

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
21 September 2006 (21.09.2006)

PCT

(10) International Publication Number  
**WO 2006/098938 A1**

- (51) International Patent Classification:  
*B05D 1/28* (2006.01)      *B29C 59/04* (2006.01)  
*B05D 1/26* (2006.01)
- (21) International Application Number:  
PCT/US2006/007975
- (22) International Filing Date: 6 March 2006 (06.03.2006)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:  
60/661,431      9 March 2005 (09.03.2005)      US
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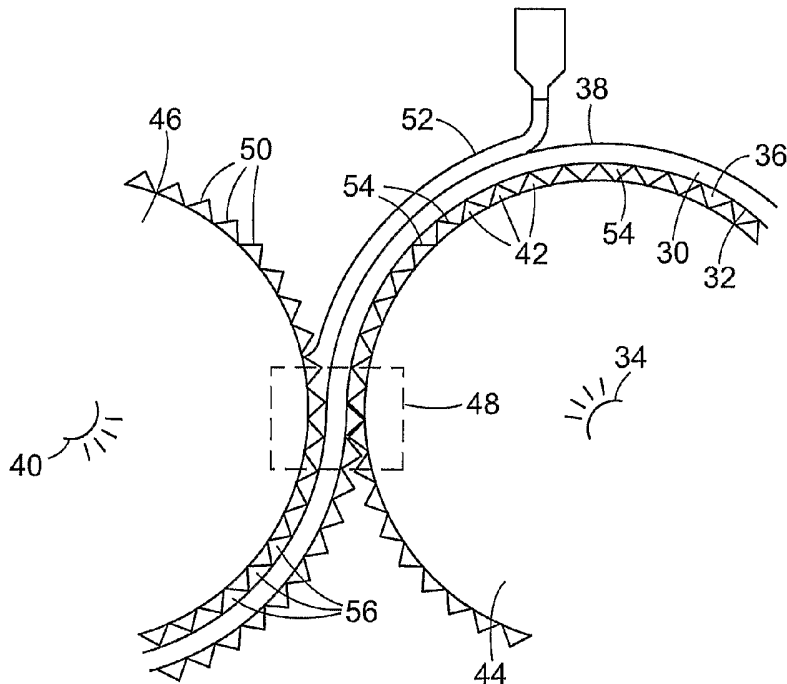
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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM,

[Continued on next page]

(54) Title: MICROREPLICATED ARTICLE AND METHOD FOR THE PRODUCTION THEREOF



(57) Abstract: A microreplicated article is disclosed. The article includes an opaque web having first and second opposed surfaces. The first surface includes a first microreplicated structure having a plurality of first features. The second surface includes a second microreplicated structure having a plurality of second features. The first microreplicated structure and the second microreplicated structure retain registration within 100 micrometers.

WO 2006/098938 A1



ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),  
European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI,  
FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT,  
RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA,  
GN, GQ, GW, ML, MR, NE, SN, TD, TG).

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

**Published:**

— *with international search report*

MICROREPLICATED ARTICLE AND METHOD FOR THE PRODUCTION THEREOF

### Technical Field

The disclosure relates generally to the continuous casting of material onto a web,  
5 and more specifically to the casting of articles having a high degree of registration  
between the patterns cast on opposite sides of the web. In particular, the disclosure relates  
to casting patterns onto opposite sides of an opaque web with a high degree of registration.

### Background

Many articles can be manufactured by applying a material that is at least  
10 temporarily in liquid form to opposite sides of a substrate. It is often the case that the  
material applied to the substrate is applied in a predetermined pattern. It is common in  
such cases for there to be at least a minimum requirement for registration between the  
patterns on opposite sides of the substrate. In some cases, it is necessary for the patterns  
on either side of a substrate to be aligned within very small tolerances.

15 A need remains, therefore, for improved techniques, apparatus and methods of  
producing two-sided substrates in which each side of the substrate bears a predetermined  
pattern in close registration with the predetermined pattern on the other side of the  
substrate. A need remains for improved techniques, apparatus and methods of  
reproducing closely registered microreplicated patterns on either side of a flexible, at least  
20 partially opaque web or substrate.

### Summary

The disclosure pertains generally to improved techniques, apparatus and methods  
of reproducing closely registered microreplicated patterns on either side of a flexible, at  
least partially opaque web or substrate.

25 Accordingly, an illustrative embodiment of the disclosure may be found in a  
microreplicated article that has a flexible opaque substrate. A first coated microreplicated  
pattern is disposed on a first surface of the flexible opaque substrate and a second  
microreplicated pattern is disposed on a second surface of the flexible opaque substrate.  
The first and second patterns are registered to within 100 micrometers. In some instances,  
30 the first and second patterns may be registered to within 10 micrometers, or even to within  
5 micrometers.

In some instances, the flexible opaque substrate is opaque to ultraviolet light. In some cases, the flexible opaque substrate blocks at least 98 percent of ultraviolet light that is incident upon the flexible opaque substrate. The flexible opaque substrate may include a polymer such as a metallized polymer that is suitable for forming a flexible circuit board.

5 In some cases, the first and second coated microreplicated patterns may individually or in combination include a conductive polymer. The first and second coated microreplicated patterns may individually or in combination include a number of distinct elements where at least some of the distinct elements are discontinuous from other distinct elements, i.e., without lands.

10 Another illustrative embodiment of the disclosure may be found in a method of making a microreplicated article that includes an opaque web substrate. The opaque web can be passed through a casting apparatus, and a first liquid may be coated onto a first surface of the opaque web or first patterned roll. The first liquid may be contacted with a first patterned roll and may be cured to create a first microreplicated pattern. A second  
15 liquid can be coated onto a second surface of the opaque web or second patterned roll. The second liquid may be contacted with a second patterned roll and may be cured to create a second microreplicated pattern. The first and second patterns can be registered to within 100 micrometers. In some instances, at least one of the first and second liquids may include a photocurable acrylate resin solution or a photocurable conductive polymer  
20 solution.

Another illustrative embodiment of the disclosure may be found in a method of making a microreplicated article that includes an opaque web. Curable material is disposed onto the web or patterned rolls. The opaque web is directed into contact with a first patterned roll including a number of opaque regions disposed on a transparent  
25 substrate. The curable material on a first side of the web is cured to form a first microreplicated pattern.

The opaque web is directed into contact with a second patterned roll including a number of opaque regions disposed on a transparent substrate. The curable material on a second side of the web is cured to form a second microreplicated pattern. The first and  
30 second sides of the web are patterned while the web is in continuous motion such that the first and second patterns are maintained in continuous registration to within 100 micrometers, or in some cases to within 5 micrometers.

In some instances, introducing curable material onto the web includes disposing curable material onto the first side of the web or first patterned roll prior to the first side of the web contacting the first patterned roll, and disposing curable material onto the second side of the web or second patterned roll prior to the second side of the web contacting the second patterned roll. In some cases, at least a portion of curing the curable material on the first side of the web occurs simultaneously with at least a portion of curing the curable material on the second side of the web.

In some cases, curing the curable material on the first side of the web includes subjecting the curable material to ultraviolet radiation that passes at least partially through the first patterned roll. Curing the curable material on the second side of the web may include subjecting the curable material to ultraviolet radiation that passes at least partially through the second patterned roll.

The above summary of the present disclosure is not intended to describe each disclosed embodiment or every implementation of the present disclosure. The Figures, Detailed Description and Examples which follow more particularly exemplify these embodiments.

### Definitions

In the context of this disclosure, "registration," means the positioning of structures on one surface of the web in a defined relationship to other structures on the opposite side of the same web.

In the context of this disclosure, "web" means a sheet of material having a fixed dimension in a first direction and either a predetermined or indeterminate length in a second direction that is orthogonal to the first direction.

In the context of this disclosure, "continuous registration," means that at all times during rotation of first and second patterned rolls the degree of registration between structures on the rolls is better than a specified limit.

In the context of this disclosure, "microreplicated" or "microreplication" means the production of a microstructured surface through a process where the structured surface features retain an individual feature fidelity during manufacture, from product-to-product, that varies no more than about 100 micrometers.

In the context of this disclosure, "curing energy" refers to electromagnetic radiation having a particular wavelength or band of wavelengths suitable for curing a

curable material. The phrase “curing energy” may be modified by a term identifying the wavelength or band of wavelengths. For example, “ultraviolet curing energy” refers to energy within a band of wavelengths that is considered to be ultraviolet and that is suitable for curing a particular material. The phrase “curable material”, when used in conjunction with “curing energy”, refers to a material that may be cured, polymerized or cross-linked when exposed to “curing energy”.

In the context of this disclosure, “opaque” refers to a material that blocks at least a significant amount of electromagnetic radiation of a particular wavelength or band of wavelengths. A material may be considered to be opaque to energy of a first wavelength, but not be opaque to energy of a second wavelength. A material that is “opaque” to energy of a particular wavelength may block at least 95 percent of the energy of that particular wavelength that is incident upon the material. An “opaque” material may block 98 percent or even more than 99 percent of the energy of that particular wavelength that is incident upon the material.

A material may be described as “opaque to curing energy”, meaning that the material blocks at least 95 percent of the curing energy (of a particular wavelength or band of wavelengths) incident upon the material. A material described as “opaque to ultraviolet energy” would block at least 95 percent of ultraviolet radiation incident upon the material.

A material such as a flexible web or substrate may be described as “opaque”, meaning that the flexible web or substrate blocks at least 95 percent of the electromagnetic energy of a particular wavelength or band of wavelengths incident upon the flexible web or substrate. A flexible web or substrate may be described as “opaque to curing energy”, meaning that the flexible web or substrate blocks at least 95 percent of the curing energy (of a particular wavelength or band of wavelengths) incident upon the flexible web or substrate. A flexible web or substrate described as “opaque to ultraviolet energy” would block at least 95 percent of ultraviolet radiation incident upon the flexible web or substrate.

As used within the context of this disclosure, “transparent” refers to a material that transmits, or permits passage, of at least a significant amount of electromagnetic radiation of a particular wavelength or band of wavelengths. A material may be considered to be transparent to energy of a first wavelength, but not be transparent to energy of a second wavelength. A material that is “transparent” to energy of a particular wavelength may

transmit or permit passage at least 10 percent of the energy of that particular wavelength that is incident upon the material. A “transparent” material may transmit or permit passage of 25 percent or even more than 50 percent of the energy of that particular wavelength that is incident upon the material.

5 A material may be described as “transparent to curing energy”, meaning that the material transmits or permits passage of at least 10 percent of the curing energy (of a particular wavelength or band of wavelengths) incident upon the material. A material described as “transparent to ultraviolet energy” would transmit or permit passage of at least 10 percent of ultraviolet radiation incident upon the material.

### 10 **Brief Description of the Figures**

The disclosure may be more completely understood in consideration of the following detailed description of various embodiments of the disclosure in connection with the accompanying drawings, in which:

**FIG. 1** is a schematic illustration of a casting apparatus in accordance with an embodiment of the disclosure;

**FIG. 2** is a schematic illustration of a portion of the casting apparatus shown in **FIG. 1**;

**FIG. 3** is a partial illustration of a patterned roll in accordance with an embodiment of the disclosure;

20 **FIGS. 4-13** demonstrate an illustrative but non-limiting method of forming the patterned roll of **FIG. 3** in accordance with an embodiment of the disclosure;

**FIGS. 14A-14E** demonstrate an illustrative but non-limiting method of forming a patterned roll in accordance with an embodiment of the disclosure;

25 **FIGS. 15A-15D** demonstrate an illustrative but non-limiting method of forming a patterned roll in accordance with an embodiment of the disclosure;

**FIGS. 16A-16D** demonstrate an illustrative but non-limiting method of forming a patterned roll in accordance with an embodiment of the disclosure;

**FIGS. 17A-17C** demonstrate an illustrative but non-limiting method of forming a patterned roll in accordance with an embodiment of the disclosure;

30 **FIGS. 18A-18C** demonstrate an illustrative but non-limiting method of forming a patterned roll in accordance with an embodiment of the disclosure;

**FIGS. 19A-19D** demonstrate an illustrative but non-limiting method of forming a patterned roll in accordance with an embodiment of the disclosure;

**FIGS. 20A-20E** demonstrate an illustrative but non-limiting method of forming a patterned roll in accordance with an embodiment of the disclosure;

5 **FIGS. 21A-21D** demonstrate an illustrative but non-limiting method of forming a patterned roll in accordance with an embodiment of the disclosure;

**FIG. 22** is a perspective view of a microreplication assembly in accordance with an embodiment of the disclosure;

10 **FIG. 23** is a perspective view of a portion of the microreplication assembly of **FIG. 22**;

**FIG. 24** is a perspective view of a portion of the microreplication assembly of **FIG. 22**;

**FIG. 25** is a schematic illustration of a roll mounting arrangement in accordance with an embodiment of the disclosure;

15 **FIG. 26** is a schematic illustration of a mounting arrangement for a pair of patterned roll in accordance with an embodiment of the disclosure;

**FIG. 27** is a schematic illustration of a motor and roll arrangement in accordance with an embodiment of the disclosure;

20 **FIG. 28** is a schematic illustration of structure for controlling the registration between rolls in accordance with an embodiment of the disclosure;

**FIG. 29** is a schematic illustration of a control algorithm for controlling registration in accordance with an embodiment of the disclosure; and

**FIG. 30** is a diagrammatic cross-sectional view of an article made in accordance with an embodiment of the disclosure;

25 While the disclosure is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the disclosure to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of  
30 the disclosure.



### Detailed Description

Generally, the present disclosure pertains to producing two-sided microreplicated structures having a first microreplicated pattern on a first surface of a web and a second microreplicated pattern on a second surface of the web. The system generally includes a first patterning assembly and a second patterning assembly. Each respective assembly creates a microreplicated pattern on either a first or second surface of the web. A first pattern can be created on the first surface of the web and a second pattern can be created on the second surface of the web.

In some instances, the apparatus and methods discussed herein result in a web having a microreplicated structure on each opposing surface of the web that can be manufactured by continuously forming microreplicated structures on opposite surfaces of the web while keeping the microreplicated structures registered generally to within 100 micrometers of each other. In some instances, the microreplicated structures may remain registered within 50 micrometers. In some cases, the microreplicated structures may remain registered within 20 micrometers. In some instances, the microreplicated structures may remain registered within 10 micrometers or even within 5 micrometers.

The following description should be read with reference to the drawings, in which like elements in different drawings are numbered in like fashion. The drawings, which are not necessarily to scale, depict selected embodiments and are not intended to limit the scope of the disclosure. Although examples of construction, dimensions, and materials are illustrated for the various elements, those skilled in the art will recognize that many of the examples provided have suitable alternatives that may be utilized.

#### Casting Assembly

**FIG. 1** illustrates an example casting apparatus **10** for producing a two-sided web **12** that includes registered microreplicated structures on opposing surfaces. In some instances, the casting apparatus **10** includes first and second coating means **16, 20**, a nip roller **14**, and first and second patterned rolls **18, 24**. In some instances, first coating means **16** may be a first extrusion die **16** while second coating means may be a second extrusion die **20**. In the illustrated embodiment, the first and second curable liquid is disposed on the web surface prior to passing through the first and second patterned rolls, respectively. In other embodiments, the first curable liquid is disposed on the first

patterned roll and the second curable liquid is disposed on the second patterned roll, which is then transferred to the web from the patterned rolls.

Web 12 may be presented to the first extrusion die 16, which dispenses a first curable liquid layer coating 22 onto the web 12. Nip roller 14 presses first coating 22 into the first patterned roller 18. In some cases, nip roller 14 can be a rubber covered roller. While on the first patterned roll 18, the coating 22 is cured using an energy source 26 adapted to provide suitable curing energy. In some instances, energy source 26 may be adapted to provide ultraviolet light. The term "ultraviolet light" refers to light having a wavelength in a range from 200 to 500 nanometers or from 200 to 400 nanometers.

A second curable liquid layer 28 is coated on the opposite side of the web 12 using a second side extrusion die 20. The second layer 28 is pressed into the second patterned tool roller 24 and the curing process repeated for the second coating layer 28. Registration of the two coating patterns is achieved by maintaining the tool rollers 18, 24 in a precise angular relationship with one another, as will be described hereinafter.

FIG. 2 provides a closer view at first and second patterned rolls 44 and 46. First and second patterned rolls 44, 46 may be considered as particular embodiments of patterned rolls 18, 24 as discussed with respect to FIG. 1. Other patterns are contemplated, as will be discussed in greater detail subsequently. First patterned roll 44 has a first pattern 42 for forming a microreplicated surface. Second pattern roll 46 has a second microreplicated pattern 50. In the illustrated embodiment, first and second patterns 42, 50 are the same pattern. In other instances, the first and second patterns may be different.

As a web 30 passes over the first patterned roll 44, a first curable liquid (not shown) on a first surface 32 may be cured by curing energy provided by an energy source 34 near a first region 36 on the first patterned roll 44. A first microreplicated patterned structure 54 is formed on the first side 43 of the web 30 after the liquid is cured. The first patterned structure 54 is a negative of the pattern 42 on the first patterned roll 44. After the first patterned structure 54 is formed, a second curable liquid 52 is dispensed onto a second surface 38 of the web 30. To insure that the second liquid 52 is not cured prematurely, the second liquid 52 is isolated from the first energy source 34, typically by locating the first energy source 34 so that energy emitted by the first energy source 34 does not fall on the second liquid 52. If desired, the curing sources can be located inside

their respective patterned rolls. As such, the opaque nature of web 30 can aid in preventing undesired curing.

After the first patterned structure 54 is formed, the web 30 continues along the first roll 44 until it enters a gap region 48 between the first and second patterned rolls 44, 46. The second liquid 52 then engages the second pattern 50 on the second patterned roll 46 and is shaped into a second microreplicated structure, which is then cured by curing energy emitted by a second energy source 40. As the web 30 passes into the gap 48 between first and second patterned rolls 44, 46, the first patterned structure 54, which is by this time substantially cured and bonded to the web 30, restrains the web 30 from slipping while the web 30 begins moving into the gap 48 and around the second patterned roller 46. This removes web stretching and slippages as a source of registration error between the first and second patterned structures formed on the web.

By supporting the web 30 on the first patterned roll 44 while the second liquid 52 comes into contact with the second patterned roll 46, the degree of registration between the first and second microreplicated structures 54, 56 formed on opposite sides 32, 38 of the web 30 becomes a function of controlling the positional relationship between the surfaces of the first and second patterned rolls 44, 46. The S-wrap of the web around the first and second patterned rolls 44, 46 and between the gap 48 formed by the rolls minimizes effects of tension, web strain changes, temperature, microslip caused by mechanics of nipping a web, and lateral position control. The S-wrap can maintain the web 30 in contact with each roll over a wrap angle of 180 degrees, though the wrap angle can be more or less depending on the particular requirements.

### **Patterned Roll**

In some instances, it may be useful to provide microreplicated patterns onto either side of a flexible web or substrate that is opaque, particularly, opaque to curing energy. In other instances, it may be useful to provide microreplicated patterns onto either side of a flexible web or substrate that is transparent, particularly, transparent to curing energy. When the web or substrate is opaque to the curing energy necessary to cure the materials applied to the web in liquid form, the materials cannot simply be cured by passing curing energy through the web or substrate to contact the liquid resin. In these cases, it may be useful to use a patterned roll that is transparent to a particular curing energy or includes

portions that are transparent to curing energy. In some cases, only one patterned roll is transparent.

**FIG. 3** is a partial illustration of an illustrative but non-limiting patterned roll and should not be considered as being to scale. Instead, the pattern has been exaggerated for clarity. Patterned roll can, as illustrated and as will be discussed in greater detail, may be formed by an additive method in which materials are deposited onto the surface of a transparent cylinder or other suitable shape. In some embodiments, it is believed that patterned roll may be formed using various subtractive methods in which material is removed from a transparent cylinder or other suitable shape.

Patterned roll includes a transparent cylinder **102** that can be formed of any suitable material. In some instances, transparent cylinder **102** is formed of a material that is transparent to the curing energy that will cure the curable material that will be applied to patterned roll. In some instances, as illustrated, transparent cylinder **102** can be made from a glass such as quartz.

As illustrated, in particular, patterned roll includes a quartz cylinder **102**. Quartz cylinder **102** may be of any suitable dimensions, although in some cases quartz cylinder **102** may have a length of 3 inches and a radius of 3 inches. Quartz cylinder **102** may be a substantially solid cylinder, or, as illustrated, quartz cylinder **102** may be a hollow cylinder.

In some cases, it may be useful to apply a thin tie layer **104** to the surface of the quartz cylinder **102**. This may assist subsequent materials in adhering or bonding to the quartz. In some instances, tie layer **104** is thin enough to not materially change the optical properties of the quartz cylinder **102**. At a minimum, tie layer **104** can be thin enough to remain transparent to curing energy. Tie layer **104** may be formed of any suitable material and using any suitable application technique. In some instances, tie layer **104** includes or consists of titanium and is applied via sputtering.

Once tie layer **104** has been formed, subsequent materials may be added to patterned roll. While particular processing steps are illustrated in **FIGS. 4-13**, and will be discussed in detail with respect to the Example, a variety of opaque materials may be applied to tie layer **104**. Suitable opaque materials include metals such as chrome, copper or aluminum, and curable polymers such as silicone and epoxy. Suitable materials may be

applied and patterned using any suitable technique, such as sputtering, etching, and the like.

In the illustrated embodiment, the features of patterned roll have been formed in two steps. First, layers **106** have been deposited onto tie layer **104** and subsequently  
5 patterned. Layers **108** have been formed and patterned on top of layers **106**. Layers **106** and layers **108** may be formed of different materials or they may be formed of the same material. In some instances, layers **106** may be formed by sputtering a layer of chrome onto tie layer **104**. In some instances, layers **108** may be formed by plating chrome onto layers **106**.

10 In **FIG. 3**, the opaque features of patterned roll stand above the surface of quartz cylinder **102**. In some contemplated embodiments, such as those discussed with respect to **FIGS. 14-21**, the opaque features are actually closer to an outer surface of the substrate, while the transparent features actually penetrate the substrate. In either event, the opaque features may be considered as being farther from a radial center of patterned roll than are  
15 the transparent features.

In some instances, a patterned roll may be formed from either machinable or non-machinable transparent substrates. Several contemplated manufacturing techniques are described herein in **FIGS. 14-21**. It should be noted that in **FIGS. 14-21**, only a very small part of a transparent substrate is shown, for ease of illustration. While only a single  
20 transparent feature is shown for each potential manufacturing technique, it should be noted that of course a patterned roll will include a number of features. Moreover, it should be noted that a patterned roll will be cylindrical, while for ease of illustration and because only a very small part of the roll is shown, **FIGS. 14-21** appear rectangular.

**FIGS. 14A-14E** illustrate a potential method of forming opaque features on a non-machinable transparent substrate that includes adding a machinable layer. In **FIG. 14A**, a  
25 non-machinable, transparent, substrate **200** is provided. Examples of non-machinable, transparent substrates include glasses such as quartz. As shown in **FIG. 14B**, a titanium tie layer **202** may be applied to substrate **200** using any suitable technique such as sputtering. A copper seed layer **204** may be sputtered onto titanium tie layer **202** as seen  
30 in **FIG. 14C**. Additional copper may be plated onto copper seed layer **204** to form copper layer **206**, as seen in **FIG. 14D**.

**FIG. 14E** shows that copper layer **206** could be machined in any suitable manner to provide a transparent feature **208** positioned within copper layer **206**, which is of course opaque. In some instances, transparent feature **208** could be formed simply by a machining process such as micromilling, laser ablation, diamond turning or EDM  
5 processing. In some cases, additional processing such as a brief chemical etch may be useful in exposing transparent substrate **200** without damaging transparent substrate **200**.

In some instances, other materials may be used for the machinable layer **206**. For example, machinable layer **206** could be formed from an opaque epoxy or a machinable ceramic that could be coated in a “green” state and sintered after shaping.

**FIGS. 15A-15D** illustrate another potential method of forming opaque features on a non-machinable transparent substrate **200** that includes adding a machinable layer. In **FIG. 15B**, a transparent epoxy layer **210** may be added to the transparent substrate **200** to help protect the transparent substrate during subsequent machining. As seen in **FIG. 15C**, an opaque epoxy layer **212** has been added on top of the transparent epoxy layer **210**. In  
10 **FIG. 15D**, opaque epoxy layer **212** has been machined using any suitable technique to form transparent feature **214**.

**FIGS. 16A-D** illustrate another potential method of forming opaque features on a non-machinable transparent substrate **200** that includes adding a machinable layer. Transparent substrate **200** is shown in **FIG. 16A**. In **FIG. 16B**, a relatively thicker  
20 transparent epoxy layer **210** has been added atop transparent substrate **200**. A relatively thinner opaque epoxy layer **212** has been added on transparent epoxy layer **210** as shown in **FIG. 16C**. In **FIG. 16D**, the opaque epoxy layer **212** and the transparent epoxy layer **210** have been machined using any suitable technique to form transparent feature **216**. As an alternate, it may be feasible to machine transparent feature **216** into a transparent epoxy  
25 layer, then coat the tops of the transparent epoxy layer with an opaque epoxy layer.

**FIGS. 17A-17C** illustrate a potential method of forming opaque features on a machinable transparent substrate. **FIG. 17A** shows a machinable transparent substrate **220** that can be formed of a machinable transparent polymer. In some instances, substrate **220** can be formed from PMMA (poly methyl methacrylate). In **FIG. 17B**, an opaque coating  
30 **222** such as sputtered aluminum or copper has been added onto transparent substrate **220**. Alternatively, it is contemplated that opaque coating **222** could also be formed from an

opaque epoxy or even an opaque filled epoxy. As shown in FIG. 17C, a transparent feature 224 can be formed using any suitable machining technique.

FIGS. 18A-C illustrate another potential method of forming opaque features on machinable transparent substrate 220. In FIG. 18B, transparent substrate 220 has been machined using any suitable technique to form transparent feature 226. Subsequently, as shown in FIG. 18C, the portions of transparent substrate 220 beyond transparent feature 226 may be coated with an opaque coating 228.

FIGS. 19A-19D illustrate a potential method of using a separately-created master mold to replicate raised features on a transparent substrate. The raised features can then be coated to be opaque. In FIG. 19A, a master mold 230 can be cut from any suitable material using standard precision machining techniques. Master mold 230 can be seen to include protrusion 232, which will ultimately form a transparent feature.

As seen in FIG. 19B, master mold 230 can be filled with an opaque epoxy material 234 and then is applied to the surface of a desired substrate 236 such as quartz or PMMA as seen in FIG. 19C. The epoxy can be allowed to cure, and then master mold 230 may be removed, as seen in FIG. 19D, leaving substrate 236 having a transparent feature 238 with an opaque layer 234 on either side of the transparent feature 238.

FIGS. 20A-20E illustrate another potential method of using a separately-created master mold to replicate raised features on a transparent substrate. The raised features can then be coated to be opaque. In FIG. 20A, a master mold 240 can be cut from any suitable material using standard precision machining techniques. Master mold 240 can be seen to include protrusion 242, which will ultimately form a transparent feature.

As seen in FIG. 20B, master mold 240 can be filled with a transparent epoxy material 244 and then is applied to the surface of a desired substrate 246 such as quartz or PMMA as seen in FIG. 20C. The epoxy can be allowed to cure, and then master mold 240 may be removed, as seen in FIG. 20D, leaving substrate 246 having a transparent feature 248. As seen in FIG. 20E, an opaque epoxy layer 250 can be applied to transparent epoxy layer 244 on either side of the transparent feature 248.

FIGS. 21A-21D illustrate another potential method of using a separately-created master mold to replicate raised features on a transparent substrate. The raised features can then be coated to be opaque. In FIG. 21A, a master mold 252 can be cut from any

suitable material using standard precision machining techniques. Master mold 252 can be seen to include protrusion 254, which will ultimately form a transparent feature.

As seen in FIG. 21B, master mold 252 has been imprinted directly into a machinable transparent substrate 256. In FIG. 21C, master mold 252 has been removed, leaving transparent substrate 256 including transparent feature 258. As shown in FIG. 21D, transparent substrate 256 can be coated with an opaque epoxy layer 258 on either side of transparent feature 258.

### Casting Apparatus

Referring now to FIGS. 22-23, an example embodiment of a system 110 including a roll to roll casting apparatus 120 is illustrated. In the depicted casting apparatus 120, a web 122 is provided to the casting apparatus 120 from a main unwind spool (not shown). The exact nature of web 122 can vary widely, depending on the product being produced. However, the casting apparatus 120 is capable of handling a web 122 that is both flexible and transparent and/or opaque, as discussed previously. The web 122 is directed around various rollers 126 into the casting apparatus 120.

Accurate tension control of the web 122 is beneficial in achieving optimal results, so the web 122 may be directed over a tension-sensing device (not illustrated). If an optional liner web is used to protect the web 122, the liner web (not illustrated) can be separated at the unwind spool and directed onto a liner web wind-up spool (not shown). The web 122 can be directed via an idler roll to a dancer roller for precision tension control. Idler rollers can direct the web 122 to a position between nip roller 154 and first coating head 156.

A variety of coating methods may be employed. In some embodiments, as illustrated, first coating head 156 is a die coating head. The web 122 then passes between the nip roll 154 and first patterned roll 160. The first patterned roll 160 has a patterned surface 162, and when the web 122 passes between the nip roller 154 and the first patterned roll 160 the material dispensed onto the web 122 by the first coating head 156 is shaped into a negative of patterned surface 162.

While the web 122 is in contact with the first patterned roll 160, material is dispensed from second coating head 164 onto the other surface of web 122. In parallel with the discussion above with respect to the first coating head 156, the second coating head 164 is also a die coating arrangement including a second extruder (not shown) and a



second coating die (not shown). In some embodiments, the material dispensed by the first coating head **156** is a composition including a polymer precursor and intended to be cured to solid polymer with the application of curing energy such as ultraviolet radiation.

Material that has been dispensed onto web **122** by the second coating head **164** is then brought into contact with second patterned roll **174** with a second patterned surface **176**. In parallel with the discussion above, in some embodiments, the material dispensed by the second coating head **164** is a composition including a polymer precursor and intended to be cured to solid polymer with the application of curing energy such as ultraviolet radiation.

At this point, the web **122** has had a pattern applied to both sides. A peel roll **182** may be present to assist in removal of the web **122** from second patterned roll **174**. In some instances, the web tension into and out of the casting apparatus is nearly constant.

The web **122** having a two-sided microreplicated pattern is then directed to a wind-up spool (not shown) via various idler rolls. If an interleave film is desired to protect web **122**, it may be provided from a secondary unwind spool (not shown) and the web and interleave film are wound together on the wind-up spool at an appropriate tension.

Referring to **FIGS. 22-24**, first and second patterned rolls are coupled to first and second motor assemblies **210**, **220**, respectively. Support for the motor assemblies **210**, **220** is accomplished by mounting assemblies to a frame **230**, either directly or indirectly. The motor assemblies **210**, **220** are coupled to the frame using precision mounting arrangements. In the illustrated embodiment, for example, first motor assembly **210** is fixedly mounted to frame **230**. Second motor assembly **220**, which is placed into position when web **122** is threaded through the casting apparatus **120**, may need to be positioned repeatedly and therefore can be movable, both in the cross- and machine direction.

Movable motor arrangement **220** may be coupled to linear slides **222** to assist in repeated accurate positioning, for example, when switching between patterns on the rolls. Second motor arrangement **220** also includes a second mounting arrangement **225** on the backside of the frame **230** for positioning the second patterned roll **174** side-to-side relative to the first patterned roll **160**. In some cases, second mounting arrangement **225** includes linear slides **223** allowing accurate positioning in the cross machine directions.

Referring to **FIG. 25**, a motor mounting arrangement is illustrated. A motor **633** for driving a tool or patterned roll **662** is mounted to the machine frame **650** and connected

through a coupling **640** to a rotating shaft **601** of the patterned roller **662**. The motor **633** is coupled to a primary encoder **630**. A secondary encoder **651** is coupled to the tool to provide precise angular registration control of the patterned roll **662**. Primary **630** and secondary **651** encoders cooperate to provide control of the patterned roll **662** to keep it in registration with a second patterned roll, as will be described further hereinafter.

Reduction or elimination of shaft resonance is important as this is a source of registration error allowing pattern position control within the specified limits. Using a coupling **640** between the motor **633** and shaft **650** that is larger than general sizing schedules specify will also reduce shaft resonance caused by more flexible couplings. Bearing assemblies **660** are located in various locations to provide rotational support for the motor arrangement.

In the example embodiment shown, the tool roller **662** diameter can be smaller than its motor **633** diameter. To accommodate this arrangement, tool rollers may be installed in pairs, arranged in mirror image. In **FIG. 26**, two tool roller assemblies **610**, **710** are installed as mirror images in order to be able to bring the two tool rollers **662**, **762** together. Referring also to **FIG. 22**, the first motor arrangement is typically fixedly attached to the frame and the second motor arrangement is positioned using movable optical quality linear slides.

Tool roller assembly **710** is quite similar to tool roller assembly **610**, and includes a motor **733** for driving a tool or patterned roll **762** is mounted to the machine frame **750** and connected through a coupling **740** to a rotating shaft **701** of the patterned roller **762**. The motor **733** is coupled to a primary encoder **730**. A secondary encoder **751** is coupled to the tool to provide precise angular registration control of the patterned roll **762**. Primary **730** and secondary **751** encoders cooperate to provide control of the patterned roll **762** to keep it in registration with a second patterned roll, as will be described further hereinafter.

Reduction or elimination of shaft resonance is important as this is a source of registration error allowing pattern position control within the specified limits. Using a coupling **740** between the motor **733** and shaft **750** that is larger than general sizing schedules specify will also reduce shaft resonance caused by more flexible couplings. Bearing assemblies **760** are located in various locations to provide rotational support for the motor arrangement.

Because the feature sizes on the microreplicated structures on both surfaces of a web are desired to be within fine registration of one another, the patterned rolls should be controlled with a high degree of precision. Cross-web registration within the limits described herein can be accomplished by applying the techniques used in controlling machine-direction registration, as described hereinafter.

For example, to achieve about 10 micrometers end-to-end feature placement on a 10-inch circumference patterned roller, each roller must be maintained within a rotational accuracy of  $\pm 32$  arc-seconds per revolution. Control of registration becomes more difficult as the speed the web travels through the system is increased.

Applicants have built and demonstrated a system having 10-inch circular patterned rolls that can create a web having patterned features on opposite surfaces of the web that are registered to within 2.5 micrometers. Upon reading this disclosure and applying the principles taught herein, one of ordinary skill in the art will appreciate how to accomplish the degree of registration for other microreplicated surfaces.

Referring to **FIG. 27**, a schematic of a motor arrangement **800** is illustrated. Motor arrangement **800** includes a motor **810** including a primary encoder **830** and a drive shaft **820**. Drive shaft **820** is coupled to a driven shaft **840** of patterned roll **860** through a coupling **825**. A secondary, or load, encoder **850** is coupled to the driven shaft **840**. Using two encoders in the motor arrangement described allows the position of the patterned roll to be measured more accurately by locating the measuring device (encoder) **850** near the patterned roll **860**, thus reducing or eliminating effects of torque disturbances when the motor arrangement **800** is operating.

#### **Apparatus Control**

Referring to **FIG. 28**, a schematic of the motor arrangement of **FIG. 27**, is illustrated as attached to control components. In the example apparatus shown in **FIGS. 1-3**, a similar set-up would control each motor arrangement **210** and **220**. Accordingly, motor arrangement **900** includes a motor **910** including a primary encoder **930** and a drive shaft **920**. Drive shaft **920** is coupled to a driven shaft **940** of patterned roll **960** through a coupling **930**. A secondary, or load, encoder **950** is coupled to the driven shaft **940**.

Motor arrangement **900** communicates with a control arrangement **965** to allow precision control of the patterned roll **960**. Control arrangement **965** includes a drive module **966** and a program module **975**. The program module **975** communicates with the

drive module 966 via a line 977, for example, a SERCOS fiber network. The program module 975 is used to input parameters, such as set points, to the drive module 966. Drive module 966 receives input 480 volt, 3-phase power 915, rectifies it to DC, and distributes it via a power connection 973 to control the motor 910. Motor encoder 912 feeds a position signal to control module 966 via line 972. The secondary encoder 950 on the patterned roll 960 also feeds a position signal back to the drive module 966 via to line 971. The drive module 966 uses the encoder signals to precisely position the patterned roll 960. The control design to achieve the degree of registration is described in detail below.

In the illustrative embodiments shown, each patterned roll is controlled by a dedicated control arrangement. Dedicated control arrangements cooperate to control the registration between first and second patterned rolls. Each drive module communicates with and controls its respective motor assembly.

The control arrangement in the system built and demonstrated by Applicants include the following. To drive each of the patterned rolls, a high performance, low cogging torque motor with a high-resolution sine encoder feedback (512 sine cycles x 4096 drive interpolation >> 2 million parts per revolution) was used, model MHD090B-035-NG0-UN, available from Bosch-Rexroth (Indramat). Also the system included synchronous motors, model MHD090B-035-NG0-UN, available from Bosch-Rexroth (Indramat), but other types, such as induction motors could also be used.

Each motor was directly coupled (without gearbox or mechanical reduction) through an extremely stiff bellows coupling, model BK5-300, available from R/W Corporation. Alternate coupling designs could be used, but bellows style generally combines stiffness while providing high rotational accuracy. Each coupling was sized so that a substantially larger coupling was selected than what the typical manufacturers specifications would recommend.

Additionally, zero backlash collets or compressive style locking hubs between coupling and shafts are preferred. Each roller shaft was attached to an encoder through a hollow shaft load side encoder, model RON255C, available from Heidenhain Corp., Schaumburg, IL. Encoder selection should have the highest accuracy and resolution possible, typically greater than 32 arc-sec accuracy. Applicants' design, 18000 sine cycles per revolution were employed, which in conjunction with the 4096 bit resolution drive interpolation resulted in excess of 50 million parts per revolution resolution giving a

resolution substantially higher than accuracy. The load side encoder had an accuracy of +/- 2 arc-sec; maximum deviation in the delivered units was less than +/- 1 arc-sec.

In some instances, each shaft may be designed to be as large a diameter as possible and as short as possible to maximize stiffness, resulting in the highest possible resonant  
5 frequency. Precision alignment of all rotational components is desired to ensure minimum registration error due to this source of registration error.

Referring to **FIG. 29**, identical position reference commands were presented to each axis simultaneously through a SERCOS fiber network at a 2 ms update rate. Each axis interpolates the position reference with a cubic spline, at the position loop update rate  
10 of 250 microsecond intervals. The interpolation method is not critical, as the constant velocity results in a simple constant times time interval path. The resolution is critical to eliminate any round off or numerical representation errors. Axis rollover is also addressed. In some cases, it is important that each axis' control cycle is synchronized at the current loop execution rate (62 microsecond intervals).

15 The top path **1151** is the feed forward section of control. The control strategy includes a position loop **1110**, a velocity loop **1120**, and a current loop **1130**. The position reference **1111** is differentiated, once to generate the velocity feed forward terms **1152** and a second time to generate the acceleration feed forward term **1155**. The feed forward path **1151** helps performance during line speed changes and dynamic correction.

20 The position command **1111** is subtracted from current position **1114**, generating an error signal **1116**. The error **1116** is applied to a proportional controller **1115**, generating the velocity command reference **1117**. The velocity feedback **1167** is subtracted from the command **1117** to generate the velocity error signal **1123**, which is then applied to a PID controller. The velocity feedback **1167** is generated by  
25 differentiating the motor encoder position signal **1126**. Due to differentiation and numerical resolution limits, a low pass Butterworth filter **1124** is applied to remove high frequency noise components from the error signal **1123**. A narrow stop band (notch) filter **1129** is applied at the center of the motor – roller resonant frequency. This allows substantially higher gains to be applied to the velocity controller **1120**. Increased  
30 resolution of the motor encoder also would improve performance. The exact location of the filters in the control diagram is not critical; either the forward or reverse path are acceptable, although tuning parameters are dependent on the location.

A PID controller could also be used in the position loop, but the additional phase lag of the integrator makes stabilization more difficult. The current loop is a traditional PI controller; gains are established by the motor parameters. The highest bandwidth current loop possible will allow optimum performance. Also, minimum torque ripple is desired.

5           Minimization of external disturbances is important to obtaining maximum registration. This includes motor construction and current loop commutation as previously discussed, but minimizing mechanical disturbances is also important. Examples include extremely smooth tension control in entering and exiting web span, uniform bearing and seal drag, minimizing tension upsets from web peel off from the roller, uniform rubber nip  
10 roller. In the current design a third axis geared to the tool rolls is provided as a pull roll to assist in removing the cured structure from the tool.

#### **Web Material**

The web material can be any suitable material on which a microreplicated patterned structure can be created. A number of different materials may be used,  
15 depending on the ultimate use of the microreplicated patterned structure. If, for example, the microreplicated patterned structure will form a flexible circuit board, the web material may be a metallized polymeric film such as metallized KAPTON.

#### **Coating Material**

The liquid from which the microreplicated structures are created can be a curable  
20 photocurable material, such as acrylates curable by UV light. One of ordinary skill in the art will appreciate that other coating materials can be used, for example, polymerizable material, and selection of a material will depend on the particular characteristics desired for the microreplicated structures. For example, if a flexible circuit board is being made, the coating material may include a conductive or insulating polymer. In some  
25 embodiments, the coating material includes an electroplate masking material and/or nonconductive or insulating polymers.

Examples of coating means that useful for delivering and controlling liquid to the web or patterned roll are, for example, die or knife coating, coupled with any suitable pump such as a syringe or peristaltic pump. One of ordinary skill in the art will appreciate  
30 that other coating means can be used, and selection of a particular means will depend on the particular characteristics of the liquid to be delivered to the web or patterned roll.

Examples of curing energy sources are infrared radiation, ultraviolet radiation, visible light radiation, or microwave. One of ordinary skill in the art will appreciate that other curing sources can be used, and selection of a particular web material/curing source combination will depend on the particular article (having microreplicated structures in registration) to be created.

#### **Microreplicated Article**

**FIG. 30** schematically illustrates a contemplated coated microreplicated article **1200** formed according to the methods and using the apparatus described herein. Article **1200** includes a flexible opaque web **1202** and a number of schematic elements disposed on either side of opaque web **1202**. Element **1204** is disposed opposite element **1206**. Similarly, element **1208**, element **1212** and element **1216** are disposed opposite element **1210**, element **1214** and element **1218**, respectively. It should be noted that these elements can be considered as generically representing a number of different potential elements. These elements may be circuitry, for example. In some embodiments, the microreplicated pattern includes an electroplate mask that can pass through an additive circuit plating step.

In some embodiments, such as that illustrated, there may be little or no lands between adjacent elements. For example, there may be little or no coated material remaining on opaque web **1202** between element **1204** and element **1208**. This may have advantages if, for example, the coated material is an electrically conductive material or an electroplate mask. In some embodiments, an additional washing step can remove uncured material from the microreplicated pattern to produce a microreplicated features having no land areas and separated from one another. In other instances, article **1202** may include lands, i.e. coated material remaining on opaque web **1202** between adjacent elements.

#### **Example**

**FIGS. 4-13** illustrate an additive process for forming a patterned roll much like patterned roll of **FIG. 3**. Quartz tubes 3 inches long and 3 inches in radius were cleaned with water, acetone and methyl ethyl ketone (MEK), and were then placed under a UV lamp for 15 minutes. The quartz tubes were then mounted on a rotating table in a high vacuum sputter chamber, and the pressure within the chamber was slowly reduced to  $1 \times 10^{-6}$  Torr over a period of one hour. A strip of chrome plated steel previously mounted within the chamber was electrically connected to an arc welder. The arc welder passed a

current through the metal strip and the metal strip was thus heated to red hot. The rotating quartz tubes were washed by the resulting IR radiation for 10 minutes.

Once the quartz tubes were cleaned, a quartz cylinder **102** as seen in **FIG. 4** was sputtered with a thin layer **104** of chrome, which acts as an adhesion layer between the quartz and the nickel layer to follow.

Next, and as shown schematically in **FIG. 5**, a nickel metallization layer **110** was sputtered onto the chrome tie layer **104**.

Next, and as shown schematically in **FIG. 6**, a protective copper layer **112** was applied over the nickel metallization layer **110**. The copper layer **112** was a sacrificial layer that was intended to protect the nickel layer **110** from contamination and oxidation during subsequent processing steps.

Next, and as shown schematically in **FIG. 7**, a photoresist (SC Resists, Arch Semiconductor Photopolymers Company) layer **114** has been added on top of the copper layer **112**. The height of the photoresist layer **114** ultimately sets the height of the features being formed on quartz cylinder **102**. In the Example, the photoresist layer **114** was formed to be 50 micrometers thick, and was softbaked at 115 degrees Celsius for 30 seconds prior to exposure.

Next, and as shown schematically in **FIG. 8**, the photoresist layer **114** was patterned by shining light in a desired pattern onto the photoresist layer **114**. Consequently, the photoresist layer **114** now has portions **116** that will remain, and portions **118** that will be removed after developing.

Next, and as shown schematically in **FIG. 9**, the photoresist was developed. After sitting for at least 30 minutes, the photoresist was subjected to a post exposure bake at 115 degrees Celsius for 1 minute. The photoresist was then developed via exposure to developing solution for 30 to 60 seconds. Consequently, resist portions **116** remain on copper layer **112** while resist portions **118** have been removed.

Next, and as shown schematically in **FIG. 10**, the exposed portions of copper layer **112** were removed in an etching process. Sodium persulfate was used to remove the exposed copper because sodium persulfate reacts quickly with copper but slowly with the chrome underlying the copper, as it is desirable to keep the chrome layer as thick as possible.



Next, and as shown schematically in **FIG. 11**, chrome sections **120** were plated onto the freshly exposed chrome layer **110**, in between resist regions **116**. Chrome sections **120** were plated using low current densities on the order of  $1\text{mA}/17\text{mm}^2$ . As the current density increases, even at levels as low as  $20\text{mA}/17\text{mm}^2$ , either internal stress was high, causing the chrome to peel off, or severe pitting occurred. The geometry of chrome sections **120** were determined by resist regions **116**.

Next, and as shown schematically in **FIG. 12**, the remaining cured photoresist, in resist regions **116**, were removed using a basic solution. Finally, and as shown schematically in **FIG. 13**, the remaining copper layer **112** was removed using a sodium persulfate bath as discussed above. The resulting patterned roll has opaque regions corresponding to nickel **110** and chrome sections **120**, and transparent regions corresponding to where tie layer **104** is not covered by opaque material.

The disclosure should not be considered limited to the particular examples described above, but rather should be understood to cover all aspects of the disclosure as set out in the attached claims. Various modifications, equivalent processes, as well as numerous structures to which the disclosure can be applicable will be readily apparent to those of skill in the art upon review of the instant specification.

**WE CLAIM:**

1. A microreplicated article comprising:  
a flexible opaque substrate having a first surface and a second surface;  
5 a first coated microreplicated pattern on the first surface; and  
a second coated microreplicated pattern on the second surface, wherein the first  
and second patterns are registered to within 100 micrometers.
2. The article of claim 1, wherein the first and second patterns are registered  
10 to within 10 micrometers.
3. The article of claim 1, wherein the first and second patterns are registered  
to within 5 micrometers.
4. The article of claims 1 to 3, wherein the flexible opaque substrate is opaque  
15 to ultraviolet light.
5. The article of claim 4, wherein the flexible opaque substrate blocks at least  
98 percent of ultraviolet light that is incident upon the flexible opaque substrate.  
20
6. The article of claims 1 to 5, wherein the flexible opaque substrate  
comprises polymer suitable for forming a flexible circuit board.
7. The article of claim 6, wherein the flexible opaque substrate comprises a  
25 metallized polymer.
8. The article of claims 1 to 7, wherein the first coated microreplicated pattern  
comprises a photocurable polymer.
9. The article of claims 1 to 8, wherein the second coated microreplicated  
30 pattern comprises a photocurable polymer.

10. The article of claims 1 to 9, wherein the first coated microreplicated pattern comprises a plurality of distinct elements, and at least some of the distinct elements are discontinuous from other distinct elements.
11. The article of claims 1 to 10, wherein the second coated microreplicated pattern comprises a plurality of distinct elements, and at least some of the distinct elements are discontinuous from other distinct elements.
12. A method of making a microreplicated article including an opaque web having a first surface and an opposing second surface, the method comprising:  
    passing an opaque web having a first surface and an opposing second surface through a casting apparatus having a first patterned roll and a second patterned roll;  
    contacting a first liquid with the first patterned roll and the first surface;  
    curing the first liquid to create a first microreplicated pattern;  
    contacting a second liquid with the second patterned roll and the second surface while the first microreplicated pattern is in contact with the first pattern roll; and  
    curing the second liquid to create a second microreplicated pattern, wherein the first and second patterns are registered to within 100 micrometers.
13. The method of claim 12, wherein contacting the first liquid comprises contacting a photocurable acrylate resin with the first patterned roll and the first surface.
14. The method of claims 12 or 13, wherein contacting the second liquid comprises contacting a photocurable acrylate resin with the second patterned roll and the second surface.
15. The method of claims 12 to 14, wherein contacting the first liquid comprises contacting a photocurable insulating polymer with the second patterned roll and the second surface.

16. The method of claims 12 to 15, wherein contacting the second liquid comprises contacting a photocurable insulating polymer with the second patterned roll and the second surface.

17. A method of making a microreplicated article comprising an opaque web having a first side and an opposing second side, the method comprising steps of:

disposing curable material onto a web having a first side and an opposing second side, or onto a first patterned roll and second patterned roll;

directing the opaque web into contact with the first patterned roll, the first patterned roll comprising a first plurality of opaque regions disposed on a transparent substrate;

curing the curable material on the first side of the web to form a first microreplicated pattern;

directing the opaque web into contact with the second patterned roll, the second patterned roll comprising a second plurality of opaque regions disposed on a transparent substrate; and

curing the curable material on the second side of the web to form a second microreplicated pattern;

wherein the first and second sides of the web are patterned while the web is in continuous motion such that the first and second patterns are maintained in continuous registration to within 100 micrometers.

18. The method of claim 17, wherein the first and second patterns are transferred to first and second sides of the web in registration to within 5 micrometers.

19. The method of claim 18, wherein disposing curable material onto the web comprises:

disposing curable material onto the first side of the web prior to the first side of the web contacting the first patterned roll; and

disposing curable material onto the second side of the web prior to the second side of the web contacting the second patterned roll.

20. The method of claims 18 or 19, wherein disposing curable material onto the first patterned roll and second patterned roll comprises:

disposing curable material onto a first patterned roll prior to the first side of the web contacting the first patterned roll; and

disposing curable material onto the second patterned roll prior to the second side of the web contacting the second patterned roll.

21. The method of claims 17 to 20, wherein at least a portion of curing the curable material on the first side of the web occurs simultaneously with at least a portion of curing the curable material on the second side of the web.

22. The method of claims 17 to 21, wherein curing the curable material on the first side of the web comprises subjecting the curable material to ultraviolet radiation that passes at least partially through the first patterned roll.

23. The method of claim 17 to 22, wherein curing the curable material on the second side of the web comprises subjecting the curable material to ultraviolet radiation that passes at least partially through the second patterned roll.

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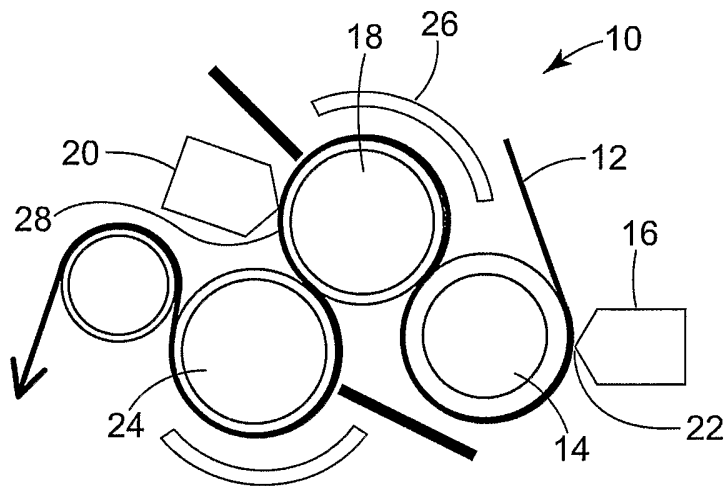


FIG. 1

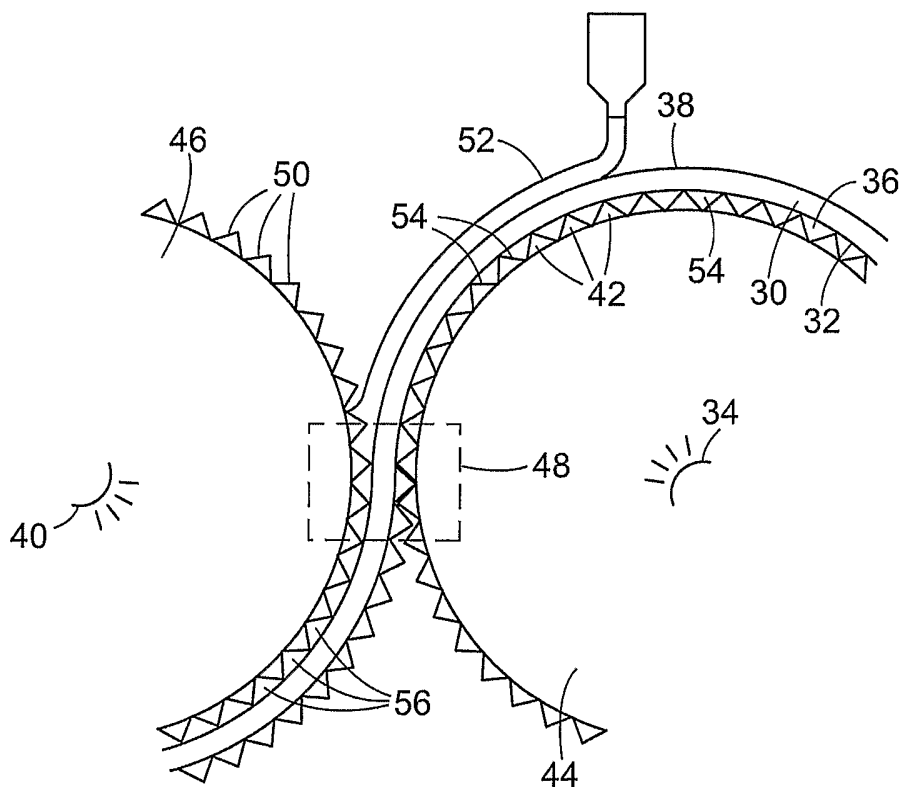
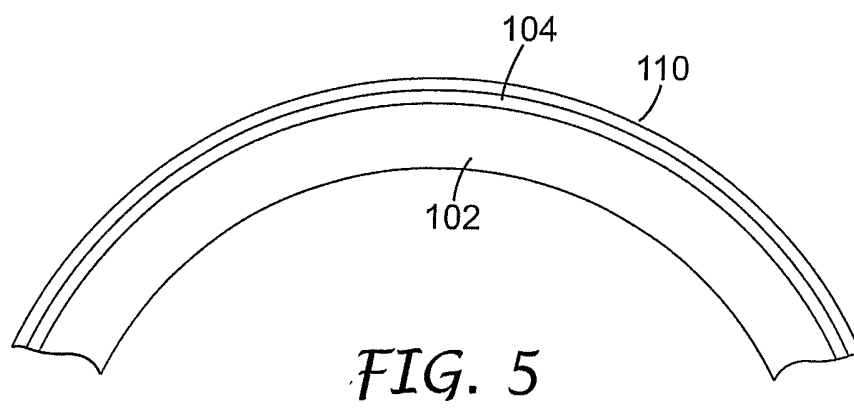
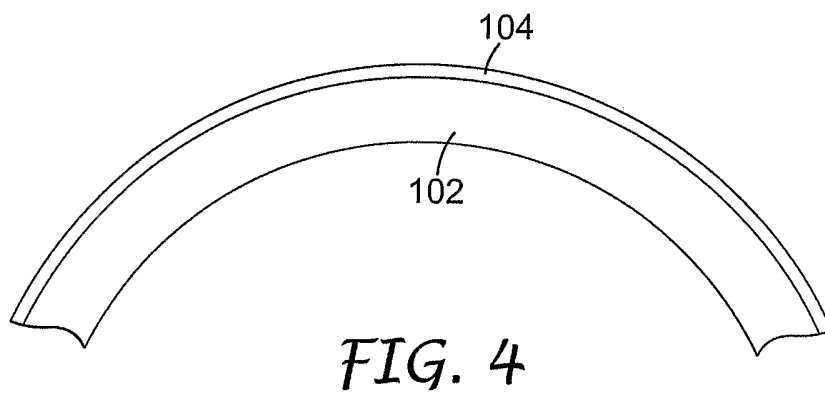
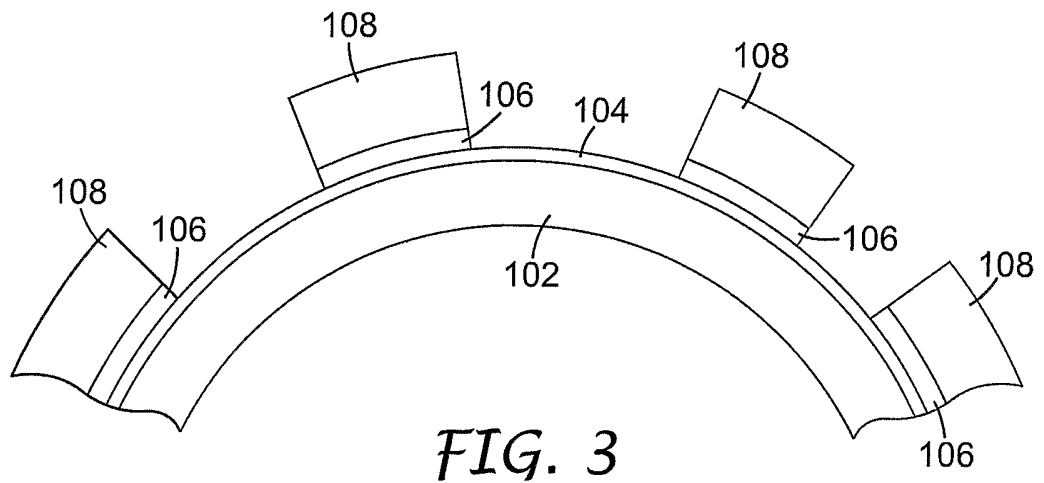


FIG. 2



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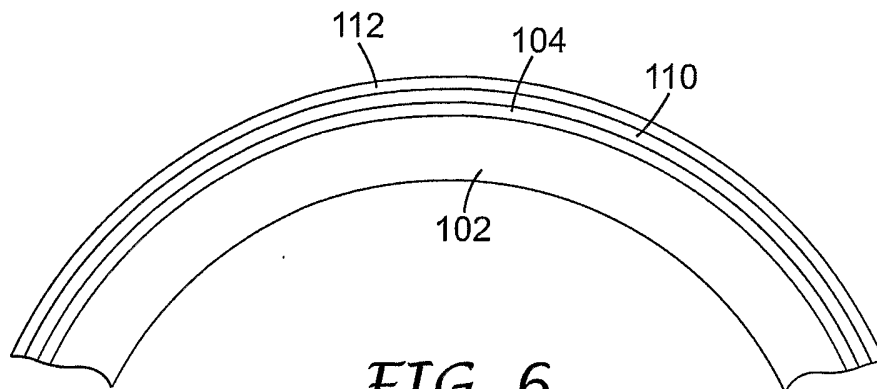


FIG. 6

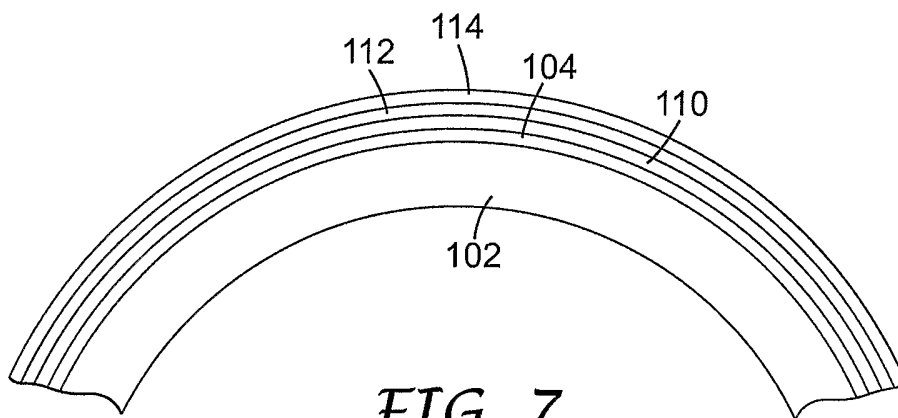


FIG. 7

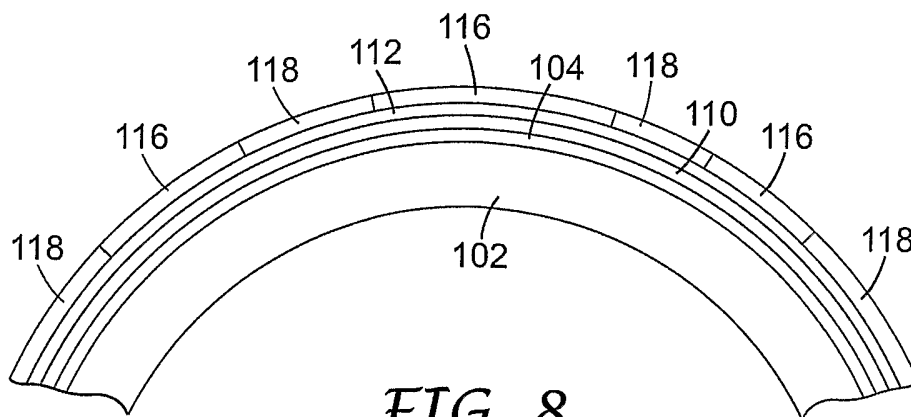
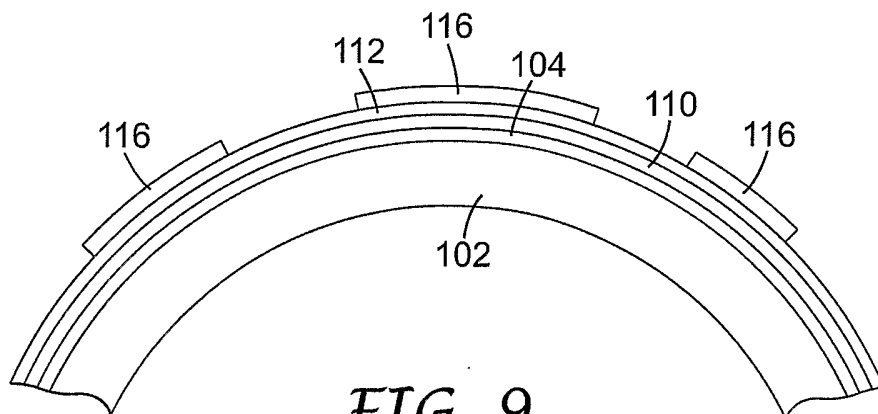
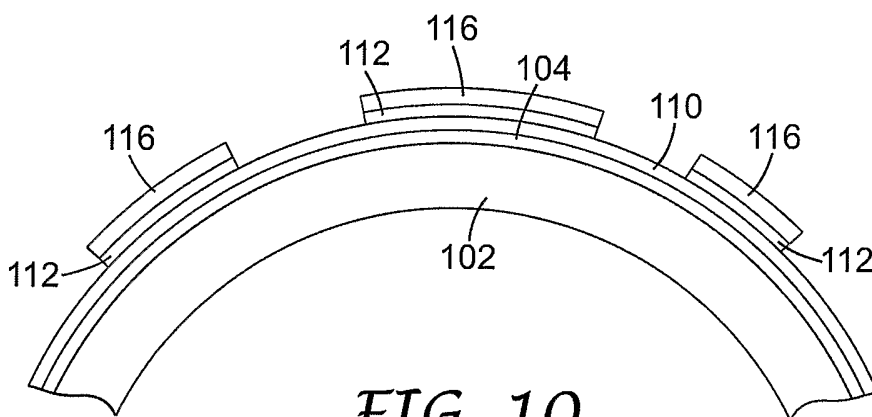


FIG. 8

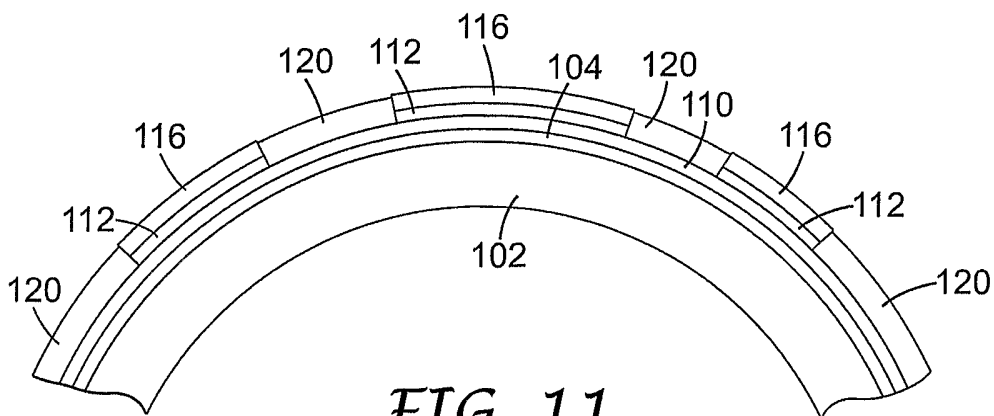




**FIG. 9**

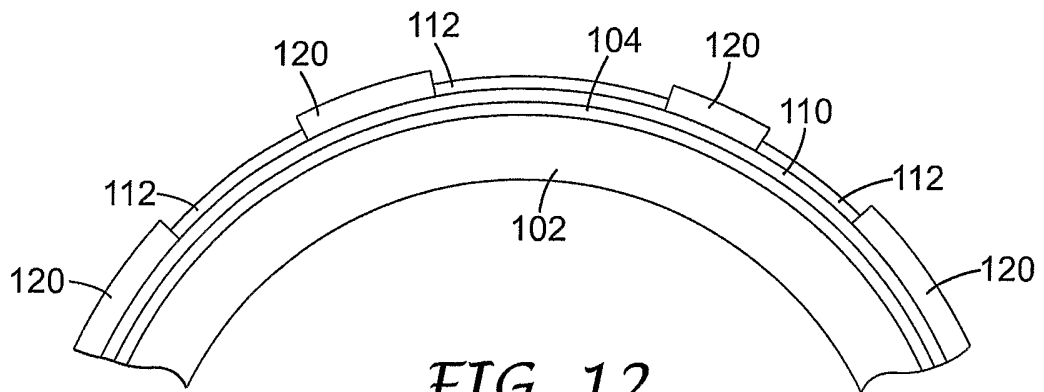


**FIG. 10**

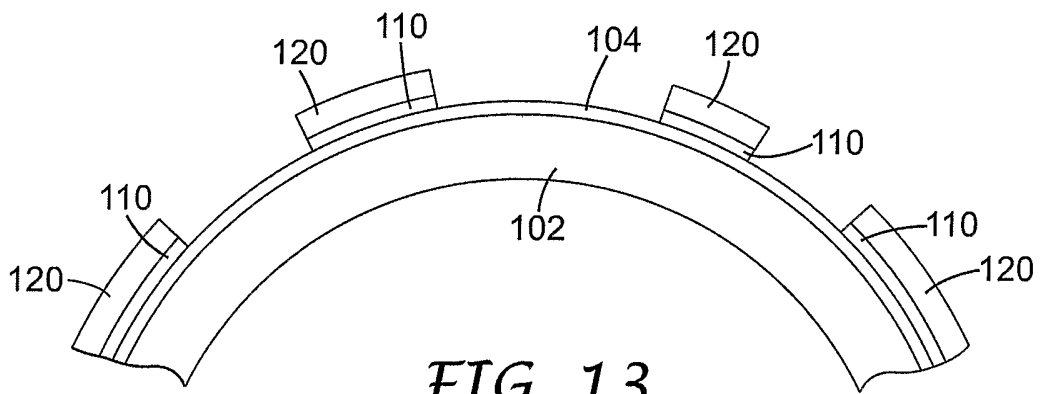


**FIG. 11**

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*FIG. 12*



*FIG. 13*

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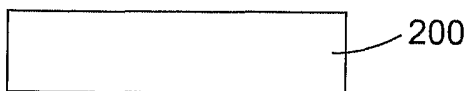


FIG. 14A

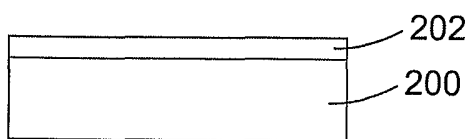


FIG. 14B

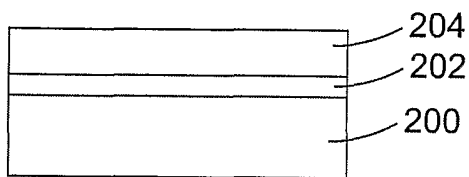


FIG. 14C

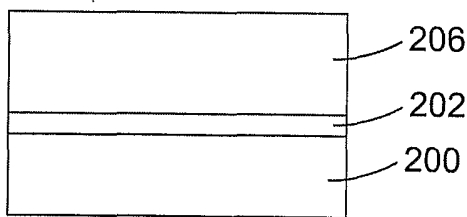


FIG. 14D

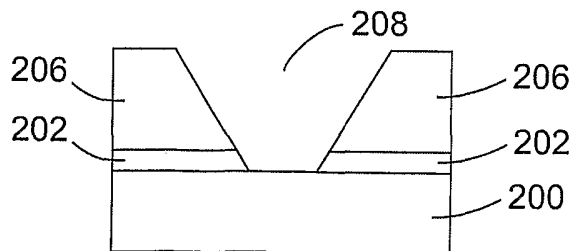


FIG. 14E

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FIG. 15A

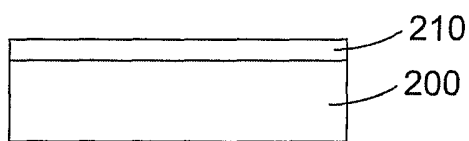


FIG. 15B

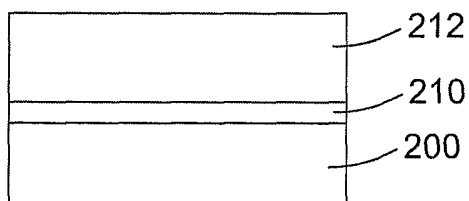


FIG. 15C

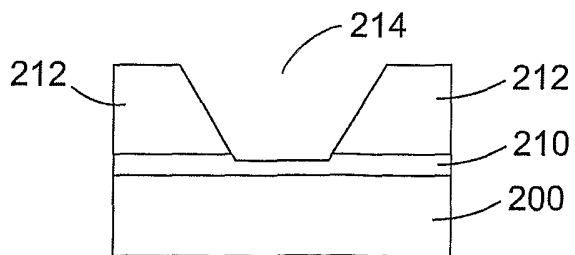


FIG. 15D

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FIG. 16A

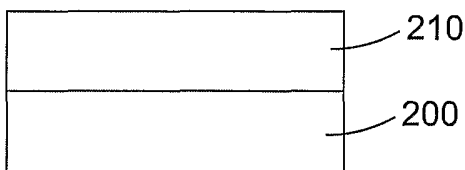


FIG. 16B

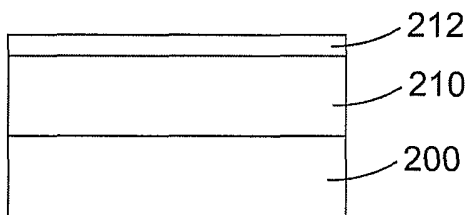


FIG. 16C

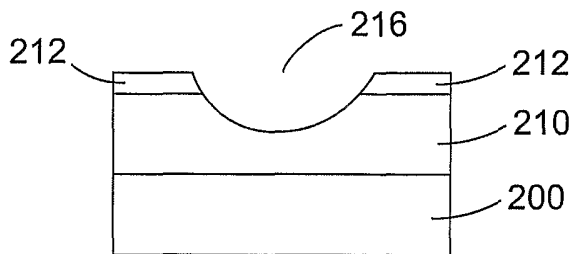


FIG. 16D

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FIG. 17A

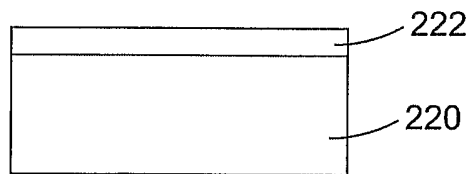


FIG. 17B

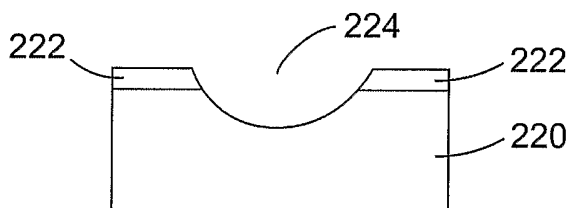


FIG. 17C

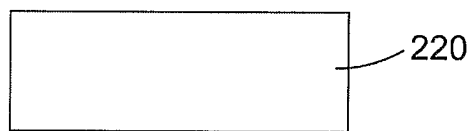


FIG. 18A

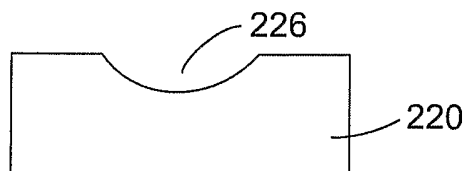


FIG. 18B

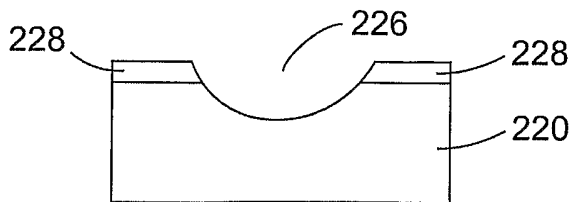


FIG. 18C

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FIG. 19A

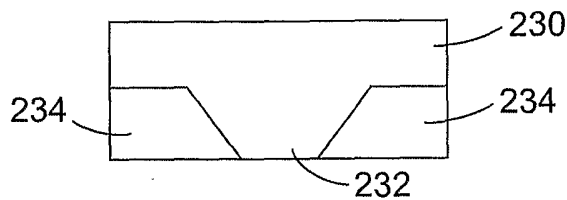


FIG. 19B

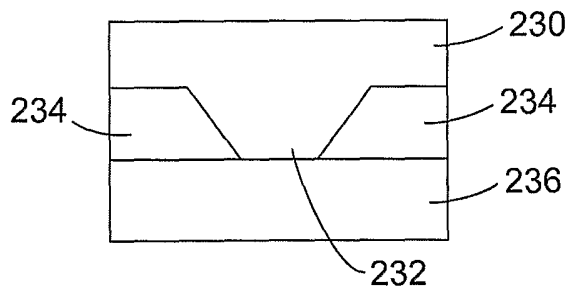


FIG. 19C

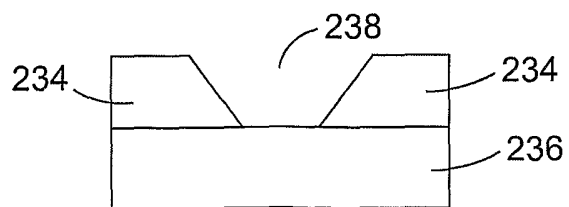


FIG. 19D

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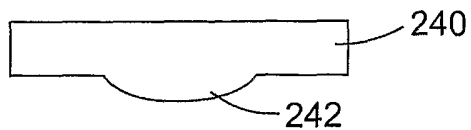


FIG. 20A

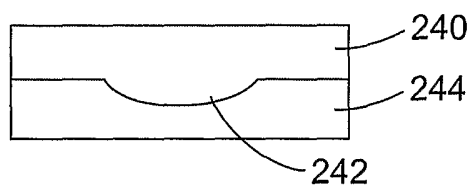


FIG. 20B

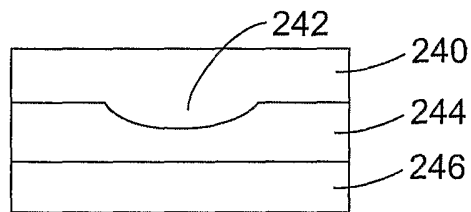


FIG. 20C

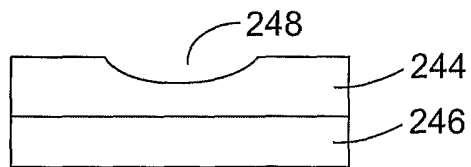


FIG. 20D

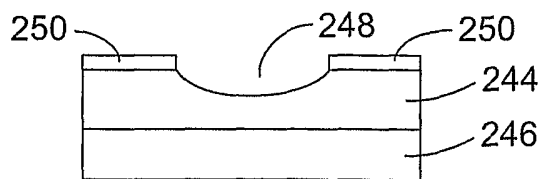


FIG. 20E



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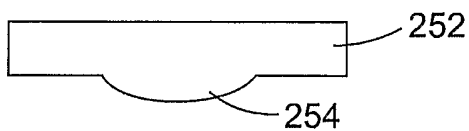


FIG. 21A

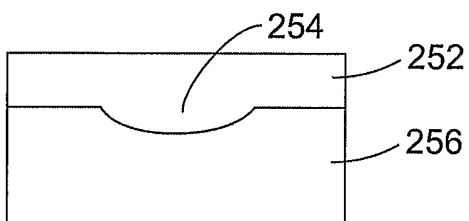


FIG. 21B

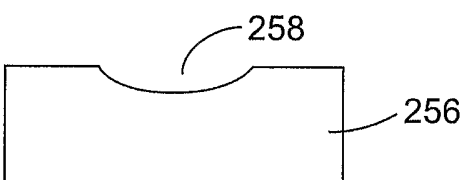


FIG. 21C

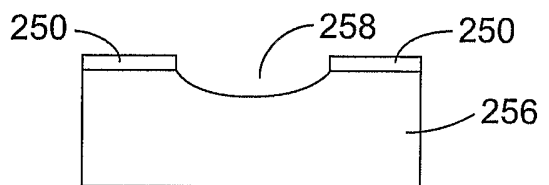


FIG. 21D

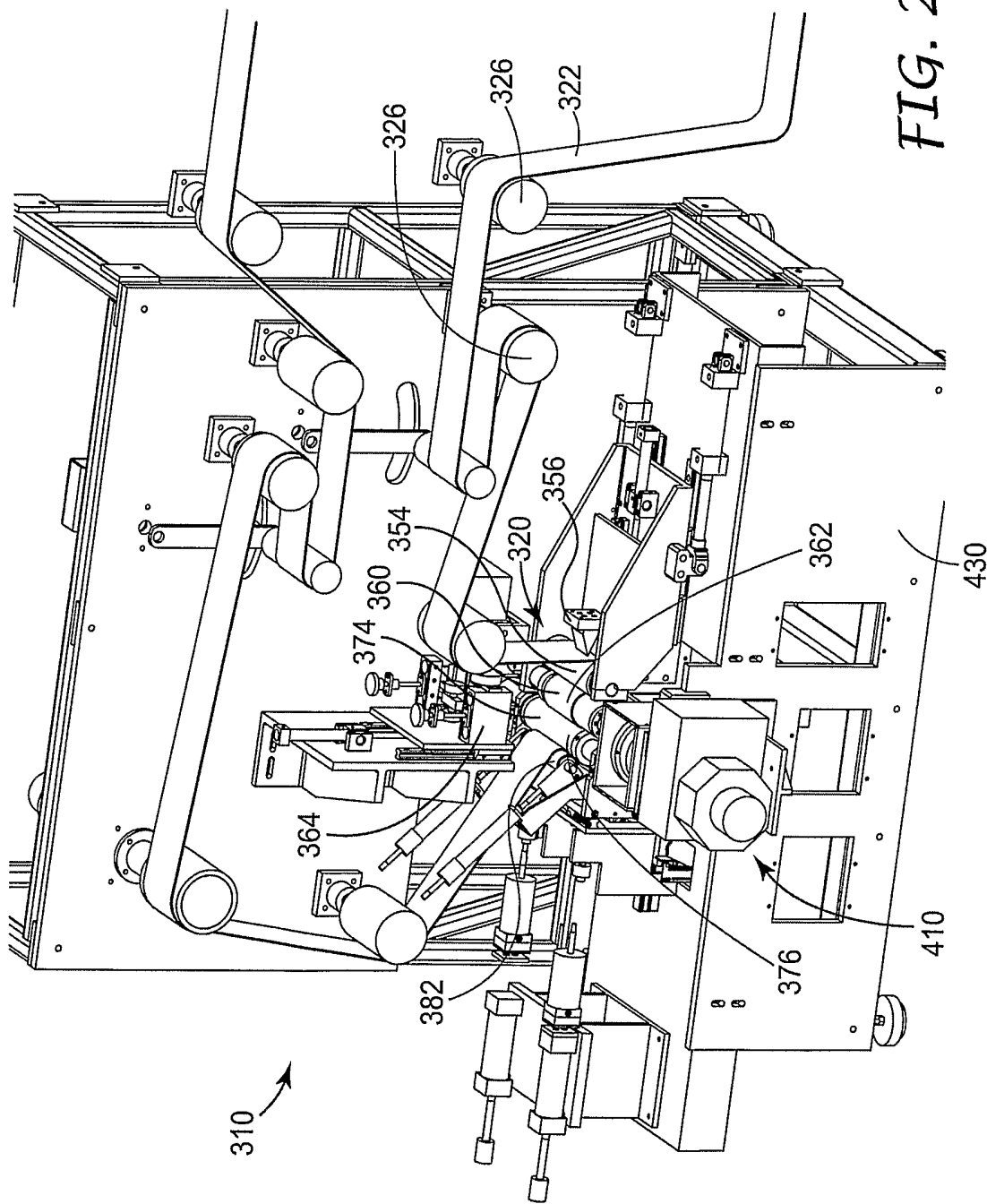


FIG. 22

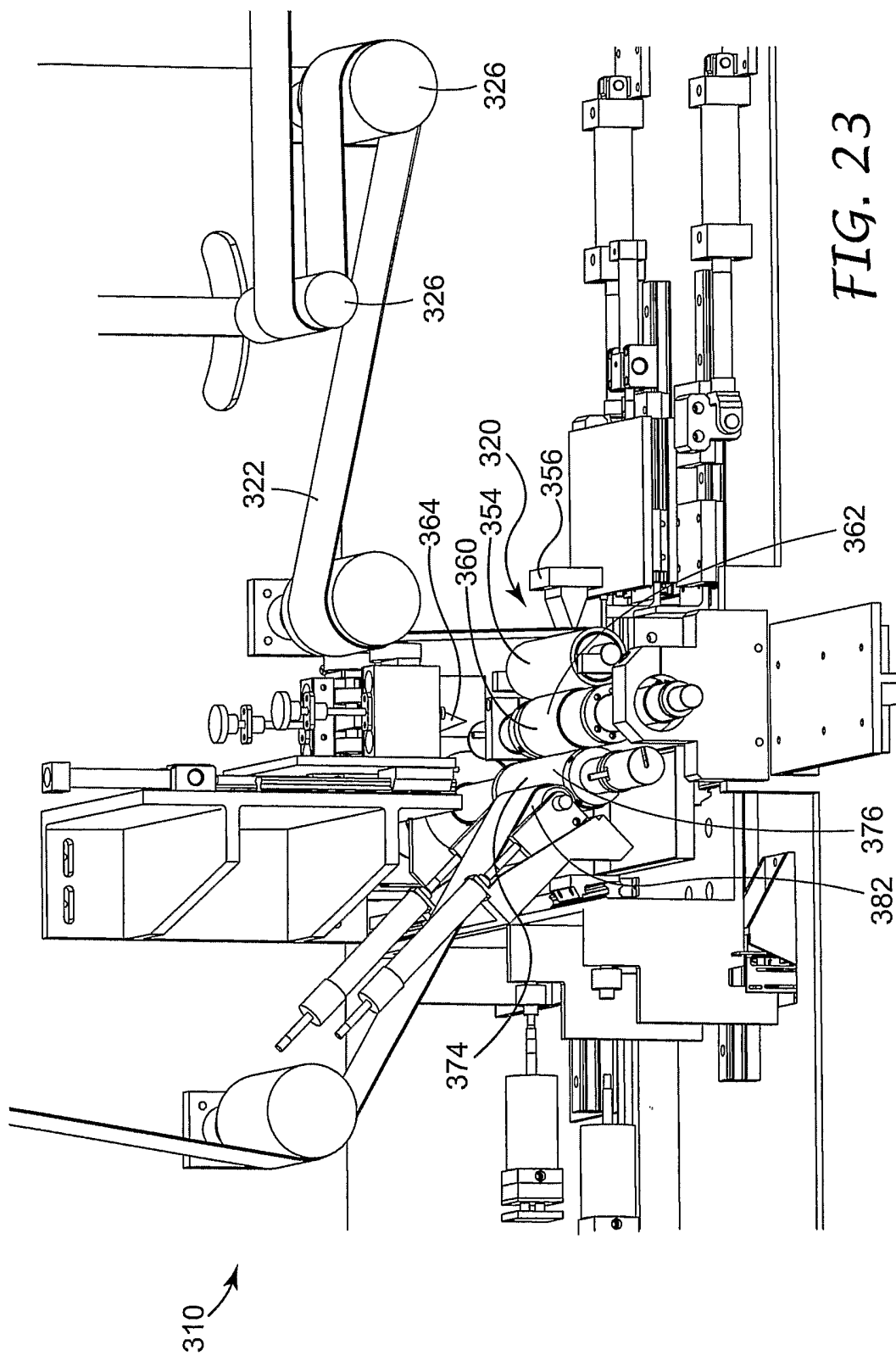


FIG. 23

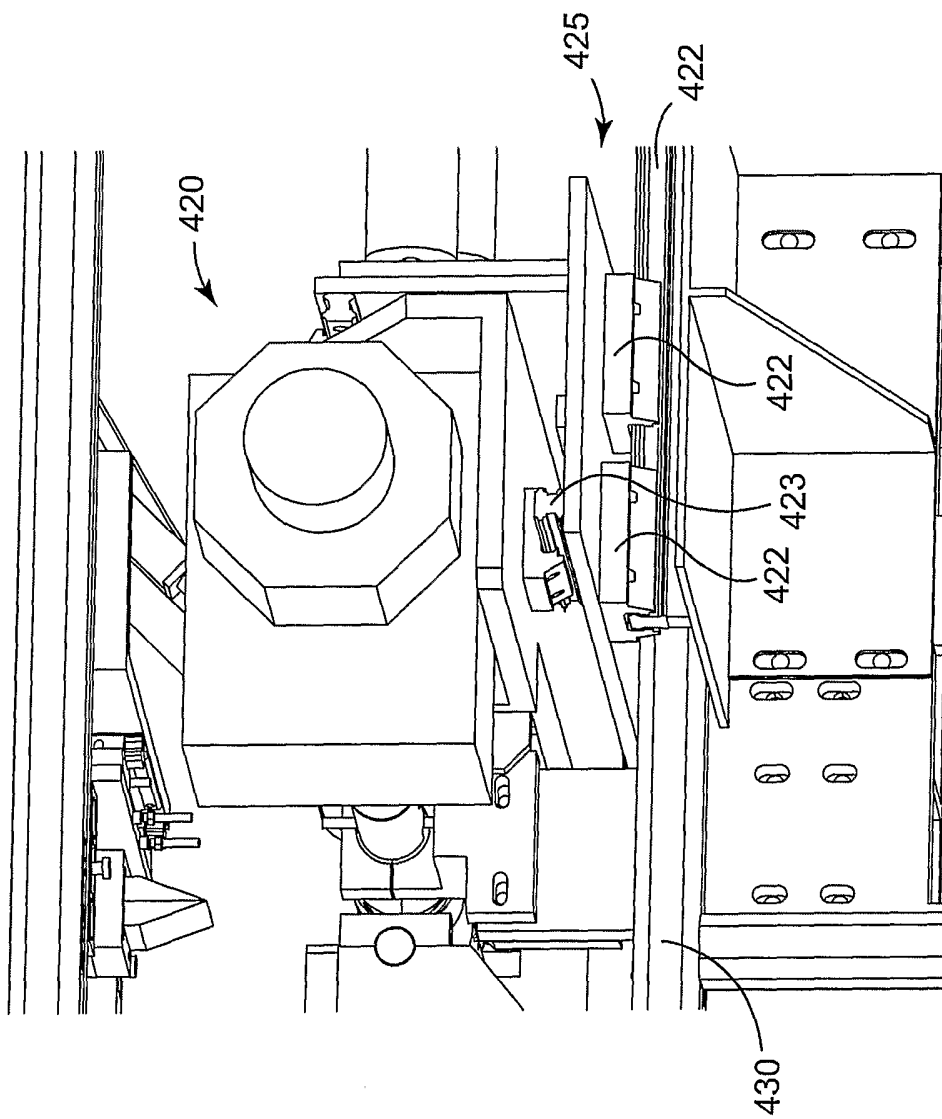


FIG. 24

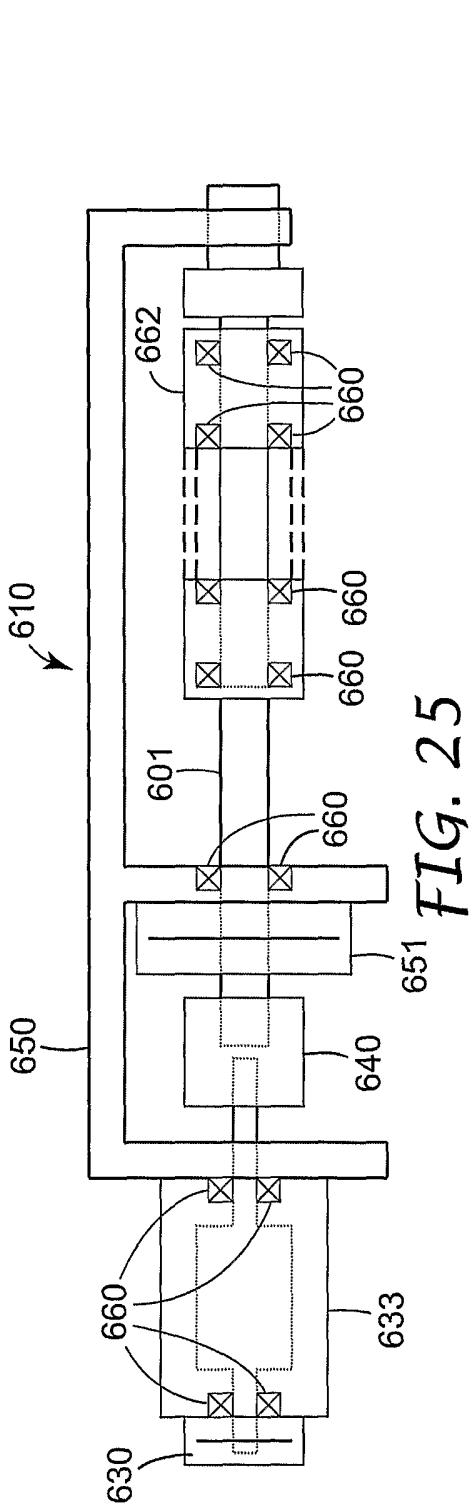


FIG. 25

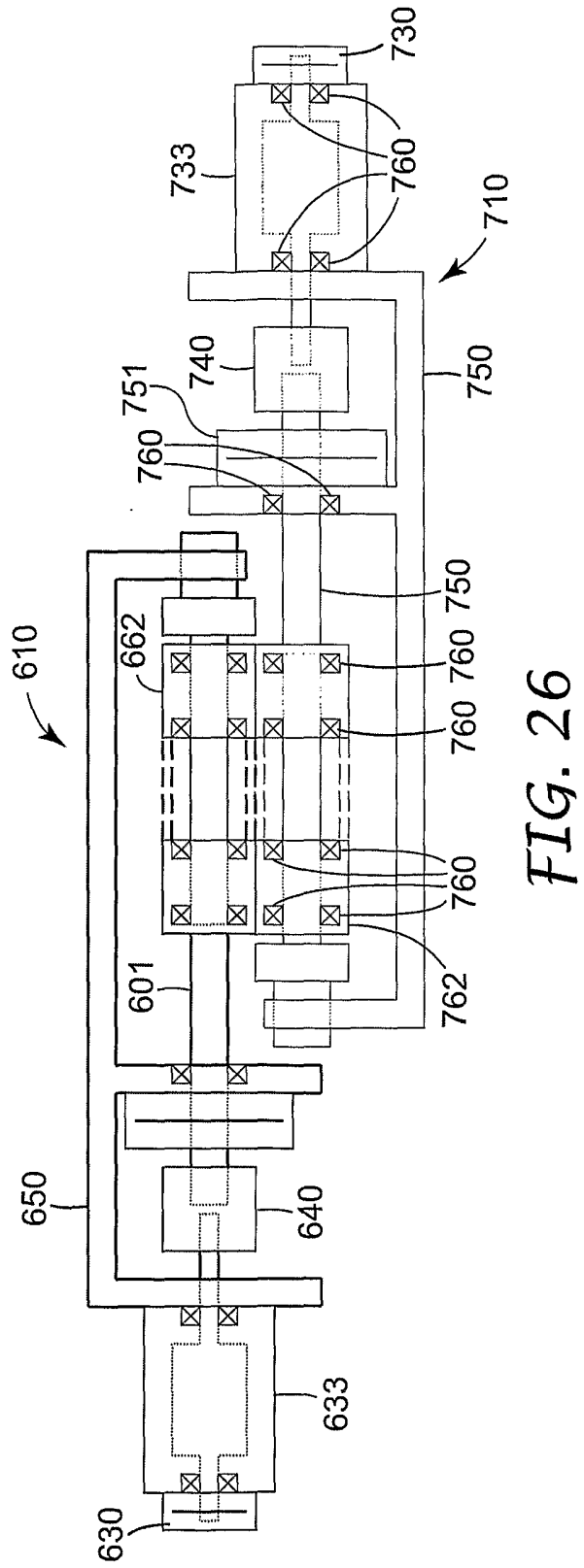


FIG. 26

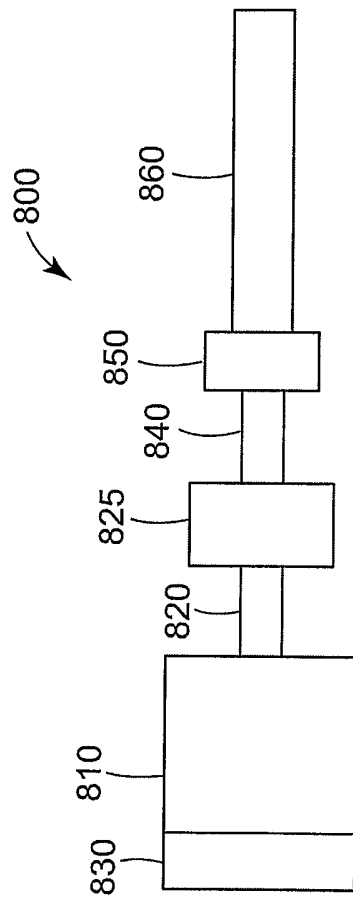


FIG. 27

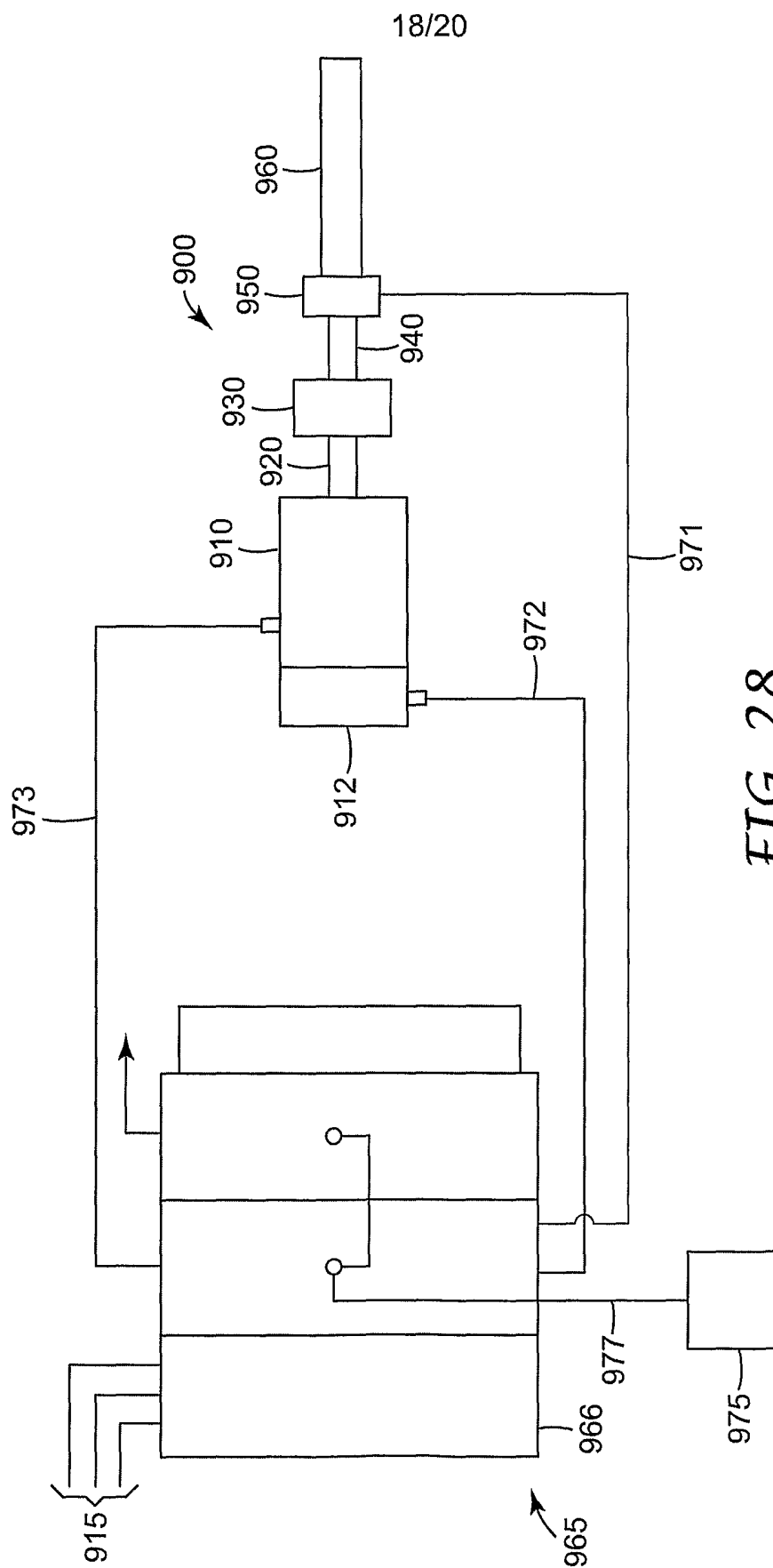


FIG. 28

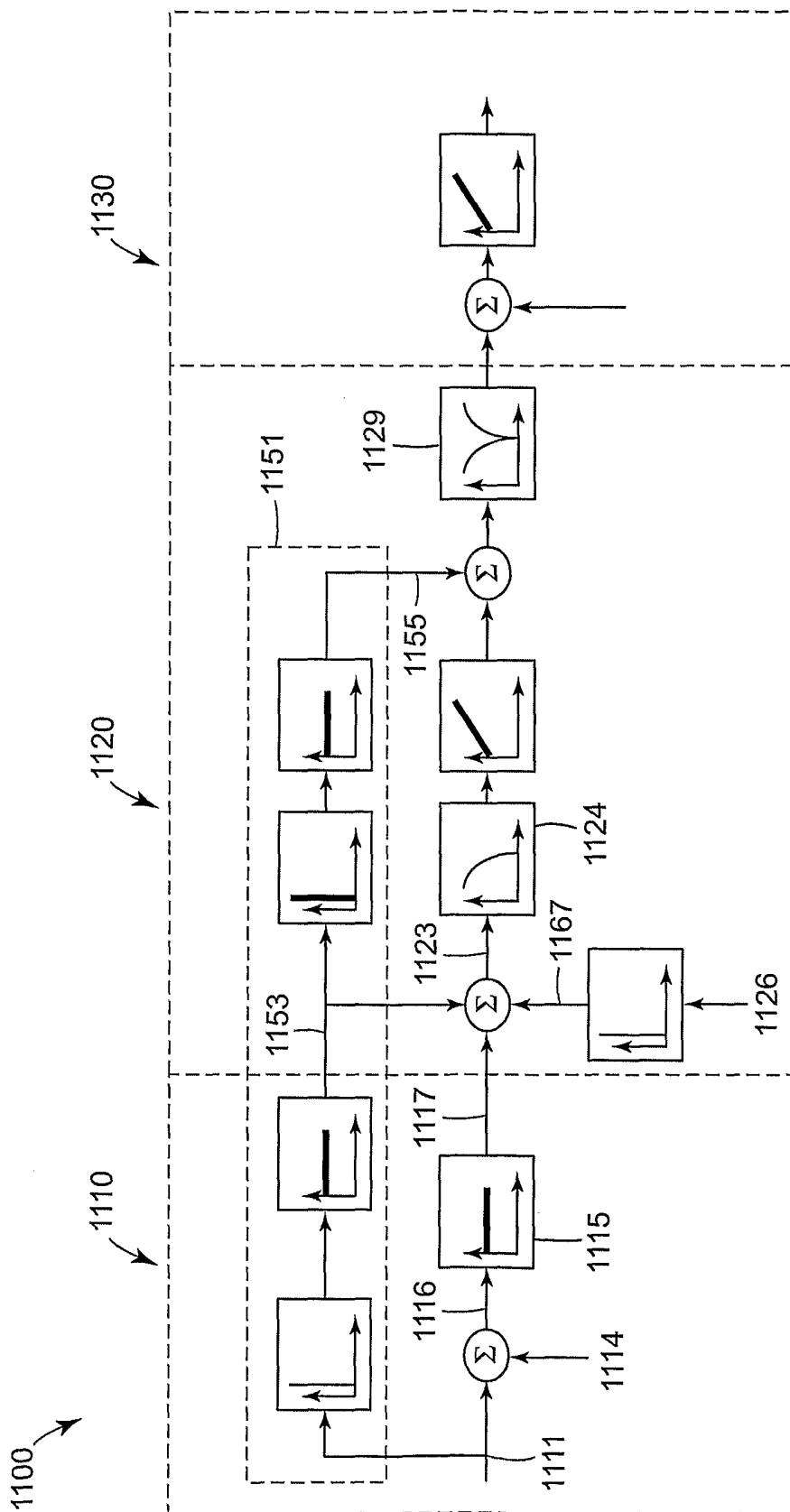
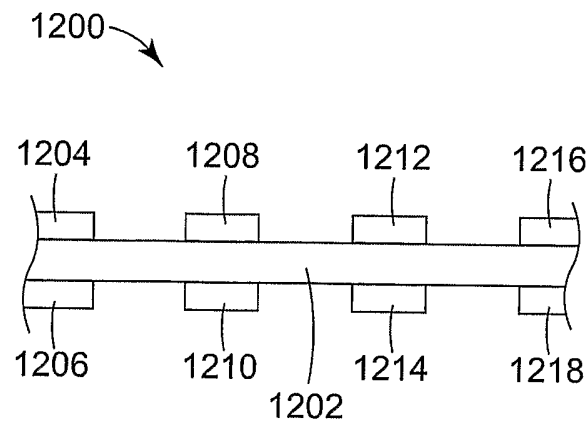


FIG. 29





*FIG. 30*

# INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2006/007975

<b>A. CLASSIFICATION OF SUBJECT MATTER</b> INV. B05D1/28      B05D1/26      B29C59/04				
According to International Patent Classification (IPC) or to both national classification and IPC				
<b>B. FIELDS SEARCHED</b>				
Minimum documentation searched (classification system followed by classification symbols) B05D B29C				
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched				
Electronic data base consulted during the international search (name of data base and, where practical, search terms used) EPO-Internal				
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>				
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.		
A	US 5 330 799 A (SANDOR ET AL) 19 July 1994 (1994-07-19) figures 8,9	1-23		
A	EP 0 623 440 A (N.V. PHILIPS' GLOEILAMPENFABRIEKEN; KONINKLIJKE PHILIPS ELECTRONICS N.) 9 November 1994 (1994-11-09) figure 1	22,23		
A	US 4 892 336 A (KAULE ET AL) 9 January 1990 (1990-01-09) figure 9	1-23		
P,X	WO 2005/025845 A (3M INNOVATIVE PROPERTIES COMPANY) 24 March 2005 (2005-03-24) the whole document	1-4, 8-19,21		
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<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C.				
<input checked="" type="checkbox"/> See patent family annex.				
* Special categories of cited documents :				
<table style="width: 100%; border: none;"> <tr> <td style="width: 50%; border: none; vertical-align: top;">                     *A* document defining the general state of the art which is not considered to be of particular relevance                      *E* earlier document 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                 </td> <td style="width: 50%; border: none; vertical-align: top;">                     *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.                      *&amp;* document member of the same patent family                 </td> </tr> </table>			*A* document defining the general state of the art which is not considered to be of particular relevance *E* earlier document 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
*A* document defining the general state of the art which is not considered to be of particular relevance *E* earlier document 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	Date of mailing of the international search report			
13 June 2006	04/07/2006			
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer  Connor, M			

# INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2006/007975

C(Continuation), DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P, X	WO 2005/025837 A (3M INNOVATIVE PROPERTIES COMPANY) 24 March 2005 (2005-03-24) the whole document -----	1-4, 8-19, 21

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Information on patent family members

International application No PCT/US2006/007975
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WO 2005025845	A	24-03-2005	EP 1663626 A1 US 2005052750 A1	07-06-2006 10-03-2005
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