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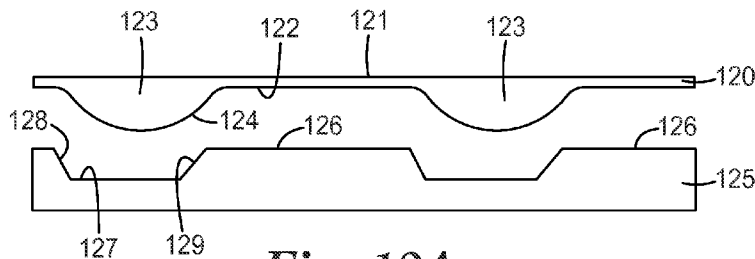


Fig. 12A

(57) Abstract: A profiled extrusion replication process is disclosed that includes steps of (a) extruding a molten material through an extrusion die having at least one profiled die lip to form a molten extrudate having first and second major extrudate surfaces and having a first structural feature in the first major extrudate surface; (b) bringing the molten extrudate into contact with a tool surface comprising one or more second structural features so as to cause a portion of the first structural feature in the first major extrudate surface to contact the one or more second structural features on the tool surface; and (c) cooling the molten extrudate to provide the structured film. Structured films and apparatus for making structured films are also disclosed.



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PROFILED EXTRUSION REPLICATION

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to Provisional Patent application 61/319,012, filed
5 March 30, 2010, the disclosure of which is incorporated by reference in its entirety herein.

FIELD

The present disclosure relates to methods for profiled extrusion replication,
extrusion replicated films, and an apparatus for profiled extrusion replication.
10

BACKGROUND

Extrusion replication is a commonly used process in which resin is melted in an
extruder, shaped into a molten mass (e.g., a sheet) in a die, and then cast or pressed
between two surfaces, such as two rolls or two belts, to form a film.

15 When rolls are used, one roll typically has a smooth surface, and the second roll
frequently has a structured surface. The high nip load between the two rolls forces the
melted resin into concave areas in the structured surface. The resulting film bears a
negative of the image on the surface of the structured roll. Replicated structures on such
films have varying levels of precision dependent on a number of factors used during the
20 extrusion process. Critical variables that influence the level of precision include the
temperatures of the melted resin and the two rolls, the nip force applied to the material as
it passes between the rolls, and material characteristics of both the rolls and melted resin,
including the viscosity of the resin, for example.

Extrusion replication is often concerned with making films that have discrete
25 features on one or both sides. Typically, the films are otherwise substantially planar,
having a substantially constant caliper. It is difficult to make films having precisely
shaped features that are large in caliper in comparison to an average base thickness.
Extrusion replicated films that have a protruding structural feature that is large in
comparison to an average base thickness of the film often contain defects such as
30 depressions in the side of the film opposite that of the structural feature, possibly due to
incomplete flow of resin into the a replicating tool surface during the formation of the
large feature.

SUMMARY

There is a need for additional methods that enable the production of films having precisely shaped features.

5 According to one exemplary embodiment of the present invention, the process for making a structured film comprises the steps of (a) extruding a molten material through an extrusion die having at least one profiled die lip to form a molten extrudate having first and second major extrudate surfaces and having a first structural feature in the first major extrudate surface; (b) bringing the molten extrudate into contact with a tool surface
10 comprising one or more second structural features so as to cause a portion of the first structural feature in the first major extrudate surface to contact the one or more second structural features on the tool surface; and (c) cooling the molten extrudate to form a structured film.

 In a further embodiment of the invention an apparatus for extrusion replication is
15 described, comprising: an extruder equipped with a profiled extrusion die having at least one profiled die lip; and, a tool having a structured surface positioned to receive molten extrudate from the profiled extrusion die.

 The terms “comprises” and variations thereof do not have a limiting meaning where these terms appear in the description and claims.

20 The words “preferred” and “preferably” refer to embodiments of the invention that may afford certain benefits, under certain circumstances. However, other embodiments may also be preferred, under the same or other circumstances. Furthermore, the recitation of one or more preferred embodiments does not imply that other embodiments are not useful, and is not intended to exclude other embodiments from the scope of the invention.

25 As used herein, “a,” “an,” “the,” “at least one,” and “one or more” are used interchangeably. Thus, for example, an extrudate comprising “a” structural feature can be interpreted to mean that the extrudate includes “one or more” structural features.

 As used herein, the term “or” is generally employed in its sense including “and/or” unless the content clearly dictates otherwise. The term “and/or” means one or all of the
30 listed elements or a combination of any two or more of the listed elements.

 As used herein, all numbers are assumed to be modified by the term “about” and preferably by the term “exactly.” Notwithstanding that the numerical ranges and

parameters setting forth the broad scope of the invention are approximations, the numerical values set forth in the specific examples are reported as precisely as possible. All numerical values, however, inherently contain certain errors necessarily resulting from the standard deviation found in their respective testing measurements.

5 Also herein, the recitations of numerical ranges by endpoints include all numbers subsumed within that range (e.g., 1 to 5 includes 1, 1.5, 2, 2.75, 3, 3.80, 4, 5, etc.). Also, a numerical range that includes “up to” a certain value includes that value.

The foregoing summary is not intended to describe every possible embodiment or implementation of the present invention. Those of ordinary skill in the art will gain an understanding of the invention upon review of the remaining sections herein, including the Detailed Description, the non-limiting Examples and the appended claims.

10

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic representation of an apparatus for extrusion replication.

15 FIG. 2 is a cutaway perspective view of a die having a die insert such as used in the disclosed apparatus.

FIG. 3 is a perspective view of a die insert used to form a film in accordance with the disclosed apparatus viewed from the die insert exit.

FIG. 4 is a perspective view of a structured roll showing grooved features.

20 FIG. 5 is a fragmentary top perspective view of a molten extrudate of the current invention, showing structural features on a first major extrudate surface.

FIG. 6 is a fragmentary bottom perspective view of the arrangement shown in FIG. 5.

FIG. 7 is a cross-sectional view taken generally along the line 7—7, FIG. 5.

25 FIG. 8 is a cross-sectional view of an alternate embodiment of a molten extrudate of the current invention.

FIG. 9 is a cross-sectional view of another alternate embodiment of a molten extrudate of the current invention.

30 FIG. 10A and 10B are a schematic representation showing a prior art of extrusion replication of large features in a thin film.

FIG. 11A and 11B are a schematic representation showing the coordination of structural features on an extrudate with structural features on a tool surface.

FIG. 12A-D show an embodiment of the replication process of the invention.

FIG. 13A-C shows an embodiment of an article of the current disclosure having sinusoidal grooves.

5 FIG. 14 is a top view of a sinusoidal groove pattern in a web according to an embodiment of the current disclosure.

FIG. 15 is a partial view of a profiled die lip according to the current disclosure.

In the various figures, reference numerals are used to identify elements of the described embodiments, and like reference numbers typically indicate like elements.
10 Unless otherwise indicated, the figures and drawings in this document are not to scale but are provided solely for the purpose of illustrating different embodiments of the invention. In particular the dimensions of the various components are depicted in illustrative terms only, and no relationship between the dimensions of the various components should be
15 inferred from the drawings, unless so indicated. Although terms such as "top", "bottom", "upper", "lower", "under", "over", "front", "back", "outward", "inward", "up" and "down", and "first" and "second" may be used in this disclosure, it should be understood that those terms are used in their relative sense only unless otherwise noted. In particular, in some embodiments certain components may be present in interchangeable and/or
20 identical multiples (e.g., pairs). For these components, the designation of "first" and "second" may apply to the order of use, as noted herein (with it being irrelevant as to which one of the components is selected to be used first).

DETAILED DESCRIPTION

25 It will be understood that the terminology employed to describe the various embodiments herein is intended to have meaning consistent with its usage by those of ordinary skill in the art. However, certain terms will be understood to have the specific meanings recited herein.

30 By "structured surface" it is meant that a surface of an article, including a surface of an extruded material ("extrudate") as well as a surface of a tool, deviates from a substantially planar or other smooth surface. When describing a tool, a structured surface

may include features such as grooves, ridges, geometric shapes, other structures, or the like. When used in describing an extruded material, a structured surface may be indicated by the presence of discrete areas of different thicknesses such as extrudate having first and second regions wherein the first region is thicker than the second region, or vice versa. In
5 some embodiments, a structured surface may be described as having at least one thick region and at least one thin region, and the thick regions and thin regions may be interspersed across the surface of the extrudate.

“Molten” is used herein to describe material that is at a temperature above its softening point and having a viscosity low enough to flow under pressure.

10 Described below are various embodiments of a process that combines steps of (a) extruding a molten material through a profiled die, (b) bringing the molten extrudate into contact with a tool surface comprising one or more structural features, and (c) cooling the extrudate produce a structured film. Exemplary embodiments include an alignment of a structural feature in a major surface of the extrudate with one or more structural features
15 on the tool surface.

FIG. 1 shows a schematic representation of one embodiment of an apparatus **10** for performing an extrusion replication process according to the present invention. Apparatus **10** comprises extruder **11** and profiled die **12** through which a molten resin is extruded as a molten extrudate **13**. From die **12**, molten extrudate **13** advances to point
20 **P_A** where the extrudate passes between nip roll **14** rotating in a first direction (as noted by arrow **A₁**) and tool roll **15** rotating in an opposite direction (as noted by arrow **A₂**). At point **P_A**, nip roll **14** forces a portion of molten extrudate **13** into contact with one or more structural features (not shown) on the outer surface **16** of tool roll **15**. In the present embodiment, outer surface **17** of nip roll **14** is smooth and in some embodiments is coated
25 with a conformable material (e.g., a silicone or EPDM). As nip roll **14** and tool roll **15** rotate, outer surface **17** of nip roll **14** rotationally advances into and then away from molten extrudate **13**. As the extrudate **13** advances beyond the nip, it begins to harden (e.g., at about point **P_B**). By about point **P_C**, molten extrudate **13** is substantially hardened as it then comes into contact with conveyer roll **18** rotating in a direction as noted by
30 arrow **A₃**. At point **P_D**, substantially hardened molten extrudate **13** separates from tool roll surface **16** of tool roll **15** and proceeds in a direction as noted by arrow **A₄** along outer surface **19** of conveyer roll **18**. The hardened extrudate is now a continuous web of

structured film **20** having one or more structural features **21**. The film **20** may be further processed in a manner known by those of ordinary skill in the art.

FIG. 2 schematically illustrates an embodiment of an extrusion die **22** of the type used in a method for forming a profiled extrudate of the current description. Generally, the various embodiments of the method of the present invention include extruding an
5 initial melt stream **23** through a profiled extrusion die insert **24**, as shown in **FIG. 3**. In some exemplary configurations, profiled extrusion die insert **24** has at least one profiled die lip **35** having die lip profile features **36**. Profiled die exit opening **37** is non-rectilinear, meaning that exit opening **37** as a whole is in a form other than a rectangular shape;
10 however, portions of profile die exit opening **37** could be rectilinear in form. Features **36** on profiled die lip **35** can be made by milling, machining, grinding, electron discharge machining or any other suitable method. Die insert **24** may be removed and replaced by a die insert of a different profile, if desired. It will be understood that the profiled die exit opening **37** may have a variety of shapes, to accommodate extrudate profiles of different
15 configurations. Referring to **FIG. 15**, a front elevational view of a portion of a die lip **1500** is shown. The die lip **1500** is similar to the die lip **35** discussed above, wherein die lip **1500** has a profile that is a combination of non-rectilinear portions **1510** and rectilinear portions **1520**.

Although the profiled die insert is shown in the embodiment discussed above as a
20 separate element located within the die, those of ordinary skill in the art will appreciate that the profiled die insert could also be formed integrally with the die in which it is located as long as it has the profile features described.

FIG. 4 shows a schematic representation of an end portion of one embodiment of a
25 tool roll **15** having an outer surface **46** and one or more structural features **48**. It should be understood that the tool roll surface may have structural features **48** other than the simple grooves shown, and may include features such as grooves, ridges, or geometric shapes. It will also be understood that a tool surface could also be on an endless belt or other continuous surface having one or more structural features **48**. In the embodiment shown, structural features **48** in the tool surface are provided to form features **21** in the structured
30 film.

Methods for extruding films or articles are known in the art and are further described in U. S. Published Patent Application No. 2006/0147686 (Ausen et al.) and U.

S. Pat. No. 5,232,777 (Sipinen et al.), the entire disclosures of which are incorporated herein by reference. Generally, the material from which the profiled extrudate of the present description is formed is such that when it is hot it is substantially pliable and/or formable, but once cooled it retains a selected configuration. Because the resin material of
5 the present description is extrudable when hot, it may be extruded through a profiled extrusion die, i.e. a die having an outlet that is of a selected configuration to impart a predetermined shape or “profile” to the material extruded therethrough.

The profile imparted to the molten extrudate **13** is partially determined by a profile incorporated into the die lip. The profile can be substantially planar on one surface, or
10 may have structures on both surfaces. The structures on either surface may be positioned at any location across the width of the extrudate. The structures on the extrudate profile may have individual structures separated by planar surface regions, or may have a series of features in close proximity across the width of the extrudate. Furthermore, multiple structures may be positioned close together and can be considered as a single larger
15 structure for some embodiments. The structures may have any desired geometry and size as long as it is conducive to being formed by way of flow of the resin material through the die profile.

FIGS. 5—7 illustrate various views of a non-limiting embodiment of a molten extrudate of the current invention. Referring to **FIG. 5**, the reference numeral **51**
20 generally designates a molten extrudate. Molten extrudate **51** is configured in a particular structure that comprises an extrudate base **52** which is substantially planar and has an average base thickness h_B and first and second major extrudate surfaces **53** and **54** respectively. In the embodiment shown, molten extrudate **51** is unitary in construction; that is, it is formed in one piece and does not contain any pattern of holes or apertures
25 therein. Other embodiments of extrudate **51** may comprise more than one layer of material, resulting from a co-extrusion process to be described below.

For the embodiment shown in **FIGS. 5—7**, first major extrudate surface **53** comprises a plurality of first structural features, or thick zones, **55**. First structural features **55** are spaced from one another by substantially continuous thin zones or areas
30 **56**. Thin zones **56** have a thickness, which in the embodiment shown in **FIGS. 5 - 7** is substantially the same as an average base thickness h_B of the molten extrudate. Thick zones **55** and thin zones **56** are interspersed across the width of molten extrudate **51**. The

widths of thick zones **55** and thin zones **56** are predetermined so as to enable the formation of corresponding structural features (e.g., features **21** in **FIG. 1**) along a first major surface of a structured film such as the film **20**, for example.

It is noted that the shape of first structural features **55** of the embodiment in **FIGS. 5—7** is shown as generally rounded, corresponding to a semi-oval, or semi-circular arrangement. It will be understood that a variety of shapes may be utilized. For example, in **FIG. 8**, a cross-section of an embodiment is illustrated wherein the thick regions **85** have a generally square cross-section and are separated by thin zones **86**. From a comparison of **FIGS. 7** and **8** it will be understood that a variety of cross-sectional shapes can be provided. Each type of cross-section shown may have an advantage for particular applications.

In **FIG. 9**, an embodiment of a molten extrudate is shown that differs significantly from the previous figures, in that structural features **95** project in both directions (here shown as up and down) from base **92**. The features projecting from both sides of the base may or may not be aligned with each other or have any relationship in terms of size, geometry, location, number or other factor. Such an arrangement may be preferred, in some situations, for structured films where a property such as enhanced stiffness, for example, may be desirable.

For the embodiments shown in **FIGS. 7, 8** and **9**, all of the structural features in a given embodiment are shown as having substantially identical cross-sectional areas. It will be understood that such is not required, and thick regions having different areas of cross-section, and indeed different overall shapes, may be provided. For example, in some embodiments, a combination of various thicknesses of thick regions across the width of molten extrudate may enable enhanced fine control of the degree of film stiffness in structured film.

A wide range of average base thicknesses can be used, for example average base thicknesses in a non-limiting range of 25 μm to 600 μm may be used, including ranges of 50 μm to 400 μm , and 100 μm to 200 μm .

Heights of structural features can be in a non-limiting range of 25 μm to 2000 μm , including ranges of 50 μm to 500 μm , and 100 μm to 250 μm .

The ratio of the height of structural features to an average base thickness can be in a non-limiting range of 0.1:1 to 5:1, including ratios of 0.5:1 to 2:1, and 1:1 to 1.5:1.

The geometry of the profile can be closely matched to the geometry of the profile in the tool roll, or may be significantly different. The precise geometry of the extrudate profile that contacts a tool roll (e.g., tool roll **15** in **FIG. 1**) will be affected by a number of factors including material rheology, process conditions such as extruder throughput rate and the rate at which the extrudate is drawn from the die, among others. It will also be affected by the geometry of the profile in the die opening. In particular, there may be swelling of the extrudate upon exiting the die opening, and rounding of sharp features such as in rectilinear profiles.

Resin may be fed into the profiled die **12** by an extruder (not shown) that may be a single screw or a twin screw extruder. A single type of resin can be extruded through profiled die **12**, or alternatively, two or more types of resin can be coextruded to form an extrudate with multiple layers. A process for producing co-extruded polymeric materials is described in U.S. Pat. No. 6,489,003 (Levitt et al.), the entire disclosure of which is incorporated herein by reference. Co-extrusion can occur by passing different melt streams from different extruders into (1) a multiple slotted feed block and then into a single layer film die or (2) a multiple manifold die. In the multiple slotted feed block technique, at least two different materials are fed from different extruders into different slots (usually 2 to over 200) in a feed block. The individual streams are merged in the feed block and enter a die as a layered stack that flows out into layered sheets as the material leaves the die. The multiple manifold die combines the different molten streams from different extruders at the die lip. This method is usually limited to 2-3 layered films because of the increased complexity as the number of layers is increased.

In cases of co-extrusion, interlayer adhesion may benefit from including one or more reactive species into the layers to create a reactive tie layer at the interface or by incorporating into the construction separate layers that have affinities to both principal layers, as described in U. S. Pat. No. 6,489,003 (Levitt et al.), the entire disclosure of which is incorporated herein by reference.

Molten extrudate **13** emerging from profiled die **12** is passed through a nip. In some exemplary configurations, the nip comprises a smooth press roll and a structured roll having a structure on the surface thereof, or both the press roll and tool roll may have

structure on their surfaces. Alternatively, one or both of the nipping surfaces may be on an endless belt or other continuous surface configuration. An example of a process for producing a film using an endless belt is described in U.S. Pat. No. 5,204,037 (Fujii). The molten extrudate **13** emerging from profiled die **12** is sufficiently molten to fill the spaces
5 within structures present on the rolls at the nip, while also having sufficient melt strength or modulus to substantially retain the cross-sectional profile generated by extrusion through the profiled die, up until the extrudate passes into the nip.

Press roll **14** can be made of metal, e.g. steel such as stainless steel, or aluminum, or any other appropriate material. Press roll **14** can have a diameter of, for example, from
10 about 20 cm or less to about 60 cm or more. Press roll **14** may have a plated surface **17** formed with, e.g., chromium, copper, nickel, nickel-phosphorous plating, or any other serviceable plating, or the press roll may have a conformable surface layer (e.g., silicone or EPDM). Outer surface **17** on press roll **14** can have a mirror finish, or can have a structured surface. The roll is typically cooled with water or other fluid.

15 In some embodiments, outer surface **17** of press roll **14** may comprise structural features (not shown), so that structured film **20** has features on both major surfaces. An example of the type of cross-section that can be made by this process is that shown in **FIG. 9**.

Tool roll **15** can be made of metal, e.g. steel such as stainless steel, or aluminum,
20 or any other appropriate material. Tool roll **15** can have a diameter of for example, from about 20 cm or less to about 60 cm or more. Tool roll **15** may have a plated surface formed with, e.g., chromium, copper, nickel, nickel-phosphorous plating, or any other serviceable plating. In the various embodiments described herein, tool roll **15** typically is provided with a structured surface. Tool roll **15** can transfer its structured surface profile
25 to structured film **20** so that structured film **20** possesses a surface profile complementary to that of the tool roll **15**. The tool roll may have an outer layer, such as a metal sleeve or laminated coating that contains the structural features to be replicated.

Various known methods can be used for providing structured surface **16** on tool roll **15**, include various combinations of engraving, diamond turning, and other techniques
30 known in the art.

The structural features on structured roll **15** may comprise one or more features with geometries including, but not limited to, rails, prisms, wedges, lenses, wells, posts. It

is generally preferred that the features on the structured roll are oriented in down-web dimension, though they need not be linear, as shown in embodiments in **FIG. 13A** and **FIG. 14** where the structural features have a sinusoidal pattern oriented in a down-web dimension. There may additionally be features with some portions oriented in a cross-web dimension.

In some embodiments, the structural features in tool roll **15** are continuous, non-interrupted features in the down-web dimension, such that there is a steady consumption of resin into the tool surface features matching the steady volume of the extrudate features. In other embodiments, discontinuous tool surface features may be provided on the surface **16** of tool roll **15**. Discontinuous structures may include individual wells, for example, resulting in compact protrusions along the finished surface of the structured film **20**.

Suitable materials for use as resin material generally include any of a variety of materials that can be heated into a flowable melt and resolidified into a film. The following are examples of resin material: thermoplastic polymers such as polyethylene, polypropylene, polystyrenes, polymethylmethacrylate, polyamide, polyester, polycarbonate, polymethyleneoxide, polybutyleneterephthalate as well as copolymers such as styrene acrylonitrile copolymers, styrene (meth)acrylate copolymers, styrene maleic anhydride copolymers, nucleated semi-crystalline polyesters, copolymers of polyethylenenaphthalate, polyimide copolymers, polyetherimide, polyethylene oxides and copolymers of acrylonitrile, butadiene, and styrene and blends of these materials with each other as well as other resins.

In some embodiments, molten resin may be extruded at a temperature of approximately 250° Celsius or at a temperature within the range from about 200° to about 300° Celsius. The actual temperature of the extrudate is chosen to be appropriate for that particular resin.

Resin may contain additives such as, but not limited to, powders such as fumed silica, talc, or clay; magnetic, electrically conductive, thermally conductive, electrically and thermally conductive, or nonconductive particulates; fibers; glass or polymeric hollow microspheres, glass or polymeric solid microspheres, expandable polymeric microspheres, antistatic agents, lubricants, wetting agents, flow control agents, tackifying resins, surfactants, pigments, dyes, colorants, coupling agents, plasticizers, and antioxidants; a light diffusion agent, a UV absorber, a thermal stabilizer, filler, and an antistatic agent.

As described herein, the various embodiments of the invention utilize a profiled die that provides an extrudate having a molten profiled configuration that includes sufficient material to fill the features on the surface of a structured tool roll. Typically, the molten extrudate includes opposing major surfaces that are neither planar nor parallel with one another. Referring to **Fig. 10A**, a standard prior art extrusion replication situation is illustrated where a molten extrudate **100** has opposing major surfaces **101** and **102** which are substantially planar, such that the major surfaces of the molten extrudate can be regarded as being substantially flat or nearly parallel with one another. Molten extrudate **100** is shown in proximity to a structured tool **103**, having a tool surface **104** that includes structural features **105**. **FIG. 10B** illustrates what can potentially happen when substantially flat extrudate **100** is pressed into contact with structured tool **103**. As a result of insufficient material in the extrudate **100**, a major surface **102** of the extrudate **100**, as well as the resulting finished film, includes depressions **106**, resulting from a flow of molten extrudate **100** into features **105** on the tool surface. When the size of structural features **105** is small compared to the thickness of substantially flat molten extrudate **100**, a flow of molten extrudate to fill in structural features **105** may result in only slight depressions **106**. This effect is somewhat less pronounced in processes utilizing a tool surface with very shallow structural features.

In another embodiment (not shown), molten extrudate is allowed to form a “pool” of molten material at the entrance to a nip comprising at least one structured tool surface. In such an embodiment, the amount of molten material in the “pool” is maintained at a predetermined volume or mass to prevent the pool from getting too low and incompletely filling the depressions in the structured tool surface.

The methods described herein are useful for making a variety of replicated films **20** where it is helpful to minimize the flows within extrudate **13** during the filling of features on a structured roll surface. By providing a profiled extrusion die **22** having features in cross-web alignment with a structured surface on at least one structured roll **15**, a profiled extrudate may be obtained that has a defined variability in caliper along the cross-web dimension, wherein that defined variability in caliper is aligned with a defined cross-web variability of features on the structured surface. The cross-web alignment of extrudate caliper with the structured surface on a structured roll may minimize the need for extrudate material to flow into the depressions or away from ridges, in contrast to the

flows that would result from applying a substantially flat extrudate to the structured surface. By tailoring the cross-web caliper of the extrudate, improved control in the cross-web caliper of the replicated film article may be obtained.

FIG. 11A shows an embodiment of the invention wherein molten extrudate **110** has first major extrudate surface **111** and second major extrudate surface **112**, the first major extrudate surface **111** having first structural features **116**. Molten extrudate **110** is positioned in proximity to a structured tool **113**, having a tool surface **114** that includes one or more second structural features **115**. In **FIG. 11B**, molten extrudate **110** is shown after being brought into contact with tool surface **114** so as to cause a portion of first structural feature **116** to contact a second structural feature **115** on the tool surface. In a subsequent step (not shown), molten extrudate **110** is cooled and can be removed from the structured tool **113** to provide a structured film **20**.

In **FIG. 11A**, structural features **115** and **116** are each shown as being rectilinear, with 90-degree corners; however, the structural features may deviate from rectilinear, to include a variety of geometries capable of being aligned and then pressed or nipped together during a replication step and subsequently being able to be released. For example, structural features **115** and **116** may have corners that are slightly rounded.

Typically, for an extrudate having structural features on only one major surface and a nip with a press roll having a substantially smooth surface and a tool roll with features on its surface, it is desirable for the cross sectional area of the extrudate features to be similar to, but not necessarily the same as, the cross sectional area of the tool feature or features to which it is aligned. Doing so will result in a film having a first surface with structures, and a substantially planar second surface, as in **FIG. 12A-C**.

FIG. 12A shows an embodiment of the invention wherein a molten extrudate **120** has major surfaces **121** and **122**, and has a profile similar to the example given in **FIG. 7**, and oriented here to align thick zones **123** of the molten extrudate with structural features in a tool **125**, shown here in profile and having surfaces **127**, **128**, and **129** that define structural features in tool surface **126**. Molten extrudate **120** is brought into contact with the tool surface so as to cause a portion of structural features **123** on major extrudate surface **122** to contact the structural features in the tool surface, as shown in **FIG. 12C**. Molten extrudate **120** is cooled and then removed from the tool surface, to provide the structured film **200** which has structural features **130**, defined by surfaces **137**, **138**, and

139, as shown in **FIG. 12D**. It will be understood that tool surface **126**, which may be on a tool such as tool roll **15**, may comprise additional, smaller features (not shown) that may be useful in providing additional, smaller features to the structured film in “thin zone” **122**.

5 In some embodiments, the molten extrudate can have a profile closely matched to the geometry of the one or more structural features in the tool surface, such as structural features **1230** in extrudate **1200** shown in **FIG. 12B**. In a non-limiting embodiment, extrudate **1200** has major extrudate surfaces **1210** and **1220**, and structural features **1230** having corners **1241** and **1242**, here shown as rounded corners. In other embodiments,
10 either or both of these corners **1241** and **1242**, or other corners on the extrudate surface, may be more rounded or less rounded, or the corners may be sharp, as may be desirable for some embodiments.

 In some embodiments, it may be desirable for a cross-sectional area of extrudate features to closely match a cross-sectional area of tool surface features. In some
15 embodiments, a ratio of a cross-web cross-sectional area of the first structural feature to a cross-web cross-sectional area of a second structural feature is about 1.0. For example, **FIG. 12A** shows first structural feature **123** that may have a cross-web cross-sectional area that is similar to the cross-web cross-sectional area of the structural feature defined by surfaces **127**, **128**, and **129** in the surface of tool **125**.

20 In some embodiments of the invention, it may be desirable for a cross-sectional area of the extrudate features to be greater than a cross-sectional area of a tool surface feature (or features), in which case contacting a portion of the extrudate structural feature with the tool surface feature (or features) results in a film with a thicker base caliper in specific cross-web regions results. In this type of embodiment, it may be desirable for the
25 press roll to have a conformable surface, in order to allow for the flow of molten extrudate to protrude beyond a substantially planar surface of the extrudate opposite the surface that is in contact with the tool roll.

 In **FIGS. 13A** and **13B**, an embodiment of structured film **1310** is shown, having grooves **1312** on a major surface thereof. “Grooves” here may include ridges **1313** and
30 valleys **1314**. In some embodiments of structured film **1310**, and as shown in **FIG. 13A**, there may be a combination of grooved regions and “ungrooved” (i.e., substantially flat) regions **1315**. In **FIG. 13A**, grooves **1312** have a sinusoidal pattern.

FIG. 13B shows a partial cross-sectional view perpendicular to axis **1330**, showing floor or base **1316** and at least one groove **1312** that comprises ridge **1313** and valleys **1314a** and **1314b** flanking either side of ridge **1313**. Valleys **1314a** and **1314b** have a base thickness R_0 , and width Y , and ridge **1313** has height R_i and width X , X as shown in **FIG. 13B** is about twice the width of Y , although other ratios could be selected. The relative dimensions R_0 , R_i , X , and Y may be varied according to the properties desired in structured film **1310**. For example, in some embodiments, it may be desirable for structured film **1310** to have a degree of stiffness resulting from a selection of X to be about twice the width of Y .

To explain how structured film **1310** might be produced, reference is made to **FIG. 14**, which shows schematically a view of tool surface **1400** from a perspective orthogonal to the cross-web (CW) and down-web (DW) dimensions. Extrudate region **1410** is shown contacting a set of sinusoidal tool surface structures **1420** in a manner that overlaps the solid lines **1420**, which here represent depressions in the tool surface that are the negative of grooves **1312** in **FIG. 13A**. The broken sinusoidal lines **1450** in **FIG. 14** represent shallower depressions that may optionally be present in the tool surface. Extrudate region **1410** can be formed by extrusion over a profiled die lip, for example the profiled die lip shown schematically in **FIG. 13C**, having non-rectilinear portion **1380** and rectilinear portion **1390**. The dimensions of **1380** may be selected to form an extrudate feature having sufficient width and volume to fill tool surface features **1420**. In this case, each die lip feature **1380** may have a width to form an extrudate feature that contacts the tool surface from edge **1430** to edge **1440**. In another embodiment, die lip feature **1380** may be selected to generate extrudate feature **1411** having a width that is narrower than the overall width of the set of sinusoidal tool surface depressions **1421**, as schematically shown at points **1415** and **1416**.

Example

Additional embodiments and features thereof are set for the in the following non-limiting Example.

A structured replicated film having surface structure similar to that shown in **FIG. 13A** was prepared using a copolyester polymer (Estar PETG 6763 obtained from

Eastman Chemical Co., Kingsport, TN) and the following procedure. A 32 mm (24 L/D) 4 - zone single screw extruder (11 RPM) was used to melt and extrude the PETG polymer into a 20 centimeter wide conventional coat-hanger film die equipped with two removable die lips. One of the die lips was shaped to have a profile like that shown in **FIG. 13C** using conventional wire EDM (electron discharge machining) techniques. The first zone of the extruder was water-cooled at approximately 25°C. The second zone of the extruder was set at 210°C while the remaining zones were set at 180°C. The die temperature was maintained at 170°C. The melt temperature of the polymer in the die was 246°C. The molten polymer was extruded through the profiled die lip and vertically downward into a nip configured with a 32 cm diameter temperature controlled steel tool roll (52°C) on one side and a 32 cm diameter chill (24°C) roll (having a silicone rubber coating) on the opposite side. The steel roll was fitted with a structured aluminum sleeve which had been machined with a series of sinusoidal grooves around the roll complementary to the surface structure of the film surface shown in **FIG. 13A**. A nip force of 3200 N per lineal cm was used. The profiled die lip was positioned such that the shaped side of the extrudate contacted the grooves on the surface of the tool roll, and the profiles in the extrudate were aligned with the appropriate grooves in the tool roll. The extrudate was in contact with the tool roll for approximately 180 degrees of wrap on the roll. The film was pulled from the tool roll at 5.5 meters/min using a driven peel-off rubber coated roll that was slightly oversped relative to the tool roll speed.

It will be apparent to those skilled in the art that the specific exemplary structures, features, details, configurations, etc., that are disclosed herein can be modified and/or combined in numerous embodiments. All such variations and combinations are contemplated by the inventor as being within the bounds of the conceived invention. Thus, the scope of the present invention should not be limited to the specific illustrative structures described herein, but rather by the structures described by the language of the claims, and the equivalents of those structures. To the extent that there is a conflict or discrepancy between this specification and the disclosure in any document incorporated by reference herein, this specification will control.

What is claimed is:

1. A process for making a structured film, comprising steps of:
 - (a) extruding a molten material through an extrusion die having at least one
5 profiled die lip to form a molten extrudate having first and second major extrudate
surfaces and having a first structural feature in the first major extrudate surface;
 - (b) bringing the molten extrudate into contact with a tool surface comprising
one or more second structural features so as to cause a portion of the first structural feature
in the first major extrudate surface to contact at least one of the second structural features
10 on the tool surface; and
 - (c) cooling the molten extrudate to provide the structured film.
2. The process of claim 1 wherein extruding a molten material comprises extruding
the molten material vertically downward and into contact with the tool surface.
15
3. The process of claim 1, wherein extruding a molten material comprises extruding
one or more thermoformable materials selected from the group consisting of a polyolefin,
an olefin-containing polymer, and combinations of two or more of the foregoing.
- 20 4. The process of claim 1, wherein extruding a molten material is performed using a
single screw extruder.
5. The process of claim 1, wherein extruding a molten material is performed using a
twin screw extruder.
25
6. The process of claim 1, wherein extruding a molten material comprises extruding
one or more polymeric material selected from the group consisting of polyethylene,
polypropylene, polystyrene, polymethylmethacrylate, polyamide, polyester,
polycarbonate, polymethyleneoxide, polybutyleneterephthalate, styrene acrylonitrile
30 copolymer, styrene (meth)acrylate copolymer, styrene maleic anhydride copolymer,
nucleated semi-crystalline polyester, polyethylenenaphthalate copolymer, polyimide

copolymer, polyetherimide, polyethylene oxide, polyacrylonitrile-co-polybutadiene-co-polystyrene, and combinations of two or more of the foregoing.

5 7. The process of claim 1, wherein extruding a molten material comprises extruding one or more polymeric material from the group consisting of cyclic olefin copolymers, polyethylene naphthalate, polyethylene terephthalate, polyacrylate, polymethylmethacrylate, polycarbonate, polymethylpentene, styrene acrylonitrile, and combinations of two or more of the foregoing.

10 8. The process of claim 1, wherein bringing the molten extrudate into contact with a tool surface in step b) comprises nipping the molten extrudate between the tool surface and a nip roll, wherein the tool surface is a surface on a tool roll.

9. The process of claim 8 wherein at least one of the nip roll or the tool roll is cooled.

15 10. The process of claim 1, wherein bringing the molten extrudate into contact with a tool surface in step b) comprises nipping the molten extrudate between the tool surface and a nip roll, wherein the tool surface is a surface on an endless belt.

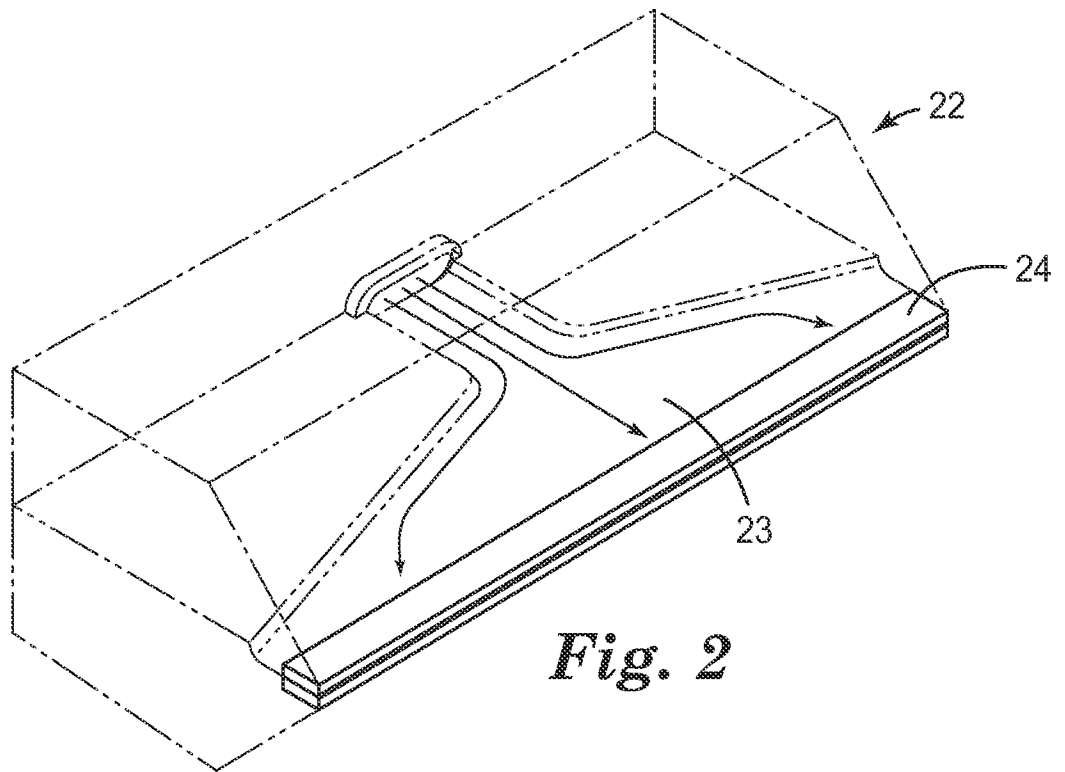
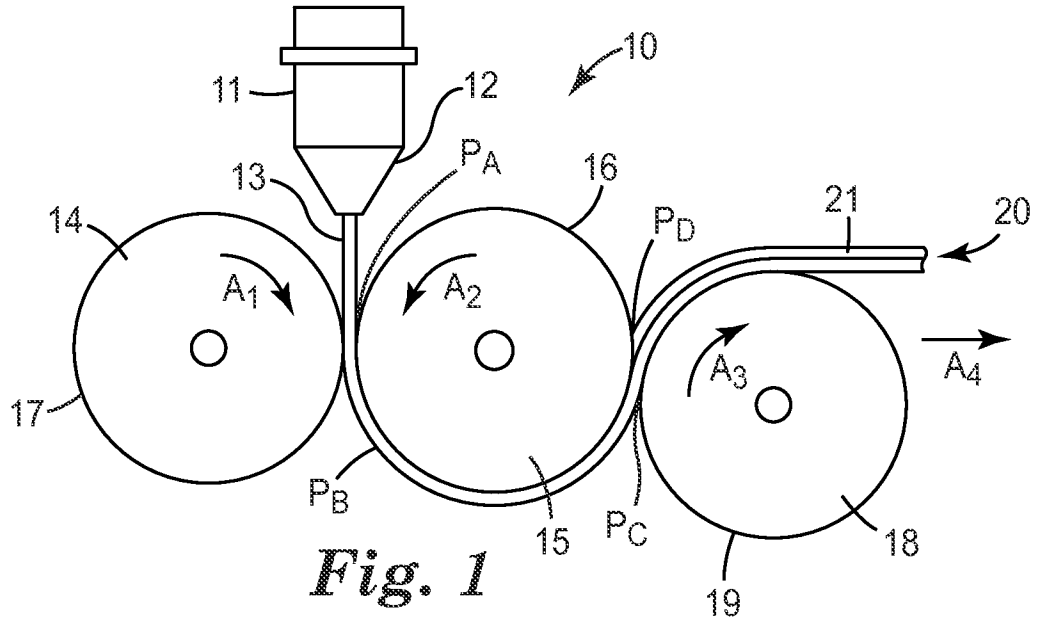
20 11. The process of claim 1, wherein bringing the molten extrudate into contact with a tool surface in step b) comprises nipping the molten extrudate between the tool surface and a nip surface, wherein the nip surface is a surface on an endless belt.

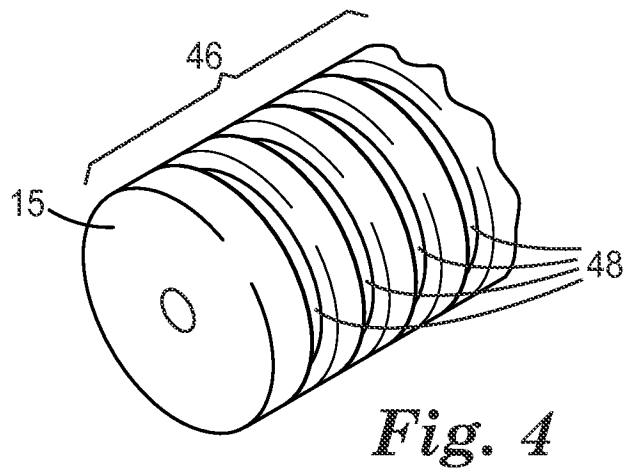
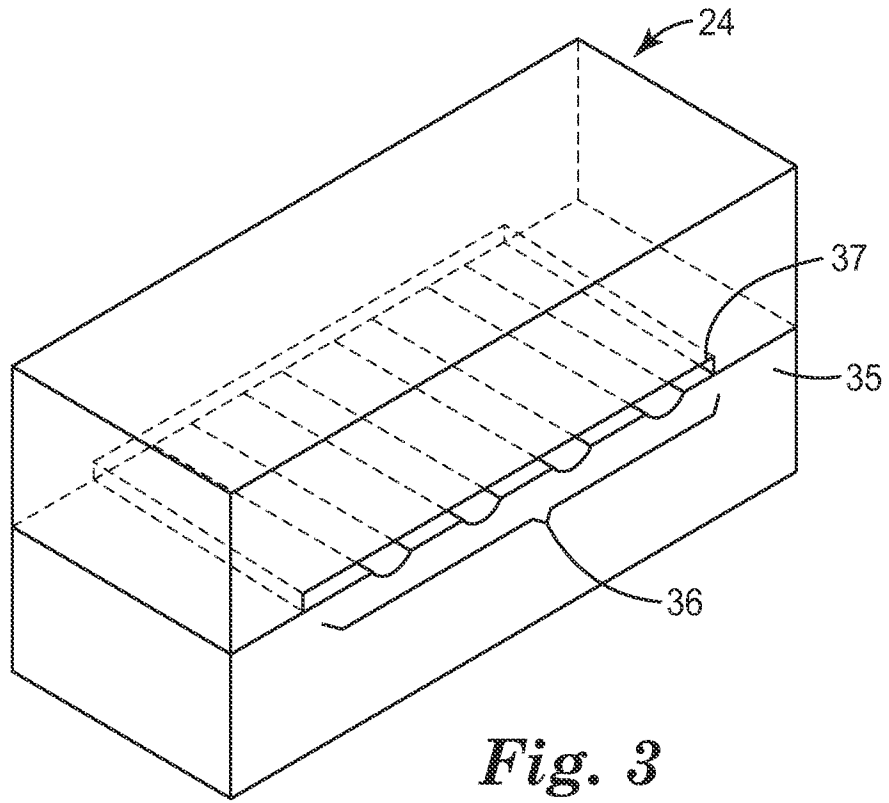
25 12. The process of claim 1 wherein step b) occurs at a temperature above a glass transition temperature of the molten extrudate.

13. The process of claim 1 wherein the portion of the first structural feature contacts at least two of the second structural features located on the tool surface.

30 14. The process of claim 1 wherein a ratio of a cross-web cross-sectional area of the first structural feature to a cross-web cross-sectional area of a second structural feature is about 1.0.

15. A structured film made according to the process of any one of the preceding claims.
16. An apparatus for extrusion replication, comprising:
5 an extruder equipped with a profiled extrusion die having at least one profiled die lip; and,
a tool having a structured surface positioned to receive molten extrudate from the profiled extrusion die.
- 10 17. The apparatus of claim 16, wherein the tool comprises a tool roll.
18. The apparatus of claim 16, wherein the tool comprises an endless belt.
19. The apparatus of claim 16, wherein the extruder is a single screw extruder.
- 15 20. The apparatus of claim 16, wherein the extruder is a twin screw extruder.
21. The apparatus of either of claims 17 or 18, further comprising a nip roll to form a nip with the tool.
- 20 22. The apparatus of claim 21, wherein the nip roll has a structured surface.
23. The apparatus of claim 21, wherein the nip roll has a conformable surface.





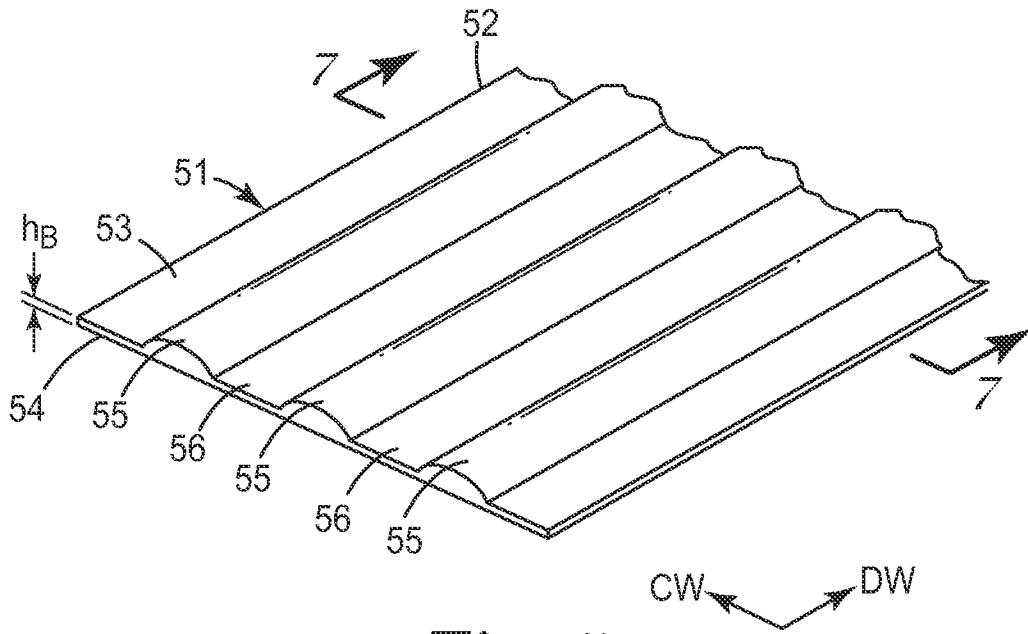


Fig. 5

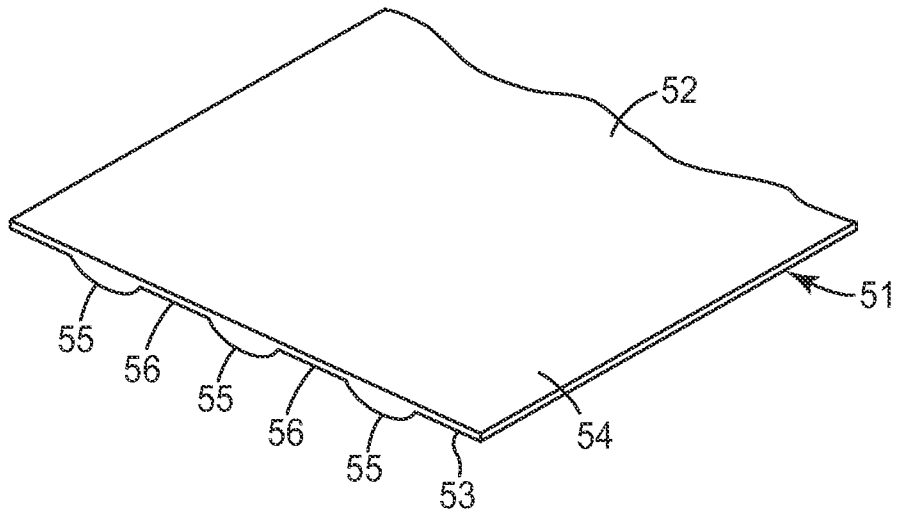


Fig. 6

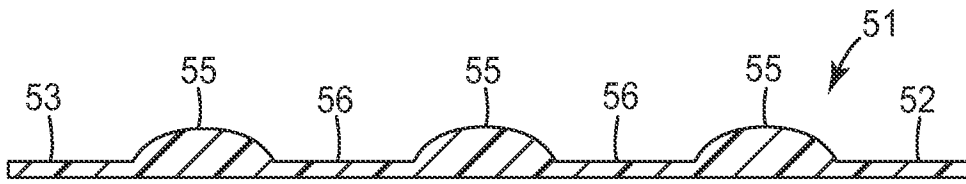


Fig. 7

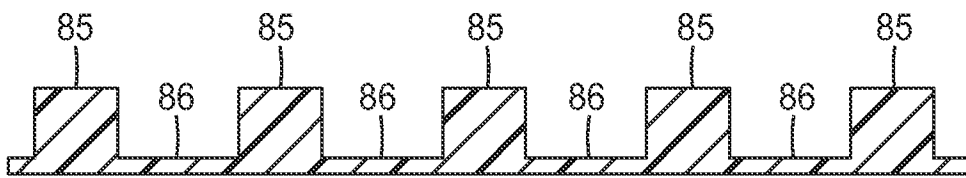


Fig. 8

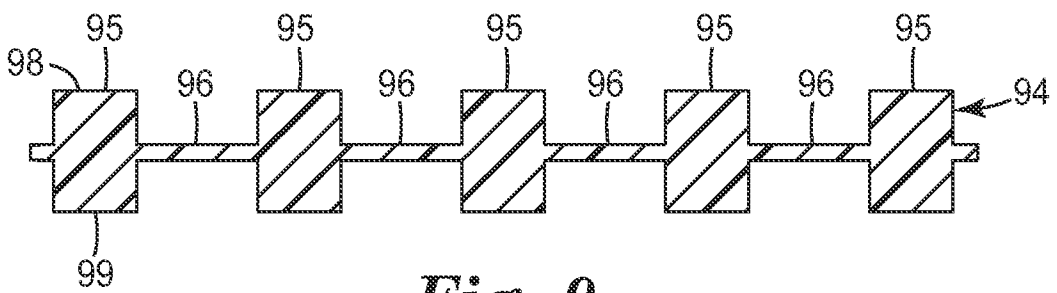


Fig. 9

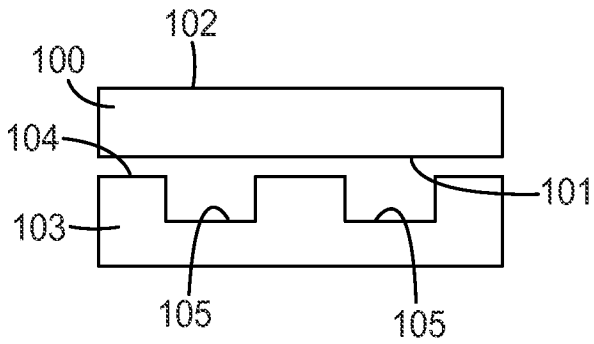


Fig. 10A
Prior Art

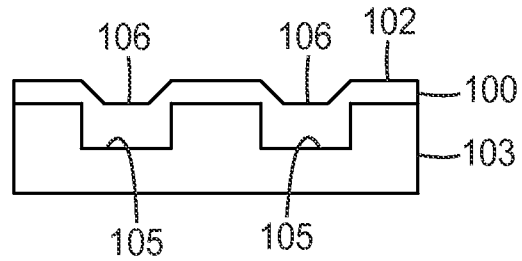


Fig. 10B
Prior Art

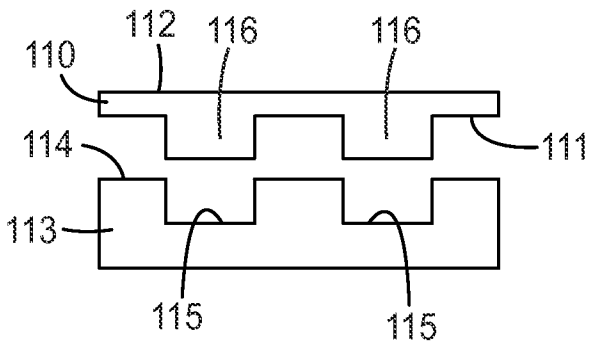


Fig. 11A

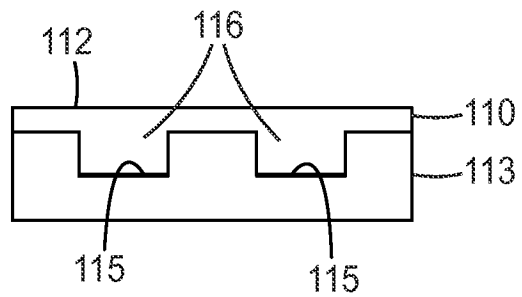


Fig. 11B

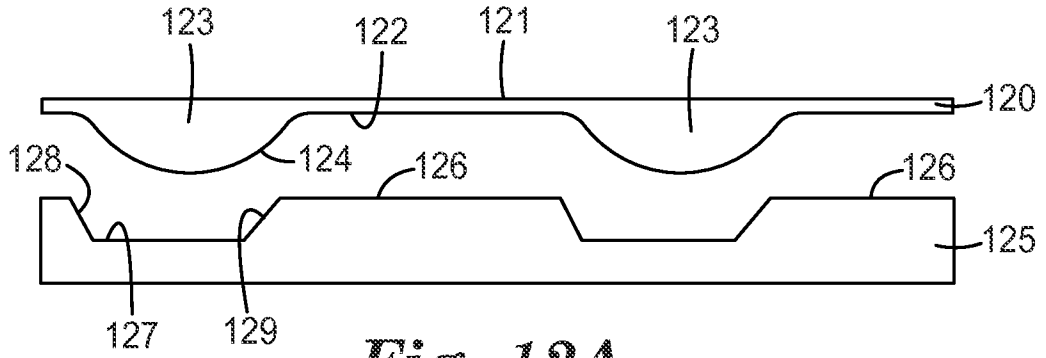


Fig. 12A

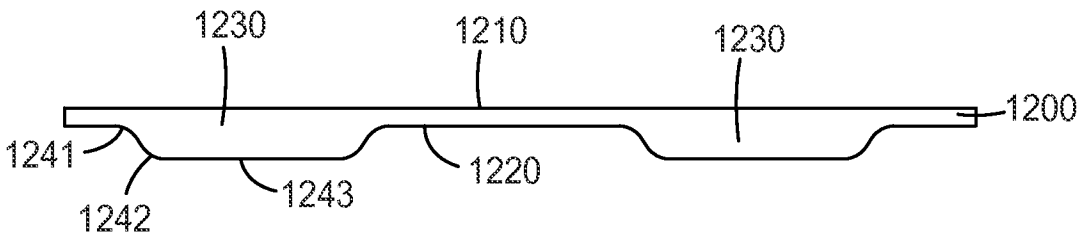


Fig. 12B

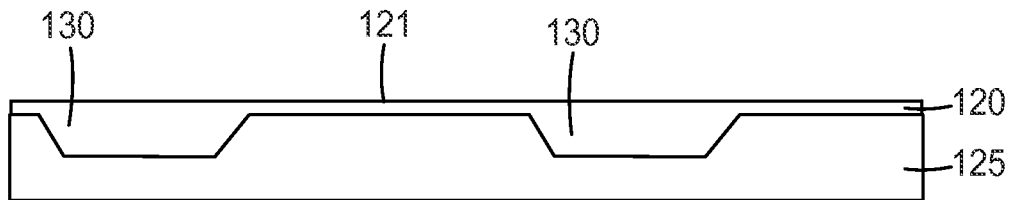


Fig. 12C

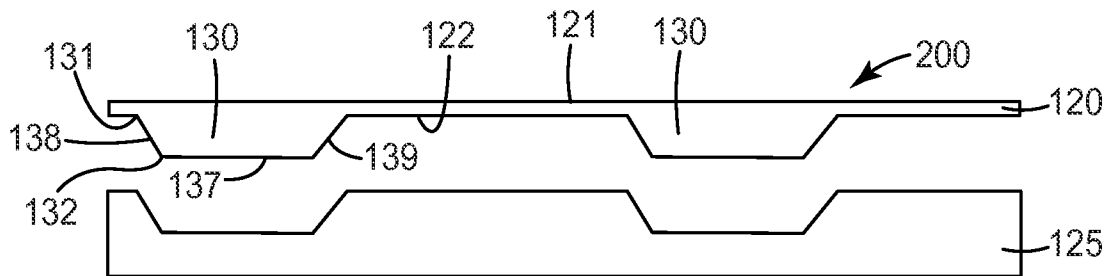


Fig. 12D

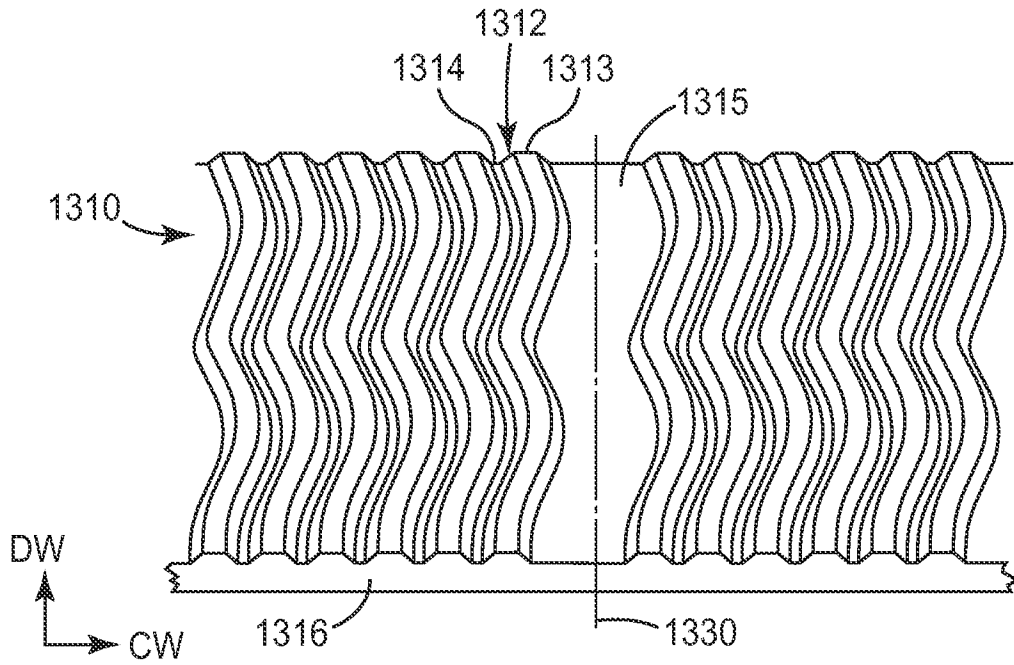


Fig. 13A

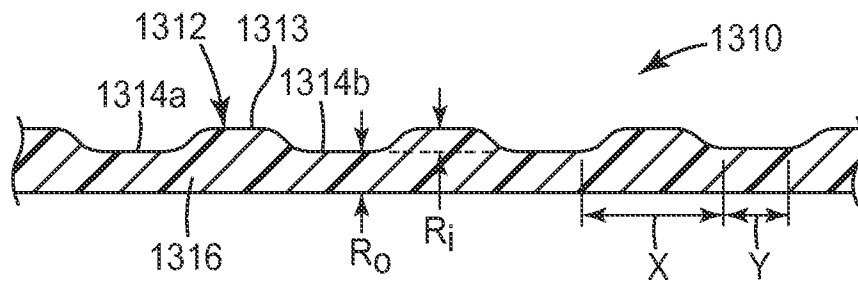


Fig. 13B

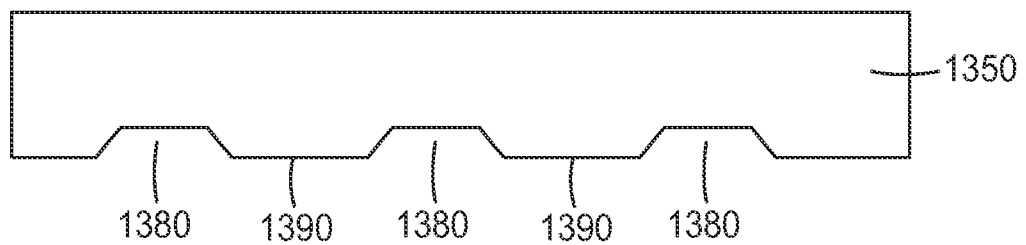


Fig. 13C

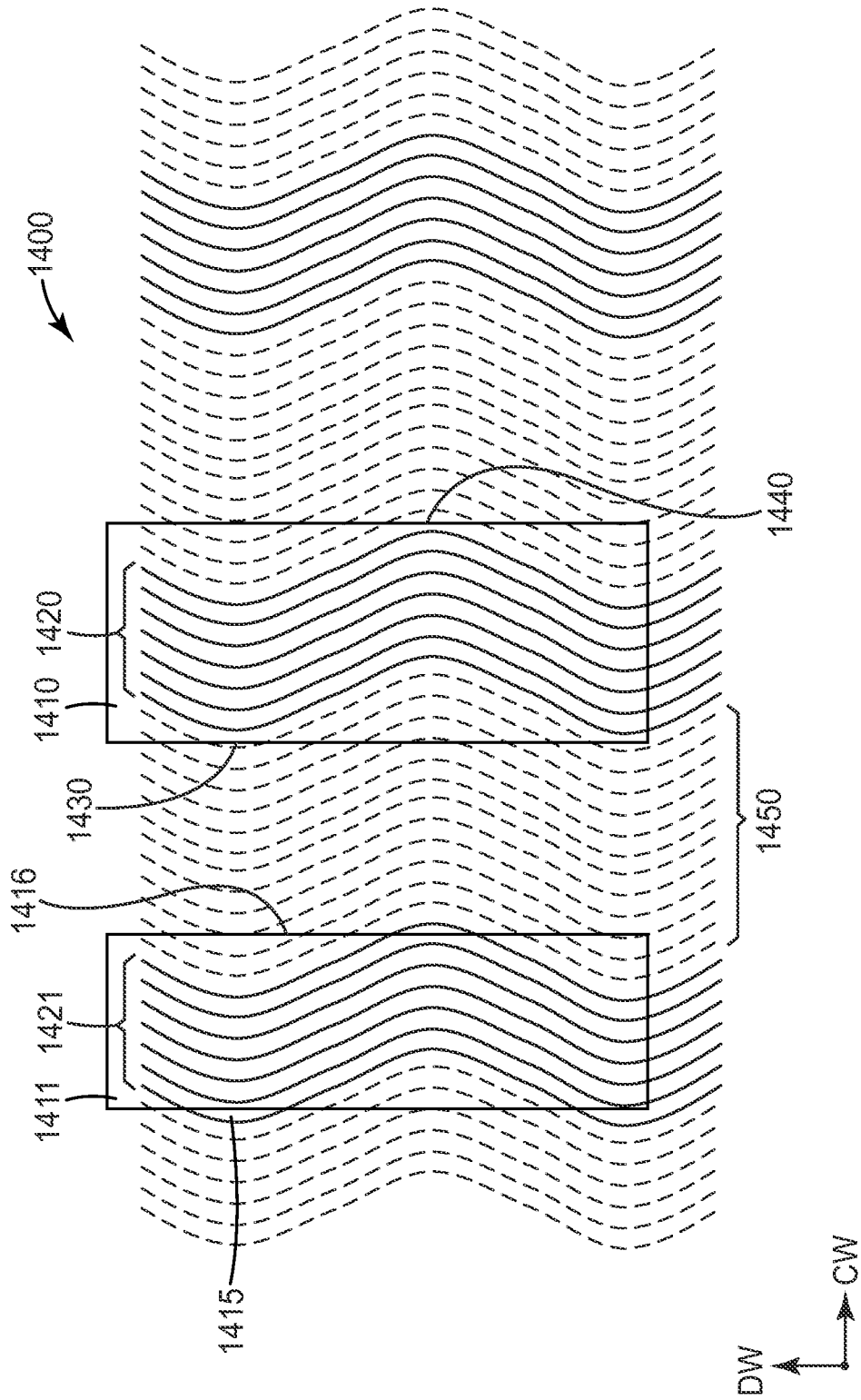


Fig. 14

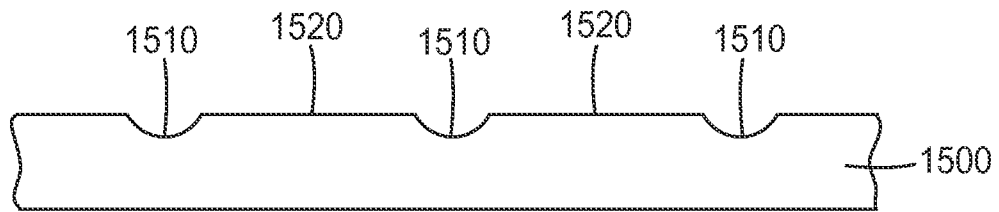


Fig. 15