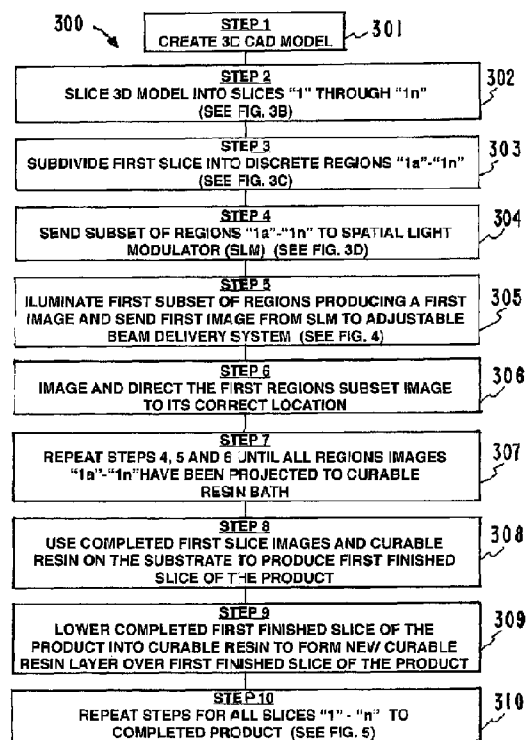




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[Continued on next page]

(54) Title: LARGE AREA PROJECTION MICRO STEREO LITHOGRAPHY

**FIG. 3A**

(57) Abstract: A large area projection micro stereolithography (LAPuSL) system uses an addressable spatial light modulator (SLM) in coordination with an optical scanning system to make very large stereolithographically produced objects. The SLM is imaged onto a photosensitive material with an optical system that has the ability to scan the image over a large area and speedily manufacture large scale complex three dimensional components with micro scale features.



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LARGE AREA PROJECTION MICRO STEREOLITHOGRAPHY

STATEMENT AS TO RIGHTS TO APPLICATIONS MADE UNDER
FEDERALLY SPONSORED RESEARCH AND DEVELOPMENT

[0001] The United States Government has rights in this application pursuant to Contract No. DE-AC52-07NA27344 between the United States Department of Energy and Lawrence Livermore National Security, LLC for the operation of Lawrence Livermore National Laboratory.

BACKGROUND

Field of Endeavor

[0002] The present application relates to additive manufacturing and more particularly to large area projection micro stereolithography.

State of Technology

[0003] This section provides background information related to the present disclosure which is not necessarily prior art.

[0004] United States Patent No. 4,575,330 to Charles W. Hull for apparatus for production of three-dimensional objects by stereolithography issued May 11, 1986 provides the state of technology information reproduced below.

[0005] It is common practice in the production of plastic parts and the like to first design such a part and then painstakingly produce a prototype of the part, all involving considerable time, effort and expense. The design is then reviewed and, oftentimes, the laborious process is again and again repeated until the design has been optimized. After design optimization, the next step is

production. Most production plastic parts are injection molded. Since the design time and tooling costs are very high, plastic parts are usually only practical in high volume production. While other processes are available for the production of plastic parts, including direct machine work, vacuum-forming and direct forming, such methods are typically only cost effective for short run production, and the parts produced are usually inferior in quality to molded parts.

[0006] In recent years, very sophisticated techniques have been developed for generating three-dimensional objects within a fluid medium which is selectively cured by beams of radiation brought to selective focus at prescribed intersection points within the three-dimensional volume of the fluid medium. Typical of such three-dimensional systems are those described in U.S. Pat. Nos. 4,041,476; 4,078,229; 4,238,840 and 4,288,861. All of these systems rely upon the buildup of synergistic energization at selected points deep within the fluid volume, to the exclusion of all other points in the fluid volume, using a variety of elaborate multibeam techniques. In this regard, the various approaches described in the prior art include the use of a pair of electromagnetic radiation beams directed to intersect at specified coordinates, wherein the various beams may be of the same or differing wavelengths, or where beams are used sequentially to intersect the same points rather than simultaneously, but in all cases only the beam intersection points are stimulated to sufficient energy levels to accomplish the necessary curing process for forming a three-dimensional object within the volume of the fluid medium. Unfortunately, however, such three-dimensional forming systems face a number of problems with regard to resolution and exposure control. The loss of radiation intensity and image forming resolution of the focused spots as the intersections move deeper into the fluid medium create rather obvious complex control situations. Absorption, diffusion, dispersion and

defraction all contribute to the difficulties of working deep within the fluid medium on any economical and reliable basis.

[0007] Yet there continues to be a long existing need in the design and production arts for the capability of rapidly and reliably moving from the design stage to the prototype stage and to ultimate production, particularly moving directly from computer designs for such plastic parts to virtually immediate prototypes and the facility for large scale production on an economical and automatic basis.

[0008] Accordingly, those concerned with the development and production of three-dimensional plastic objects and the like have long recognized the desirability for further improvement in more rapid, reliable, economical and automatic means which would facilitate quickly moving from a design stage to the prototype stage and to production, while avoiding the complicated focusing, alignment and exposure problems of the prior art three dimensional production systems.

[0009] United States Patent No. 6,200,646 to Douglas C. Neckers et al for method for forming polymeric patterns, relief images and colored polymeric bodies using digital light processing technology issued March 13, 2001 provides the state of technology information reproduced below.

The use of photopolymerizable resins to create patterns is known. One process for generating polymeric patterns requires making a mask either through photographic techniques on film or ionographic techniques on glass. The mask is placed between a radiation source such as a UV or visible lamp and the photopolymeric material (liquid, gel or solid) such that the desired light pattern

passes through the mask to generate a solid polymer in the desired pattern.

These mask techniques are used in photoresists as well as for making 3D objects.

[0010] United States Patent No. 7,088,432 to Xiang Zhang for dynamic mask projection stereo micro lithography issued August 8, 2006 provides the state of technology information reproduced below.

[0011] Micro-electro-mechanical systems (MEMS) devices have been found in many sensing applications such as airbag sensors, as well as chemical and biological sensors. The use of micro actuators is the key to making MEMS fully active, intelligent "micro-system" devices, capable of both sensing and actuating. Current IC-based micromachining processes, used to fabricate MEMS devices, have certain limitations in achieving the above goals. First, most of the IC-based micromachining processes cannot be used to fabricate complex 3D micro parts with high aspect ratios. Second, only a few semiconductors and other materials can be processed by the current IC-based micromachining for MEMS. Many other important engineering materials, such as smart ceramics, functional polymers, and metal alloys, can not be directly incorporated into MEMS through the conventional IC-based micromachining processes.

[0012] As an alternative, an x-ray LIGA (German Lithography, electroforming and molding) process was developed to fabricate microstructures with high aspect ratio. However, the x-ray LIGA process has not found a large number of industrial applications due to its poor industrial accessibility and operational cost. In addition, complex 3D structures can not be achieved by an LIGA process. A novel microfabrication process, the micro stereolithography (.mu.SL) was introduced to fabricate high aspect ratio and complex 3D microstructure by single beam scanning. [Ikuta, K., Ogata, T., and Kojima, S.,

1996, "Development of mass productive micro stereo lithography", Proc. IEEE MEMS'96, pp. 301 305.]

[0013] Sophisticated 3D parts can be made by scanning an UV beam on a liquid monomer resin, curing the resin into solid polymer layer by layer, and stacking together all layers with various contours.

[0014] Recently, liquid crystal display projection micro-stereolithography has been used by groups in Europe to project a layer image onto the photo-resist. However, due to the large pixel size and very low transmission in UV, the device's resolution is limited and contrast is poor. Macro scale stereo-lithography, on the other hand, has been around for more than 15 years, mainly with single beam scanning, and commercial applications in this area have also been established such as by 3D Systems Inc. Only recently, scientists have started to use digital light processing technology, for example, using a commercial digital micro-mirror display projector from Texas Instrument to do macro-scale stereo-lithography. However, they use mainly a commercial optical setup from Texas Instruments and focus on macro-scale fabrication for structure and automotive applications rapid prototyping.

[0015] The article "Ultralight, Ultrastiff Mechanical Metamaterials" by Xiaoyu Zheng et al in *Science*, Vol. 344, Issue 6190, June 20, 2014, pages 1373-1376 provides the state of technology information reproduced below.

[0016] We report a group of ultralight mechanical metamaterials that maintain a nearly linear scaling between stiffness and density spanning three orders of magnitude in density, over a variety of constituent materials. We use the term "mechanical metamaterials" to refer to materials with certain mechanical properties defined by their geometry rather than their composition.

The materials described here are highly ordered, nearly isotropic, and have high structural connectivity within stretch-dominated, face-centered cubic (fcc) architectures. The ultralow-density regime is accessed by fabricating microlattices with critical features ranging from ~20 mm down to ~40 nm. The densities of samples produced in this work ranged from 0.87 kg/m³ to 468 kg/m³, corresponding to 0.025% to 20% relative density.

[0017] A stretch-dominated unit cell structure, consisting of b struts and j frictionless joints and satisfying Maxwell's criterion, $M = b - 3j + 6 > 0$, is substantially more mechanically efficient—with a higher stiffness-to-weight ratio (defined as E/ρ)—than its bend-dominated counterpart. This is attributed to its struts carrying load under compression or tension rather than bending. A fundamental lattice building block of this type is the octet-truss unit cell (Fig. 1A), whose geometric configuration was proposed by Deshpande et al. The cell has a regular octahedron as its core, surrounded by eight regular tetrahedral distributed on its faces (fig. S1). All the strut elements have identical aspect ratios, with 12 solid rods or hollow tubes connected at each node. The cubic symmetry of the cell's fcc structure generates a material with nearly isotropic behavior. The relative density of such octet-truss unit cells can be approximated by $\rho = 26.64(d/L)^2$, where L and d are the length and diameter of each beam element. On the macroscale, under uniaxial compressive loading, the relative compressive stiffness and yield strength of these structures theoretically show linear scaling relationships: $E/E_s \propto (\rho/\rho_s)$ and $\sigma/\sigma_s \propto (\rho/\rho_s)$. A cubic lattice is readily constructed by periodic packing of the unit cell along its three principal directions (Fig. 1, B and C). Alternate orientations of the bulk lattice relative to the unit cell's principal axes can likewise be constructed (fig. S2), with the fundamental tessellation of space by the unit cell remaining the same.

[0018] To study how the loading direction and lattice orientation of an octet-truss lattice affects its E-r scaling relationship, we analyzed, fabricated, and tested them in a variety of orientations (figs. S1 to S5). In addition to these stretch-dominated lattices, as a point of comparison, a bend-dominated tetrakaidecahedron unit cell of the same size scale was generated and the corresponding cubic-symmetric foams (known as Kelvin foams) were fabricated with a variety of densities (Fig. 1, D to F).

[0019] The fabrication of these microlattices is enabled by projection microstereolithography, a layer-by-layer additive micromanufacturing process capable of fabricating arbitrary three-dimensional microscale structures. In contrast to other three-dimensional (3D) rapid prototyping methods such as 3D printing and ultraviolet (UV) projection waveguide systems (44), this type of fabrication technology is ideal for 3D lattices with high structural complexity and with feature sizes ranging from tens of micrometers to centimeters.

SUMMARY

[0020] Features and advantages of the disclosed apparatus, systems, and methods will become apparent from the following description. Applicant is providing this description, which includes drawings and examples of specific embodiments, to give a broad representation of the apparatus, systems, and methods. Various changes and modifications within the spirit and scope of the application will become apparent to those skilled in the art from this description and by practice of the apparatus, systems, and methods. The scope of the apparatus, systems, and methods is not intended to be limited to the particular forms disclosed and the application covers all modifications, equivalents, and

alternatives falling within the spirit and scope of the apparatus, systems, and methods as defined by the claims.

[0021] Applicant has developed a large area projection micro stereolithography (LAPuSL) system to speedily manufacture large scale complex three dimensional components with micro scale features. The LAPuSL apparatus, systems, and methods use an addressable spatial light modulator (SLM) in coordination with an optical scanning system to make very large stereolithographically produced objects. The SLM is imaged onto a photosensitive material with an optical system that has the ability to direct the image of the SLM over a large area thereby producing a build plane that is much larger than one individual image of the SLM. The pattern change on the SLM is coordinated with where the optical system is directing the image of the SLM. The pattern is updated as the image is moved to a new position via the beam directing optics to effectively create a continuous large image in the photosensitive material. This scanned image is much larger than a single image of the SLM. This enables small feature sizes to be produced over a large area. A single LAPuSL projection and scanning optical system covers a significant area. Individual LAPuSL systems can then be combined together so that their build planes optically overlap to produce even larger stereolithographically fabricated items. The size of the optically projected build plane produced by one LAPuSL system is large enough so that a second LAPuSL system can be brought in next to the first so that their build planes overlap. In this way, the coordination with the SLM pattern change, the scanning optics moving the image, and then two or more LAPuSL's acting as subsystems allow the build plane area to be indefinitely increased which then enable larger size parts to be produced.

[0022] The Large Area Projection Micro Stereolithography (LAPuSL) apparatus, systems, and methods can be used to produce large items (hundreds of millimeters in size) with small highly detailed features (10s of microns). Parts produced can be used as master patterns for injection molding, thermoforming, blow molding, and various metal casting processes. The Large Area Projection Micro Stereolithography (LAPuSL) apparatus, systems, and methods can be used to quickly make parts with great complexity and detail. This increased speed and the ability to make parts with small features over a large size distinguishes the LAPuSL apparatus, systems, and methods from other techniques. Rapidly prototyping objects allows the production of customized products for individual customers.

[0023] The apparatus, systems, and methods are susceptible to modifications and alternative forms. Specific embodiments are shown by way of example. It is to be understood that the apparatus, systems, and methods are not limited to the particular forms disclosed. The apparatus, systems, and methods cover all modifications, equivalents, and alternatives falling within the spirit and scope of the application as defined by the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The accompanying drawings, which are incorporated into and constitute a part of the specification, illustrate specific embodiments of the apparatus, systems, and methods and, together with the general description given above, and the detailed description of the specific embodiments, serve to explain the principles of the apparatus, systems, and methods. It is to be understood that the accompanying drawings are not to scale and are not to be used to define the precise proportions of the elements shown in the drawings.

[0025] FIG. 1 is a flow chart that illustrates a Prior Art dynamic mask projection stereo micro lithography system.

[0026] FIG. 2 provides additional information about the Prior Art system illustrated in FIG. 1.

[0027] FIG. 3A is a flow chart illustrating one embodiment of the disclosed large area projection micro stereolithography (LAPuSL) apparatus, systems, and methods.

[0028] FIGS. 3B-3E provide additional details of individual steps of the flow chart of FIG. 3.

[0029] FIG. 4 is a schematic depiction illustrating the adjustable beam delivery system projecting and scanning the first subset of regions image.

[0030] FIG. 5 is a schematic depiction illustrating repeating the steps for all slices to complete the product.

[0031] FIGS. 6A-6I illustrate the overlapping of the projection images.

[0032] FIG. 7 is a schematic depiction illustrating ganging multiple large area projection micro stereolithography systems together to produce an ultra large area projection micro stereolithography system.

[0033] FIGS. 8A and 8B illustrate an object produced by the disclosed LAPuSL system.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[0034] Referring to the drawings, to the following detailed description, and to incorporated materials, detailed information about the apparatus, systems, and methods is provided including the description of specific embodiments. The detailed description serves to explain the principles of the apparatus, systems, and methods. The apparatus, systems, and methods are susceptible to

modifications and alternative forms. The application is not limited to the particular forms disclosed. The application covers all modifications, equivalents, and alternatives falling within the spirit and scope of the apparatus, systems, and methods as defined by the claims.

Prior Art

[0035] Referring to the drawing and in particular to FIGS. 1 and 2, a Prior Art dynamic mask projection stereo micro lithography system is illustrated. The Prior Art dynamic mask projection stereo micro lithography system is illustrated and described in U.S. Patent No. 7,088,432 to Xiang Zhang, assigned to the Regents of the University of California, issued August 8, 2006 for dynamic mask projection stereo micro lithography. The disclosure of U.S. Patent No. 7,088,432 is incorporated herein by this reference. FIG. 1 is a flow chart and FIG. 2 is a schematic depiction of the Prior Art dynamic mask projection stereo micro lithography system.

[0036] Referring to FIG. 1, a flow chart that illustrates a series of steps used in the Prior Art dynamic mask projection stereo micro lithography system. The flow chart is designated generally by the reference numeral 8. The steps of the flow chart 8 are described below.

Step 1 - 3D SOLID MODEL DESIGNED (Reference Numeral 1) – In step 1 a 3D solid model is designed by any suitable method, e.g., by bit mapping or by computer aided design (CAD) software at a PC/controller.

Step 2 - CAD MODEL ELECTRONICALLY SLICED INTO SERIES OF 2D LAYERS (Reference Numeral 2) – In step 2 the CAD model is electronically sliced into series of 2-dimensional data files, i.e., 2D layers, each defining a planar cross section through the device to be constructed, and which may be individually stored.

Step 3 - EACH 2D LAYER DATA SENT TO A DMD CHIP (Reference Numeral 3) - In step 3 Each 2D layer data is used to control a DMD display via the PC. A beam shutter, which may be an electronic or mechanical shutter, or any other type, is controlled by the PC and in turn controls a light beam which then travels through a beam homogenizer and a narrow band filter, impinging on a mirror of a prism to reflect therefrom to a DMD chip.

Step 4 - ACTINIC WAVELENGTHS OF EACH 2-D LAYER IS SENT FROM DMD CHIP TO A BEAM CONDITIONING SYSTEM (Reference Numeral 4) - In step 4 actinic wavelengths of the image pass a beam splitter and is then reflected by a mirror to a beam conditioning system which consists of appropriate apertures and lenses, and then to and through a reduction projection system (which is available commercially from lithography tool companies).

Step 5 - PROJECTED IMAGE IS FOCUSED AT PHOTORESIST/PHOTO-CURABLE COMPOSITION TO EXPOSE THE LAYER TO CURE IT (Reference Numeral 5) - In step 5, the projected image is in focus at a particular plane in a photoresist/photo-curable composition in a supporting container so that the actinic light preferentially exposes the desired layer to cure it.

Step 6 - AFTER ONE LAYER IS CURED THE COMPOSITION UNDERGOES RELATIVE MOVEMENT BY A Z ELEVATOR STAGE THAT CARRIES THE CURED LAYER DOWN AND A SECOND LAYER OF FRESH PHOTORESIST IS FORMED TO BE EXPOSED (Reference Numeral 6) - In step 6 after one layer is cured, or at least partially cured sufficient to retain its integrity, the composition and focusing optics undergo relative movement. In a particular embodiment of the invention, a computer controlled z elevator stage that carries the cured layer moves down and a second layer of fresh photoresist is formed to be exposed.

Step 7 - THE LAYER-BY-LAYER PROCESS CONTINUES UNTIL A 3D OBJECT IS FABRICATED (Reference Numeral 7) - In step 7 the layer-by-layer process continues until a 3D object is fabricated. The elevator motion, beam on/off, and micro-mirror display are synchronized and controlled by the computer.

[0037] Referring to FIG. 2, additional information is provided about the Prior Art dynamic mask projection stereo micro lithography system illustrated in the flow chart 8 shown in FIG. 1. FIG. 2 is a schematic depiction of the Prior Art dynamic mask projection stereo micro lithography system. The Prior Art dynamic mask projection stereo micro lithography system chart is designated generally by the reference numeral 9.

[0038] In FIG. 2, a 3D solid model is designed by any suitable method, e.g., by bit mapping or by computer aided design (CAD) software at a PC/controller 10. The CAD model is then electronically sliced into series of 2-dimensional data files, i.e., 2D layers, each defining a planar cross section through the device to be constructed, and which may be individually stored. Each 2D layer data is used to control a DMD display via the PC 10. A beam shutter 12, which may be an electronic or mechanical shutter, or any other type, is controlled by the PC 10 and in turn controls a light beam 14 which then travels through a beam homogenizer 16 and a narrow band filter 18, impinging on the mirror 20 of a prism 22 to reflect therefrom to a DMD chip 24.

[0039] The DMD chip 24 is formed with more than a half million mirrors, each individually addressed electronically and deflecting a homogenized light beam back through the prism 22. Actinic wavelengths of the image pass a beam splitter 38 and is then reflected by a mirror 28 to a beam conditioning system 30 which consists of appropriate apertures and lenses, and then to and through a

reduction projection system 32 (which is available commercially from lithography tool companies). The projected image is in focus at a particular plane in a photoresist/photo-curable composition 34 in a supporting container 36 so that the actinic light preferentially exposes the desired layer to cure it.

[0040] A source of actinic light 11 may be any number of available sources, including, but not limited to metal halide, tungsten halogen and xenon lamps or lasers, e.g., an ultraviolet light laser. A beam splitter 38 is used to assist monitoring/alignment for the fabrication.

[0041] After one layer is cured, or at least partially cured sufficient to retain its integrity, the composition and focusing optics undergo relative movement. In a particular embodiment of the invention, a computer controlled z elevator stage 42 that carries the cured layer moves down and a second layer of fresh photoresist is formed to be exposed. The layer-by-layer process continues until a 3D object is fabricated. The elevator motion, beam on/off, and micro-mirror display are synchronized and controlled by the computer 10.

LAPuSL

[0042] Applicant has developed a large area projection micro stereolithography (LAPuSL) system capable of speedily manufacturing large scale complex three dimensional components with micro scale features. The LAPuSL has the ability to make objects which can be tens to hundreds of millimeters in overall size, with features on the object that can be microns in size, and do this quickly, simply, and reliably. Applicant's large area projection micro stereolithography system (LAPuSL) produces a product by creating a three dimensional computer aided design model of the product, generating a multiplicity of two-dimensional computer generated slices of the product from

the three dimensional computer aided design model of the product, subdividing the computer generated slices of the product into discrete regions, and producing images of the discrete regions and sequentially sending the images to a curable resin to complete the product.

[0043] Referring to FIGS. 3A through 3E and FIGS. 4 and 5, a flow chart and a series of schematic depictions illustrate one embodiment of the disclosed large area projection micro stereolithography (LAPuSL) apparatus, systems, and methods.

[0044] FIG. 3A is a flow chart that illustrates one embodiment of the disclosed large area projection micro stereolithography (LAPuSL) apparatus, systems, and methods. This embodiment is designated generally by the reference numeral 300. The steps in FIG. 3A are described below.

Step 1 – CREATE 3-D CAD MODEL (Reference Numeral 301) – In step 1 a 3D CAD model is created. The 3D CAD model is designed using computer aided design (CAD) software.

Step 2 - SLICE 3D MODEL INTO SLICES (Reference Numeral 302) – In step 2 the 3-D CAD model is virtually via software sliced into a series of 2-dimensional data files (“1” through “n” files). The files are 2D layers, each defining a planar cross section through the device to be constructed, and which may be individually stored. The 2D layers defining a planar cross section through the device to be constructed are further illustrated in FIG. 3B.

Step 3 - SUBDIVIDE FIRST SLICE INTO DISCRETE REGIONS (Reference Numeral 303) – In Step 3 the 1st 2-D slice is subdivided into discrete regions virtually via software and individually stored. The 1st 2-D slice subdivided into discrete regions is further illustrated in FIG. 3C.

Step 4 - SEND A SINGLE REGION TO A SPATIAL LIGHT MODULATOR (SLM) (Reference Numeral 304) – In step 4 a single subset of regions of the 1st 2-D slice is sent to a spatial light modulator. The subset of the 1st 2-D slice being sent to a spatial light modulator is then reproduced on the face or working surface of the SLM and is further illustrated in FIG. 3D.

Step 5 – ILLUMINATE THE SLM WHICH HAS REPRODUCED THE FIRST REGIONS SUBSET TO PRODUCE A FIRST REGIONS SUBSET IMAGE AND SEND FIRST REGIONS SUBSET IMAGE TO AN ADJUSTABLE BEAM DELIVERY SYSTEM (Reference Numeral 305) – In step 5 a light source illuminates the SLM working surface which has reproduced the first subset of regions and the image is sent to an adjustable beam delivery system. The illumination of the first regions subset image and the projection/scanning of the first regions subset image are further illustrated in FIG. 4.

Step 6 – IMAGE AND DIRECT THE FIRST REGIONS SUBSET IMAGE TO ITS CORRECT LOCATION (Reference Numeral 306) – In step 6 the adjustable beam delivery system directs and projects the first regions subset image to its correct location.

Step 7 - REPEATE STEPS 4, 5 AND 6 UNTIL ALL THE REGIONS HAVE BEEN PROJECTED TO THE CURABLE RESIN BATH (Reference Numeral 307) – In step 6 the steps 4, 5 and 6 are repeated until all of the regions have been projected to the curable resin bath.

Step 8 - USE COMPLETED FIRST SLICE IMAGES AND CURABLE RESIN ON THE SUBSTRATE TO PRODUCE A FIRST FINISHED SLICE OF THE PRODUCT (Reference Numeral 308) - In step 8 the completed first slice image in the curable resin on the substrate provides a first finished slice of the product.

Step 9 - LOWER COMPLETED FIRST FINISHED SLICE OF THE PRODUCT INTO THE CURABLE RESIN BATH TO FORM A NEW CURABLE RESIN LAYER OVER FIRST FINISHED SLICE OF THE PRODUCT (Reference Numeral 309) – In step 9 the first finished slice of the product is lowered into the curable resin bath. A new curable resin layer is formed over the first finished slice of the product and the new curable resin layer is used to complete the next slice.

Step 10 - REPEAT STEPS FOR ALL SLICES TO COMPLETED PRODUCT (Reference Numeral 310) – In step 10 the steps for all slices are repeated in order to complete the product. The steps used in completing the product are further illustrated in FIG. 5.

One Slice of the 3D CAD Model

[0045] Referring to FIG. 3B, a schematic depiction illustrates one slice of the 3D CAD model that was created using computer aided design (CAD) software. The slice is designated generally by the reference numeral 302b. The 3-D CAD model was electronically sliced into a series of 2-dimensional data files (“1” through “n” files). Each of the files is a 2D layer defining a planar cross section through the device to be constructed. The 2D layer, slice 302b, defines a planar cross section through the device to be constructed.

Subdividing Slice Into Discrete Regions

[0046] Referring to FIG. 3C, a schematic depiction illustrates the subdividing of the slice 302b into discrete regions. The regions are identified as regions “1a” through “1l.”

Subset of Regions Sent to Spatial Light Modulator (SLM)

[0047] Referring to FIG. 3D, a schematic depiction illustrates the sending of a subset of regions to a spatial light modulator (SLM). As illustrated in FIG. 3D, a subset of regions of slice 302b is sent to the SLM.

Completed First Slice Image in Curable Resin

[0048] Referring to FIG. 3E, a schematic depiction illustrates that after the adjustable beam delivery system images all of the first subset of regions image 302b onto their correct and respective locations on the build plane, the completed first slice image in curable resin has now produced a first finished slice of the product.

Beam Delivery System Images to Coordinated and Controlled Locations

[0049] Referring to FIG. 4 a schematic depiction illustrates the adjustable beam delivery system projecting the first subset of regions image to its correct location. The projecting and imaging is designated generally by the reference numeral 400. FIG. 4 shows the structural elements of the system 400 identified and described below.

Reference numeral 402 - large area projection micro stereolithography (LAPuSL) system.

Reference numeral 402 – LAPuSL unit.

Reference numeral 404 – CPU.

Reference numeral 406 – SLM system.

Reference numeral 408 – optics system.

Reference numeral 410 – beam directing optics (or directing mirrors or steering mirrors).

Reference numeral 412 – optics system.

Reference numeral 414 – build plane.

Reference numeral 416 – dashed line box.

Reference numeral 418 – subset of regions.

Reference numeral 420 – region 1a.

Reference numeral 422 – region 1a after processing by the LAPuSL unit.

[0050] The structural elements of the system 400 having been identified and described, the operation of the system 400 will now be considered.

The processing of the items 418 and 420 enclosed in the dashed line box 416 takes place within the CPU. A 3-D CAD system creates a model which is sliced into layers 1-n. The first layer 418 is then divided into regions 1a-1l. Here we show 12 regions for clarity of illustration. The layer can be divided into 1a-1n regions. Region 1a is here labeled 420 and is shown cross hatched. Each of the regions is then sent to the SLM system 406 and subsequently thru 408, 410, and 412 to be projected to their appropriate locations as image 422 on the build plane 414.

Repeat Steps for All Slices to Complete Product

[0051] Referring to FIG. 5 a schematic depiction illustrates repeating the steps for all slices to complete the product. The schematic depiction is designated generally by the reference numeral 500.

[0052] In steps 6, 7, and 8 illustrated in FIG. 3A, the first image was sent to an adjustable delivery system and the steps were repeated until all of the discrete regions were projected to the curable resin bath. The completed first slice image was used to produce a first finished slice of the product. FIG. 5 illustrates the

additional procedures for completing the product. Referring again to FIG. 5, the structural elements of the system 500 are identified and described below.

Reference numeral 502 – container.

Reference numeral 504 – curable polymer bath.

Reference numeral 506 – substrate.

Reference numeral 508 – elevator system.

Reference numeral 510 – completed layers.

Reference numeral 512 – surface of polymer bath 504 (Also designated as the build plane 514)

Reference numeral 514 – build plane.

Reference numeral 516 – LAPuSL system.

Reference numeral 518 – projected image beam.

Reference numeral 520 – arrow showing beam movement.

[0053] The various structural components and steps of the system 500 having been identified and described, the operation of the system 500 will now be considered. The LAPuSL system 516 projects the image beam 518 onto the build plane 514 to cure the curable monomer material 504 and produce individual layers. The arrow 520 illustrates movement of the image beam 518. The elevator system 508 sequentially lowers the finished layers into the curable monomer bath 504 to allow a fresh layer of curable monomer material 504 to coat the previous layer. The steps for all slices are repeated to complete the product.

LAPuSL System's Overlapping Projection Images

[0054] Applicant has discovered that a superior product can be produced by overlapping the projection images. As previously illustrated in FIGS. 4 and 5 the adjustable beam delivery system projects the subsets of regions images to

their correct location relative to the substrate and the curable polymer resin. Applicant discovered that without overlapping, the product produced would sometimes have lines between the locations of adjacent projection images. FIGS. 6A-6I illustrate the overlapping of the projection images. The overlapping of the projection images solves the potential problem of lines in the product between the locations of adjacent projection images. The various structural components and steps of the overlapping of the projection images are identified and described below.

Reference numeral 600 – Substrate.

Reference numeral 602 – Area that represent a finished layer.

Reference numeral 604 – First Projected Image.

Reference numeral 606 – Overlap (Unspecified Dimension).

Reference numeral 608 – Dark Region.

Reference numeral 610 – Second Projected Image.

Reference numeral 612 – Third Projected Image.

Reference numeral 614 – Forth Projected Image.

Reference numeral 616 – Fifth Projected Image.

Reference numeral 618 – Sixth Projected Image.

Reference numeral 620 – Next to Final Projected Image.

Reference numeral 622 – Dark Region.

Reference numeral 624 – Dark Region.

Reference numeral 626 – Final Projected Image.

[0055] The various structural components and steps of the overlapping of the projection images having been identified and described, the operation of the system will now be considered. FIGS. 6A-6I illustrate a multi-step depiction of

the projected images overlapping. In FIGS. 6A through 6I Applicant will illustrate and describe a system of overlapping projected images.

[0056] Shown in FIG. 6A is a substrate 600 and an area 602 in dashed lines that represents a finished layer of overlapping projected images. FIG. 6B shows a first projected image 604 overlapping the area 602 by some unspecified dimension 606. Also shown is an area will not be part of the finished layer and is designated as dark region 608 in FIG. 6C.

[0057] FIG. 6C shows a second projected image 610 that overlaps the first projected image 604 by the same amount of overlap 606. Also shown is the smaller dark region 608.

[0058] FIG. 6D shows a third projected image 612 that again overlaps the previously projected image 610 by the same overlap 606. This projected image 612 and succeeding images are illustrated as 614 on FIG. 6E; 616 on FIG. 6F; 618 on FIG. 6G; 620 on FIG. 6H; and 626 on FIG. 6I.

[0059] FIG. 6H shows the next to final projected image 620 overlapping area 602 by the overlapping dimension 606. A dark region 622 is formed during this image projection.

[0060] FIG. 6I shows that the final projected image 626 overlaps again by 606 forming a dark region 624. The foregoing steps provide a completed layer.

[0061] Applicant's LAPuSL system provides a large area projection micro stereolithography system for producing the final product by the previously described overlapping the projection images. A three dimensional computer aided design model of the product is first created. Then a multiplicity of two-dimensional computer generated slices of the product are generate from the three dimensional computer aided design model of the product. The slices including a first slice, a second slice, and additional slices. The first slice is

subdivided into discrete regions including a first subset of regions, a second subset of regions, and additional subsets of regions. The first subset of regions is sent to a spatial light modulator. The first subset of regions is illuminated to produce a first subset of regions image. The first subset of regions image is sent to an adjustable beam delivery system. The adjustable beam delivery system projects and scans the first subset of regions image to a curable resin. The steps are repeated for the second subset of regions and the additional subsets of regions to complete a first slice of the product. Applicant's LAPuSL system utilizes the above described overlapping projected images in creating the first slice of the product. All of steps are repeated for the second slice and the additional slices to complete the final product.

Ganging Multiple Systems

[0062] The LAPuSL system described above can be improved by ganging multiple large area projection micro stereolithography systems together to produce an ultra large area projection micro stereolithography system. FIG. 7 is a schematic depiction illustrating ganging multiple large area projection micro stereolithography systems together to produce an ultra large area projection micro stereolithography system. The schematic depiction is designated generally by the reference numeral 700. The structural elements of the system 700 are identified and described below.

Reference numeral 702 – first LAPuSL system.

Reference numeral 704 – second LAPuSL system.

Reference numeral 706 – third LAPuSL system.

Reference numeral 708 – fourth LAPuSL system.

Reference numeral 710 – container.

Reference numeral 712 – elevator system.

Reference numeral 714 – substrate.

Reference numeral 716 – curable polymer bath.

Reference numeral 718 – completed layers.

Reference numeral 720 – surface of polymer bath.

Reference numeral 722 – build plane.

Reference numeral 724 – projected image beams.

[0063] The various structural components and steps of the system 700 having been identified and described, the operation of the system 700 will now be considered. FIG. 7 is a schematic depiction illustrating ganging multiple large area projection micro stereolithography systems together to produce an ultra large area projection micro stereolithography system.

[0064] As illustrated in FIG. 7, a first LAPuSL system 702, a second LAPuSL system 704, a third LAPuSL system 706 and a fourth LAPuSL system 708 are positioned above a container 710 containing a curable polymer bath 716. An elevator system 712 moves the layers into and out of the curable polymer bath 716.

[0065] The system 700 for ganging multiple large area projection micro stereolithography systems together to produce an ultra large area projection micro stereolithography system utilizes the previously describe individual system. The system 700 projects multiple build areas 724 that overlap the image onto the build plane 720, 722 to cure the curable polymer material 716, 722 and produce individual layers 718. The elevator system 712 sequentially lowers the finished layers into the curable polymer bath 716 to allow a fresh layer of curable polymer material 722 to coat the previous layer. The steps for all slices are repeated to complete the product.

[0066] The LAPuSL can then be combined with other LAPuSL systems to make even larger overall objects. This combining of more than one LAPuSL together is very powerful and enables essentially limitless increase in the size of the objects which can be produced. To explain how this is done; X is defined as the diameter of the area which can be scanned by one LAPuSL system, the physical size of the scan lens and scanning optics is made to be smaller than X. So with the scan area large enough and the body of the LAPuSL small enough two or more LAPuSL's can be placed together so the area they scan overlaps each other. The images being written by the two or more systems are coordinated together to utilize this now even larger overall area. With two LAPuSL systems coordinated together the area covered is $2X$ minus the overlap area, if three systems areas are combined they can cover $3X$ minus the overlap area and so on. In this way larger and larger objects can be fabricated.

Object Produced by the Disclosed LAPuSL System

[0067] Referring now to FIGS. 8A and 8B, an object produced by the disclosed LAPuSL system is illustrated. The object is designated generally by the reference numeral 800. As illustrated in FIG. 8A, the object 800 can be tens to hundreds of millimeters in overall size with portions that are microns in size. An area 802 of the object 800 is shown enlarged in FIG. 8B. The area 802 shows that portions can be microns in size. The disclosed LAPuSL system has the ability to make objects which can be tens to hundreds of millimeters in overall size with features on the object that can be microns in size. There is no Prior Art system that can produce such objects practically or efficiently.

Metal or Ceramic Products

[0068] The disclosed apparatus and methods also provide a large area projection micro stereolithography system for producing a metal or ceramic product. The adjustable beam delivery system projects and scans the layer images to a curable resin containing metal or ceramic particles producing an object with a base polymer and metal or ceramic particles dispersed throughout the object. The base polymer is subsequently removed by thermal decomposition leaving behind the metal or ceramic product. This is further described in the article "Ultralight, Ultrastiff Mechanical Metamaterials" by Xiaoyu Zheng et al in *Science*, Vol. 344, Issue 6190, June 20, 2014, pages 1373-1376; which is incorporated herein by this reference.

[0069] Although the description above contains many details and specifics, these should not be construed as limiting the scope of the application but as merely providing illustrations of some of the presently preferred embodiments of the apparatus, systems, and methods. Other implementations, enhancements and variations can be made based on what is described and illustrated in this patent document. The features of the embodiments described herein may be combined in all possible combinations of methods, apparatus, modules, systems, and computer program products. Certain features that are described in this patent document in the context of separate embodiments can also be implemented in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiment can also be implemented in multiple embodiments separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features

from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination. Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. Moreover, the separation of various system components in the embodiments described above should not be understood as requiring such separation in all embodiments.

[0070] Therefore, it will be appreciated that the scope of the present application fully encompasses other embodiments which may become obvious to those skilled in the art. In the claims, reference to an element in the singular is not intended to mean "one and only one" unless explicitly so stated, but rather "one or more." All structural and functional equivalents to the elements of the above-described preferred embodiment that are known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the present claims. Moreover, it is not necessary for a device to address each and every problem sought to be solved by the present apparatus, systems, and methods, for it to be encompassed by the present claims.

Furthermore, no element or component in the present disclosure is intended to be dedicated to the public regardless of whether the element or component is explicitly recited in the claims. No claim element herein is to be construed under the provisions of 35 U.S.C. 112, sixth paragraph, unless the element is expressly recited using the phrase "means for."

[0071] While the apparatus, systems, and methods may be susceptible to various modifications and alternative forms, specific embodiments have been

shown by way of example in the drawings and have been described in detail herein. However, it should be understood that the application is not intended to be limited to the particular forms disclosed. Rather, the application is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the application as defined by the following appended claims.

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THE CLAIMS ARE:

Claim 1. A large area projection micro stereolithography method for producing a product, comprising the steps of:

create a three dimensional computer aided design model of the product,
generate a multiplicity of two-dimensional computer generated slices of the product from said three dimensional computer aided design model of the product,

subdivide said computer generated slices of the product into discrete regions,

produce images of said discrete regions and sequentially send said images to a curable resin to complete the product.

Claim 2. The large area projection micro stereolithography method for producing a product of claim 1 wherein said step of producing images of said discrete regions and sequentially sending said images to a curable resin includes sending said images to a curable resin so that said images overlap.

Claim 3. The large area projection micro stereolithography method for producing a product of claim 1 wherein said step of producing images of said discrete regions and sequentially sending said images to a curable resin includes

the step of projecting images of said discrete regions and sequentially sending said images to a substrate in said curable resin to form a layer of the product and

wherein said step of producing images of said discrete regions and sequentially send said images to a curable resin includes the additional steps of projecting the remaining images of said discrete regions and sequentially

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sending said remaining images to said layer in said curable resin of the product to complete the product.

Claim 4. The large area projection micro stereolithography method for producing a product of claim 1 further comprising the steps of ganging additional large area projection micro stereolithography methods to complete the product.

Claim 5. A large area projection micro stereolithography method for producing a product, comprising the steps of:

- create a three dimensional computer aided design model of the product;
- generate a multiplicity of two-dimensional computer generated slices of the product from said three dimensional computer aided design model of the product including a first slice, a second slice, and additional slices;

- subdivide said first slice into discrete regions including a first subset of regions, a second subset of regions, and additional subsets of regions;

- send said first subset of regions to a spatial light modulator;

- illuminate said first subset of regions to produce a first subset of regions image;

- send said first subset of regions image to an adjustable beam delivery system;

- use said adjustable beam delivery system to project and scan said first subset of regions image to a curable resin;

- repeat the above steps for said second subset of regions and said additional subsets of regions to complete said first slice of the product; and

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repeat the above steps for said second slice and said additional slices to complete the product.

Claim 6. The large area projection micro stereolithography method of claim 5 wherein said steps of sending said first, second, and additional subsets of regions to said spatial light modulator comprises sending said first, second, and additional subsets of regions to galvanometer scanning mirrors.

Claim 7. The large area projection micro stereolithography method of claim 5 wherein said steps of sending said first, second, and additional subsets of regions to said spatial light modulator comprises sending said first, second, and additional subsets of regions to polygonal mirror beam scanning optics.

Claim 8. The large area projection micro stereolithography method of claim 5 wherein said steps of sending said first, second, and additional subsets of regions to said spatial light modulator comprises sending said first, second, and additional subsets of regions to a motorized mirror mounts beam scanning optics.

Claim 9. The large area projection micro stereolithography method of claim 5 wherein said steps of sending said first, second, and additional subsets of regions to said spatial light modulator comprises sending said first, second, and additional subsets of regions to a rotating prisms beam scanning optics.

Claim 10. The large area projection micro stereolithography method of claim 5 wherein said step of sending said first, second, and additional subsets of

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regions images to an adjustable beam delivery system comprises sending said first, second, and additional subsets of regions images to an adjustable beam delivery system that includes a flat field scan lens.

Claim 11. The large area projection micro stereolithography method of claim 5 wherein said step of repeating the above steps for said second subset of regions and said additional subsets of regions comprises overlapping said first subset of regions image, said second subset of regions image, and said additional subsets of regions images.

Claim 12. The large area projection micro stereolithography method of claim 5 further comprising the step of ganging an additional first LAPuSL system, an additional second LAPuSL system, and an additional LAPuSL systems together to complete the product.

Claim 13. The large area projection micro stereolithography method of claim 5 wherein said step of using said adjustable beam delivery system to project and scan said first subset of regions image to a curable resin comprises using said adjustable beam delivery system to project and scan said first subset of regions image to a curable resin with dispersed metal particles producing a product having resin with dispersed metal particles and further comprising the step of removing the resin from said product having resin with dispersed metal particles by thermal decomposition producing a metal product.

Claim 14. The large area projection micro stereolithography method of claim 5 wherein said step of using said adjustable beam delivery system to

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project and scan said first subset of regions image to a curable resin comprises using said adjustable beam delivery system to project and scan said first subset of regions image to a curable resin with dispersed ceramic particles producing a product having resin with dispersed ceramic particles and further comprising the step of removing the resin from said product having resin with dispersed ceramic particles by thermal decomposition producing a ceramic product.

Claim 15. The large area projection micro stereolithography method of claim 5 wherein said step of using said adjustable beam delivery system to project and scan said first subset of regions image to a curable resin comprises using said adjustable beam delivery system to project and scan said first subset of regions image to a curable resin with dispersed ceramic particles producing a product having resin with dispersed metal and ceramic particles and further comprising the step of removing the resin from said product having resin with dispersed metal and ceramic particles by thermal decomposition producing a metal and ceramic product.

Claim 16. A large area projection micro stereolithography apparatus for producing a product comprising:

means for creating a three dimensional computer aided design model of the product;

means for generating a multiplicity of two-dimensional computer generated slices of the product from said three dimensional computer aided design model of the product including a first slice, a second slice, and additional slices;

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means for subdividing said first slice into discrete regions including a first subset of regions, a second subset of regions, and additional subsets of regions;

means for sending said subset of regions to a spatial light modulator;

means for illuminating said subset of regions to produce a first subset of regions image;

means for sending subset of regions image to an adjustable beam delivery system;

means for using said adjustable beam delivery system to project and scan said first subset of regions image to a curable resin;

means for repeating the above steps for said second subset of regions and said additional subsets of regions to complete said first slice of the product; and

means for repeating the above steps for said second slice and said additional slices to complete the product.

Claim 17. A large area projection micro stereolithography apparatus for producing a product comprising:

a computer system adapted to create a three dimensional model of the product;

said computer system adapted to generate a multiplicity of two-dimensional computer generated slices of the product from said three dimensional model of the product including a first slice, a second slice, and additional slices;

said computer system adapted to subdivide said first slice into subsets of regions including a first subset of regions, a second subset of regions, and additional subsets of regions;

a spatial light modulator;

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a system that sends said subsets of regions from said computer system to said spatial light modulator;

said spatial light modulator adapted to illuminate said first subset of regions to produce a first subset of regions image, to illuminate said second subset of regions to produce a second subset of regions image, and to illuminate said additional subsets of regions to produce additional subsets of regions images;

an adjustable beam delivery system;

a system that sends said first subset of regions image, said second subset of regions image, and said additional subset of regions images from said spatial light modulator to said adjustable beam delivery system;

a curable resin;

said adjustable beam delivery system adapted to project and scan said first subset of regions image to said curable resin;

said adjustable beam delivery system adapted to repeat the above steps for said second subset of regions image and said additional subsets of regions images to complete said first slice of the product; and

said adjustable beam delivery system adapted to repeat the above steps for said second slice and said additional slices to complete the product.

Claim 18. The large area projection micro stereolithography apparatus of claim 17 wherein said spatial light modulator is a digital micromirror device.

Claim 19. The large area projection micro stereolithography apparatus of claim 17 wherein said spatial light modulator is a liquid crystal on silicon device.

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Claim 20. The large area projection micro stereolithography apparatus of claim 17 wherein said adjustable beam delivery system includes a flat field scan lens.

Claim 21. The large area projection micro stereolithography apparatus of claim 17 wherein said adjustable beam delivery system is adapted to project and scan said first subset of regions image to said curable resin, is adapted to project and scan said second subset of regions image to said curable resin, and is adapted to project and scan said additional subsets of regions image to said curable resin and overlap said first subset of regions image, said second subset of regions image, and said additional subsets of regions images.

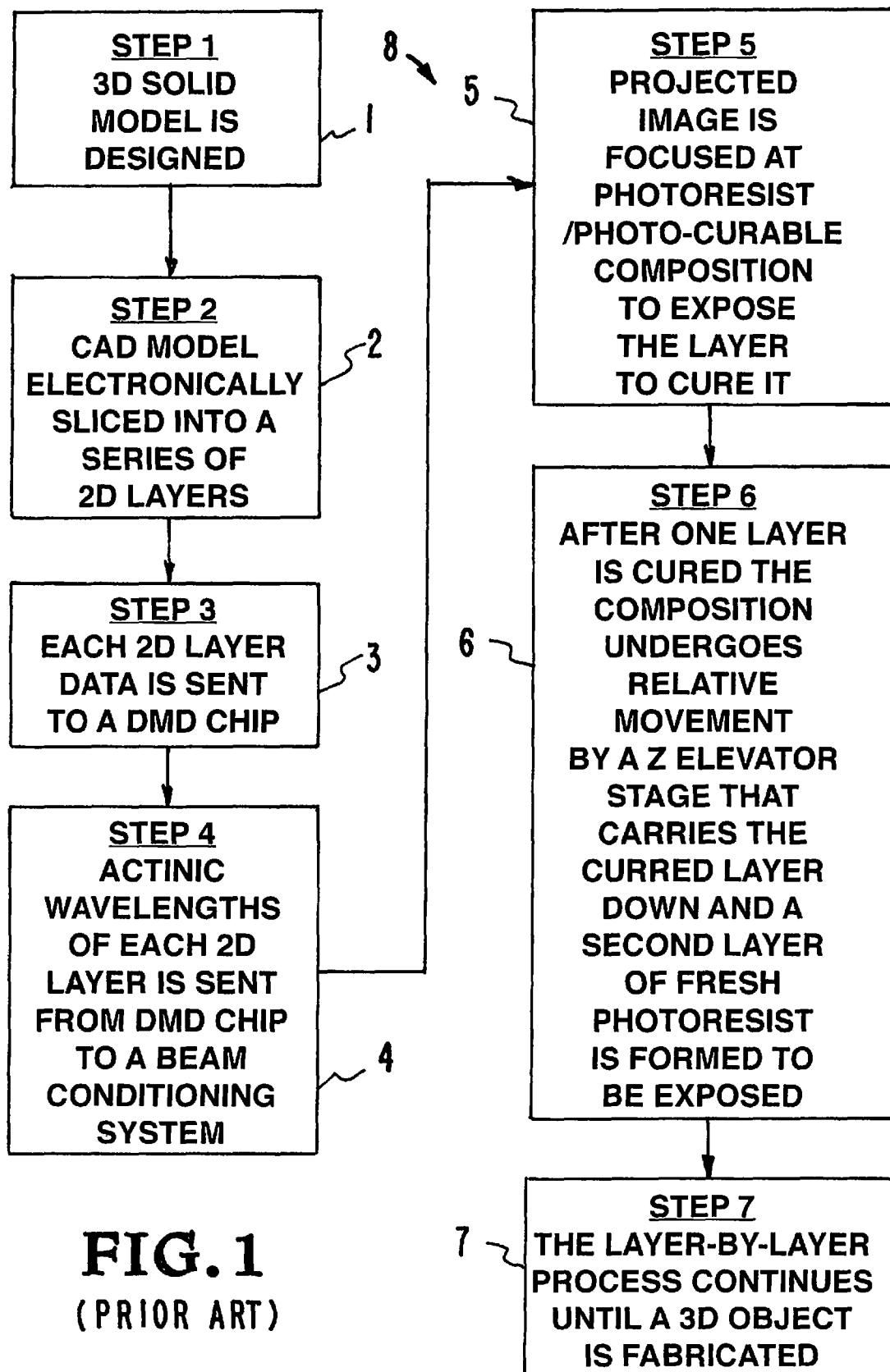
Claim 22. The large area projection micro stereolithography apparatus of claim 17 further comprising an additional first LAPuSL system, an additional second LAPuSL system, and an additional LAPuSL systems that are ganged together to complete the product.

Claim 23. The large area projection micro stereolithography apparatus of claim 17 wherein said curable resin includes dispersed metal particles and wherein said adjustable beam delivery system adapted to repeat the above steps for said second slice and said additional slices to complete the product comprises an adjustable beam delivery system adapted to repeat the above steps to complete the product having resin with dispersed metal particles and further comprising a thermal decomposition system for removing the resin from said product having resin with dispersed metal particles and producing a metal product.

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Claim 24. The large area projection micro stereolithography apparatus of claim 17 wherein said curable resin includes dispersed ceramic particles and wherein said adjustable beam delivery system adapted to repeat the above steps for said second slice and said additional slices to complete the product comprises an adjustable beam delivery system adapted to repeat the above steps to complete the product having resin with dispersed ceramic particles and further comprising a thermal decomposition system for removing the resin from said product having resin with dispersed ceramic particles and producing a ceramic product.

Claim 25. The large area projection micro stereolithography apparatus of claim 17 wherein said curable resin includes dispersed metal and ceramic particles and wherein said adjustable beam delivery system adapted to repeat the above steps for said second slice and said additional slices to complete the product comprises an adjustable beam delivery system adapted to repeat the above steps to complete the product having resin with dispersed metal and ceramic particles and further comprising a thermal decomposition system for removing the resin from said product having resin with dispersed metal and ceramic particles and producing a metal and ceramic product.



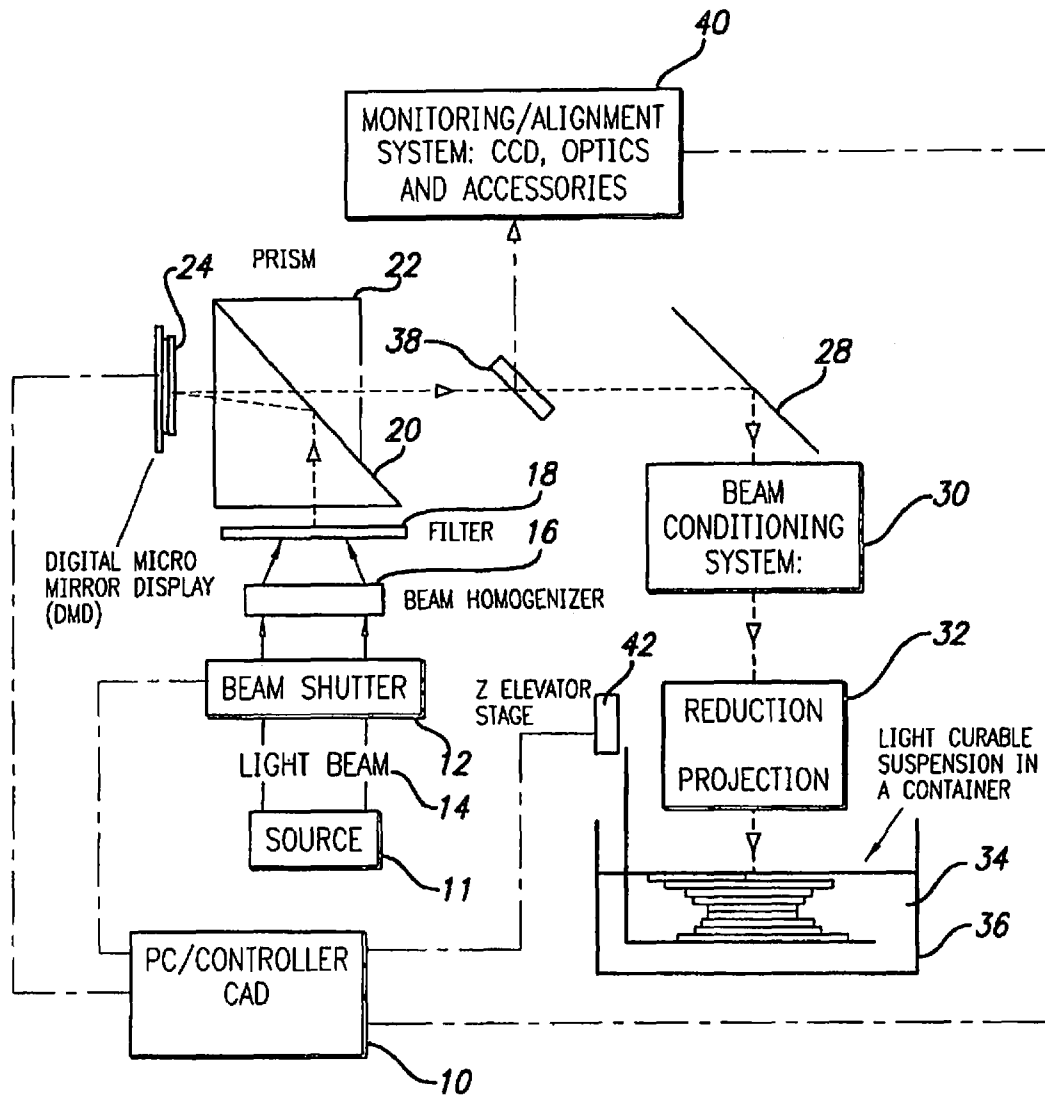
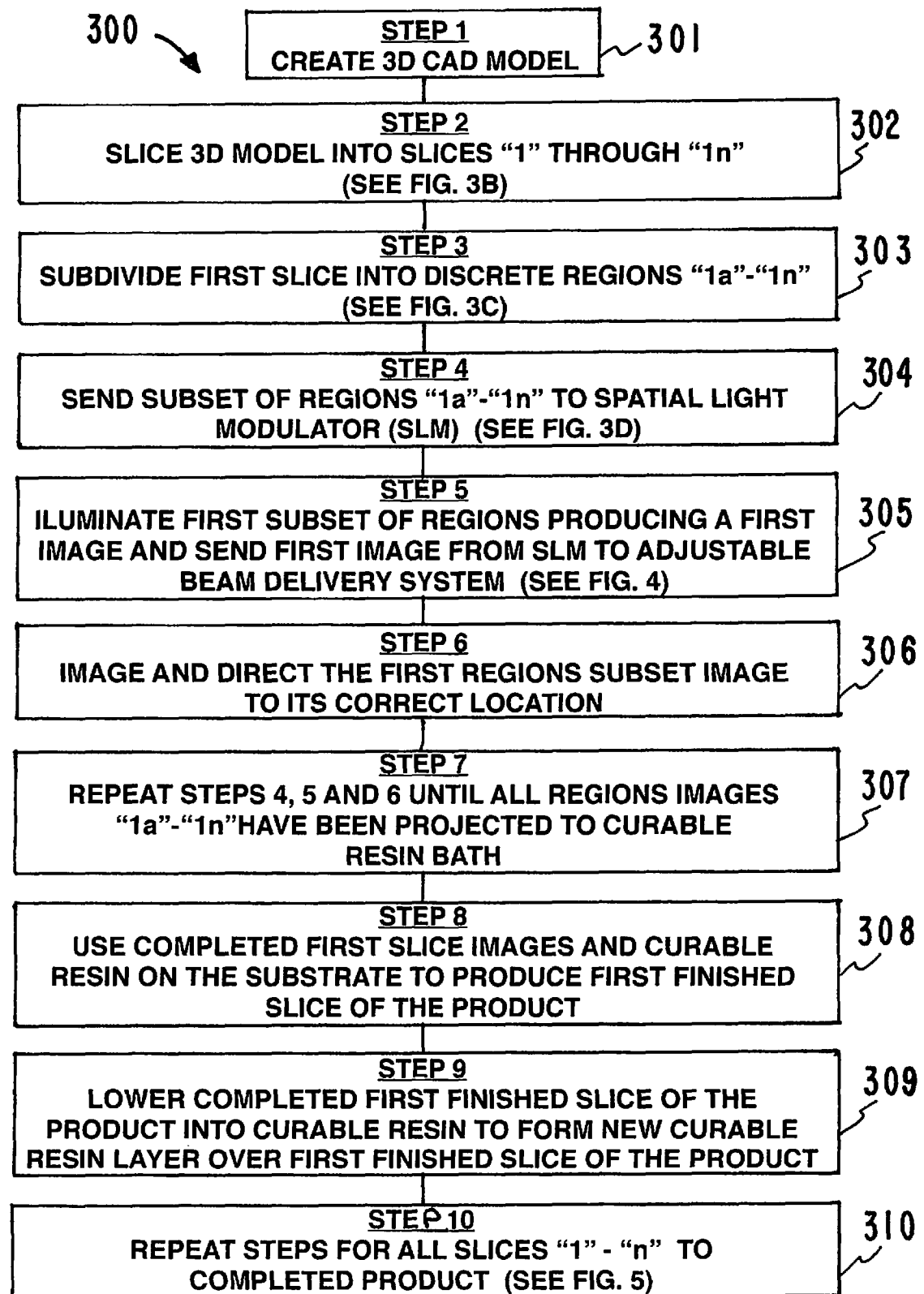


FIG. 2
(PRIOR ART)

**FIG. 3A**

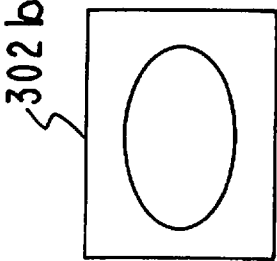


FIG. 3B

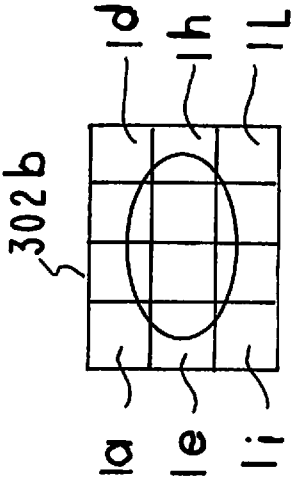


FIG. 3C

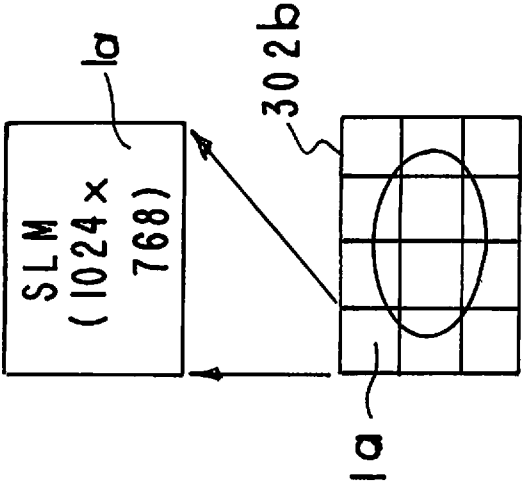


FIG. 3D

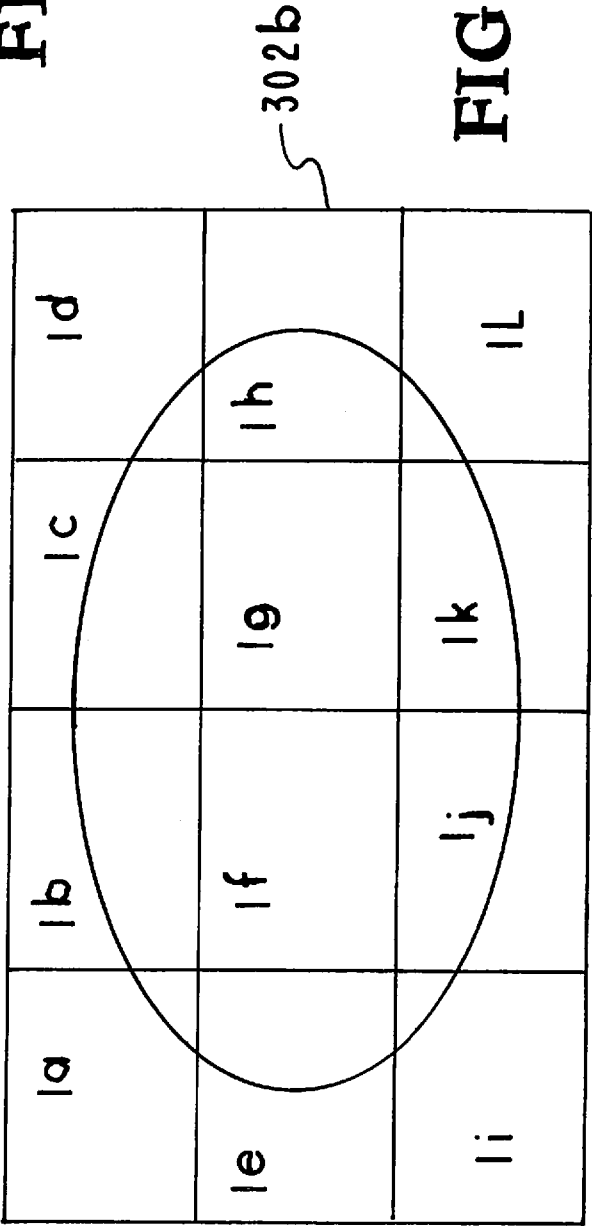
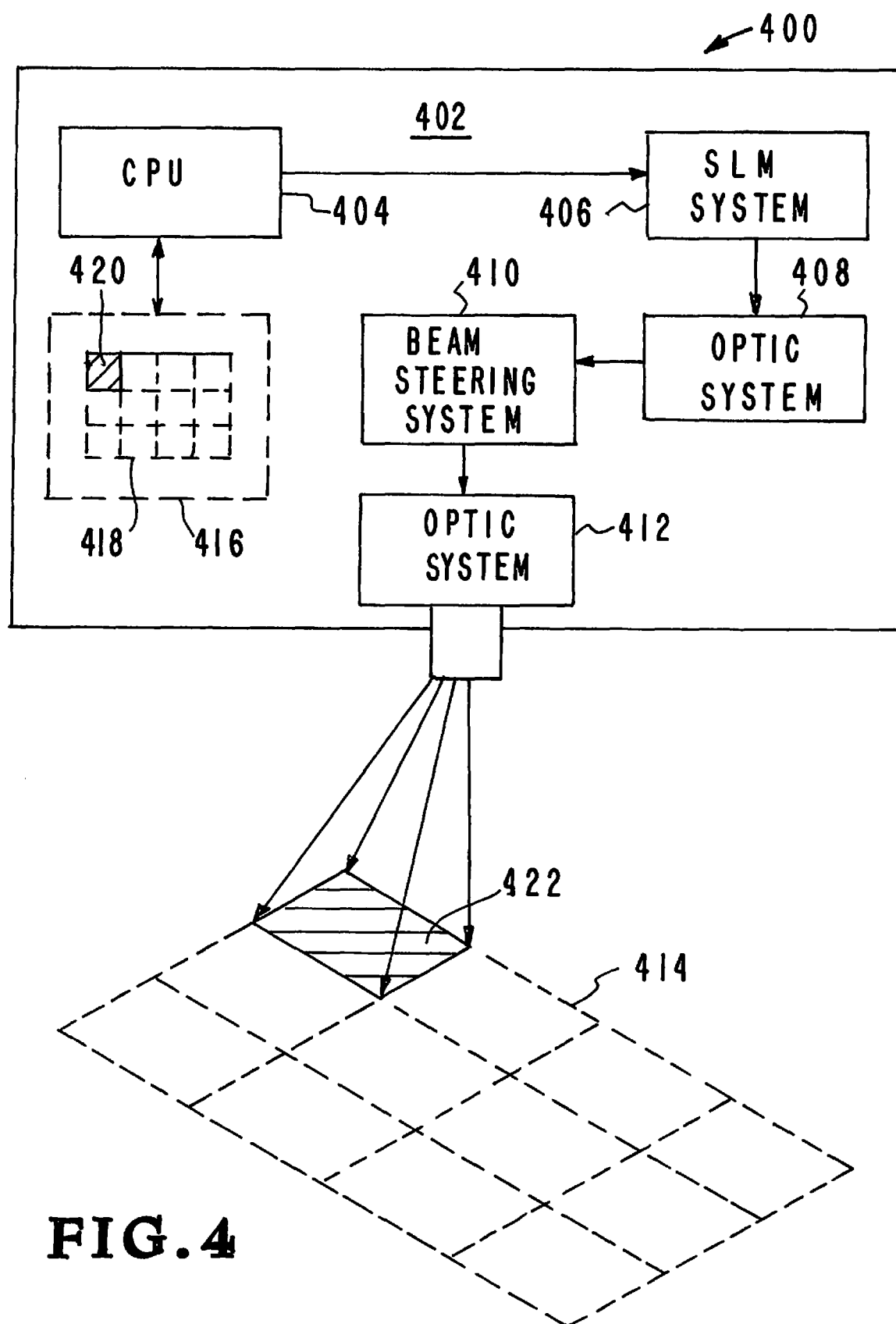


FIG. 3E



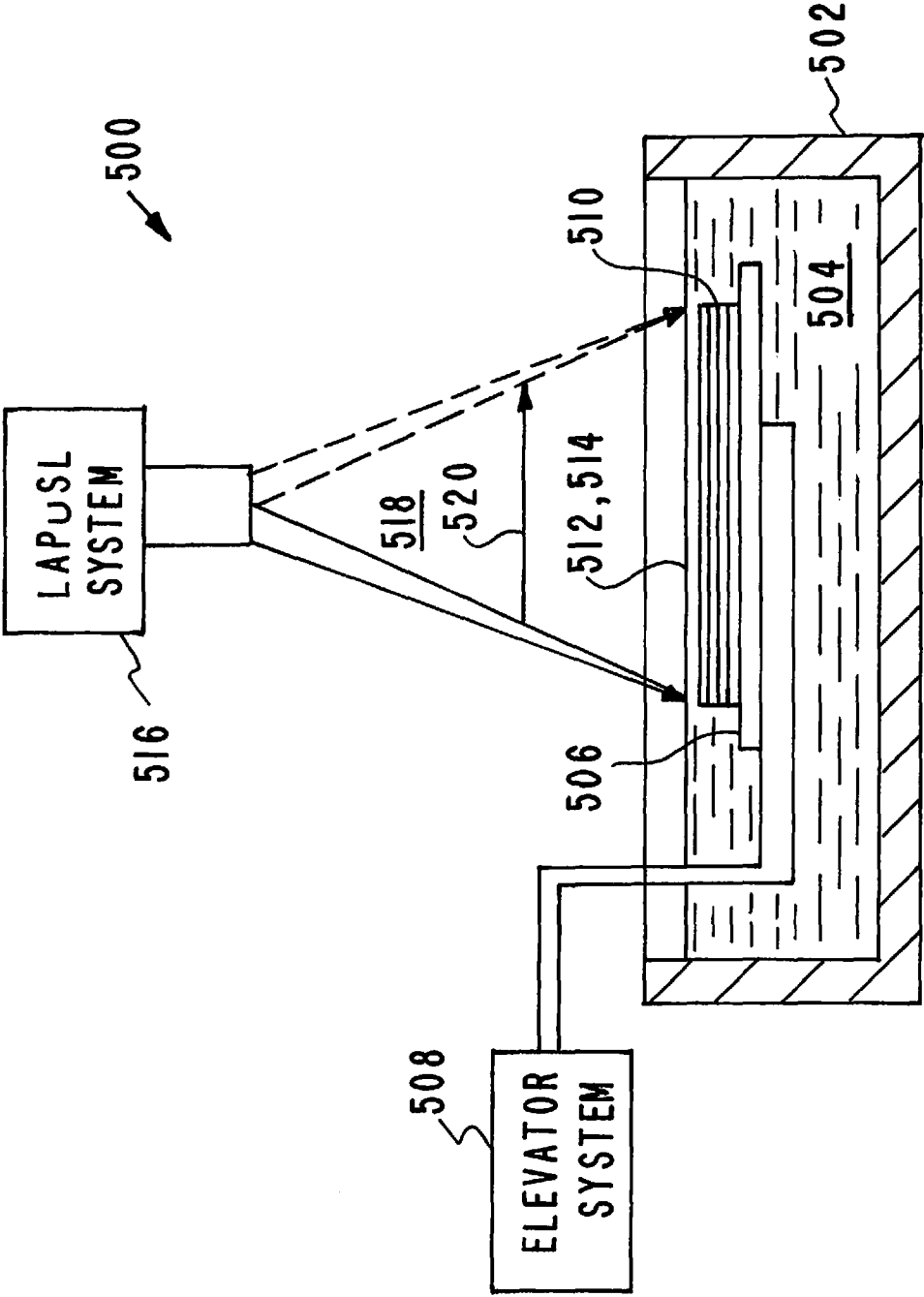


FIG. 5

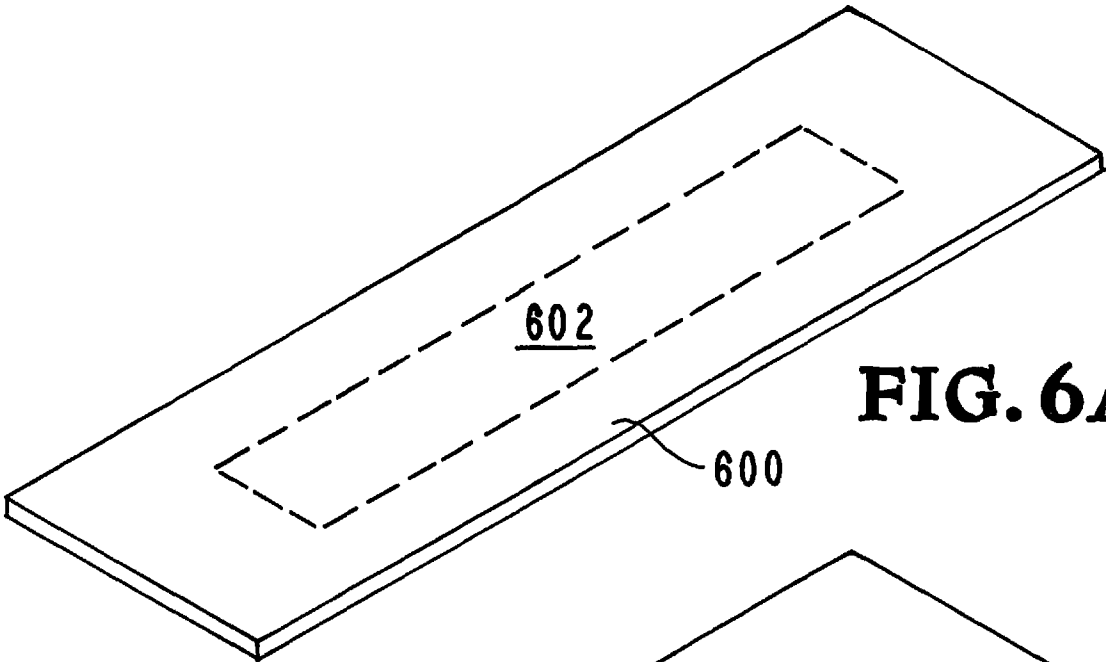


FIG. 6A

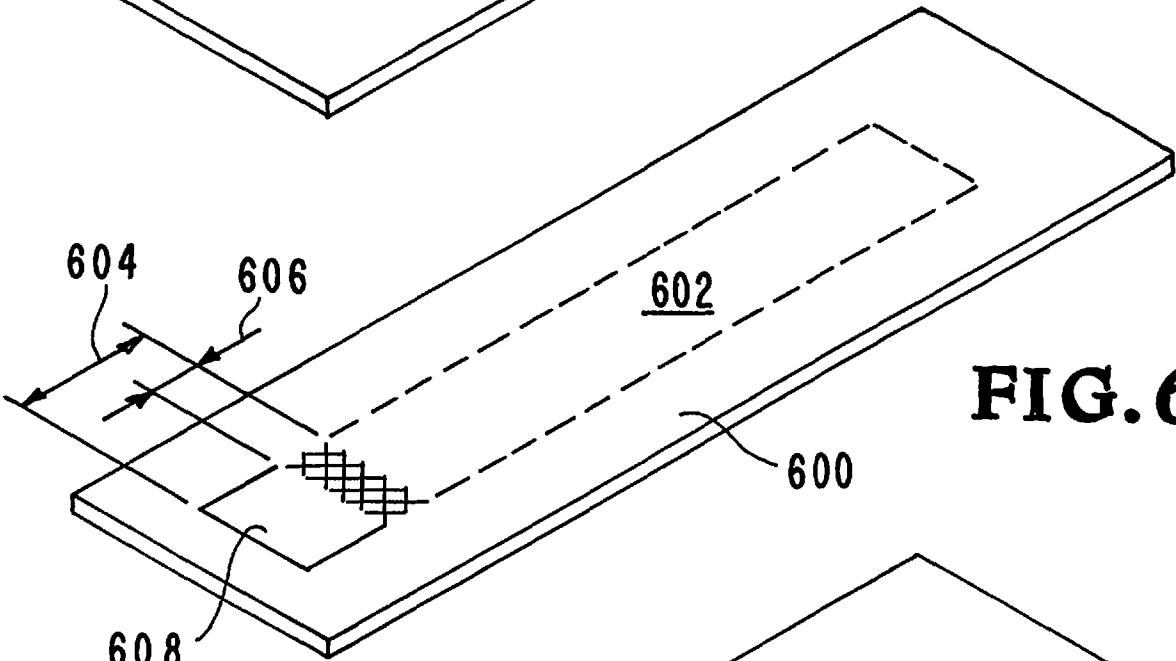


FIG. 6B

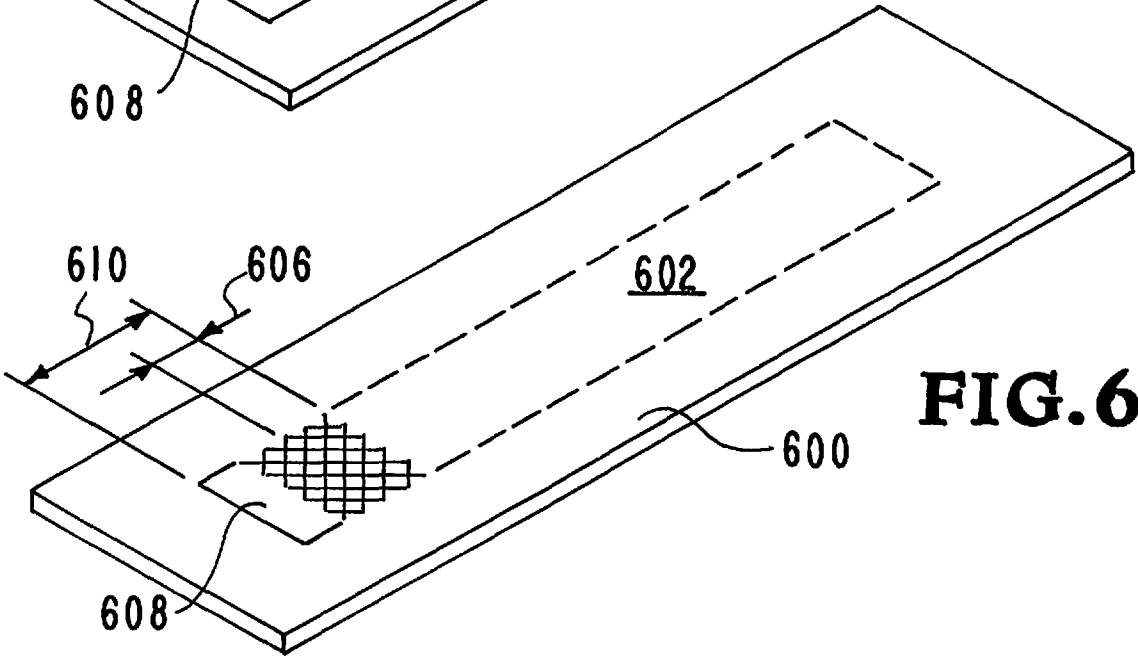
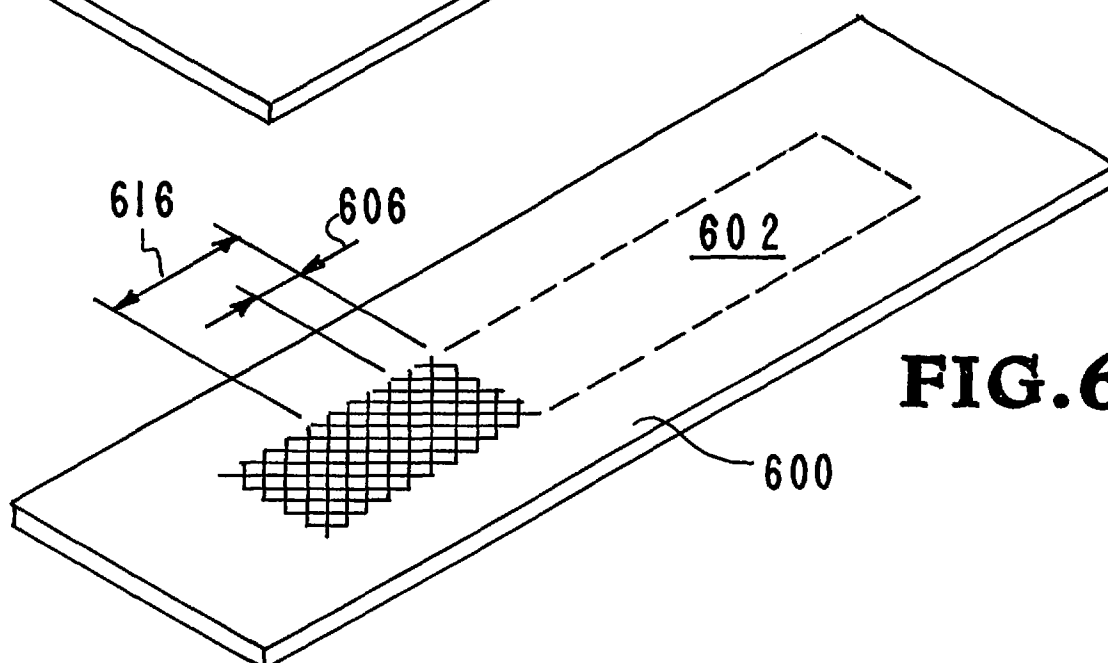
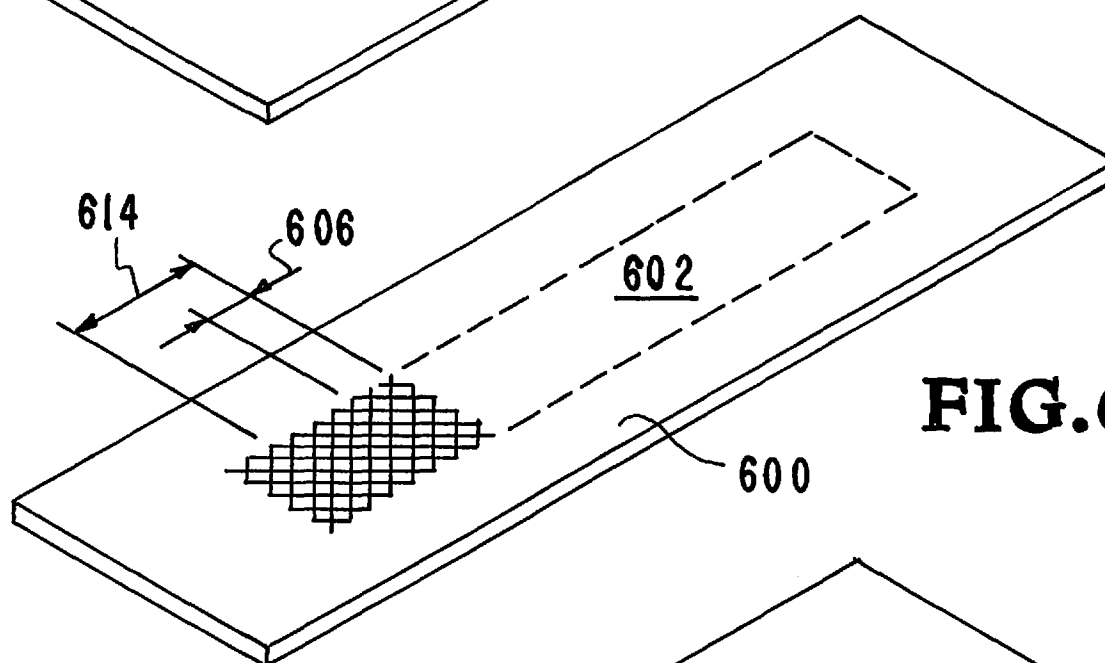
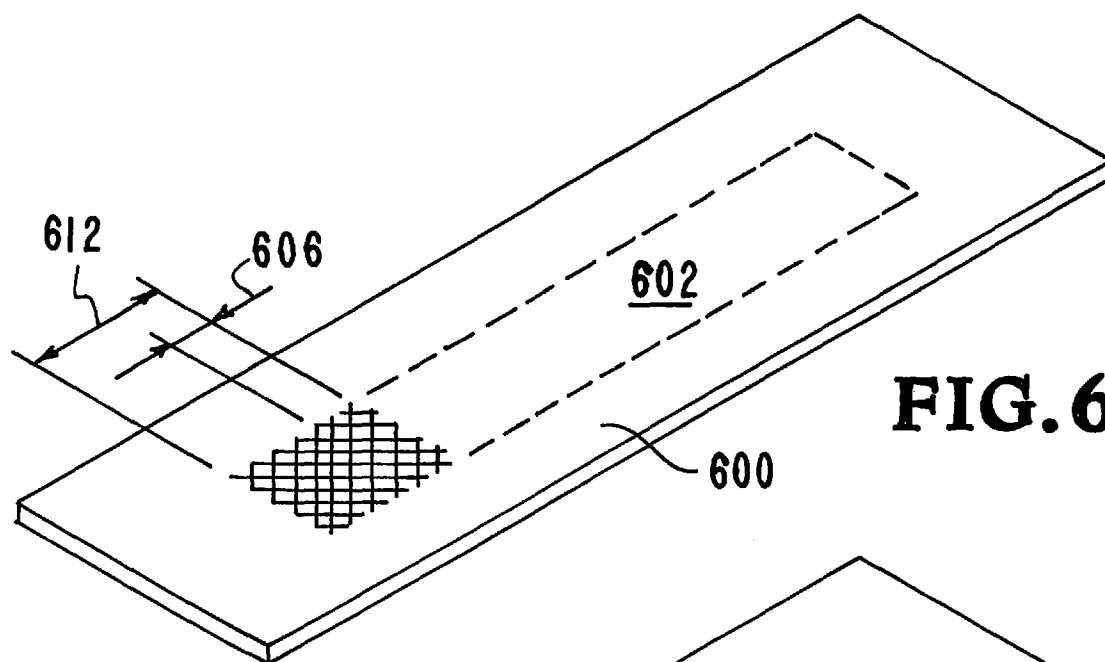
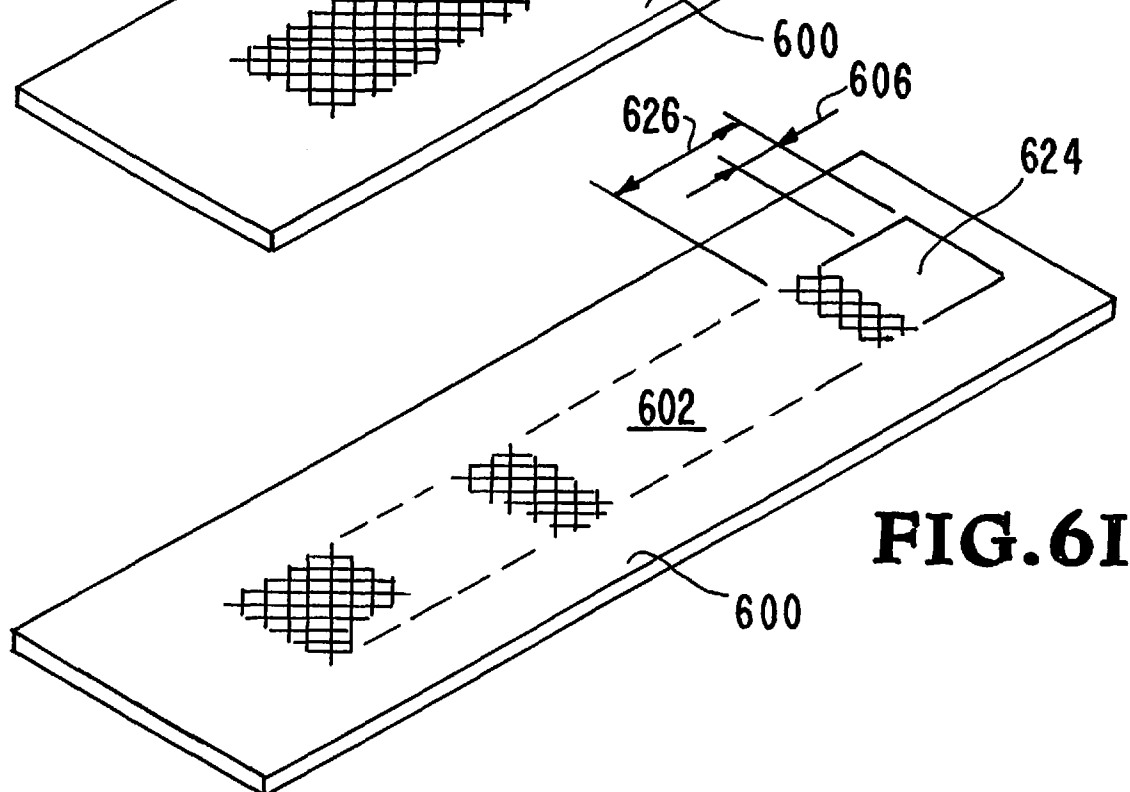
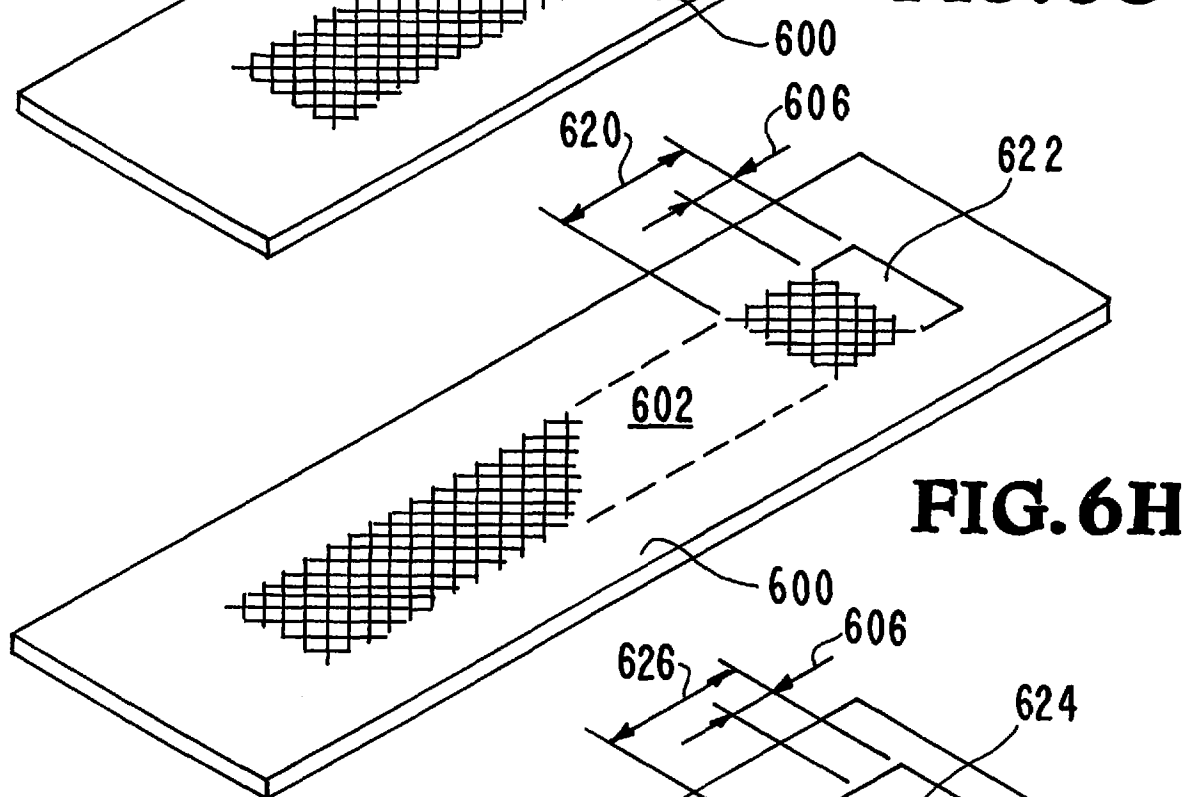
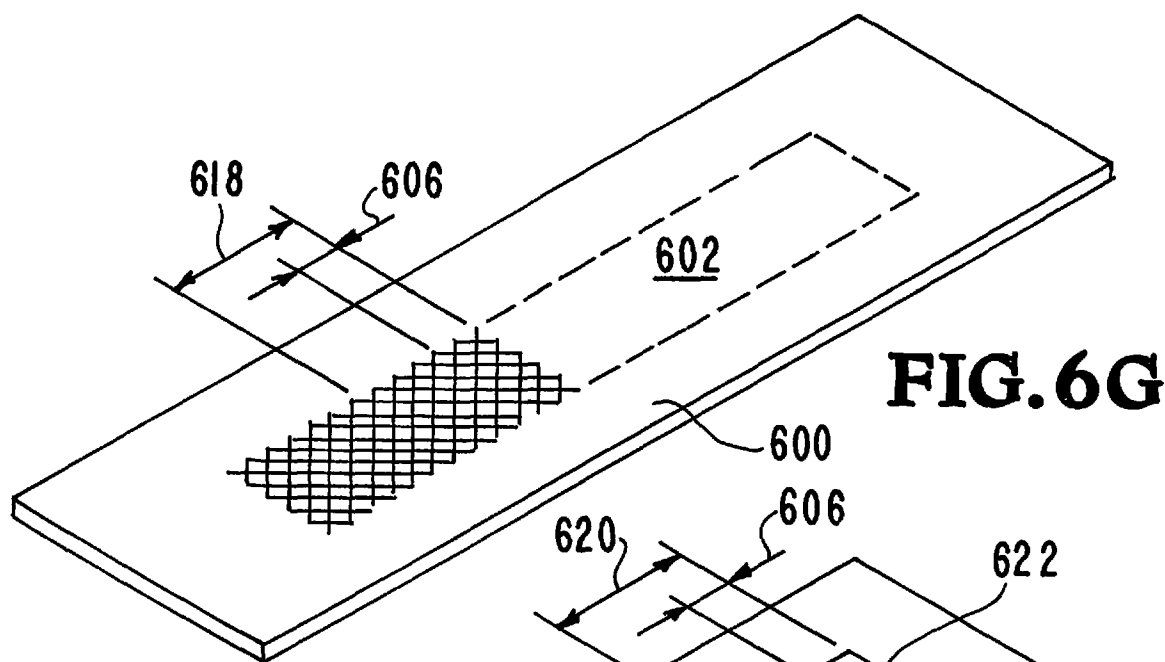


FIG. 6C





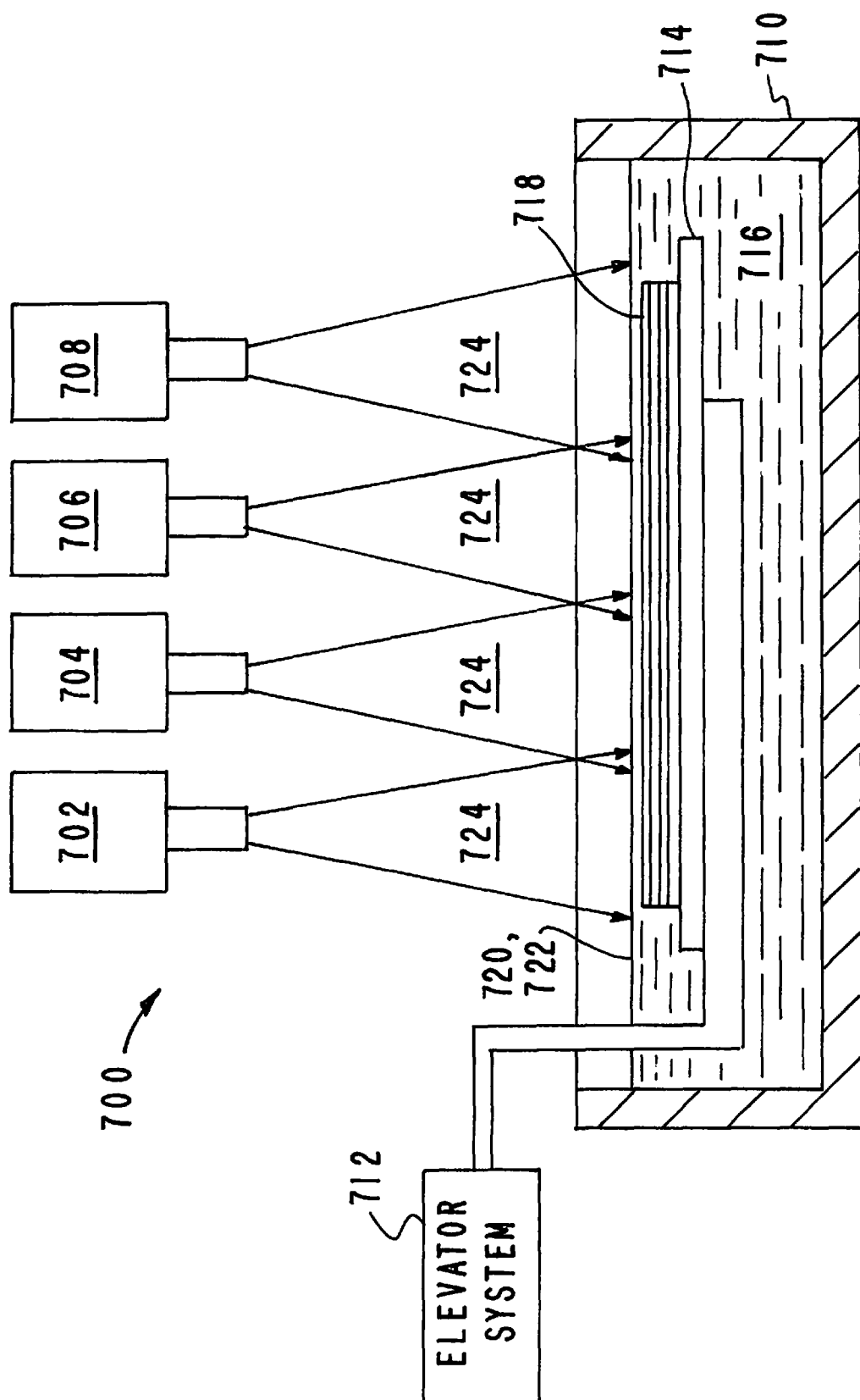
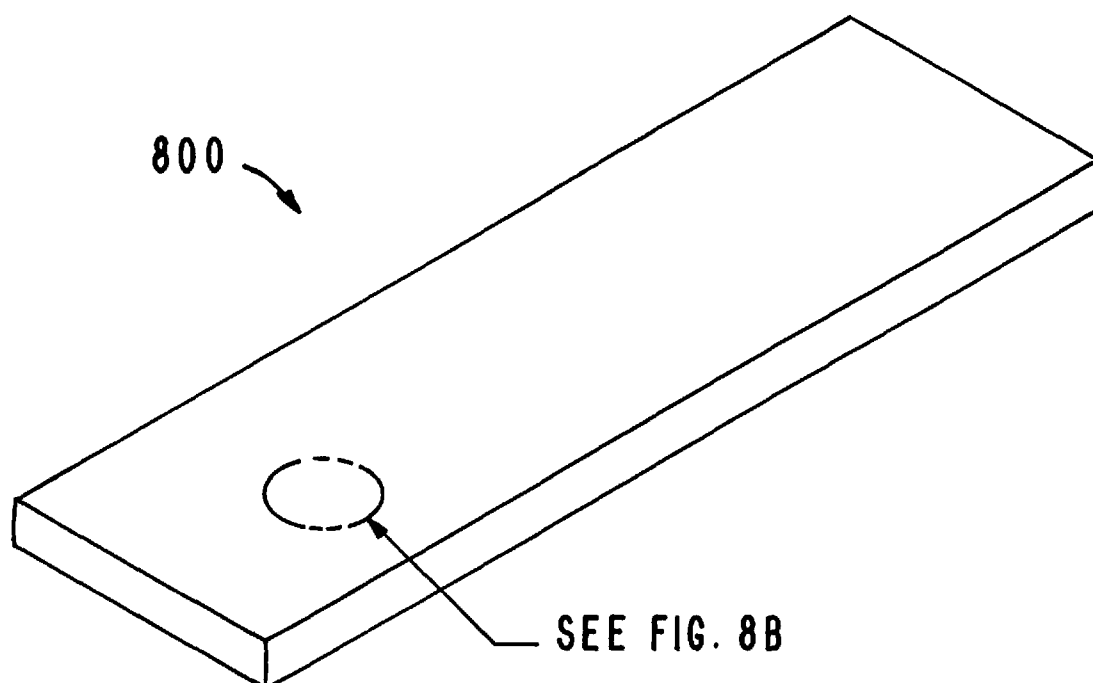
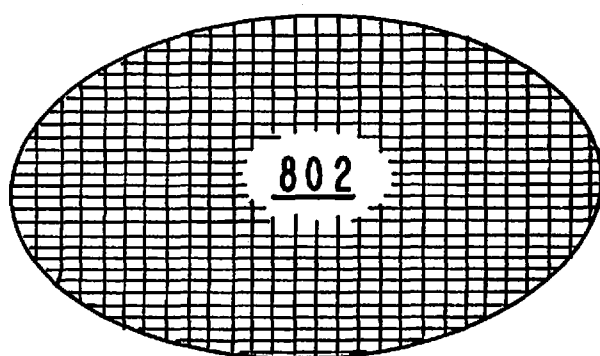


FIG. 7

**FIG. 8A****FIG. 8B**

A. CLASSIFICATION OF SUBJECT MATTER**G03H 1/26(2006.01)i, G03H 1/02(2006.01)i, G02B 5/00(2006.01)i**

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)

G03H 1/26; G06F 17/10; B32B 5/26; G06F 19/00; B29C 3500; G03F 700; B32B 37/12; G06F 7/60; B29C 35/08; G03H 1/02; G02B 5/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & keywords: 3D CAD model, 2D slices, discrete regions, curable resin, large area projection micro stereolithography**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6505089 B1 (DONG YOL YANG et al.) 07 January 2003 See column 4, line 51 - column 5, line 6; column 6, lines 45-55; and figures 1, 7.	1-25
Y	US 8636496 B2 (SUMAN DAS et al.) 28 January 2014 See column 6, lines 36-44; column 7, lines 9-39; column 9, line 22 - column 11, line 27; column 12, line 48 - column 14, line 4; claims 1, 5; and figures 4-5.	1-25
A	US 8660825 B2 (GURUNATHAN SARAVANA KUMAR) 25 February 2014 See column 5, line 49 - column 6, line 38; and figure 2.	1-25
A	US 6833234 B1 (THEODORE M. BLOOMSTEIN et al.) 21 December 2004 See column 30, line 43 - column 33, line 8; and figure 16.	1-25
A	US 2013-0171431 A1 (ROBERT SWARTZ et al.) 04 July 2013 See paragraphs [0036]-[0069]; and figures 1A-1B.	1-25



Further documents are listed in the continuation of Box C.



See patent family annex.

* 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

Date of the actual completion of the international search

08 July 2016 (08.07.2016)

Date of mailing of the international search report

11 July 2016 (11.07.2016)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea

Facsimile No. +82-42-481-8578

Authorized officer

LEE, EUN KYU

Telephone No. +82-42-481-3580



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/020971

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6505089 B1	07/01/2003	JP 03472779 B2 JP 2000-296561 A KR 10-0291953 B1 KR 10-2000-0060365 A	02/12/2003 24/10/2000 01/06/2001 16/10/2000
US 8636496 B2	28/01/2014	US 2010-0003619 A1 US 2014-0103581 A1	07/01/2010 17/04/2014
US 8660825 B2	25/02/2014	US 2012-0299917 A1 US 8260589 B1	29/11/2012 04/09/2012
US 6833234 B1	21/12/2004	None	
US 2013-0171431 A1	04/07/2013	EP 2776233 A2 EP 2776233 A4 WO 2013-033273 A2 WO 2013-033273 A3	17/09/2014 08/07/2015 07/03/2013 15/05/2014