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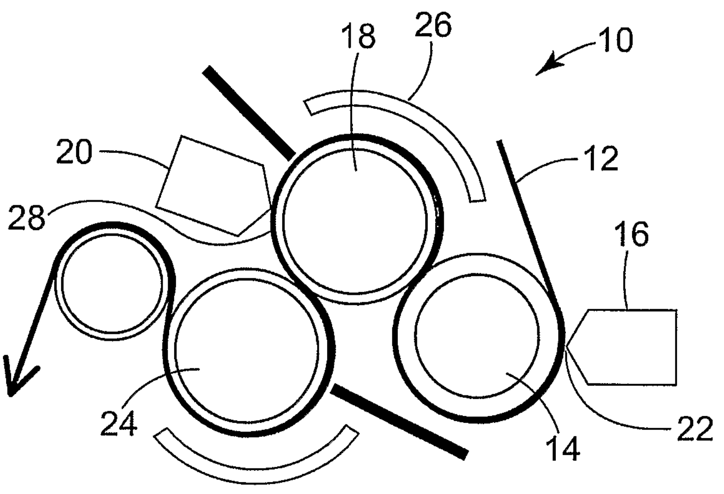
(54) Title: APPARATUS AND METHOD FOR PRODUCING TWO-SIDED PATTERNED WEB IN REGISTRATION



(57) Abstract: An apparatus and a method for casting a patterned surface on both sides of an opaque web. The apparatus includes a first patterned roll (18) , a second pattered roll (20) , and a means for rotating the first and second patterned rolls (18,20) such that their patterns are transferred to opposite sides of the web (12) while it is in continuous motion. During this process, their patterns are the first and second patterned rolls (18, 20) comprise a plurality of regions opaque to the curing energy maintained in continuous registration to within at least 100 micrometers.

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APPARATUS AND METHOD FOR PRODUCING TWO-SIDED PATTERNED WEB IN REGISTRATION

Technical Field

The disclosure relates generally to the continuous casting of material onto a web, 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 a web with a high degree of registration.

Background

Many articles can be manufactured by applying a material that is at least 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.

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 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 web or substrate.

Accordingly, an illustrative embodiment of the disclosure may be found in an assembly that includes an energy source adapted to provide curing energy. The assembly includes a first patterned roll having a number of regions that are opaque to the curing energy disposed on a substrate that is transparent to the curing energy. The opaque regions define a first pattern. The assembly includes a second patterned roll that define a second pattern. The second patterned roll can have a number of regions that are opaque to the curing energy disposed on a substrate that is transparent to the curing energy, where the opaque regions define a second pattern.

The assembly also includes means for rotating the first and second patterned rolls such that the first and second patterns are maintained in continuous registration to within 100 micrometers. In some instances, the first and second patterns are maintained in continuous registration to within 10 micrometers.

In some instances, the opaque regions block, scatter, absorb or reflect at least 98 percent of the curing energy incident upon the opaque regions. In some cases, the transparent substrates permit at least 25 percent of the curing energy incident upon the transparent substrates to pass through. In some cases, the substrates define an outer substrate surface, and the opaque regions extend radially outwardly from the outer substrate surface. In some instances, the opaque regions are located at a periphery of the substrate, and the transparent regions of the substrate extend inwardly from the periphery.

Another illustrative embodiment of the disclosure may be found in an apparatus that includes an energy source that is adapted to provide curing energy, a first patterned roll and a second patterned roll. The energy source may be adapted to provide ultraviolet light. The first patterned roll includes a number of regions that are opaque to the curing energy disposed on a substrate that is transparent to the curing energy. The opaque regions define a first raised pattern. The second patterned roll includes a number of regions that are opaque to the curing energy disposed on a substrate that is transparent to the curing energy. The opaque regions define a second raised pattern.

The apparatus also includes one or more feed rolls that are adapted to provide a web and to feed the web into contact with the first and second patterned rolls. In some embodiments, the web has first and second sides and can be opaque to the curing energy. A first dispenser is adapted to dispose a curable material onto the first side of the web or the first patterned roll before the web contacts the first patterned roll and a second dispenser is adapted to dispose a curable material onto the second side of the web or the second patterned roll before the web contacts the second patterned roll.

The apparatus also includes means for rotating the first and second patterned rolls such that the first and second raised patterns are imprinted in the curable material on the first and second sides of the web while the web is in continuous motion, and the first and second raised patterns are maintained in continuous registration on the first and second sides of the web to within 100 micrometers. In some instances, the first and second raised patterns are maintained in continuous registration to within 10 micrometers.

In some instances, the opaque regions block, scatter, absorb or reflect at least 98 percent of the curing energy incident upon the opaque regions. In some cases, the transparent substrates permit at least 10 percent of the curing energy incident upon the transparent substrates to pass through. In some instances, the web permits less than 2 percent of curing energy incident on the web to pass through the web.

In some instances, the transparent substrates may include a glass cylinder and may in particular cases include a quartz cylinder. The transparent substrates may be a polymeric cylinder such as a PMMA (poly methyl methacrylate) cylinder. The opaque regions may include materials such as chrome, copper, aluminum or epoxy.

The energy source may, in some instances, be adapted to provide curing energy that passes at least partially through the first patterned roll and/or at least partially through the second patterned roll. The energy source may include a first curing energy source disposed within the first patterned roll and a second curing energy source disposed within the second patterned roll.

Another illustrative embodiment of the disclosure may be found in a method of patterning an opaque web that has a first side and a second side. Curable material is disposed onto the opaque web, which is then directed into contact with a first patterned roll having a number of raised opaque regions disposed on a transparent substrate. Ultraviolet radiation is directed at least partially through the first patterned roll, thereby curing the curable material on the first side of the opaque web to form a first pattern. The opaque web is then directed into contact with a second patterned roll having a number of opaque regions disposed on a transparent substrate. Ultraviolet radiation is directed at least partially through the second patterned roll, thereby curing the curable material on the second side of the opaque web to form a second pattern. 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. In some instances, the first and second patterns are maintained to within 10 micrometers.

In some instances, disposing curable material onto the opaque 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.

Another illustrative embodiment of the disclosure may be found in a patterned roll that includes a curing energy transparent cylinder, a tie layer disposed on the curing energy transparent cylinder, and a number of curing energy opaque features disposed on the tie layer to form a pattern. The curing energy transparent cylinder permits at least 10 percent of curing energy light incident upon the cylinder to pass through the cylinder while the curing energy opaque features block at least 98 percent of curing energy light incident upon the curing energy opaque features. In some particular instances, the curing energy transparent cylinder includes quartz, the tie layer includes titanium, and the curing energy opaque feature includes chrome.

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 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.

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.

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;

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;

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;

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;

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;

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;

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;

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;

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 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 structured **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 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**.

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 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 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 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 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 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 **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 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 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 **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 features 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 ± 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 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 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).

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.

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 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 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.

Minimization of external disturbances is important to obtain 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 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, 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 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 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 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 1×10^{-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 $1mA/17mm^2$. As the current density increases, even at levels as low as $20mA/17mm^2$, 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. An assembly comprising:

an energy source adapted to provide curing energy;

a first patterned roll comprising a first plurality of regions opaque to the curing energy disposed on a first substrate transparent to the curing energy, the first plurality of regions opaque to the curing energy defining a first pattern;

a second patterned roll comprising a second plurality of regions defining a second pattern; and

means for rotating the first and second patterned rolls such that the first and second patterns are maintained in continuous registration to within 100 micrometers.

2. The assembly of claim 1 wherein the second patterned roll comprises a second plurality of regions opaque to the curing energy disposed on a second substrate transparent to the curing energy, the second plurality of regions opaque to the curing energy defining a second pattern.

3. The assembly of claims 1 or 2, wherein the first and second patterns are maintained in continuous registration to within 10 micrometers.

4. The assembly of claims 1 to 3, wherein the first plurality of regions block at least 98 percent of the curing energy incident upon the first plurality of regions.

5. The assembly of claims 1 to 4, wherein the first substrate permits at least 25 percent of the curing energy incident upon the first substrate to pass through the first substrate

6. The assembly of claims 1 to 5, wherein the first substrate defines a first substrate outer surface, and the first plurality of regions extend radially outward from the first substrate outer surface.

7. The assembly of claim 2, wherein the second substrate defines a second substrate outer surface, and the second plurality of regions extend radially outward from the second substrate outer surface.

8. The assembly of claims 1 to 7, wherein the first substrate defines an outer periphery, the first plurality of regions are located near the outer periphery, and portions of the first substrate not covered by the first plurality of regions extend inwardly from the outer periphery.

9. The assembly of claim 2, wherein the second substrate defines an outer periphery, the second plurality of regions are located near the outer periphery, and portions of the second substrate not covered by the second plurality of regions extend inwardly from the outer periphery.

10. An apparatus comprising:

an energy source adapted to provide curing energy;

a first patterned roll comprising a first plurality of regions opaque to the curing energy disposed on a first substrate transparent to the curing energy, the first plurality of regions defining a first raised pattern;

a second patterned roll comprising a second plurality of regions opaque to the curing energy disposed on a second substrate transparent to the curing energy, the second plurality of regions defining a second raised pattern;

one or more feed rolls adapted to provide a web and to feed the web into contact with the first and second patterned rolls, the web having first and second sides;

a first dispenser adapted to dispose a curable material onto the first side of the web, or onto the first patterned roll before the web contacts the first patterned roll;

a second dispenser adapted to dispose a curable material onto the second side of the web, or onto the second patterned roll before the web contacts the second patterned roll; and

means for rotating the first and second patterned rolls such that the first and second raised patterns are imprinted in the curable material on the first and second sides of the web while the web is in continuous motion, and the first and second raised patterns are maintained in continuous registration on the first and second sides of the web to within 100 micrometers.

11. The apparatus of claim 10, wherein the first and second patterns are in continuous registration on the first and second sides of the web to within 10 micrometers.

12. The apparatus of claims 10 or 11, wherein the first plurality of regions block at least 98 percent of the curing energy incident upon the first plurality of regions.

13. The apparatus of claims 10 to 12, wherein the second plurality of regions block at least 98 percent of the curing energy incident upon the second plurality of regions.

14. The apparatus of claims 10 to 13, wherein the first substrate permits at least 25 percent of the curing energy incident upon the first substrate to pass through the first substrate

15. The apparatus of claims 10 to 14, wherein the second substrate permits at least 25 percent of the curing energy incident upon the second substrate to pass through the second substrate.

16. The apparatus of claims 10 to 15, wherein the web permits less than 2 percent of curing energy incident on the web to pass through the web.

17. The apparatus of claims 10 to 16, wherein the energy source is adapted to provide ultraviolet curing energy.

18. The apparatus of claims 10 to 17, wherein the first substrate comprises a glass cylinder.

19. The apparatus of claims 10 to 18, wherein the first substrate comprises a polymeric cylinder.

20. The apparatus of claims 10 to 19, wherein the second substrate comprises a glass cylinder.

21. The apparatus of claims 10 to 20, wherein the second substrate comprises a quartz cylinder.

22. The apparatus of claims 10 to 21, wherein the second substrate comprises a polymeric cylinder.

23. The apparatus of claims 10 to 22, wherein the first plurality of regions comprise a material selected from the group consisting of chrome, copper, aluminum, and epoxy.

24. The apparatus of claims 10 to 23, wherein the second plurality of regions comprise a material selected from the group consisting of chrome, copper, aluminum, and epoxy.

25. The apparatus of claims 10 to 24, wherein the energy source adapted to provide curing energy comprises a first curing energy source disposed within the first patterned roll and a second curing energy source disposed within the second patterned roll.

26. A method for patterning an opaque web having a first side and a second side, the method comprising steps of:

patterning a curable material onto a web having a first side and a second side with a first patterned roll and a second patterned roll, the first patterned roll comprising a first plurality of raised opaque regions disposed on a transparent substrate and the second patterned roll comprising a second plurality of raised opaque regions disposed on a transparent substrate; and

directing ultraviolet radiation at least partially through the first patterned roll and second patterned roll, thereby curing the curable material on the first side of the web to form a first pattern and curing the curable material on the second side of the web to form a second 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.

27. The method of claim 26, wherein the first and second patterns are transferred to first and second sides of the web in registration to within 10 micrometers.

28. The method of claims 26 or 27, wherein disposing curable material onto the web comprises:

disposing curable material onto the 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.

29. A patterned roll, comprising:

a curing energy transparent cylinder having an outer surface, the curing energy transparent cylinder permitting at least 10 percent of curing light incident upon the cylinder to pass through the cylinder;

a tie layer disposed on the outer surface of the curing energy transparent cylinder; and

a plurality of curing energy opaque features disposed on the tie layer to form a pattern, the curing energy opaque features blocking at least 95 percent of curing light incident upon the curing energy opaque features.

30. The patterned roll of claim 29, wherein the curing energy transparent cylinder comprises a quartz cylinder.

31. The patterned roll of claims 29 or 30, wherein the tie layer comprises a titanium tie layer.

32. The patterned roll of claims 29 to 31, wherein the plurality of curing energy opaque features comprises a plurality of chrome features.

33. The patterned roll of claims 29 to 32, wherein at least selected curing energy opaque features are surrounded by curing energy transparent substrate surface.

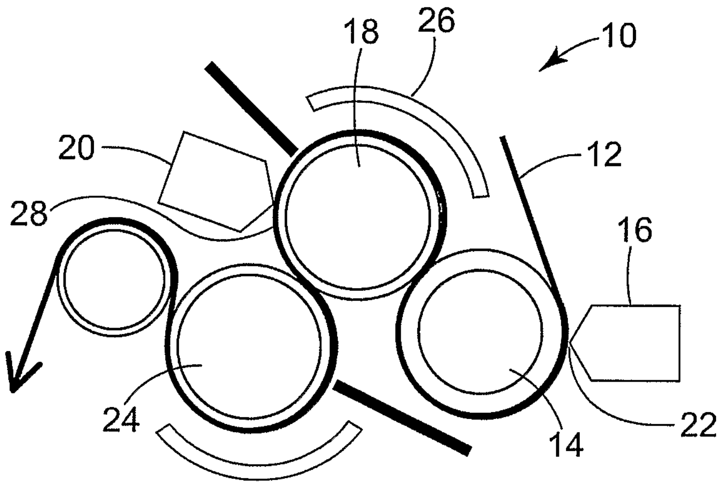
18
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FIG. 1

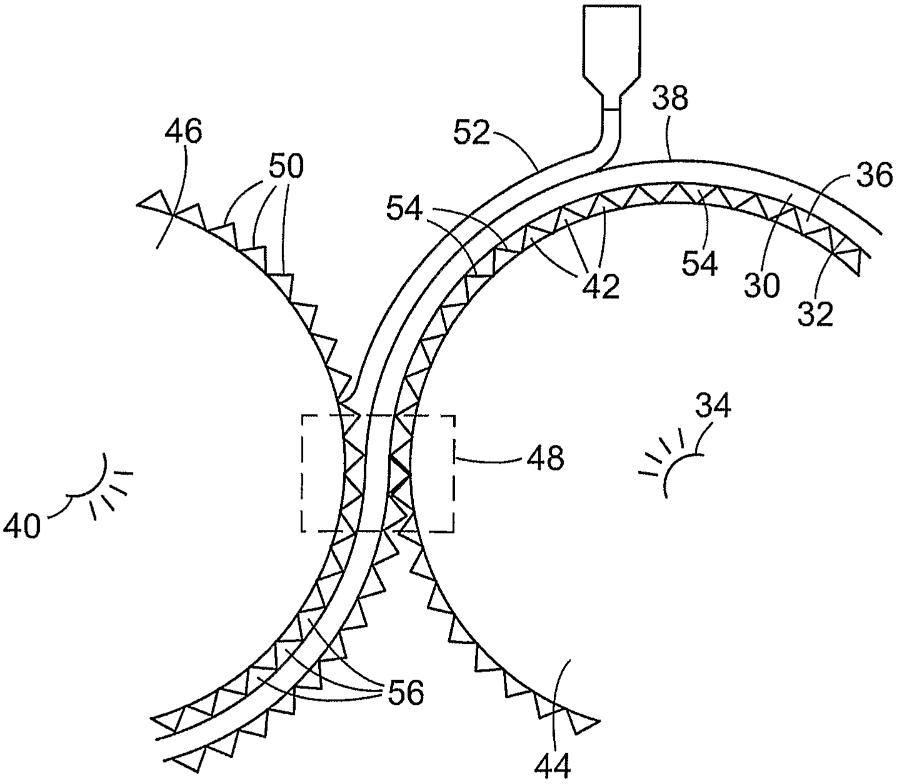
38
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FIG. 2

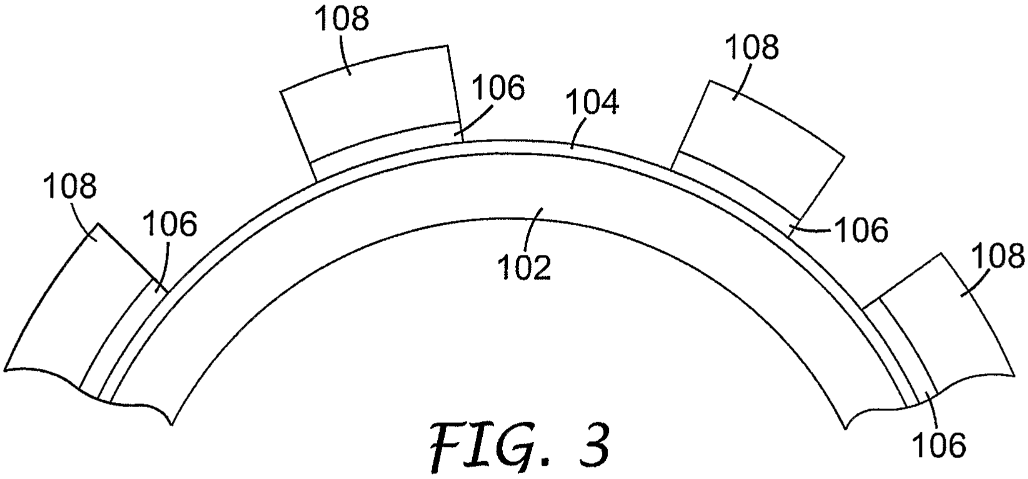

FIG. 3

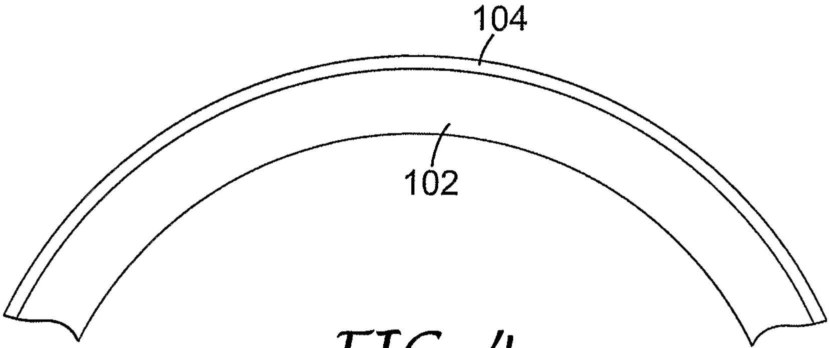

FIG. 4

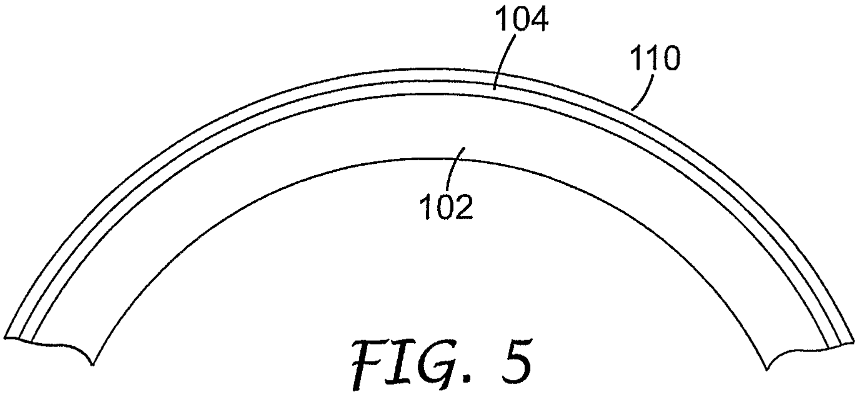

FIG. 5

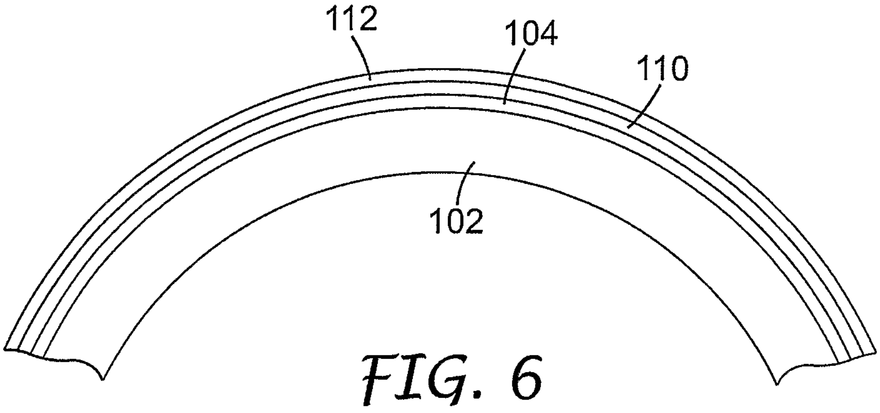

FIG. 6

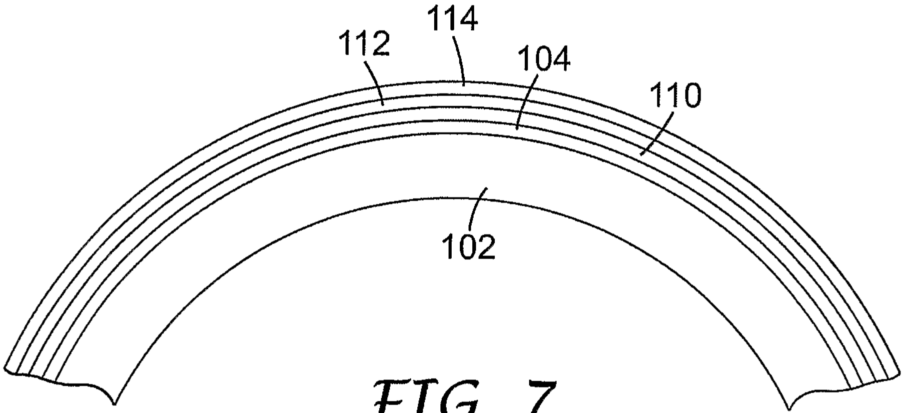

FIG. 7

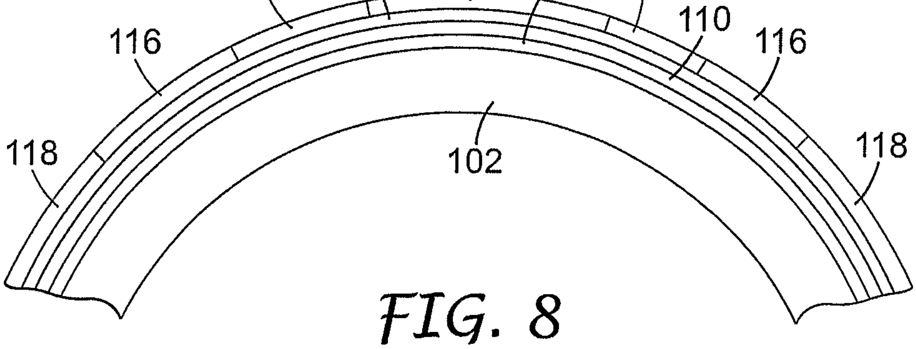

FIG. 8

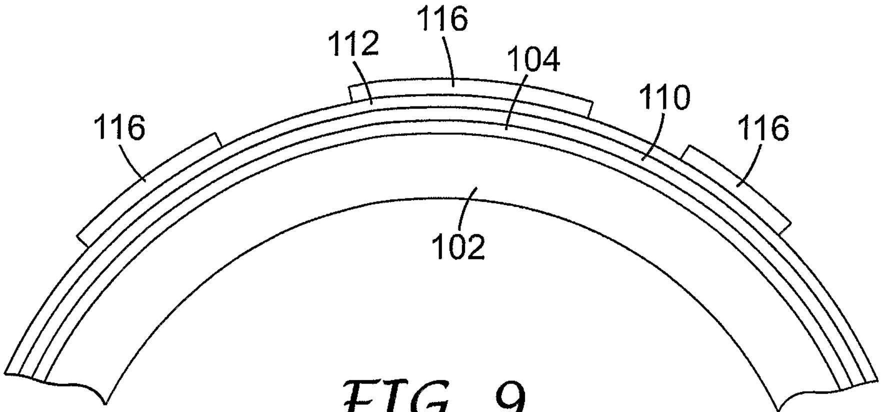

FIG. 9

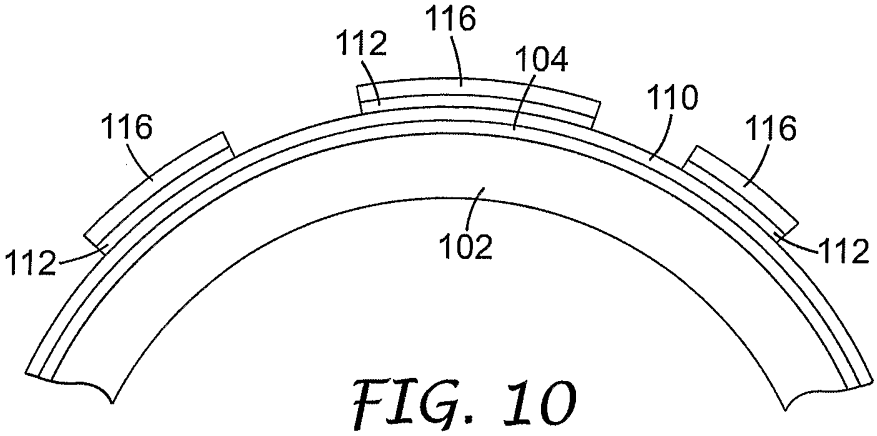

FIG. 10

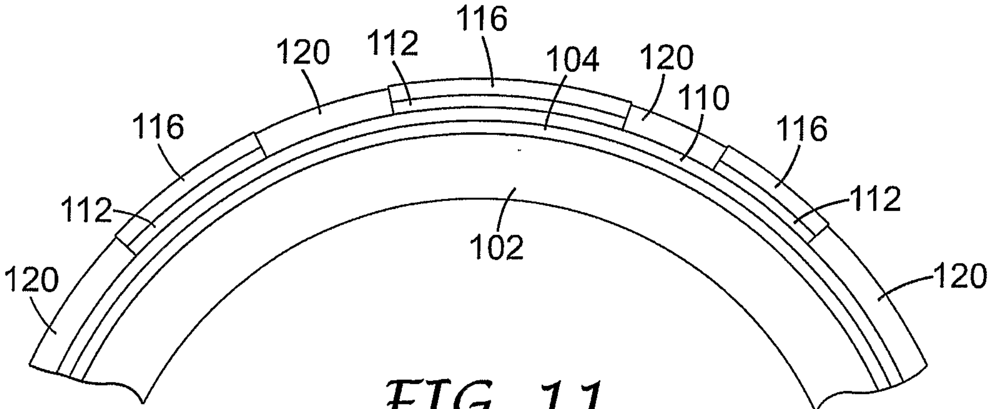

FIG. 11

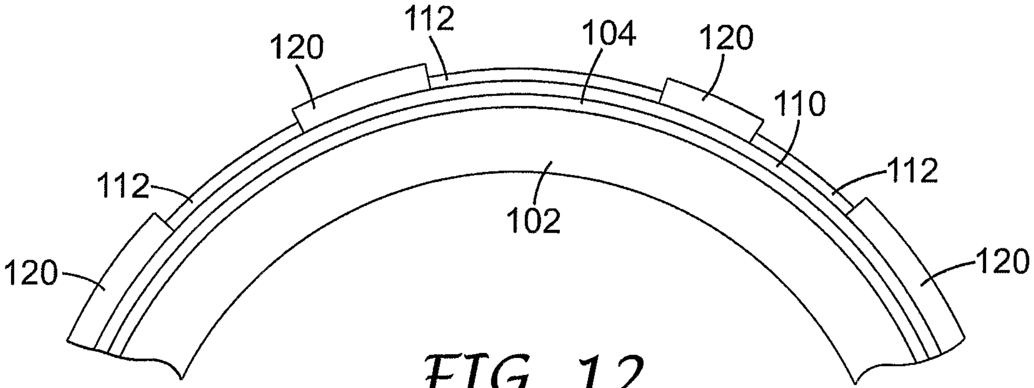
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FIG. 12

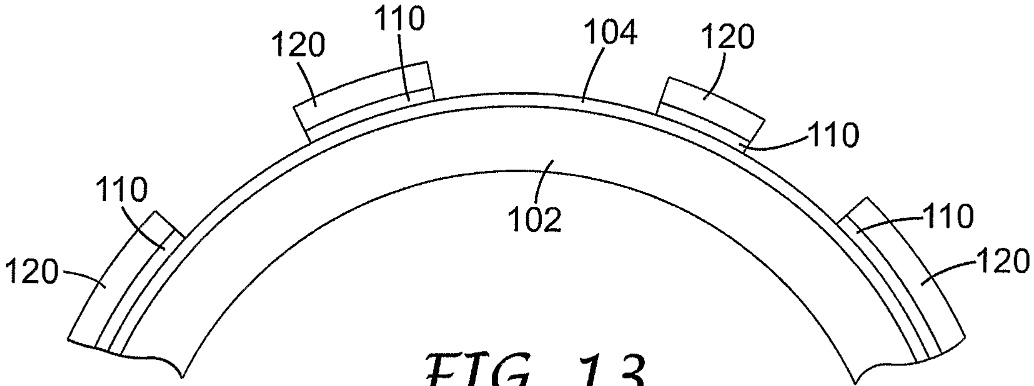
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FIG. 13

FIG. 14A

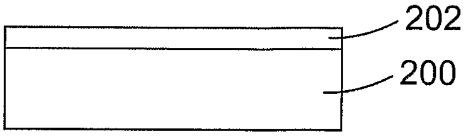

FIG. 14B

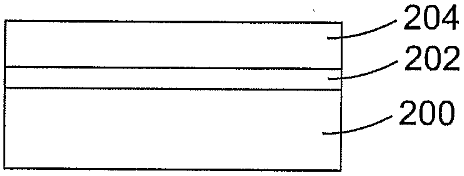

FIG. 14C

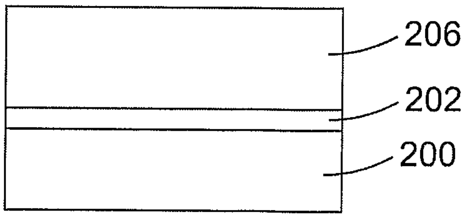

FIG. 14D

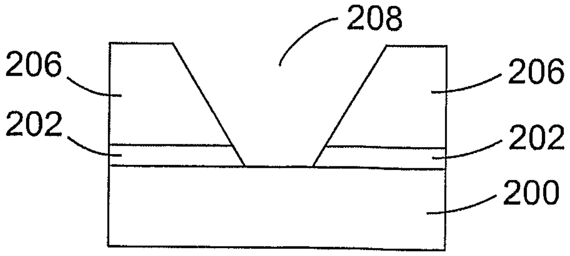

FIG. 14E

FIG. 15A

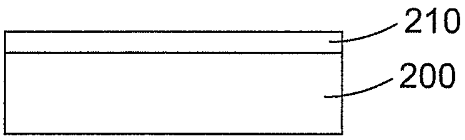

FIG. 15B

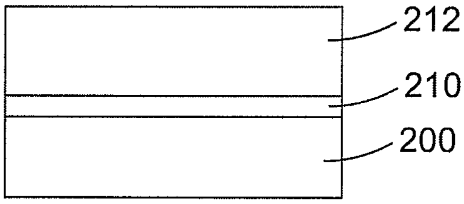

FIG. 15C

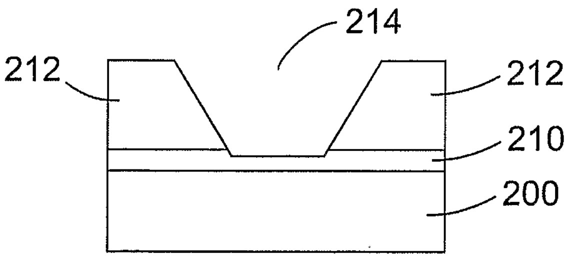

FIG. 15D

FIG. 16A

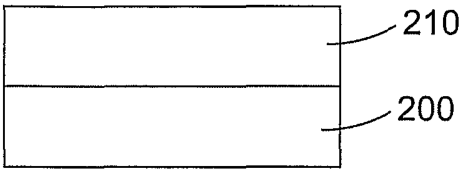

FIG. 16B

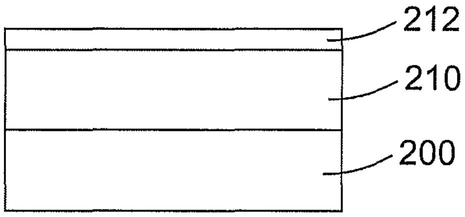

FIG. 16C

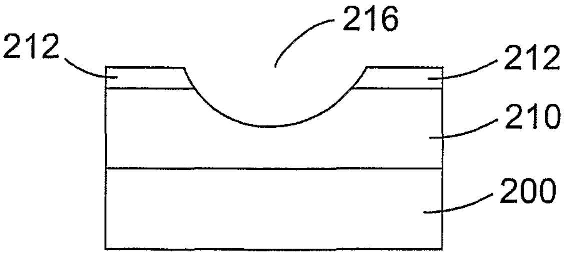

FIG. 16D

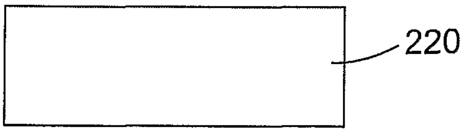

FIG. 17A

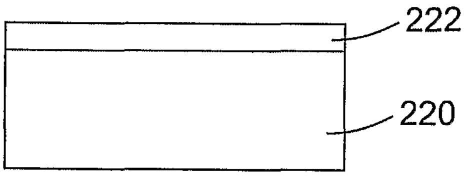

FIG. 17B

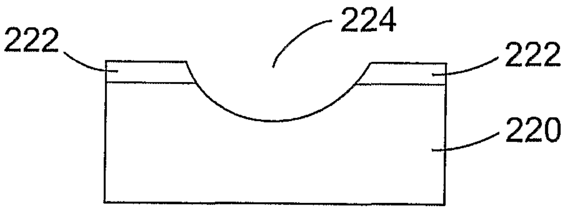

FIG. 17C

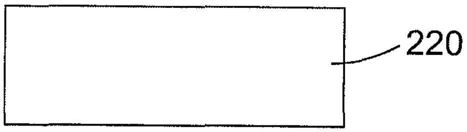

FIG. 18A

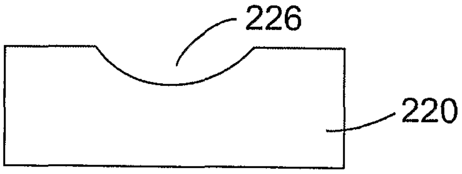

FIG. 18B

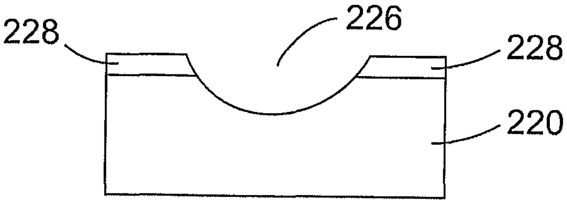

FIG. 18C

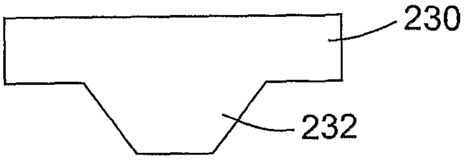

FIG. 19A

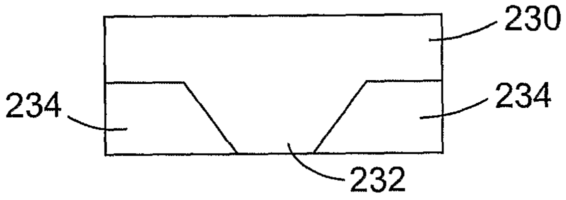

FIG. 19B

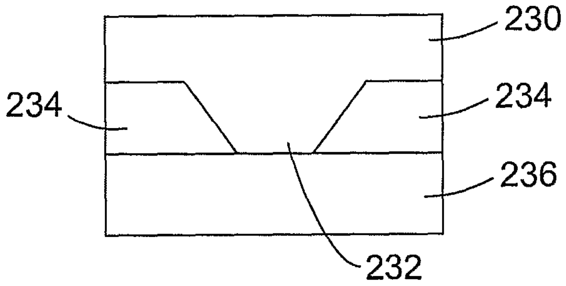

FIG. 19C

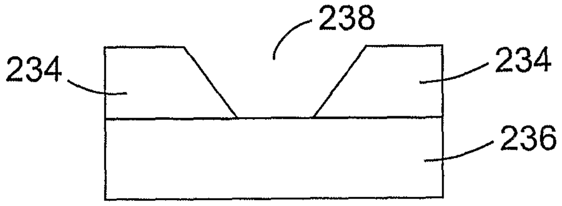

FIG. 19D

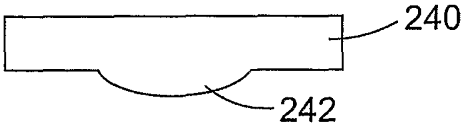

FIG. 20A

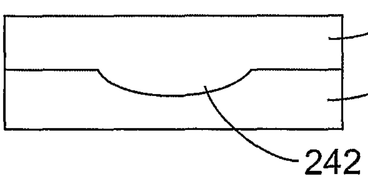

FIG. 20B

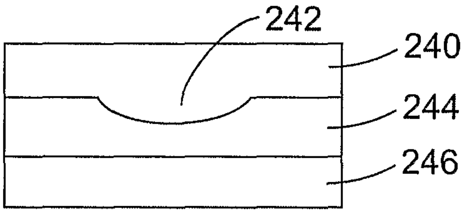

FIG. 20C

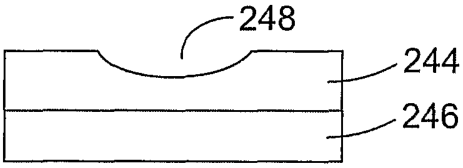

FIG. 20D

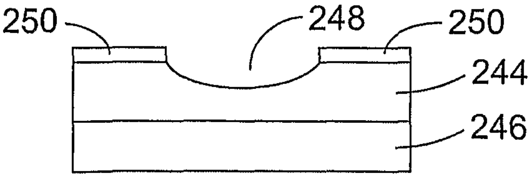

FIG. 20E

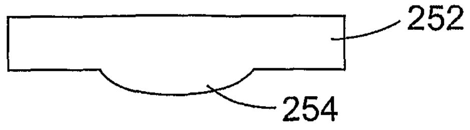

FIG. 21A

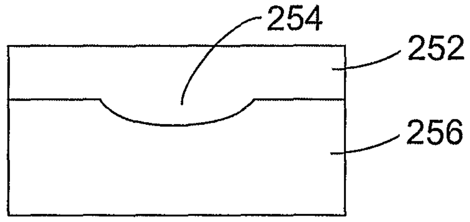

FIG. 21B

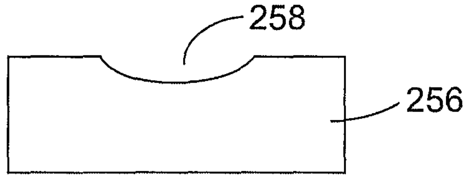

FIG. 21C

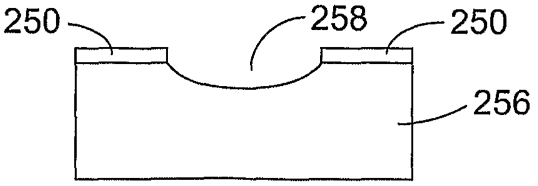

FIG. 21D

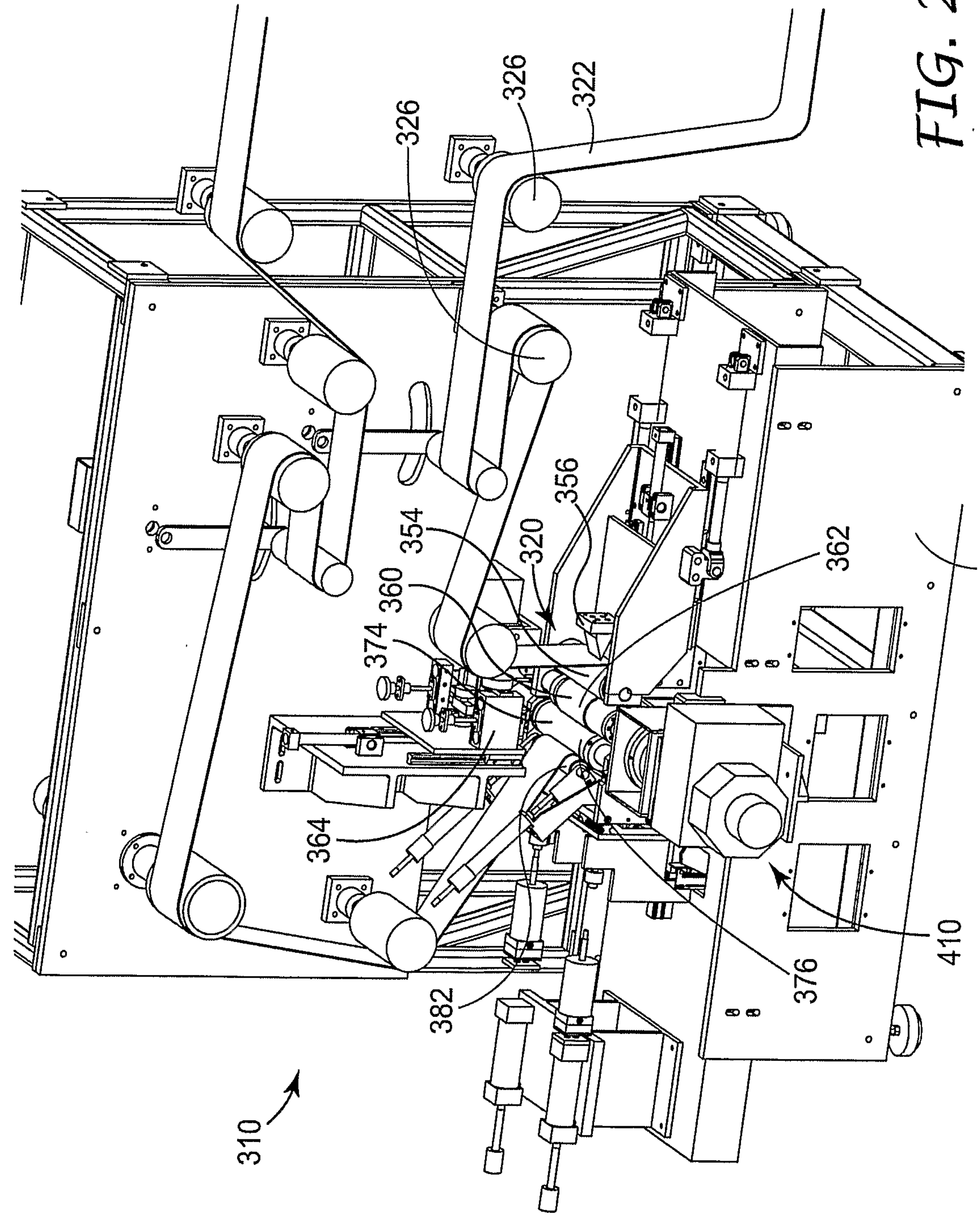

FIG. 22

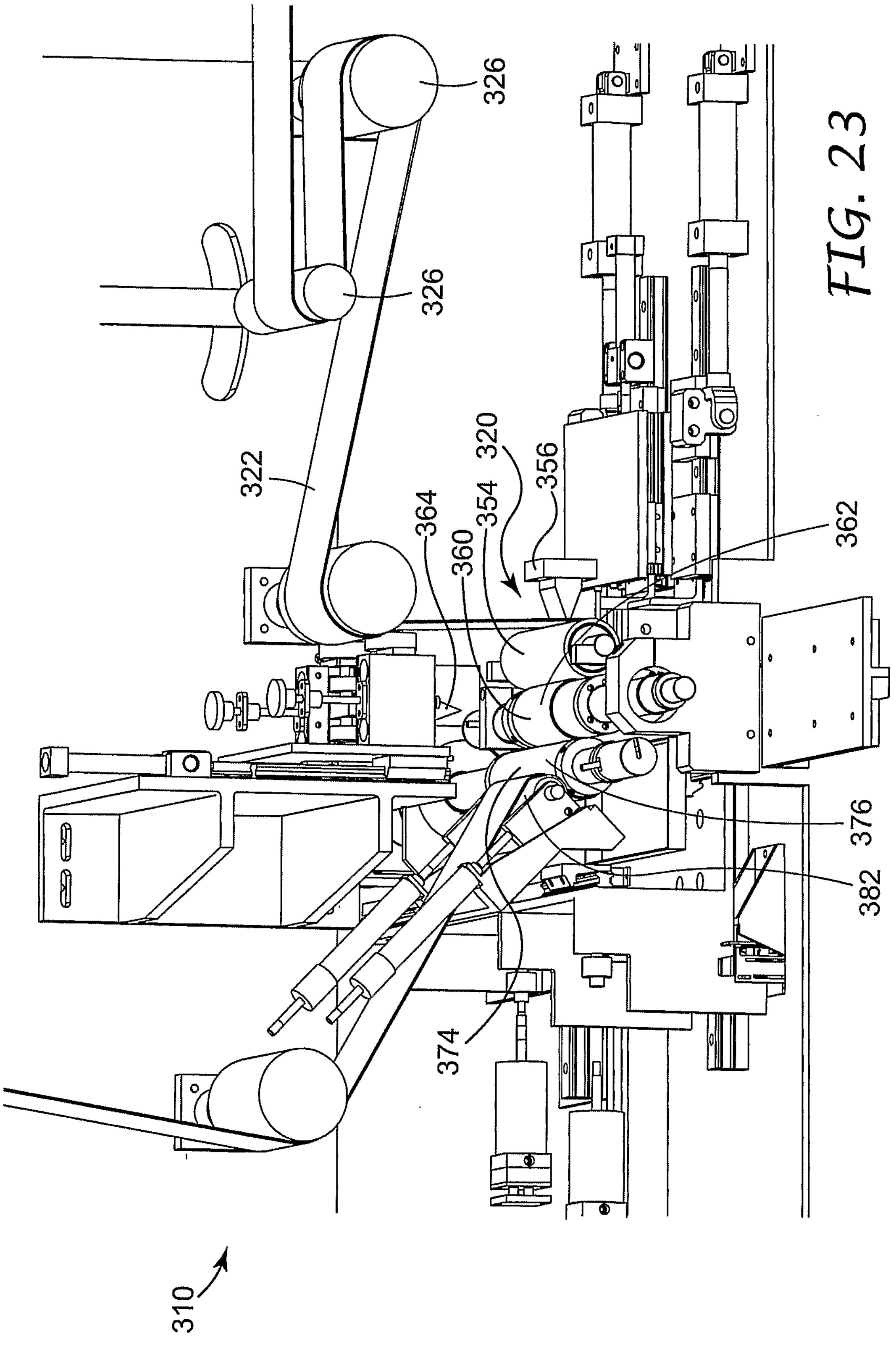

FIG. 23

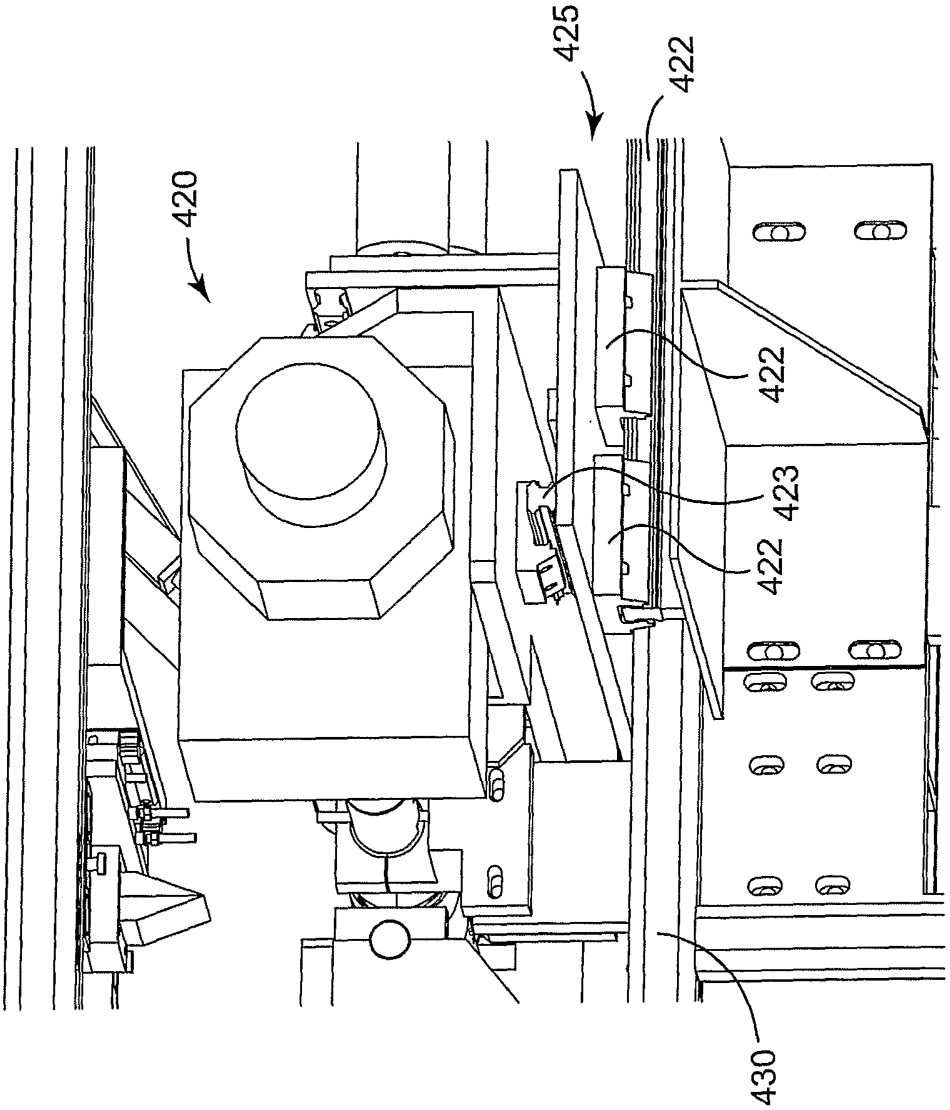

FIG. 24

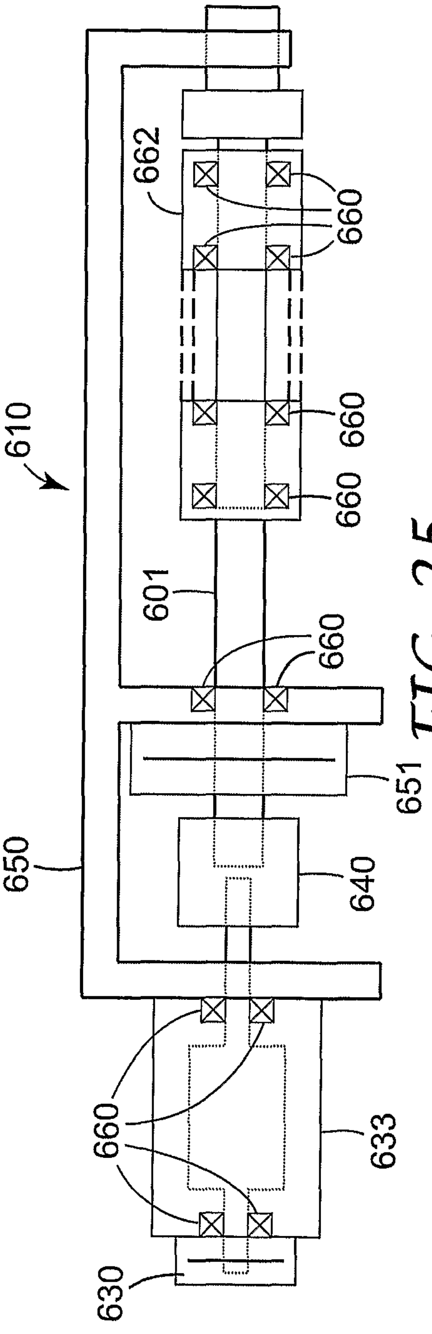
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FIG. 25

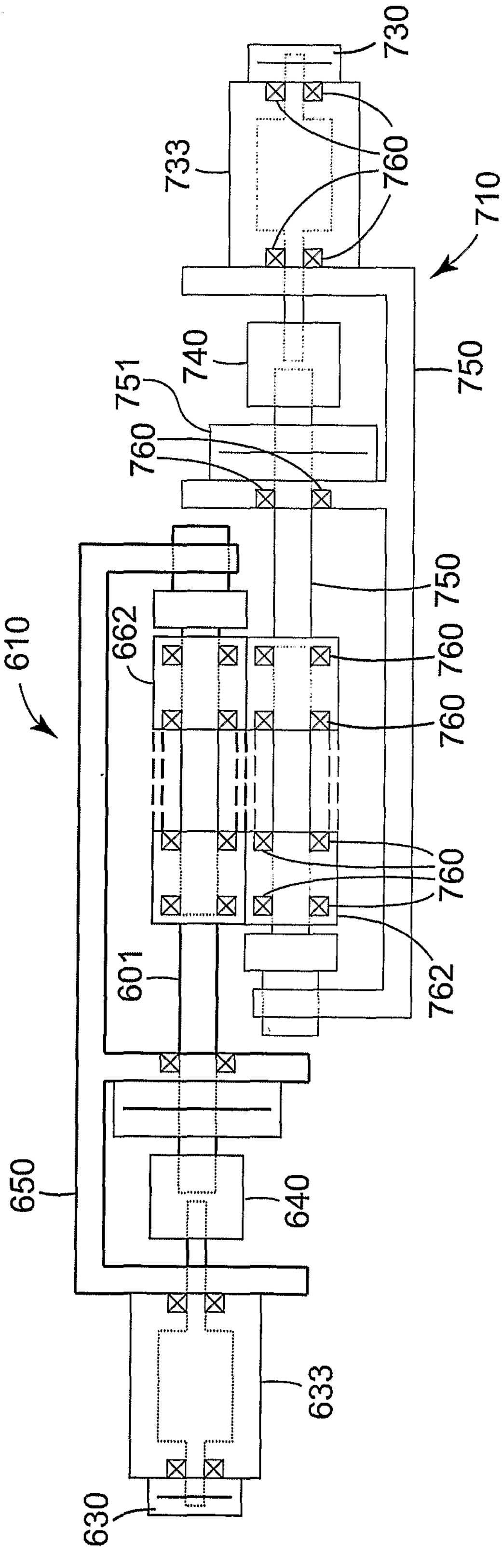
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FIG. 26

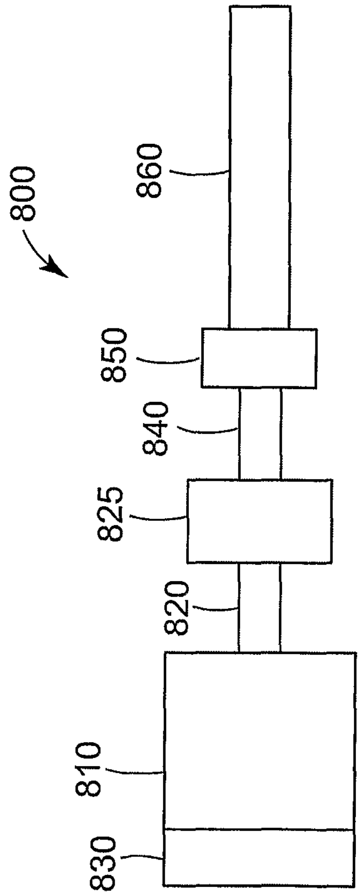

FIG. 27

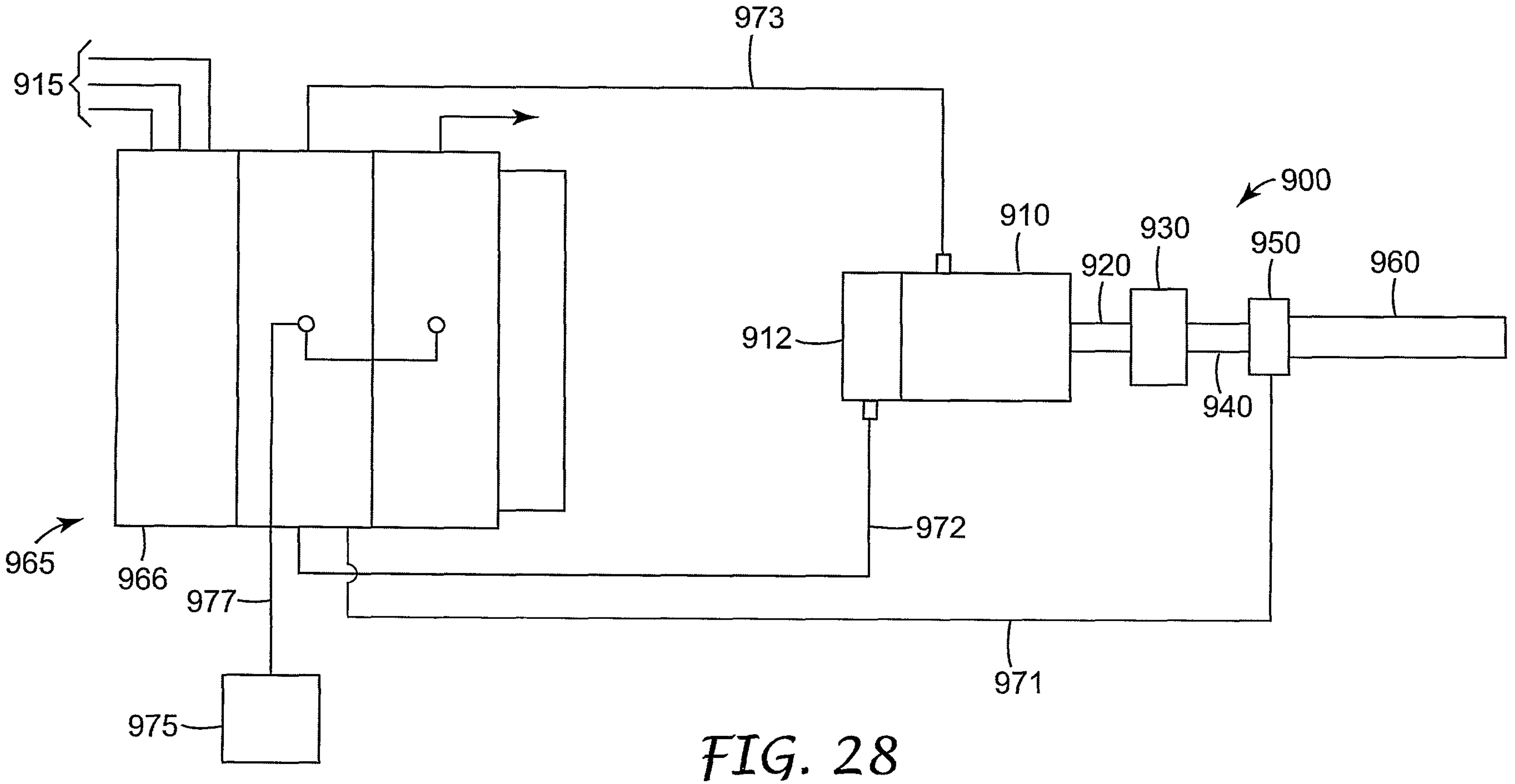

FIG. 28

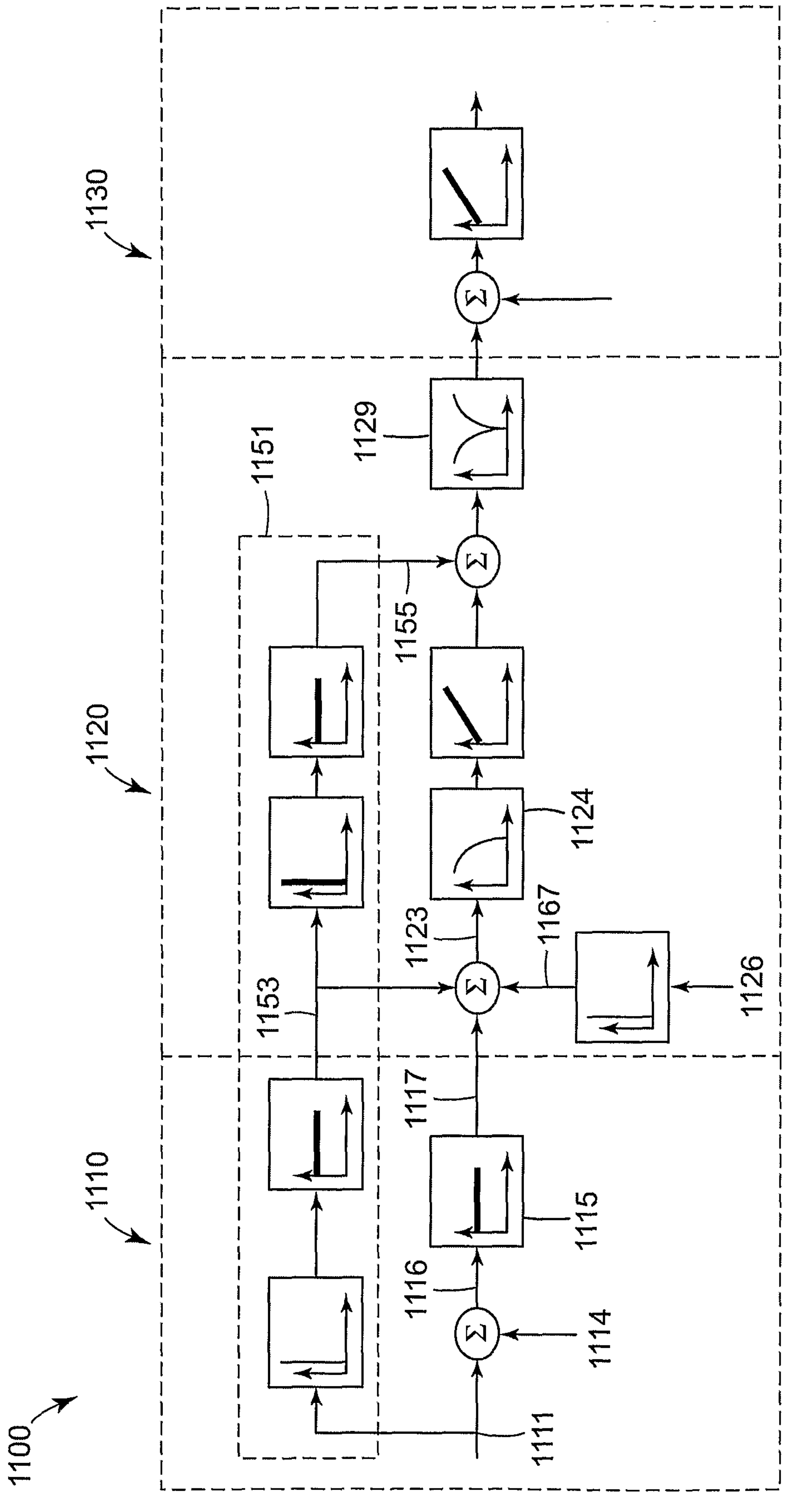
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FIG. 29

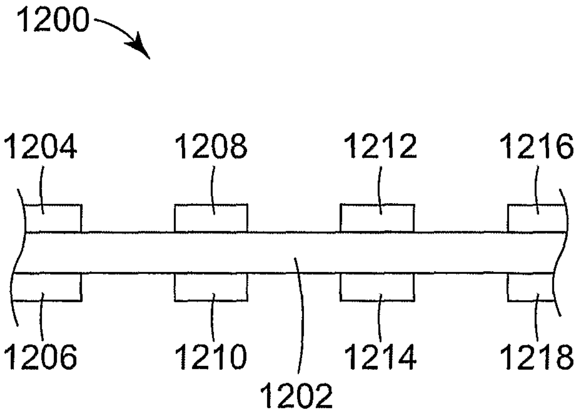

FIG. 30

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/007972

A. CLASSIFICATION OF SUBJECT MATTER
INV. B29C39/14 B29C35/08 G03F7/00

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)
B29C G03F

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, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0 896 259 A (HSM HOLOGRAPHIC SYSTEMS MUENCHEN GMBH) 10 February 1999 (1999-02-10) paragraphs [0002], [0016] - [0022], [0030], [0029], [0038] - [0045]; figures 1-3,5-7	1-33
Y	US 5 330 799 A (SANDOR ET AL) 19 July 1994 (1994-07-19) column 4, line 52 - column 10, line 68; figures 8-10	1-33
Y	US 5 259 926 A (KUWABARA ET AL) 9 November 1993 (1993-11-09) column 5, line 18 - line 29; claims 22-26; figure 5	1-33

-/--

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

☒ See patent family annex.

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Date of the actual completion of the international search
5 July 2006

Date of mailing of the international search report
13/07/2006

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Fax: (+31–70) 340–3016

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Kopp, C

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/007972

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 1 473 594 A (HEWLETT-PACKARD DEVELOPMENT COMPANY, L.P) 3 November 2004 (2004-11-03) paragraphs [0004], [0005], [0049], [0105], [0106]; claims 17-19,26,28,31,32; figures 31b,32,33,41,42	1-33
Y	EP 0 405 898 A (CANON KABUSHIKI KAISHA) 2 January 1991 (1991-01-02) column 7, line 20 - line 51; figure 1	1-33
Y	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 09, 13 October 2000 (2000-10-13) -& JP 2000 183253 A (KYOCERA CORP), 30 June 2000 (2000-06-30) abstract; figures	31
Y	US 5 425 848 A (HAISMA ET AL) 20 June 1995 (1995-06-20) claims; figures	1-33
A	US 2004/094262 A1 (CANTI MAX) 20 May 2004 (2004-05-20) abstract	1-33

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2006/007972

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			WO	02068189	A2	06-09-2002
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			JP	2004530539	T	07-10-2004