; a vibration control table; a robot system with cassettes for automatically loading and unloading of substrates and molds; a microscopic system for measuring the spatial relation between the mold and the substrates at multiple locations; a UV exposure light and reflective optics; a mold holder which has center opening and can change the mold size in the XY plane; and means to press one area of the substrate using the mold at a time, then separate and continue with other areas; and adjusting the gaps between the mold and the substrate so the moldable surface and molding surface is in parallel; and approaching the substrate to the mold while aligning them according to the alignment marks on the mold and the substrate, which are not present in Groups I-II.

The common technical features of Groups I-III are imprint lithography; holding a mold having a mold surface with nanostructures; a substrate having a molding surface; contact force sensors positioned for sensing the forces during imprint and separation; a stage assembly having at least two axis movement; a chamber housing configured enabling the applying of a pressure inside the chamber that is higher and/or lower than atmospheric pressure; a pressure regulator and a manifold each being fluidly coupled to the chamber for changing the pressure inside the chamber; a gas reservoir of high pressure, a regulator and piping to allow the high pressure gas; at least one vacuum pump; and a material dispensing system.

These common technical features are disclosed by US 2011/0180965 A1 Zhang, et al. (hereinafter 'Zhang'), in view of US 2009/0140445 A1 to Lu, et al. (hereinafter 'Lu'). Zhang discloses imprint lithography (fast nanoscale imprint lithography meeting the need by industrial for high throughput and overlay accuracy; paragraphs [0003], [0005]); holding a mold having a mold surface with nanostructures (mold holder 20 with mold 30 installed is loaded into chamber 10 and firmly attached to top plate of the chamber wall, where the mold has microscale or nanoscale features; figures 1, 2a-d; paragraphs [0003], [0018]); a substrate having a molding surface (substrate 32 with moldable (deformable) material 35 on its top surface (top surface of substrate) is held against chuck 23; figures 1, 2a-d; paragraphs [0017]- [0018]); a stage assembly having at least two axis movement (XYZ-motion stage assembly 21, leveler 22, chuck 23 (includes securing of the substrate), substrate 32 is moved up to contact deformed mold 30 at its center maximum deformation (deforming a portion of the mold); figures 1, 2a-d, 3; paragraphs [0017]-[0019], [0022]); a chamber housing configured enabling the applying of a pressure inside the chamber that is higher and/or lower than atmospheric pressure (chamber 10 that can achieve vacuum or pressure inside; figure 1; paragraph [0017]); a pressure regulator and a manifold each being fluidly coupled to the chamber for changing the pressure inside the chamber; a gas reservoir of high pressure, a regulator and piping to allow the high pressure gas; at least one vacuum pump (the chamber 10 is connected with pneumatic lines (piping) that independently control pumping or pressurizing of mold mini-chamber 16 and chamber volume 15, both, therefore can be pumping to vacuum (vacuum pump) and pressurized and a differential pressure between them can be established (regulator) when desired; figure 1; paragraph [0017]); and a material dispensing system (the moldable material 35 on substrate 32 could be a continuous film layer of imprinting resist spun on or a plurality of droplets of imprinting resist dispensed on to achieve desired imprinted patterns; figure 1; paragraph [0017]). Zhang does not disclose contact force sensors positioned for sensing the forces during imprint and separation. Lu discloses a contact force sensor positioned for sensing a contact force between the mold surface and the molding surface (imprint head 30 may also provide for contact force F between template 18 and substrate 12, comprising force sensors 74 (a contact force sensor) capable of measuring force F applied by imprint head 30 at different locations (positioned for sensing a contact force between the mold surface and the molding surface); figures 1, 3A-D, 7-8; paragraphs [0029], [0048]; claim 7). In order to have improved upon Zhang's high throughput and overlay accuracy (paragraph [0005]), it would have been obvious to one of ordinary skill in the art at the time of the invention to have applied Lu's contact force sensing system because, as Lu discloses, low contact force of template to substrate will prevent template damage (paragraph [0058]) while providing high throughput.

Since the common technical features are previously disclosed by Zhang, in view of Lu, these common features are not special and so Groups I-III lack unity.