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## (54) Title: COEXTRUDED, CROSSLINKED POLYOLEFIN FOAM WITH KEE CAP LAYERS

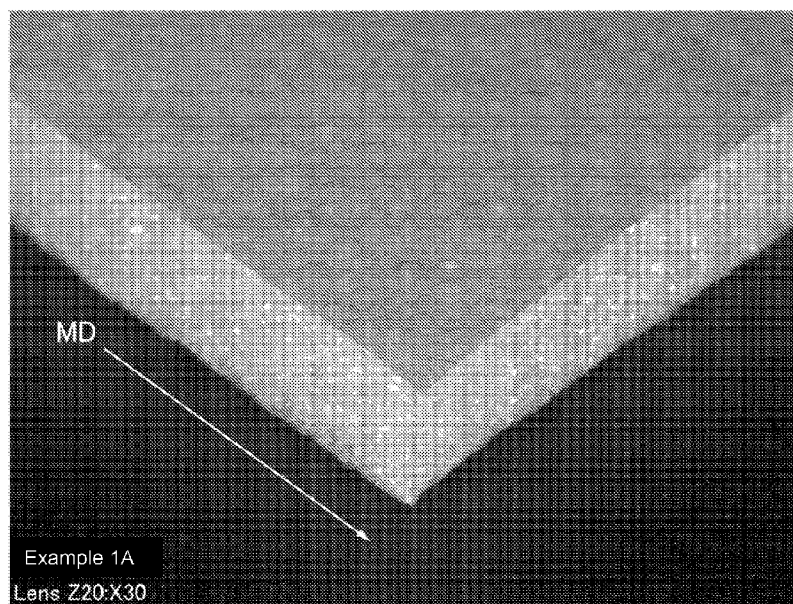


Figure 1A

(57) **Abstract:** The present disclosure is directed to a physically crosslinked, closed cell continuous multilayer foam structure comprising at least one foam polypropylene/polyethylene layer with a KEE cap layer. The multilayer foam structure can be obtained by coextruding a multilayer structure comprising at least one foam layer composition layer with at least one cap layer composition layer, irradiating the coextruded structure with ionizing radiation, and continuously foaming the irradiated structure.



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**COEXTRUDED, CROSSLINKED POLYOLEFIN FOAM WITH KEE CAP LAYERS****CROSS-REFERENCE TO RELATED APPLICATIONS**

**[0001]** This application claims priority benefit to U.S. Non-Provisional Patent Application No. 16/370,043, filed on March 29, 2019, and U.S. Non-Provisional Patent Application No. 16/370,154, filed on March 29, 2019 the disclosure of which are hereby incorporated herein by reference in its entirety.

**FIELD OF THE INVENTION**

**[0002]** This disclosure relates to multilayer foam structures with a KEE (ketone-ethylene-ester) terpolymer cap layer. More particularly, this disclosure relates to a physically crosslinked, closed cell continuous multilayer foam structure comprising a KEE cap layer.

**BACKGROUND OF THE INVENTION**

**[0003]** Polyolefin foams can be used in various applications including, but not limited to, a trim component in a vehicle interior, a roofing membrane, and a flooring underlayment. When used in these various applications, the polyolefin foam can be bonded to polyvinyl chloride (PVC) skins or polyvinyl chloride foams. Traditionally, to obtain satisfactory adhesion between polyolefin foam and polyvinyl chloride, a surface modification treatment such as corona, plasma, or chemical was applied to the polyolefin foam. Afterwards, an adhesion primer and/or an adhesive were/was applied to the surface modified polyolefin foam to obtain satisfactory adhesion.

**[0004]** However, modifying the surface of the polyolefin foam followed by coating the foam with a primer and/or adhesive are additional processing steps between the manufacturing of the foam and the final application. This can add cost which may render the process uneconomical for commercial purposes. In addition, polyolefin surface modification – particularly with corona – can also be temporary and may not be suitable for instances where the treated foam is stored in a warehouse or a retail store for an extended period of time.

## SUMMARY OF THE INVENTION

**[0005]** It has been discovered that coextruding a polyolefin foam layer composition with a KEE (ketone-ethylene-ester) terpolymer cap layer can overcome the issues associated with both (a) treating the surface of a polyolefin foam with corona, plasma, or a chemical to modify the foam surface; and (b) applying an adhesion primer and/or an adhesive to the surface modified polyolefin foam. Since KEE is highly miscible in (and thus highly compatible with) PVC, a coextruded polyolefin foam with a KEE cap layer is expected to readily heat bond to PVC without the need for a surface treatment, a primer, and/or an adhesive. In addition, unlike corona, the KEE cap layer does not have a “shelf life” where extended periods of time in a warehouse or retail store can render the product less susceptible to adhesion to a primer or adhesive.

**[0006]** In some embodiments, a multilayer foam structure is provided, the multilayer foam structure comprising a coextruded foam layer including polypropylene, polyethylene, or a combination of polypropylene and polyethylene; and a coextruded cap layer on a side of the foam layer, the cap layer includes at least 15 wt. % ketone-ethylene-ester terpolymer and polypropylene, polyethylene, or a combination of polypropylene and polyethylene. In some embodiments, the coextruded foam layer comprises 2-15 wt. % KEE. In some embodiments, the coextruded foam layer comprises at least 70 wt. % polypropylene, polyethylene, or a combination of polypropylene and polyethylene. In some embodiments, the foam layer comprises additives in an amount of 1-20 wt. %. In some embodiments, the cap layer comprises additives in an amount of 1-8 wt. %. In some embodiments, the polypropylene has a melt flow index of 0.1-25 grams per 10 minutes at 230°C. In some embodiments, the polyethylene has a melt flow index of 0.1-25 grams per 10 minutes at 190°C. In some embodiments, the density of the multilayer foam structure is 20-250 kg/m<sup>3</sup>. In some embodiments, the multilayer foam structure has a crosslinking degree of 20-75%. In some embodiments, the multilayer foam structure has an average closed cell size of 0.05-1.0 mm. In some embodiments, the multilayer foam structure has a thickness of 0.2-50 mm.

**[0007]** In some embodiments, a laminate is provided, the laminate comprising a multilayer foam structure including a coextruded foam layer including polypropylene, polyethylene, or a combination of polypropylene and polyethylene, and a coextruded cap layer on a side of the

foam layer, the cap layer includes at least 15 wt. % KEE and polypropylene, polyethylene, or a combination of polypropylene and polyethylene; and a laminate layer on a side of the cap layer opposite the foam layer. In some embodiments, the laminate layer is a flexible film, foil, or foam. In some embodiments, the laminate layer is a semi-flexible or rigid board, plank, tile, or substrate. In some embodiments, the laminate layer comprises PVC, KEE, or a blend of PVC and KEE.

**[0008]** In some embodiments, a method of forming a multilayer structure is provided, the method comprising: coextruding a first layer including polypropylene, polyethylene, or a combination of polypropylene and polyethylene and a chemical foaming agent, and a second layer on a side of the first layer, the second layer including at least 15 wt. % ketone-ethylene-ester terpolymer and polypropylene, polyethylene, or a combination of polypropylene and polyethylene; irradiating the coextruded layers with ionizing radiation and foaming the irradiated, coextruded layers. In some embodiments, the first layer comprises 2-15 wt. % KEE. In some embodiments, the first layer comprises at least 70 wt. % polypropylene, polyethylene, or a combination of polypropylene and polyethylene. In some embodiments, the first layer comprises additives in an amount of 1-20 wt. %. In some embodiments, the second layer comprises additives in an amount of 1-8 wt. %. In some embodiments, the polypropylene has a melt flow index of 0.1-25 grams per 10 minutes at 230°C. In some embodiments, the polyethylene has a melt flow index of 0.1-25 grams per 10 minutes at 190°C. In some embodiments, the amount of chemical foaming agent in the first layer is 4-10 wt. %. In some embodiments, the chemical foaming agent comprises azodicarbonamide. In some embodiments, the first layer comprises a crosslinking agent. In some embodiments, the amount of crosslinking agent in the first layer is 1-3 wt. %. In some embodiments, the ionizing radiation is selecting from the group consisting of alpha, beta (electron beams), x-ray, gamma, and neutron. In some embodiments, the coextruded structure is irradiated up to four separate times. In some embodiments, the ionizing radiation is an electron beam with an acceleration voltage of 200-1500 kV. In some embodiments, an absorbed electron beam dosage is 10-500 kGy. In some embodiments, the ionizing radiation crosslinks the extruded structure to a crosslinking degree of 20-75%. In some embodiments, foaming comprises heating the irradiated structure with molten salt and radiant heaters or a hot air oven. In some embodiments, the multilayer foam structure has a density of 20-250 kg/m<sup>3</sup>. In some

embodiments, the multilayer foam structure has an average closed cell size of 0.05-1.0 mm. In some embodiments, the multilayer foam structure has a thickness of 0.2-50 mm.

**[0009]** Reference to “about” a value or parameter herein includes (and describes) variations that are directed to that value or parameter per se. For example, description referring to “about X” includes description of “X”. In addition, reference to phrases “less than”, “greater than”, “at most”, “at least”, “less than or equal to”, “greater than or equal to”, or other similar phrases followed by a string of values or parameters is meant to apply the phrase to each value or parameter in the string of values or parameters. For example, a statement that the layer has less than about 20 wt. %, about 15 wt. %, or about 10 wt. % of a chemical foaming agent, is meant to mean that the weight percentage of the chemical foaming agent in the layer can be less than about 20 wt. %, less than about 15 wt. %, or less than about 10 wt. %.

**[0010]** As used herein, the singular forms “a,” “an,” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It is also to be understood that the term “and/or” as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. It is further to be understood that the terms “includes,” “including,” “comprises,” and/or “comprising,” when used herein, specify the presence of stated features, integers, steps, operations, elements, components, and/or units but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, units, and/or groups thereof.

**[0011]** It is understood that aspects and embodiments described herein include “consisting” and/or “consisting essentially of” aspects and embodiments. For all methods, systems, compositions, and devices described herein, the methods, systems, compositions, and devices can either comprise the listed components or steps, or can “consist of” or “consist essentially of” the listed components or steps. When a system, composition, or device is described as “consisting essentially of” the listed components, the system, composition, or device contains the components listed, and may contain other components which do not substantially affect the performance of the system, composition, or device, but either do not contain any other components which substantially affect the performance of the system, composition, or device other than those components expressly listed; or do not contain a sufficient concentration or amount of the extra components to substantially affect the performance of the system,

composition, or device. When a method is described as “consisting essentially of” the listed steps, the method contains the steps listed, and may contain other steps that do not substantially affect the outcome of the method, but the method does not contain any other steps which substantially affect the outcome of the method other than those steps expressly listed.

**[0012]** In the disclosure, “substantially free of” a specific component, a specific composition, a specific compound, or a specific ingredient in various embodiments, is meant that less than about 5%, less than about 2%, less than about 1%, less than about 0.5%, less than about 0.1%, less than about 0.05%, less than about 0.025%, or less than about 0.01% of the specific component, the specific composition, the specific compound, or the specific ingredient is present by weight. Preferably, “substantially free of” a specific component, a specific composition, a specific compound, or a specific ingredient indicates that less than about 1% of the specific component, the specific composition, the specific compound, or the specific ingredient is present by weight.

**[0013]** Additional advantages will be readily apparent to those skilled in the art from the following detailed description. The examples and descriptions herein are to be regarded as illustrative in nature and not restrictive.

### BRIEF DESCRIPTION OF THE DRAWINGS

**[0014]** Various embodiments are described with reference to the accompanying figures, in which:

**[0015]** Figure 1A is an image of Example 1A at 30X magnification and 45° from primary surface;

**[0016]** Figure 1B is an image of Example 1B at 30X magnification and 45° from primary surface;

**[0017]** Figure 2A is an image of Example 2A at 30X magnification and 45° from primary surface;

**[0018]** Figure 2B is an image of Example 2B at 30X magnification and 45° from primary surface;

**[0019]** Figure 3 is an image of Example 3 at 30X magnification and 45° from primary surface;

**[0020]** Figure 4A is an image of Example 4A at 30X magnification and 45° from primary surface;

**[0021]** Figure 4B is an image of Example 4B at 30X magnification and 45° from primary surface;

**[0022]** Figure 5 is an image of Example 5 at 30X magnification and 45° from primary surface;

**[0023]** Figure 6 is an image of Example 6 at 30X magnification and 45° from primary surface;

**[0024]** Figure 7 is an image of Example 7 at 30X magnification and 45° from primary surface;

**[0025]** Figure 8 is an image of Example 8 at 30X magnification and 45° from primary surface;

[0026] Figure 9 is an image of Example 9 at 30X magnification and 45° from primary surface;

[0027] Figure 10 is an image of Example 10 at 30X magnification and 45° from primary surface; and

[0028] Figure 11 is an image of Example 11 at 30X magnification and 45° from primary surface.

### DETAILED DESCRIPTION OF THE INVENTION

[0029] Described herein are crosslinked, closed cell coextruded polyolefin foams with KEE cap layers, as well as methods for producing crosslinked, closed cell coextruded polyolefin foams with KEE cap layers. In particular, it has been discovered that coextruding a polyolefin foam layer composition with a KEE cap layer can overcome the issues associated with treating the surface of polyolefin foam with corona, plasma, or a chemical and/or applying an adhesion primer or adhesive to the surface modified polyolefin film. Specifically, the structures disclosed herein can readily bond to polyvinyl chloride films and polyvinyl chloride foams and can avoid rendering the product less able to adhere to primers and adhesives as shelf life increases.

[0030] The methods for producing a crosslinked, closed cell co-extruded polyolefin foam with KEE cap layer(s) may include the steps of: (a) co-extrusion; (b) irradiation; and (c) foaming.

[0031] Co-extrusion is the extrusion of multiple layers of material simultaneously. This type of extrusion can utilize two or more extruders to deliver a steady volumetric throughput of material to an extrusion head (die) which can extrude the materials in the desired form. In the co-extrusion step, compositions can be fed into multiple extruders to form an unfoamed, multilayer structure. For example, an "A" foam layer composition can be fed into one extruder and a "B" cap layer composition can be fed into a second extruder. The method of feeding ingredients into the extruders can be based on the design of the extruder and the material handling equipment available. Blending ingredients of the foam and cap layer compositions may be performed prior to feeding into the extruders, if necessary, to facilitate their dispersal. A Henshel mixer can be used for such blending. All ingredients can be

blended and fed through a single port in an extruder. The ingredients can also be individually fed through separate designated ports for each ingredient. For example, if the crosslinking promoter or any other additive is a liquid, the promoter and/or additives can be added through a feeding gate (or gates) on the extruder or through a vent opening on the extruder (if equipped with a vent) instead of being blended with solid ingredients. Combinations of blended ingredients and individual ingredient port feeding can also be employed.

**[0032]** Each extruder can deliver a steady amount of each composition into one or more manifolds. The one or more manifolds may then be fed through a sheeting die to create an unfoamed, co-extruded multilayer sheet. There are two common methods for co-extruding materials: (1) feed block manifolds; and (2) multi-manifolds within the die. Elements of a feed block manifold can include: (a) inlet ports for upper, middle, and lower layers; (b) a streamlined melt lamination area that channels separate flow streams into one laminated melt stream inside the feed block; (c) an adapter plate between the feed block and the sheet die; and/or (d) a sheet die (similar to a monolayer die), wherein the laminated melt stream enters the center of the die and spreads out along the manifold flowing out of the die exit as a distinct multilayer extrudate. Elements of a multi-manifold die can be: (a) similar to a monolayer die, except that there is more than one feed channel; (b) that each melt channel has its own choker bar for flow control; and/or (c) that the melt streams converge inside the die near the exit and emerge as a distinct multilayer extrudate.

**[0033]** Layer thicknesses of a multilayer structure provided herein can be determined by the design of the manifold(s) and/or die. For example, an 80/20 feed block manifold can deliver compositions in approximately a 4:1 ratio when the speed and size of each extruder is matched accordingly. A 50/50 feed block manifold can deliver compositions in approximately a 1:1 ratio when the speed and size of each extruder is matched accordingly. These ratios can be altered by changing, for example: (a) the amount of material fed into each extruder; (b) the relative extrusion speed between one extruder and another; (c) the relative size of each extruder; and/or (d) the composition (i.e., the viscosity) of the individual layers.

**[0034]** The thickness of the overall multilayer sheet can be controlled by the overall die gap. However, the overall multilayer sheet thickness can also be adjusted by stretching (i.e.,

"drawing") the melted multilayer extrudate and/or flattening the melted multilayer extrudate through a nip.

**[0035]** The multilayer structures disclosed herein can include at least two layers made up of different compositions, where at least one of the layers can contain KEE (ketone-ethylene-ester) terpolymer. In addition, the multilayer structures can include at least one layer made up of a foamable or foamed composition. In some embodiments, the multilayer structures can include at least one "A" polyolefin foam layer and at least one "B" KEE cap layer. In some embodiments, the "B" KEE cap layer can also include polyolefin. In some embodiments, the "A" polyolefin foam layer can also include KEE. In some embodiments, the "B" KEE cap layer can also be foamable or foamed.

**[0036]** A foamable composition fed into the extruder can include at least one polypropylene, at least one polyethylene, and/or a combination thereof. In some embodiments, the foam layer composition can form a polyolefin foam layer (A) of the multilayered structure. In some embodiments, the foam layer composition can form a KEE cap layer (B) of the multilayer structure.

**[0037]** The polypropylene of a foamable composition may contain an elastic or softening component. An elastic or softening component is typically an ethylene or rubber component and thus includes, but is not limited to, polypropylene, impact modified polypropylene, polypropylene-ethylene copolymer, impact modified polypropylene-ethylene copolymer, metallocene polypropylene, metallocene polypropylene-ethylene copolymer, metallocene polypropylene olefin block copolymer (with a controlled block sequence), polypropylene based polyolefin plastomer, polypropylene based polyolefin elasto-plastomer, polypropylene based polyolefin elastomer, polypropylene based thermoplastic polyolefin blend, and polypropylene based thermoplastic elastomeric blend. Furthermore, the polypropylene may be modified with polyether amine.

**[0038]** The polyethylene of a foamable composition includes, but is not limited to, LDPE, LLDPE (homopolymer, copolymer with butene or hexene or octene, terpolymer with butene and/or hexene and/or octene), VLDPE (homopolymer, copolymer with butene or hexene or octene, terpolymer with butene and/or hexene and/or octene), VLLDPE (homopolymer, copolymer with butene or hexene or octene, terpolymer with butene and/or hexene and/or

octene), HDPE, polyethylene-propylene copolymer, metallocene polyethylene, metallocene ethylene-propylene copolymer, and metallocene polyethylene olefin block copolymer (with a controlled block sequence), any of which may contain grafted compatibilizers or copolymers that contain acetate and/or ester groups.

**[0039]** The foam layer composition fed into the extruder can also include at least one KEE. KEE includes ketone-ethylene-ester terpolymers. One example is ethylene/n-butyl acrylate/carbon monoxide (E/nBA/CO) terpolymer. Other examples include ethylene/vinyl acetate/carbon monoxide (E/VA/CO) terpolymer and ethylene/2-ethyl hexyl acrylate/carbon monoxide (E/EHA/CO) terpolymer. These polymers can exhibit various short chain branching and monomer sequences.

**[0040]** In some embodiments, the amount of at least one polypropylene and/or at least one polyethylene in a foam layer composition can be greater than or equal to about 70 PPR%, about 75 PPR%, about 80 PPR%, about 85 PPR%, about 90 PPR%, or about 95 PPR% of the composition. In some embodiments, the amount of at least one polypropylene and/or at least one polyethylene in a foam layer composition can be less than or equal to about 100 PPR%, about 95 PPR%, about 90 PPR%, about 85 PPR%, about 80 PPR%, or about 75 PPR% of the composition. In some embodiments, the amount of at least one polypropylene and/or at least one polyethylene in a foam layer composition can be at least about 50 wt. %, about 60 wt. %, about 65 wt. %, about 70 wt. %, about 75 wt. %, about 80 wt. %, about 85 wt. %, or about 90 wt. % of the foam composition. In some embodiments, the amount of at least one polypropylene and/or at least one polyethylene in a foam layer composition can be less than or equal to about 95 wt. %, about 90 wt. %, about 85 wt. %, about 80 wt. %, about 75 wt. %, about 70 wt. %, about 65 wt. %, or about 60 wt. % of the foam layer composition. In some embodiments, the amount of at least one polypropylene and/or at least one polyethylene in a foam layer composition can be about 50-95 wt. %, about 65-90 wt. %, about 70-90 wt. %, or about 70-85 wt. % of the foam layer composition.

**[0041]** In some embodiments, the amount of KEE can be less than or equal to about 20 PPR%, about 15 PPR%, about 10 PPR%, or about 5 PPR% of the foam layer composition. In some embodiments, the amount of KEE can be greater than or equal to about 0.1 PPR%, about 1 PPR%, about 5 PPR%, about 10 PPR%, or about 15 PPR% of the foam layer

composition. In some embodiments, the amount of KEE in a foam layer composition can be less than or equal to about 20 wt. %, about 15 wt. %, about 10 wt. %, about 5 wt. %, or about 1 wt.% of the foam layer composition. In some embodiments, the amount of KEE can be greater than or equal to about 0.1 wt. %, about 1 wt.%, about 5 wt. %, about 10 wt. %, or about 15 wt. % of the foam layer composition. In some embodiments, the amount KEE can be about 0.1-20 wt. %, about 1-15 wt. %, about 2-10 wt. %, or about 3-5 wt. % of the foam layer composition.

**[0042]** A cap layer composition fed into the extruder can include at least one KEE and at least one polypropylene and/or at least one polyethylene (the KEE, polypropylene, and polyethylene as described above). In some embodiments, the cap layer composition can form a KEE cap layer (B) of the multilayer structure.

**[0043]** In some embodiments, the amount of KEE in a cap layer composition can be greater than or equal to about 15 PPR%, about 30 PPR%, about 40 PPR%, about 50 PPR%, about 60 PPR%, about 70 PPR%, about 80 PPR%, or about 90 PPR% of the cap layer composition. In some embodiments, the amount of KEE in a cap layer composition can be less than or equal to about 100 PPR%, about 90 PPR%, about 80 PPR%, about 70 PPR%, about 60 PPR%, about 50 PPR%, about 40 PPR%, or about 30 PPR% of the cap layer composition. In some embodiments, the KEE in a cap layer composition can be at least about 15 wt. %, about 30 wt. %, about 40 wt. %, about 50 wt. %, about 60 wt. %, about 70 wt. %, about 80 wt. %, about 90 wt. %, or about 95 wt. % of the cap layer composition. In some embodiments, the amount of KEE in a cap layer composition can be less than or equal to about 100 wt. %, about 95 wt. %, about 90 wt. %, about 80 wt. %, about 70 wt. %, about 60 wt. %, about 50 wt. %, about 40 wt. %, or about 30 wt. % of the cap layer composition. In some embodiments, the KEE in a cap layer composition can be about 15-85 wt. %, about 30-70 wt. %, or about 40-60 wt. % of the cap layer composition.

**[0044]** In some embodiments, the amount of at least one polypropylene and/or at least one polyethylene in a cap layer composition can be less than or equal to about 85 PPR%, about 70 PPR%, about 60 PPR%, about 50 PPR%, about 40 PPR%, about 30 PPR%, about 20 PPR%, about 15 PPR%, or about 10 PPR% of the cap layer composition. In some embodiments, the amount of at least one polypropylene and/or at least one polyethylene in a cap layer

composition can be greater than or equal to about 5 PPR%, about 10 PPR%, about 15 PPR%, about 20 PPR%, about 30 PPR%, about 40 PPR%, about 50 PPR%, about 60 PPR%, or about 70 PPR% of the cap layer composition. In some embodiments, the amount of at least one polypropylene and/or at least one polyethylene in a cap layer composition can be less than or equal to about 85 wt. %, about 70 wt. %, about 60 wt. %, about 50 wt. %, about 40 wt. %, about 30 wt. %, about 20 wt. %, about 15 wt. %, or about 10 wt. % of the cap layer composition. In some embodiments, the amount of at least one polypropylene and/or at least one polyethylene in a cap layer composition can be greater than or equal to about 5 wt. %, about 10 wt. %, about 15 wt. %, about 20 wt. %, about 30 wt. %, about 40 wt. %, about 50 wt. %, about 60 wt. %, or about 70 wt. % of the cap layer composition. In some embodiments, the amount of at least one polypropylene and/or at least one polyethylene in a cap layer composition can be about 15-85 wt. %, about 30-70 wt. %, or about 40-60 wt. % of the cap layer composition.

**[0045]** Since a broad range of multilayer structures and foam articles can be created with the disclosed compositions, a broad range of polypropylenes, polyethylenes, and KEE can be employed in the compositions to meet various in-process manufacturing requirements and commercial end use requirements.

**[0046]** Non-limiting examples of commercially available ketone-ethylene-ester (KEE) terpolymers include, but are not limited to, the ELVALOY® HP Series (E/nBa/Co terpolymers) from the Dow Chemical Company (e.g., ELVALOY® HP441, ELVALOY® HP641, etc.) and ELVALOY® 741, ELVALOY® 742, and ELVALOY® 4924 (E/VA/CO terpolymers) also from the Dow Chemical Company.

**[0047]** A non-limiting example of “polypropylene” is an isotactic homopolypropylene. Commercially available examples include, but are not limited to, FF018F from Braskem, 3271 from Total Petrochemicals, and COPYLENE™ CH020 from Conoco.

**[0048]** A non-limiting example of an “impact modified polypropylene” is a homopolypropylene with ethylene-propylene (EP) copolymer rubber. The rubber can be amorphous or semicrystalline but is not in sufficient quantities to render the material any plastomeric or elastomeric properties. A few non-limiting examples of commercially

available “impact modified polypropylene” are TI4003F and TI4015F from Braskem, and PRO-FAX® 8623 and PRO-FAX® SB786 from LyondellBasell.

**[0049]** “Polypropylene-ethylene copolymer” is polypropylene with random ethylene units. A few non-limiting examples of commercially available “polypropylene-ethylene copolymer” are 6232, 7250FL, and Z9421 from Total Petrochemicals, 6D20 and DS6D81 from Braskem, and PRO-FAX® RP311H and ADSYL™ 7415 XCP from LyondellBasell.

**[0050]** “Impact modified polypropylene-ethylene copolymer” is polypropylene with random ethylene units and with ethylene-propylene (EP) copolymer rubber. The rubber can be amorphous or semicrystalline, but is not in sufficient quantities to render the material any plastomeric or elastomeric properties. A non-limiting example of a commercially available impact modified polypropylene-ethylene copolymer is PRISMA® 6910 from Braskem.

**[0051]** “Metallocene polypropylene” is metallocene syndiotactic homopolypropylene, metallocene atactic homopolypropylene, and metallocene isotactic homopolypropylene. Non-limiting examples of “metallocene polypropylene” are those commercially available under the trade names METOCENE™ from LyondellBasell and ACHIEVE™ from ExxonMobil. Metallocene polypropylenes are also commercially available from Total Petrochemicals and include, but are not limited to, grades M3551, M3282MZ, M7672, 1251, 1471, 1571, and 1751.

**[0052]** “Metallocene polypropylene-ethylene copolymer” is metallocene syndiotactic, metallocene atactic, and metallocene isotactic polypropylene with random ethylene units. Commercially available examples include, but are not limited to, Lumicene® MR10MX0 and Lumicene® MR60MC2 from Total Petrochemicals and Purell® SM170G from LyondellBasell.

**[0053]** “Metallocene polypropylene olefin block copolymer” is a polypropylene with alternating crystallizable hard “blocks” and amorphous soft “blocks” that are not randomly distributed – that is, with a controlled block sequence. An example of “metallocene polypropylene olefin block copolymer” includes, but is not limited to, the INTUNE™ product line from the Dow Chemical Company.

**[0054]** “Polypropylene based polyolefin plastomer” (POP) and “polypropylene based polyolefin elastoplastomer” are both metallocene and non-metallocene propylene based copolymers with plastomeric and elastoplastomeric properties. Non-limiting examples are those commercially available under the trade name VERSIFY™ (metallocene) from the Dow Chemical Company, VISTAMAXX™ (metallocene) from ExxonMobil, and KOATTRO™ (non-metallocene) from LyondellBasell (a butene-1 based line of plastomeric polymers – certain grades are butene-1 homopolymer based and others are polypropylene-butene-1 copolymer based materials).

**[0055]** “Polypropylene based polyolefin elastomer” (POE) is both metallocene and non-metallocene propylene based copolymer with elastomeric properties. Non-limiting examples of propylene based polyolefin elastomers are those polymers commercially available under the trade names VERSIFY™ (metallocene) from the Dow Chemical Company and VISTAMAXX™ (metallocene) from ExxonMobil.

**[0056]** “Polypropylene based thermoplastic polyolefin blend” (TPO) is polypropylene, polypropylene-ethylene copolymer, metallocene homopolypropylene, and metallocene polypropylene-ethylene copolymer, which have ethylene-propylene copolymer rubber in amounts great enough to give the thermoplastic polyolefin blend (TPO) plastomeric, elastoplastomeric or elastomeric properties. Non-limiting examples of polypropylene based polyolefin blend polymers are those polymer blends commercially available under the trade names EXCELINK™ from JSR Corporation, THERMORUN™ and ZELAS™ from Mitsubishi Chemical Corporation, ADFLEX™ and SOFTELL™ from LyondellBasell, and TELCAR™ from Teknor Apex Company.

**[0057]** “Polypropylene based thermoplastic elastomer blend” (TPE) is polypropylene, polypropylene-ethylene copolymer, metallocene homopolypropylene, and metallocene polypropylene-ethylene copolymer, which have diblock or multiblock thermoplastic rubber modifiers (SEBS, SEPS, SEEPS, SEP, SERC, CEBC, HSB and the like) in amounts great enough to give the thermoplastic elastomer blend (TPE) plastomeric, elastoplastomeric, or elastomeric properties. Non-limiting examples of polypropylene based thermoplastic elastomer blend polymers are those polymer blends commercially available under the trade

name GLS™ DYNAFLEX™ and GLS™ VERSAFLEX™ from Polyone Corporation, MONPRENE® from Teknor Apex Company, and DURAGRIP® from A. Schulman.

**[0058]** “VLDPE” and “VLLDPE” are very low density polyethylene and very linear low density polyethylene containing an elastic or softening component, typically  $\alpha$ -olefins of butene and/or hexene and/or octene. Non-limiting examples of VLDPE and VLLDPE are commercially available under the tradename FLEXOMER™ from the Dow Chemical Company and particular grades of STAMYLEX™ from Borealis.

**[0059]** “LDPE” and “LLDPE” are low density polyethylene and linear low density polyethylene, respectively. Non-limiting examples of LDPE and LLDPE include at least those provided by ExxonMobil™ (e.g., LLP8501.67) and the Dow Chemical Company (e.g., DFDA-7059 NT 7). Commercial LLDPE polymers are typically copolymers containing  $\alpha$ -olefins of butene and/or hexene and/or octane.

**[0060]** “Metallocene polyethylene” is metallocene based polyethylene with properties ranging from non-elastic to elastomeric. Non-limiting examples of metallocene polyethylene are commercially available under the trade name ENGAGE™ from the Dow Chemical Company Chemical Company, ENABLE™ and EXCEED™ from ExxonMobil™, and QUEO™ from Borealis.

**[0061]** “Metallocene polyethylene olefin block copolymer” is a polyethylene with alternating crystallizable hard “blocks” and amorphous soft “blocks” that are not randomly distributed – that is, with a controlled block sequence. An example of “metallocene polyethylene olefin block copolymer” includes, but is not limited to, the INFUSE™ product line from the Dow Chemical Company Chemical Company.

**[0062]** These polyethylenes may also be copolymers and terpolymers containing acetate and/or ester groups. The comonomer groups include, but are not limited to, vinyl acetate, methyl acrylate, ethyl acrylate, butyl acrylate, glycidyl methacrylate, and acrylic acid. Non-limiting examples are commercially available under the tradename BYNEL®, ELVAX® and ELVALOY® from The Dow Chemical Company; EVATANE®, LOTADER®, and LOTRYL® from Arkema; ESCORENE™, ESCOR™, and OPTEMA™ from ExxonMobil.

**[0063]** The polypropylenes and polyethylenes listed above can be functionalized.

Functionalized polypropylenes and polyethylenes include a grafted monomer. Typically, the monomer has been grafted to the polypropylene or polyethylene by a free radical reaction. Suitable monomers for preparing functionalized polypropylenes and polyethylenes are, for example, olefinically unsaturated monocarboxylic acids, e.g. acrylic acid or methacrylic acid, and the corresponding tert-butyl esters, e.g. tert-butyl (meth) acrylate, olefinically unsaturated dicarboxylic acids, e.g. fumaric acid, maleic acid, and itaconic acid and the corresponding mono- and/or di-tert-butyl esters, e.g. mono- or di-tert-butyl fumarate and mono- or di-tert-butyl maleate, olefinically unsaturated dicarboxylic anhydrides, e.g. maleic anhydride, sulfo- or sulfonyl-containing olefinically unsaturated monomers, e.g. p-styrenesulfonic acid, 2-(meth)acrylamido-2-methylpropenesulfonic acid or 2-sulfonyl-(meth)acrylate, oxazolinyl-containing olefinically unsaturated monomers, e.g. vinyloxazolines and vinyloxazoline derivatives, and epoxy-containing olefinically unsaturated monomers, e.g. glycidyl (meth)acrylate or allyl glycidyl ether.

**[0064]** The most commonly commercially available functionalized polypropylenes are the ones functionalized with maleic anhydride. Non-limiting examples are the ADMER® QF and QB Series from Mitsui Chemicals, the PLEXAR® 6000 Series from LyondellBasell, the BYNEL® 5000 Series from the Dow Chemical Company, and the OREVAC® PP Series from Arkema.

**[0065]** The most commonly commercially available functionalized polyethylenes are also those functionalized with maleic anhydride. Non-limiting examples are the ADMER® NF and SE Series from Mitsui Chemicals, the PLEXAR® 1000, 2000, and 3000 Series from LyondellBasell, the BYNEL® 2100, 3000, 3800, 3900, 4000 Series from the Dow Chemical Company, and the OREVAC® PE, T, and some of the LOTADER® Series from Arkema.

**[0066]** Polyethylenes functionalized with other grafted monomers are also commercially available. Non-limiting examples include the BYNEL® 1100, 2200, and 3100 Series from the Dow Chemical Company and the LOTADER® AX Series from Arkema.

**[0067]** Note that polymers other than polypropylene and polyethylene functionalized with maleic anhydride are also commercially available. For example, the ROYALTUF® Series from Addivant are a series of EPDM rubbers functionalized with maleic anhydride. In

another example, the KRATON™ FG series from Kraton are a series of SEBS polymers functionalized with maleic anhydride.

**[0068]** The composition of any foamable layer and any cap layer provided herein can contain at least one polypropylene having a melt flow index from about 0.1 to about 25 grams per 10 minutes at 230°C and/or at least one polyethylene having a melt flow index from about 0.1 to about 25 grams per 10 minutes at 190°C. In some embodiments, the melt flow index of the polypropylene(s) and/or polyethylene(s) is preferably from about 0.3 to about 20 grams per 10 minutes at 230°C and at 190°C, respectively, and more preferably from about 0.5 to about 15 grams per 10 minutes at 230°C and at 190°C, respectively. The “melt flow index” (MFI) value for a polymer is defined and measured according to ASTM D1238 at 230°C for polypropylenes and polypropylene based materials and at 190°C for polyethylenes and polyethylene based materials using a 2.16 kg plunger for 10 minutes. The test time may be reduced for relatively high melt flow resins.

**[0069]** The MFI can provide a measure of flow characteristics of a polymer and is an indication of the molecular weight and processability of a polymer material. High MFI values correspond to low viscosities. If the MFI values are too high, extrusion according to the present disclosure cannot be satisfactorily carried out. Problems associated with MFI values that are too high include low pressures during extrusion, problems setting the thickness profile, uneven cooling profile due to low melt viscosity, poor melt strength, and/or machine problems. Conversely, low MFI values correspond to high viscosities. MFI values that are too low can cause high pressures during melt processing, sheet quality and profile problems, and higher extrusion temperatures which cause a risk of foaming agent decomposition and activation.

**[0070]** The above MFI ranges are also important for foaming processes because they can reflect the viscosity of the material, which has an effect on the foaming. Without being bound by any theory, it is believed there are several reasons why particular MFI values are more effective. A lower MFI material may improve some physical properties as the molecular chain length is greater, creating more energy needed for chains to flow when a stress is applied. Also, the longer the molecular chain (MW), the more crystal entities the chain can crystallize, thus providing more strength through intermolecular ties. However, at too low an

MFI, the viscosity becomes too high. On the other hand, polymers with higher MFI values have shorter chains. Therefore, in a given volume of a material with higher MFI values, there are more chain ends on a microscopic level relative to polymers having a lower MFI, which can rotate and create free volume due to the space needed for such rotation (e.g., rotation occurring above the  $T_g$ , or glass transition temperature of the polymer). This can increase the free volume and enables an easy flow under stress forces.

**[0071]** In addition to the polymers, the compositions fed into the extruders may also contain additives compatible with producing the disclosed multilayered structures. Common additives include, but are not limited to, organic peroxides, antioxidants, lubricants, processing aids, thermal stabilizers, colorants, flame retardants, antistatic agents, nucleating agents, plasticizers, antimicrobials, fungicides, light stabilizers, UV absorbents, anti-blocking agents, fillers, deodorizers, odor adsorbers, anti-fogging agents, volatile organic compound (VOC) adsorbers, semi-volatile organic compound (SVOC) adsorbers, thickeners, cell size stabilizers, metal deactivators, and combinations thereof. Suitable antioxidant packages include PR023, a blend of standard antioxidants developed by Toray Industries, Inc. and compounded by Techmer PM and/or PR086, a blend of antioxidants formulated by Toray Plastics (America), Inc. and blended by Amfine Chemical. A suitable processing aid may include TPM11166 from Techmer PM. An additional example of a suitable additive may include PM91399, which is a black concentrate from Techmer PM.

**[0072]** In some embodiments, the amount of additive(s) other than the chemical foaming agent(s) and the crosslinking promoter(s) in a foam layer composition and/or a cap layer composition can be less than or equal to about 20 PPR%, about 15 PPR%, about 10 PPR%, about 8 PPR%, about 6 PPR%, about 4 PPR%, about 2 PPR%, or about 1 PPR% of the composition. In some embodiments, the amount of additive(s) other than the chemical foaming agent(s) and the crosslinking promoter(s) in a foam layer composition and/or a cap layer composition can be greater than or equal to about 0.5 PPR%, about 1 PPR%, about 2 PPR%, about 4 PPR%, about 6 PPR%, about 8 PPR%, about 10 PPR%, or about 15 PPR% of the composition. In some embodiments, the amount of additive(s) other than the chemical foaming agent(s) and the crosslinking promoter(s) in a foam layer composition and/or a cap layer composition can be about 0.5-20 PPR%, about 1-10 PPR%, about 1.5-5 PPR%, or about 2-3 PPR% of the composition. In some embodiments, the amount of additive(s) other

than the chemical foaming agent(s) and the crosslinking promoter(s) in a foam layer composition can be about 1-20 wt. %, about 3-15 wt. %, about 5-10 wt. %, or about 6-8 wt. % of the foam layer composition. In some embodiments, the amount of additive(s) other than the chemical foaming agent(s) and the crosslinking promoter(s) in a cap layer composition can be about 0.5-10 wt. %, about 1-6 wt. %, or about 1.5-5 wt. % of the cap layer composition.

**[0073]** Regardless of how ingredients are fed into the extruders, the shearing force and mixing within an extruder can be sufficient to produce a homogenous layer. Co-rotating and counter-rotating twin screw extruders can provide sufficient shearing force and mixing through the extruder barrel to extrude a layer with uniform properties.

**[0074]** Specific energy is an indicator of how much work is being applied during the extrusion of the ingredients for a layer and how intensive the extrusion process is. Specific energy is defined as the energy applied to a material being processed by the extruder, normalized to a per kilogram basis. The specific energy is quantified in units of kilowatts of applied energy per total material fed in kilograms per hour. Specific energy is calculated according to the formula:

$$\text{Specific Energy} = \frac{KW(\text{applied})}{\text{feedrate} \left( \frac{kg}{hr} \right)}, \text{ where}$$

$KW(\text{applied})$

$$= \frac{KW(\text{motor rating}) * (\% \text{ torque from maximum allowable in decimal form}) * RPM(\text{actual running RPM}) * 0.97 (\text{gearbox efficiency})}{\text{Max RPM (capability of extruder)}}$$

**[0075]** Specific energy can be used to quantify the amount of shearing and mixing of the ingredients within the extruder. The extruders used to form the multilayer structures disclosed herein can be capable of producing a specific energy of at least about 0.100 kW·hr/kg, preferably at least about 0.120 kW·hr/kg, and more preferably at least about 0.150 kW·hr/kg.

**[0076]** Any foamable layer can contain a chemical foaming agent (CFA). The extrusion temperature for any foamable layer can be at least 10°C below the thermal decomposition initiation temperature of the chemical foaming agent. If the extrusion temperature exceeds the thermal decomposition temperature of the foaming agent, then the foaming agent will decompose, resulting in undesirable “prefoaming.” The extrusion temperature for any cap

layer can be at least 10°C below the thermal decomposition initiation temperature of the chemical foaming agent in any foamable layer adjacent to the cap layer. If the extrusion temperature of the cap layer exceeds the thermal decomposition temperature of the foaming agent in the adjacent layer, then the foaming agent in the adjacent layer can decompose, also resulting in undesirable “prefoaming.”

**[0077]** The foam layer composition can include a variety of different chemical foaming agents. Examples of chemical foaming agents include, but are not limited to, azo compounds, hydrazine compounds, carbazides, tetrazoles, nitroso compounds, and carbonates. In addition, a chemical foaming agent may be employed alone or in any combination. One chemical foaming agent that can be used in some embodiments is azodicarbonamide (ADCA). An example of a chemical foaming agent is P.T. Lauten Otsuka Chemical's UNIFOAM® TC-18I, which is imported by Biddle Sawyer Corporation and sold in the United States as Azofam® TC-18I. ADCA's thermal decomposition typically occurs at temperatures between about 190 to 230°C. In order to prevent ADCA from thermally decomposing in the extruder, extruding temperature can be maintained at or below 190°C.

**[0078]** The amount of chemical foaming agent in a foam layer composition and/or a cap layer composition can be less than or equal to about 30 PPR%, about 20 PPR%, about 15 PPR%, about 10 PPR%, about 8 PPR%, or about 5 PPR% of the composition. In some embodiments, the amount of chemical foaming agent in a foam layer composition and/or a cap layer composition can be greater than or equal to about 1 PPR%, about 5 PPR%, about 10 PPR%, about 15 PPR%, or about 20 PPR% of the composition. In some embodiments, the amount of chemical foaming agent in a foam layer composition and/or a cap layer composition can be about 1-30 PPR%, about 2-20 PPR%, about 5-15 PPR%, or about 6-10 PPR% of the composition. In some embodiments, the amount of chemical foaming agent in a foam layer composition can be about 1-20 wt. %, about 2-15 wt. %, about 5-10 wt. %, or about 6-8 wt. % of the foam layer composition. In some embodiments, the amount of chemical foaming agent in a cap layer composition can be about 0.1-5 wt. %, about 0.5-3 wt. %, or about 1-2 wt. % of the cap layer composition. The amount of chemical foaming agent can depend on the unfoamed sheet thickness, desired foam thickness, desired foam density, materials being extruded, crosslinking percentage, type of chemical foaming agent (different foaming agents can generate significantly different quantities of gas), among others.

**[0079]** Note that the above listed amounts of chemical foaming agent can be specific to ADCA only. Other foaming agents can produce varying amounts of volumetric gas per mass of CFA and can be considered accordingly. For example, when comparing ADCA to the chemical foaming agent p-toluenesulfonyl semicarbazide (TSS), if a foamable layer contains 40 PPHR ADCA, about 63 PPHR TSS would be required to generate about the same amount of gas during the foaming step.

**[0080]** If the difference between the decomposition temperature of the thermally decomposable foaming agent and the melting point of the polymer with the highest melting point is high, then a catalyst for foaming agent decomposition may be used. Exemplary catalysts include, but are not limited to, zinc oxide, magnesium oxide, calcium stearate, glycerin, and urea. The lower temperature limit for extrusion can be that of the polymer with the highest melting point. If the extrusion temperature drops below the melting temperature of the polymer with the highest melting point, then undesirable “unmelts” appear. Upon foaming, the extruded layer that was extruded below this lower temperature limit can exhibit uneven thickness, a non-uniform cell structure, pockets of cell collapse, and other undesirable attributes.

**[0081]** Extruding an unfoamed multilayer sheet and extruding a foamed multilayer sheet (commonly referred to as “extrusion foaming”) are vastly different. Extrusion foaming can be performed with a physical foaming agent, a chemical foaming agent, or a mixture of physical and chemical foaming agents. Physical foaming agents can be inorganic and organic gases (nitrogen, carbon dioxide, pentane, butane, etc.) that are injected under high pressure directly into the polymer melt. The gases can nucleate and expand as the polymer melt exits the extrusion die to create the foamed polymer. Chemical foaming agents—such as the examples previously described—can be solids that decompose exothermally or endothermally upon a decomposition temperature to produce gases. Typical gases generated from chemical foaming agents include nitrogen, carbon monoxide, carbon dioxide, ammonia, etc. To extrusion foam a chemical foaming agent, the chemical foaming agent can be dispersed in the polymer melt and the melt heated to above the decomposition temperature of the chemical foaming agent while still in the extruder and die. A foamed polymer can be made as the polymer melt exits the extrusion die.

**[0082]** Regardless of whether the foaming agents are physical, chemical, or a combination, typical extrusion foaming generates polymer sheets where both primary surfaces are significantly rougher than equivalent structures produced in the disclosed method. The surface profile of a multilayer (as well as a single layer) foam sheet can be critical in many applications and thus extrusion foamed sheets may not be used for these applications. These applications can require a smooth foam surface to obtain desired properties such as ease of lamination to a film, fabric, fiber layer, and a leather; percentage contact area in the lamination; visual aesthetics; etc. PCT Publication WO 2016109544, which is hereby incorporated in its entirety by reference, includes examples illustrating the difference in surface roughness between extrusion foamed polymer sheets and equivalent foamed polymer sheets produced by the disclosed method.

**[0083]** The rougher surfaces of extrusion foamed articles can be generally caused by larger sized cells (when compared to the foams produced according to the present disclosure). Although the cell size and cell size distribution may not be as critical in most commercial applications, because surface roughness is a function of cell size, foams with larger cells can be less desirable than foams with smaller cells for applications requiring a smooth foam surface.

**[0084]** The thickness of the unfoamed, coextruded multilayer structure can be about 0.1 to about 30 mm, about 0.2 to about 25 mm, about 0.3 to about 20 mm, or about 0.4 to about 15 mm. Any individual A or B layer can have a thickness of at least about 0.05 mm, at least about 0.1 mm, at least about 0.15 mm, or at least about 0.2 mm. Any individual A or B layer can have a thickness of less than or equal to about 0.2 mm, about 0.15 mm, or about 0.10 mm. In some embodiments, a cap layer of the unfoamed, coextruded multilayer structure can have a thickness of about 0.1-300 microns, about 25-200 microns, or about 30-175 microns. In some embodiments, a cap layer of the unfoamed, coextruded multilayer structure can have a thickness of less than 300 microns, less than 250 microns, less than 200 microns, less than 175 microns, less than 150 microns, less than 125 microns, less than 100 microns, less than 90 microns, less than 80 microns, less than 70 microns, less than 60 microns, less than 50 microns, less than 40 microns, less than 30 microns, less than 20 microns, less than 10 microns, less than 5 microns, or less than 1 micron. In some embodiments, a cap layer of the unfoamed, coextruded multilayer structure can have a thickness of more than 1 micron, more

than 5 microns, more than 10 microns, more than 20 microns, more than 30 microns, more than 40 microns, more than 50 microns, more than 60 microns, more than 70 microns, more than 80 microns, more than 90 microns, more than 100 microns, more than 125 microns, more than 150 microns, more than 175 microns, more than 200 microns, or more than 250 microns. The unfoamed cap thickness is not limited in how thin it can be in relation to the overall unfoamed coextruded multilayered sheet, and may be as thin as about 0.1  $\mu\text{m}$ , or the typical thickness of a very thin tie layer used in multilayered flexible packaging and barrier films. In some embodiments, a foam layer of the unfoamed, coextruded multilayer structure can have a thickness of about 0.1-5 mm, about 0.5-3 mm, about 1-2 mm, or about 1-1.5 mm. In some embodiments, a foam layer of the unfoamed, coextruded multilayer structure can have a thickness of less than or equal to about 5 mm, about 3 mm, about 2 mm, about 1.5 mm, about 1 mm, or about 0.5 mm. In some embodiments, a foam layer of the unfoamed, coextruded multilayer structure can have a thickness of greater than or equal to about 0.1 mm, about 0.5 mm, about 1 mm, about 1.5 mm, about 2 mm, or about 3 mm.

**[0085]** For cases where the cap layers are either not intended to be foamed or are only lightly foamed, the cap can be thin and easily pliable when melted so as to not significantly hinder the expansion of the foamable layer(s) during the foaming step. The cap's thickness, flexibility, melt strength, and crosslinking percentage are among many physical properties that can hinder the foaming expansion of the other layer(s). Similarly, the thickness, flexibility, melt strength, and crosslinking percentage of the foamable layer(s) as well as the ultimate thickness and density of the foamed layers are also factors in whether the cap inhibits the expansion of the foamable layer(s). A general guideline for maximum cap thickness is that it should be no more than about 20%, about 15%, about 10%, or about 5% of the overall coextruded unfoamed sheet. If the cap thickness is greater than about 20% of the overall coextruded unfoamed sheet, problems with the multilayered sheet curling, buckling, and folding onto itself may occur as the multilayered sheet is heated and foamed.

**[0086]** After the coextruded sheet has been produced (e.g., by two extruders), the extruded multilayered sheet can be subjected to irradiation with ionizing radiation at a given exposure to crosslink the composition of the multilayered sheet, thereby obtaining an irradiated, crosslinked multilayer structure. Ionizing radiation is often unable to produce a sufficient degree of crosslinking on polypropylene(s), polypropylene-based materials, some

polyethylene(s), and some polyethylene-based materials. Thus, a crosslinking promoter can be added to the compositions that are fed into the extruders to promote crosslinking. Polymers crosslinked by ionizing radiation are commonly referred to as “physically crosslinked”.

**[0087]** It is important to distinguish between “physical” crosslinking and “chemical” crosslinking. In chemical crosslinking, the crosslinks are generated with crosslinking promoters but without the use of ionizing radiation. Chemical crosslinking typically involves using peroxides, silanes, or vinylsilanes. In peroxide crosslinking processes, the crosslinking typically occurs in the extrusion die. For silane and vinylsilane crosslinking processes, the crosslinking typically occurs post-extrusion in a secondary operation where the crosslinking of the extruded material is accelerated with heat and moisture. Regardless of the chemical crosslinking method, chemically crosslinked foam sheets typically exhibit primary surfaces that are significantly rougher than equivalent structures produced in the disclosed method. The surface profile of a multilayer (as well as single layer) foam sheet can be critical in many applications and thus chemically crosslinked foam sheets may not be used for these applications. These applications can require a smooth foam surface to obtain desired properties such as ease of lamination to a film, fabric, fiber layer, and a leather; percentage contact area in the lamination; visual aesthetics; etc. PCT Publication WO 2016109544 includes examples illustrating the difference in surface roughness between chemically crosslinked foamed polymer sheets and equivalent foamed polymer sheets produced by the disclosed method.

**[0088]** The rougher surfaces of chemically crosslinked foamed articles can be generally caused by larger sized cells (when compared to the foams produced according to the present disclosure). Although the cell size and size distribution is not critical in most commercial applications because surface roughness is a function of cell size, foams with larger cells can be less desirable than foams with smaller cells for applications requiring a smooth foam surface.

**[0089]** Examples of ionizing radiation include, but are not limited to, alpha, beta (electron beams), x-ray, gamma, and neutron. Among them, an electron beam having uniform energy can be used to prepare the crosslinked polyolefin foam / KEE cap structure. Exposure time,

frequency of irradiation, and acceleration voltage upon irradiation with an electron beam can vary widely depending on the intended crosslinking degree and the thickness of the multilayered structure. However, the ionizing radiation can generally be in the range of from about 10 to about 500 kGy, about 20 to about 300 kGy, or about 20 to about 200 kGy. If the exposure is too low, then cell stability may not be maintained upon foaming. If the exposure is too high, the moldability of the resulting multilayered foam structure may be poor.

Moldability is a desirable property when the multilayered foam sheet is used in thermoforming applications. Also, the unfoamed sheet may be softened by exothermic heat release upon exposure to the electron beam radiation such that the structure can deform when the exposure is too high. In addition, the polymer components may also be degraded from excessive polymer chain scission.

**[0090]** The coextruded unfoamed multilayered sheet may be irradiated up to four separate times, preferably no more than twice, and more preferably only once. If the irradiation frequency is more than about four times, the polymer components may suffer degradation so that upon foaming, for example, uniform cells will not be created in the resulting foam layer(s). When the thickness of the extruded structure is greater than about 4 mm, irradiating each primary surface of the multilayered profile with an ionized radiation can be preferred to make the degree of crosslinking of the primary surface(s) and the inner layer more uniform.

**[0091]** Irradiation with an electron beam provides an advantage in that coextruded sheets having various thicknesses can be effectively crosslinked by controlling the acceleration voltage of the electrons. The acceleration voltage can generally be in the range of from about 200 to about 1500 kV, about 400 to about 1200 kV, or about 600 to about 1000 kV. If the acceleration voltage is less than about 200 kV, then the radiation may not reach the inner portion of the coextruded sheets. As a result, the cells in the inner portion can be coarse and uneven on foaming. Additionally, acceleration voltage that is too low for a given thickness profile can cause arcing, resulting in “pinholes” or “tunnels” in the foamed structure. On the other hand, if the acceleration voltage is greater than about 1500 kV, then the polymers may degrade. In some embodiments, the radiation source may face the B layer of the coextruded, unfoamed multilayer sheet during irradiation. In some embodiments, the radiation source may face the A layer of the coextruded, unfoamed multilayer sheet during irradiation.

**[0092]** Regardless of the type of ionizing radiation selected, crosslinking is performed so that the composition of the extruded structure is crosslinked about 20 to about 75% or about 30 to about 60%, as measured by the “Toray Gel Fraction Percentage Method.” According to the “Toray Gel Fraction Percentage Method,” tetralin solvent is used to dissolve non-crosslinked components in a composition. In principle, the non-crosslinked material is dissolved in tetralin and the crosslinking degree is expressed as the weight percentage of crosslinked material in the entire composition. The apparatus used to determine the percent of polymer crosslinking includes: 100 mesh (0.0045 inch wire diameter); Type 304 stainless steel bags; numbered wires and clips; a Miyamoto thermostatic oil bath apparatus; an analytical balance; a fume hood; a gas burner; a high temperature oven; an anti-static gun; and three 3.5 liter wide mouth stainless steel containers with lids. Reagents and materials used include tetralin high molecular weight solvent, acetone, and silicone oil. Specifically, an empty wire mesh bag is weighed and the weight recorded. For each sample, 100 milligrams  $\pm$  5 milligrams of sample is weighed out and transferred to the wire mesh bag. The weight of the wire mesh bag and the sample, typically in the form of thinly sliced foam cuttings, is recorded. Each bag is attached to the corresponding number wire and clips. When the solvent temperature reaches 130°C, the bundle (bag and sample) is immersed in the solvent. The samples are shaken up and down about 5 or 6 times to loosen any air bubbles and fully wet the samples. The samples are attached to an agitator and agitated for three (3) hours so that the solvent can dissolve the foam. The samples are then cooled in a fume hood. The samples are washed by shaking up and down about 7 or 8 times in a container of primary acetone. The samples are washed a second time in a second acetone wash. The washed samples are washed once more in a third container of fresh acetone as above. The samples are then hung in a fume hood to evaporate the acetone for about 1 to about 5 minutes. The samples are then dried in a drying oven for about 1 hour at 120°C. The samples are cooled for a minimum of about 15 minutes. The wire mesh bag is weighed on an analytical balance and the weight is recorded. Crosslinking is then calculated using the formula  $100 \cdot (C-A)/(B-A)$ , where A = empty wire mesh bag weight; B = wire bag weight + foam sample before immersion in tetralin; and C = wire bag weight + dissolved sample after immersion in tetralin.

**[0093]** Suitable crosslinking promoters include, but are not limited to, commercially available difunctional, trifunctional, tetrafunctional, pentafunctional, and higher functionality

monomers. Such crosslinking monomers are available in liquid, solid, pellet, and powder forms. Examples include, but are not limited to, acrylates or methacrylates such as 1,6-hexanediol diacrylate, 1,6-hexanediol dimethacrylate, ethylene glycol diacrylate, ethylene glycol dimethacrylate, trimethylol propane trimethacrylate, tetramethylol methane triacrylate, 1,9-nonanediol dimethacrylate and 1,10-decanediol dimethacrylate; allyl esters of carboxylic acid (such as trimellitic acid triallyl ester, pyromellitic acid triallyl ester, and oxalic acid diallyl ester); allyl esters of cyanulic acid or isocyanulic acid such as triallyl cyanurate and triallyl isocyanurate; maleimide compounds such as N-phenyl maleimide and N,N'-m-phenylene bismaleimide; compounds having at least two tribonds such as phthalic acid dipropagyl and maleic acid dipropagyl; and divinylbenzene. Additionally, such crosslinking promoters may be used alone or in any combination. Divinylbenzene (DVB), a difunctional liquid crosslinking monomer, can be used as a crosslinking promoter in the present disclosure. For example, a suitable commercially-available DVB may include DVB HP by the Dow Chemical Company.

**[0094]** The amount of crosslinking promoter in a foam layer composition and/or a cap layer composition can be less than or equal to about 5 PPR%, about 4 PPR%, about 3 PPR%, about 2.5 PPR%, about 2 PPR%, about 1.5 PPR%, or about 1 PPR% of the composition. In some embodiments, the amount of crosslinking promoter in a foam layer composition and/or a cap layer composition can be greater than or equal to about 0.5 PPR%, about 1 PPR%, about 1.5 PPR%, about 2 PPR%, about 2.5 PPR%, about 3 PPR%, or about 4 PPR% of the composition. In some embodiments, the amount of crosslinking promoter in a foam layer composition and/or a cap layer composition can be about 0.1-5 PPR%, about 0.5-3 PPR%, about 1-3 PPR%, or about 2-3 PPR% of the composition. In some embodiments, the amount of crosslinking promoter in a foam layer composition can be about 0.5-5 wt. % or about 1-3 wt. % of the foam layer composition.

**[0095]** Note that the above listed amounts of crosslinking promoter can be specific to DVB only. Other crosslinking promoters can be more or less efficient in crosslinking than DVB. Thus, the required quantity for another crosslinking promoter should be considered accordingly. Crosslinking promoters can vary in crosslinking efficiency based on the ionizing radiation dosage, the polymers being crosslinked, the chemical structure of the

monomer, the number of functional groups on the monomer, and whether the monomer is a liquid or a powder.

**[0096]** Crosslinks may be generated using a variety of different techniques and can be formed both intermolecularly, between different polymer molecules, and intramolecularly, between portions of a single polymer molecule. Such techniques include, but are not limited to, providing crosslinking promoters which are separate from a polymer chain and providing polymer chains which incorporate a crosslinking promoter containing a functional group which can form a crosslink or be activated to form a crosslink.

**[0097]** After irradiating the coextruded sheet, foaming may be accomplished by heating the crosslinked multilayered sheet to a temperature higher than the decomposition temperature of the thermally decomposable blowing agent. The foaming can be performed at about 200-260°C or about 220-240°C in a continuous process. A continuous foaming process can be preferred over a batch process for production of a continuous foam sheet.

**[0098]** The foaming can be typically conducted by heating the crosslinked multilayered sheet with molten salt, radiant heaters, vertical or horizontal hot air oven, microwave energy, or a combination of these methods. The foaming may also be conducted in an impregnation process using, for example, nitrogen in an autoclave, followed by a free foaming via molten salt, radiant heaters, vertical or horizontal hot air oven, microwave energy, or a combination of these methods. Optionally, before foaming, the crosslinked multilayered sheet can be softened with preheating. This can help stabilize the expansion of the structure upon foaming, particularly with thick and stiff sheets.

**[0099]** The density of the multilayered foam sheet can be defined and measured using section or “overall” density, rather than a “core” density, as measured by JIS K6767. The multilayered foam sheets produced using the above described method can yield foams with a section, or “overall” density of about 20-250 kg/m<sup>3</sup>, about 30-200 kg/m<sup>3</sup>, or about 50-150 kg/m<sup>3</sup>. The section density can be controlled by the amount of blowing agent and the thickness of the extruded structure. If the density of the multilayered foam sheet is less than about 20 kg/m<sup>3</sup>, then the sheet may not foam efficiently due to a large amount of chemical blowing agent needed to attain the density. Additionally, if the density of the sheet is less than about 20 kg/m<sup>3</sup>, then the expansion of the sheet during the foaming step may become

increasingly difficult to control. Furthermore, if the density of the multilayered foam sheet is less than about  $20 \text{ kg/m}^3$ , then the foam may become increasingly prone to cell collapse. Thus, it may be difficult to produce a multilayered foam sheet of uniform section density and thickness at a density less than about  $20 \text{ kg/m}^3$ .

**[0100]** The multilayered foam sheet is not limited to a section density of about  $250 \text{ kg/m}^3$ . A foam having a section density of about  $350 \text{ kg/m}^3$ , about  $450 \text{ kg/m}^3$ , or about  $550 \text{ kg/m}^3$  may also be produced. However, it may be preferred that the foam sheet have a density of less than about  $250 \text{ kg/m}^3$  since greater densities can be generally cost prohibitive when compared to other materials which can be used in a given application.

**[0101]** The foam layers produced using the above method may have closed cells. Preferably, at least 90% of the cells have undamaged cell walls, preferably at least 95%, and more preferably more than 98%. The average cell size can be from about 0.05 to about 1.0 mm, and preferably from about 0.1 to about 0.7 mm. If the average cell size is lower than about 0.05 mm, then the density of the foam structure can typically be greater than  $250 \text{ kg/m}^3$ . If the average cell size is larger than 1 mm, the foam may have an uneven surface. There is also a possibility of the foam structure being undesirably torn if the population of cells in the foam does not have the preferred average cell size. This can occur when the foam structure is stretched or portions of it are subjected to a secondary process. The cell size in the foam layer(s) may have a bimodal distribution representing a population of cells in the core of the foam structure which are relatively round and a population of cells in the skin near the surfaces of the foam structure which are relatively flat, thin, and/or oblong.

**[0102]** The overall thickness of the multilayered polyolefin foam / KEE cap sheet can be about 0.2 mm to about 50 mm, about 0.4 mm to about 40 mm, about 0.6 mm to about 30 mm, or about 0.8 mm to about 20 mm. If the thickness is less than about 0.2 mm, then foaming may not be efficient due to significant gas loss from the primary surface(s). If the thickness is greater than about 50 mm, expansion during the foaming step can become increasingly difficult to control. Thus, it can be increasingly more difficult to produce a multilayered polyolefin foam / KEE cap sheet with uniform section density and thickness. In some embodiments, a cap layer of the foamed, coextruded multilayer structure can have a thickness of about 0.1-100 microns, about 1-100 microns, or about 5-75 microns. In some

embodiments, a foam layer of the foamed, coextruded multilayer structure can have a thickness of about 0.1-5 mm, about 0.5-5 mm, about 1-5 mm, about 2-5 mm, or about 2-4 mm.

**[0103]** In some embodiments, the desired thickness can be obtained by a secondary process such as slicing, skiving, or bonding. Slicing, skiving, or bonding can produce a thickness range of about 0.1 mm to about 100 mm.

**[0104]** For the cap layer(s) intended to be unfoamed or lightly foamed, the thickness of the cap layer may be reduced upon foaming of the multilayered sheet. This can be due to the foamable layer(s) expanding and consequently stretching the cap layer(s). Thus, for example, if the multilayered sheet expands to twice its original area, the cap thickness can be expected to be about halved. If the multilayered sheet expands to four times its original area, the cap thickness can be expected to be reduced to about one-quarter of its original thickness.

**[0105]** The disclosed multilayered polyolefin foam / KEE cap sheets can be used for applications where adhesion to PVC is required. The PVC can be a flexible film, foil, or foam. The PVC can also be a semi-flexible or rigid board, plank, tile, or substrate. The board, plank, tile, or substrate can be solid or foam. Importantly, the PVC may be a surface layer of a multilayered structure.

**[0106]** In some embodiments, the multilayer foam structures are laminates containing the multilayer foam and a flexible laminate layer. Preferably, the laminate layer can be applied to the KEE cap side of the multilayer foam. In these laminates, the multilayer foam structure can, for example, can be combined with a film, foil, or foam. Examples of suitable materials for such laminate layers include, but are not limited to, flexible PVC films, flexible PVC foils, and flexible PVC foams. Such layers may be manufactured using standard techniques that are well known to those of ordinary skill in the art. Importantly, the multilayer foam of the disclosure may be laminated on one or both sides with these materials and may include multiple other layers. If the multilayer foam is laminated on both sides, preferably these laminate layers can be applied to KEE cap layers of the multilayer foam.

**[0107]** The multilayer foam structures (or laminates comprising the multilayered foam structures) can also be thermoformed. To thermoform the multilayer foam structure or

laminate, the foam can be heated to the melting point of the blend for all the layers in the multilayer foam / KEE cap structure. If any layer has immiscible polymers, the multilayer foam structure may exhibit more than one melting point. In this case, the multilayer foam structure can typically be thermoformed when the foam is heated to a temperature midway between the multilayer foam layer composition's lowest melting point and highest melting point. In addition, the multilayer foam structure can be thermoformed onto a substrate such as a hard polypropylene, ABS, or wood fiber composite. A heat activated adhesive may be used to improve the bonding of the substrate to a capped or uncapped side of the multilayer foam / KEE cap structure. In cases of a laminate, the laminate layer may be on the opposite side of the substrate (for example, in cases where the laminate layer is for a protective and/or decorative purpose.) The substrate itself can also be thermoformed at the same time as the multilayer foam structure.

**[0108]** In some embodiments, the multilayer foam structures or laminates (which may or may not be thermoformed) can be used in automobile interior parts such as door panels, door rolls, door inserts, door stuffers, trunk stuffers, armrests, center consoles, seat cushions, seat backs, headrests, seat back panels, instrument panels, knee bolsters, or a headliner. These multilayer foam structures or laminates (which may or may not be thermoformed) can also be used in furniture (e.g., commercial, office, and residential furniture) such as chair cushions, chair backs, sofa cushions, sofa trims, recliner cushions, recliner trims, couch cushions, couch trim, sleeper cushions, or sleeper trims. These multilayer foam laminates or structures (which may or may not be thermoformed) can also be used in walls such as modular walls, moveable walls, wall panels, modular panels, office system panels, room dividers, or portable partitions. The multilayer foam laminates or structures can also be used in storage casing (e.g., commercial, office and residential) which can be either mobile or stationary. Furthermore, the multilayer foam laminates and structures (which may or may not be thermoformed) can also be used in coverings such as chair cushion coverings, chair back coverings, armrest coverings, sofa coverings, sofa cushion coverings, recliner cushion coverings, recliner coverings, couch cushion coverings, couch coverings, sleeper cushion coverings, sleeper coverings, wall coverings, and architectural coverings.

**[0109]** In some embodiments, the multilayer foam structures or laminates can be used as roofing membranes and as a component in roof waterproofing. For laminates: PVC, KEE,

and PVC/KEE blends are well suited as the laminate layer to the multilayer foam structure. The KEE cap layer of the multilayer foam structure may face the laminate layer.

**[0110]** In some embodiments, the multilayer foam structures are laminates containing the multilayer foam and a non-flexible laminate layer. Preferably, the multilayer foam can be applied with the KEE cap side to the laminate layer. In these laminates, the multilayer foam structure can, for example, be combined with a board, plank, tile, or substrate. The board, plank, tile, or substrate may be a foam. Such layers may be manufactured using standard techniques that are well known to those of ordinary skill in the art. Importantly, the multilayer foam of the disclosure may be laminated on one or both sides with these materials and may include multiple other layers. If the multilayer foam is laminated on both sides, preferably these laminate layers can be applied to cap layers of the multilayer foam.

**[0111]** Some embodiments include a first layer of the disclosed multilayer foam structure and a second layer consisting of either a vinyl floor tile or a wood-PVC composite for flooring or walls. In these laminates, the first layer may be joined to the adjacent tile or composite by melt bonding. Preferably, the KEE cap layer of the multilayer foam structure may on the side of the first layer facing the second layer

**[0112]** The multilayer foam attached to a vinyl floor tile or a wood-PVC composite can serve several purposes. The foam can reduce the reflected sound pressure level when the panel is impacted, for example, when walking on the panel with boots or high heeled shoes. The foam can also act as a moisture vapor barrier between the panel and sub-floor (plywood, oriented strandboard (OSB), concrete, etc.) and can help provide a more uniform laydown among multiple panels since any unevenness, bumps, or spikes (for example a protruding nailhead) on the sub-floor will be buffered by the foam. These tiles and composites are commonly installed in residential homes, office buildings, and other commercial buildings.

**[0113]** To satisfy the requirements of any of the above applications, the disclosed structures of the present disclosure may be subjected to various secondary processes, including and not limited to, embossing, corona or plasma treatment, surface roughening, surface smoothing, perforation or microperforation, splicing, slicing, skiving, layering, bonding, and hole punching.

## EXAMPLES

**Raw Materials for Examples**

[0114] The following Table 1 provides a list of various components and descriptions of those components used in the following Examples.

TABLE 1

| Component        | Type                                                  | Manufacturer                | Melt Flow Index              | Description / Notes                                                                                                                                                                                                     |
|------------------|-------------------------------------------------------|-----------------------------|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 6232             | <i>PP / PE random copolymer</i>                       | Total Petrochemicals        | 1.3 - 1.6 (2.16 kg, 230°C)   | commercially produced                                                                                                                                                                                                   |
| Infuse™ OBC 9107 | <i>OBC<br/>(PE / octene copolymer based)</i>          | Dow Chemical Company        | 0.75 - 1.25 (2.16 kg, 190°C) | commercially produced olefin block copolymer                                                                                                                                                                            |
| Adflex™ Q100F    | <i>rTPO<br/>(PP / PE random copolymer based)</i>      | LyondellBasell              | 0.5 - 0.7 (2.16 kg, 230°C)   | commercially produced reactor thermoplastic polyolefin                                                                                                                                                                  |
| Plexar® PX6006   | <i>MAH-g-PP / PE random copolymer</i>                 | LyondellBasell              | nominal 4.0 (2.16 kg, 230°C) | commercially produced maleic anhydride grafted polypropylene-polyethylene random copolymer                                                                                                                              |
| LLP8501.67       | <i>LLDPE<br/>(LLDPE / hexene copolymer)</i>           | ExxonMobil                  | 5.9 - 7.5 (2.16 kg, 190°C)   | commercially produced                                                                                                                                                                                                   |
| Elvaloy® HP441   | <i>KEE<br/>(ketone / ethylene / ester terpolymer)</i> | Dow Chemical Company        | nominal 8 (2.16 kg, 190°C)   | commercially produced "KEE": E/nBA/CO = ethylene/n-butyl acrylate/carbon monoxide terpolymer                                                                                                                            |
| Elvaloy® HP641   | <i>KEE<br/>(ketone / ethylene / ester terpolymer)</i> | Dow Chemical Company        | nominal 12 (2.16 kg, 190°C)  | commercially produced "KEE": E/nBA/CO = ethylene/n-butyl acrylate/carbon monoxide terpolymer                                                                                                                            |
| Azofoam® TC-18I  | <i>chemical foaming agent (ADCA)</i>                  | P.T. Lauten Otsuka Chemical | ---                          | commercially produced azodicarbonamide                                                                                                                                                                                  |
| DVB HP           | <i>crosslinking promoter</i>                          | Dow Chemical Company        | ---                          | commercially produced, 80% DVB content                                                                                                                                                                                  |
| "PR023"          | <i>anti-oxidant package<br/>(LDPE carrier)</i>        | Techmer PM                  | ---                          | a Toray Plastics (America) standard antioxidant package for polyolefin foam, compounded by Techmer PM, consisting of 14% antioxidants, 0.35% calcium stearate, and 85.65% low density polyethylene (LDPE) carrier resin |
| "PR086"          | <i>anti-oxidant package</i>                           | Amfine Chemical             | ---                          | a Toray Plastics (America) standard antioxidant package for polyolefin foam, 100% antioxidant powders                                                                                                                   |

|          |                                                                  |            |     |                                                                                                                |
|----------|------------------------------------------------------------------|------------|-----|----------------------------------------------------------------------------------------------------------------|
| TPM11166 | <i>processing aid<br/>(LLDPE / butene<br/>copolymer carrier)</i> | Techmer PM | --- | commercially produced<br>extrusion processing aid blend                                                        |
| PM91399  | <i>black concentrate<br/>(LDPE carrier)</i>                      | Techmer PM | --- | commercially produced<br>concentrate, 10% carbon<br>black loading, 27 Nm typical<br>carbon black particle size |

### Conversion Process for Examples

[0115] The following Table 2 provides the formulations for Examples 1-11.

|                    |                    | FORMULATIONS              |                                   |                                       |                                                    |                                      |                                            |                                                       |                                                       |                                               |                        |                                     |                                     |                                                   |                                  |
|--------------------|--------------------|---------------------------|-----------------------------------|---------------------------------------|----------------------------------------------------|--------------------------------------|--------------------------------------------|-------------------------------------------------------|-------------------------------------------------------|-----------------------------------------------|------------------------|-------------------------------------|-------------------------------------|---------------------------------------------------|----------------------------------|
| example ID         | layer ID           | resins (PPR% & overall %) |                                   |                                       |                                                    |                                      |                                            |                                                       | additives (PPR % & overall %)                         |                                               |                        |                                     |                                     |                                                   |                                  |
|                    |                    | PP-PE random copolymer    | OBC (PE / octene copolymer based) | TPPO (PP / PE random copolymer based) | MAH-g-PP / PE random copolymer (PE / hexene based) | LLDPE (PE / hexene random copolymer) | KEE (ketone / ethylene / ester terpolymer) | Elvaloy® HP441 (ketone / ethylene / ester terpolymer) | Elvaloy® HP661 (ketone / ethylene / ester terpolymer) | Azofoam® TC-181 chemical foaming agent (ADCA) | DVB x-linking promoter | anti-oxidant package (LDPE carrier) | anti-oxidant package (LDPE carrier) | processing aid (LLDPE / butene copolymer carrier) | black concentrate (LDPE carrier) |
| Examples 1A and 1B | "B" cap layer      | 6232                      | Intufuse® OBC 9:107               | Adflex™ Q100F                         | Plexar® PX6006                                     | LLP8501.67                           | Elvaloy® HP441                             | Elvaloy® HP661                                        | TC-181                                                | HP                                            | "PR023"                | "PR086"                             | TPM11166                            | PM91399                                           |                                  |
|                    |                    |                           |                                   |                                       |                                                    | 75.90%                               | 24.10%                                     |                                                       |                                                       |                                               |                        | 0.58%                               |                                     | 1.20%                                             |                                  |
|                    | "A" layer (foamed) | 50%                       | 40%                               | 10%                                   |                                                    | 74.57%                               | 23.67%                                     |                                                       | 6.75%                                                 | 2.5%                                          | 5.5%                   |                                     | 2%                                  | 1.18%                                             |                                  |
|                    |                    | 42.83%                    | 34.26%                            | 8.57%                                 |                                                    |                                      |                                            |                                                       | 5.78%                                                 | 2.14%                                         | 4.71%                  |                                     | 1.71%                               |                                                   |                                  |
| Examples 2A and 2B | "B" cap layer      |                           |                                   |                                       |                                                    | 51.22%                               | 48.78%                                     |                                                       |                                                       |                                               |                        | 0.59%                               |                                     | 2.44%                                             |                                  |
|                    |                    | 50%                       | 40%                               | 10%                                   |                                                    | 49.71%                               | 47.35%                                     |                                                       | 6.75%                                                 | 2.5%                                          | 5.5%                   |                                     | 2%                                  | 2.37%                                             |                                  |
|                    | "A" layer (foamed) | 50%                       | 40%                               | 10%                                   |                                                    |                                      |                                            |                                                       | 6.75%                                                 | 2.5%                                          | 5.5%                   |                                     | 2%                                  |                                                   |                                  |
|                    |                    | 42.83%                    | 34.26%                            | 8.57%                                 |                                                    |                                      |                                            |                                                       | 5.78%                                                 | 2.14%                                         | 4.71%                  |                                     | 1.71%                               |                                                   |                                  |
| Example 3          | "B" cap layer      |                           |                                   |                                       |                                                    | 25.93%                               | 73.89%                                     |                                                       |                                                       |                                               |                        | 0.60%                               |                                     | 3.70%                                             |                                  |
|                    |                    |                           |                                   |                                       |                                                    | 24.90%                               | 70.97%                                     |                                                       | 6.75%                                                 | 2.5%                                          | 5.5%                   |                                     | 2%                                  | 3.56%                                             |                                  |
|                    | "A" layer (foamed) | 50%                       | 40%                               | 10%                                   |                                                    |                                      |                                            |                                                       | 6.75%                                                 | 2.5%                                          | 5.5%                   |                                     | 2%                                  |                                                   |                                  |
|                    |                    | 42.83%                    | 34.26%                            | 8.57%                                 |                                                    |                                      |                                            |                                                       | 5.78%                                                 | 2.14%                                         | 4.71%                  |                                     | 1.71%                               |                                                   |                                  |
| Examples 4A and 4B | "B" cap layer      |                           |                                   |                                       |                                                    | 75.90%                               | 24.10%                                     |                                                       |                                                       |                                               |                        | 0.58%                               |                                     | 1.20%                                             |                                  |
|                    |                    |                           |                                   |                                       |                                                    | 74.57%                               | 23.67%                                     |                                                       | 6.75%                                                 | 2.5%                                          | 5.5%                   |                                     | 2%                                  | 1.18%                                             |                                  |
|                    | "A" layer (foamed) | 50%                       | 40%                               | 10%                                   |                                                    |                                      |                                            |                                                       | 6.75%                                                 | 2.5%                                          | 5.5%                   |                                     | 2%                                  |                                                   |                                  |
|                    |                    | 42.83%                    | 34.26%                            | 8.57%                                 |                                                    |                                      |                                            |                                                       | 5.78%                                                 | 2.14%                                         | 4.71%                  |                                     | 1.71%                               |                                                   |                                  |
| Example 5          | "B" cap layer      |                           |                                   |                                       |                                                    | 51.22%                               | 48.78%                                     |                                                       |                                                       |                                               |                        | 0.59%                               |                                     | 2.44%                                             |                                  |
|                    |                    |                           |                                   |                                       |                                                    | 49.71%                               | 47.35%                                     |                                                       | 6.75%                                                 | 2.5%                                          | 5.5%                   |                                     | 2%                                  | 2.37%                                             |                                  |
|                    | "A" layer (foamed) | 50%                       | 40%                               | 10%                                   |                                                    |                                      |                                            |                                                       | 6.75%                                                 | 2.5%                                          | 5.5%                   |                                     | 2%                                  |                                                   |                                  |
|                    |                    | 42.83%                    | 34.26%                            | 8.57%                                 |                                                    |                                      |                                            |                                                       | 5.78%                                                 | 2.14%                                         | 4.71%                  |                                     | 1.71%                               |                                                   |                                  |

|            |                        |        |        |        |        |        |       |       |       |
|------------|------------------------|--------|--------|--------|--------|--------|-------|-------|-------|
| Example 6  | "B" cap layer          | 25.93% |        | 73.89% |        | 0.60%  |       | 3.70% |       |
|            | "A" layer (foamed)     | 50%    | 40%    | 10%    | 42.83% | 34.26% | 8.57% | 5.78% | 2.14% |
| Example 7  | "B" cap layer (foamed) | 51.22% |        | 48.78% |        | 0.59%  |       | 2.44% |       |
|            | "A" layer (foamed)     | 50%    | 40%    | 10%    | 42.83% | 34.26% | 8.57% | 5.78% | 2.14% |
| Example 8  | "B" cap layer          | 51.22% |        | 48.78% |        | 0.59%  |       | 2.44% |       |
|            | "A" layer (foamed)     | 50%    | 36.36% | 9.09%  | 42.83% | 31.15% | 7.79% | 5.78% | 2.14% |
| Example 9  | "B" cap layer          | 25%    |        | 75%    |        | 0.58%  |       | 1.25% |       |
|            | "A" layer (foamed)     | 50%    | 40%    | 10%    | 42.83% | 34.26% | 8.57% | 5.78% | 2.14% |
| Example 10 | "B" cap layer          | 50%    |        | 50%    |        | 0.58%  |       | 1.25% |       |
|            | "A" layer (foamed)     | 50%    | 40%    | 10%    | 42.83% | 34.26% | 8.57% | 5.78% | 2.14% |
| Example 11 | "B" cap layer          | 75%    |        | 25%    |        | 0.58%  |       | 1.25% |       |
|            | "A" layer (foamed)     | 50%    | 40%    | 10%    | 42.83% | 34.26% | 8.57% | 5.78% | 2.14% |

[0116] The following Table 3 provides the coextrusion, irradiation, and properties of the multilayer structure of Examples 1-11.

| COEXTRUSION        |                    |                           |                        |                                         |                 | IRRADIATION                           |                             |                                      | FOAMING      |              |                   |                                     |                              |                         |                                                                    |
|--------------------|--------------------|---------------------------|------------------------|-----------------------------------------|-----------------|---------------------------------------|-----------------------------|--------------------------------------|--------------|--------------|-------------------|-------------------------------------|------------------------------|-------------------------|--------------------------------------------------------------------|
| example ID         | layer ID           | type                      | extruder               | specific energy of extrusion (kW-hr/kg) | melt temp. (°C) | unfoamed overall sheet thickness (mm) | unfoamed cap thickness (µm) | which layer facing radiation source? | dosage (kGy) | voltage (kV) | foaming temp (°F) | heating via molten salt or hot air? | thickness (cap=µm, foam=mm)  | overall density (kg/m³) | overall gel (two checks, %) (Toray Gel Fraction Percentage Method) |
| Examples 1A and 1B | "B" cap layer      | 50/50 feed block manifold | co-rotating twin screw | 0.20                                    | 177             | 1.49-1.55                             | 50-140                      | towards IR                           | 50.2         | 725          | 428-433           | molten salt                         | 10-50 (Ex 1A), 10-40 (Ex 1B) | 122 (Ex 1A), 75 (Ex 1B) | 44,45                                                              |
|                    | "A" layer (foamed) |                           | co-rotating twin screw | 0.18                                    | 143             |                                       |                             |                                      |              |              |                   |                                     | 2.9 (Ex 1A), 3.2 (Ex 1B)     |                         |                                                                    |
| Examples 2A and 2B | "B" cap layer      | 50/50 feed block manifold | co-rotating twin screw | 0.19                                    | 176             | 1.47-1.53                             | 50-110                      | towards IR                           | 50.2         | 725          | 428-433           | molten salt                         | 20-50 (Ex 2A), 10-40 (Ex 2B) | 119 (Ex 2A), 76 (Ex 2B) | 43,44                                                              |
|                    | "A" layer (foamed) |                           | co-rotating twin screw | 0.18                                    | 143             |                                       |                             |                                      |              |              |                   |                                     | 2.9 (Ex 2A), 3.2 (Ex 2B)     |                         |                                                                    |
| Example 3          | "B" cap layer      | 50/50 feed block manifold | co-rotating twin screw | 0.19                                    | 176             | 1.45-1.50                             | 50-110                      | towards IR                           | 50.2         | 725          | 428-433           | molten salt                         | 5-30                         | 78                      | 40,44                                                              |
|                    | "A" layer (foamed) |                           | co-rotating twin screw | 0.18                                    | 143             |                                       |                             |                                      |              |              |                   |                                     | 3.0                          |                         |                                                                    |

|                          |                              |                                 |                                  |      |     |               |        |               |      |     |         |                |                                 |                           |       |
|--------------------------|------------------------------|---------------------------------|----------------------------------|------|-----|---------------|--------|---------------|------|-----|---------|----------------|---------------------------------|---------------------------|-------|
| Examples<br>4A and<br>4B | "B" cap<br>layer             | 50/50<br>feed block<br>manifold | co-<br>rotating<br>twin<br>screw | 0.20 | 176 | 1.56-<br>1.60 | 50-130 | towards<br>IR | 50.2 | 725 | 428-433 | molten<br>salt | 10-60 (Ex 4A),<br>10-50 (Ex 4B) | 82 (Ex 4A),<br>79 (Ex 4B) | 46,47 |
|                          | "A" layer<br>(foamed)        |                                 | co-<br>rotating<br>twin<br>screw | 0.18 | 143 |               |        |               |      |     |         |                | 3.1 (Ex 4A), 3.6<br>(Ex 4B)     |                           |       |
| Example<br>5             | "B" cap<br>layer             | 50/50<br>feed block<br>manifold | co-<br>rotating<br>twin<br>screw | 0.19 | 176 | 1.53-<br>1.59 | 50-130 | towards<br>IR | 50.2 | 725 | 428-433 | molten<br>salt | 10-40                           | 79                        | 48,49 |
|                          | "A" layer<br>(foamed)        |                                 | co-<br>rotating<br>twin<br>screw | 0.18 | 143 |               |        |               |      |     |         |                | 3.4                             |                           |       |
| Example<br>6             | "B" cap<br>layer             | 50/50<br>feed block<br>manifold | co-<br>rotating<br>twin<br>screw | 0.19 | 175 | 1.48-<br>1.56 | 40-110 | towards<br>IR | 50.2 | 725 | 428-433 | molten<br>salt | 10-40                           | 77                        | 43,44 |
|                          | "A" layer<br>(foamed)        |                                 | co-<br>rotating<br>twin<br>screw | 0.18 | 143 |               |        |               |      |     |         |                | 3.2                             |                           |       |
| Example<br>7             | "B" cap<br>layer<br>(foamed) | 50/50<br>feed block<br>manifold | co-<br>rotating<br>twin<br>screw | 0.21 | 167 | 1.58-<br>1.62 | 70-100 | towards<br>IR | 50.2 | 725 | 428-433 | molten<br>salt | 5-50                            | 80                        | 44,48 |
|                          | "A" layer<br>(foamed)        |                                 | co-<br>rotating<br>twin<br>screw | 0.18 | 143 |               |        |               |      |     |         |                | 3.5                             |                           |       |
| Example<br>8             | "B" cap<br>layer             |                                 | co-<br>rotating                  | 0.23 | 169 | 1.54-<br>1.57 | 70-110 | towards<br>IR | 50.2 | 725 | 428-433 | molten<br>salt | 10-50                           | 86                        | 46,47 |

[illegible]

**[0118]** Images of the multilayered structures of Examples 1A, 1B, 2A, 2B, 3, 4A, 4B, 5, 6, 7, 8, 9, 10, and 11 at 30X magnification and 45° from primary surface can be found in Figures 1A, 1B, 2A, 2B, 3, 4A, 4B, 5, 6, 7, 8, 9, 10, and 11, respectively.

**[0119]** This application discloses several numerical ranges in the text and figures. The numerical ranges disclosed inherently support any range or value within the disclosed numerical ranges, including the endpoints, even though a precise range limitation is not stated verbatim in the specification because this disclosure can be practiced throughout the disclosed numerical ranges.

**[0120]** The above description is presented to enable a person skilled in the art to make and use the disclosure, and is provided in the context of a particular application and its requirements. Various modifications to the preferred embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the disclosure. Thus, this disclosure is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein. Finally, the entire disclosure of the patents and publications referred in this application are hereby incorporated herein by reference.

## CLAIMS

1. A multilayer foam structure comprising:  
a coextruded foam layer comprising polypropylene, polyethylene, or a combination of polypropylene and polyethylene; and  
a coextruded cap layer on a side of the foam layer, the cap layer comprising:  
at least 15 wt. % ketone-ethylene-ester (KEE) terpolymer; and  
polypropylene, polyethylene, or a combination of polypropylene and polyethylene.
2. The multilayer foam structure of claim 1, wherein the coextruded foam layer comprises 2-15 wt. % KEE.
3. The multilayer foam structure of claim 1, wherein the coextruded foam layer comprises at least 70 wt. % polypropylene, polyethylene, or a combination of polypropylene and polyethylene.
4. The multilayer foam structure of claim 1, wherein the foam layer comprises additives in an amount of 1-20 wt. %.
5. The multilayer foam structure of claim 1, wherein the cap layer comprises additives in an amount of 1-8 wt. %.
6. The multilayer foam structure of claim 1, wherein the polypropylene has a melt flow index of 0.1-25 grams per 10 minutes at 230°C.
7. The multilayer foam structure of claim 1, wherein the polyethylene has a melt flow index of 0.1-25 grams per 10 minutes at 190°C.
8. The multilayer foam structure of claim 1, wherein the density of the multilayer foam structure is 20-250 kg/m<sup>3</sup>.
9. The multilayer foam structure of claim 1, wherein the multilayer foam structure has a crosslinking degree of 20-75%.
10. The multilayer foam structure of claim 1, wherein the multilayer foam structure has an average closed cell size of 0.05-1.0 mm.

11. The multilayer foam structure of claim 1, wherein the multilayer foam structure has a thickness of 0.2-50 mm.
12. A laminate comprising:
  - a multilayer foam structure comprising:
    - a coextruded foam layer comprising polypropylene, polyethylene, or a combination of polypropylene and polyethylene; and
    - a coextruded cap layer on a side of the foam layer, the cap layer comprising:
      - at least 15 wt. % ketone-ethylene-ester (KEE) terpolymer; and
      - polypropylene, polyethylene, or a combination of polypropylene and polyethylene; and
  - a laminate layer on a side of the cap layer opposite the foam layer.
13. The laminate of claim 12, wherein the laminate layer is a flexible film or foil.
14. The laminate of claim 12, wherein the laminate layer is a semi-flexible or rigid board, plank, tile, or substrate.
15. The laminate of claim 12, wherein the laminate layer is unfoamed or foamed.
16. The laminate of claim 12, wherein the coextruded foam layer comprises 2-15 wt. % KEE.
17. The laminate of claim 12, wherein the coextruded foam layer comprises at least 70 wt. % polypropylene, polyethylene, or a combination of polypropylene and polyethylene.
18. The laminate of claim 12, wherein the foam layer comprises additives in an amount of 1-20 wt. %.
19. The laminate of claim 12, wherein the polypropylene has a melt flow index of 0.1-25 grams per 10 minutes at 230°C.
20. The laminate of claim 12, wherein the polyethylene has a melt flow index of 0.1-25 grams per 10 minutes at 190°C.
21. A flooring system, comprising:
  - a top floor layer;

a sub-floor layer; and  
at least one underlayment layer disposed between the sub-floor layer and the top floor layer, wherein the at least one underlayment layer comprises a multilayer foam structure comprising:  
a coextruded foam layer comprising polypropylene, polyethylene, or a combination of polypropylene and polyethylene; and  
a coextruded cap layer on a side of the foam layer, the cap layer comprising:  
at least 15 wt. % ketone-ethylene-ester (KEE) terpolymer; and  
polypropylene, polyethylene, or a combination of polypropylene and polyethylene.

22. A method of forming a multilayer structure comprising:  
coextruding:  
a first layer comprising:  
polypropylene, polyethylene, or a combination of polypropylene and polyethylene;  
a chemical foaming agent; and  
a second layer on a side of the first layer, the second layer comprising:  
at least 15 wt. % ketone-ethylene-ester (KEE) terpolymer; and  
polypropylene, polyethylene, or a combination of polypropylene and polyethylene;  
irradiating the coextruded layers with ionizing radiation; and  
foaming the irradiated, coextruded layers.
23. The method of claim 22, wherein the first layer comprises 2-15 wt. % KEE.
24. The method of claim 22, wherein the first layer comprises at least 70 wt. % polypropylene, polyethylene, or a combination of polypropylene and polyethylene.
25. The method of claim 22, wherein the first layer comprises additives in an amount of 1-20 wt. %.
26. The method of claim 22, wherein the second layer comprises additives in an amount of 1-8 wt. %.

27. The method of claim 22, wherein the polypropylene has a melt flow index of 0.1-25 grams per 10 minutes at 230°C.
28. The method of claim 22, wherein the polyethylene has a melt flow index of 0.1-25 grams per 10 minutes at 190°C.
29. The method of claim 22, wherein the amount of chemical foaming agent in the first layer is 4-10 wt. %.
30. The method of claim 22, wherein the chemical foaming agent comprises azodicarbonamide.
31. The method of claim 22, wherein the first layer comprises a crosslinking agent.
32. The method of claim 31, wherein the amount of crosslinking agent in the first layer is 1-3 wt. %.
33. The method of claim 22, wherein the ionizing radiation is selected from the group consisting of alpha, beta (electron beams), x-ray, gamma, and neutron.
34. The method of claim 22, wherein the coextruded structure is irradiated up to four separate times.
35. The method of claim 33, wherein the ionizing radiation is an electron beam with an acceleration voltage of 200-1500 kV.
36. The method of claim 35, wherein an absorbed electron beam dosage is 10-500 kGy.
37. The method of claim 22, wherein the ionizing radiation crosslinks the extruded structure to a crosslinking degree of 20-75%.
38. The method of claim 22, wherein foaming comprises heating the irradiated structure with molten salt and radiant heaters or a hot air oven.
39. The method of claim 22, wherein the multilayer foam structure has a density of 20-250 kg/m<sup>3</sup>.
40. The method of claim 22, wherein the multilayer foam structure has an average closed cell size of 0.05-1.0 mm.

41. The method of claim 22, wherein the multilayer foam structure has a thickness of 0.2-50 mm.

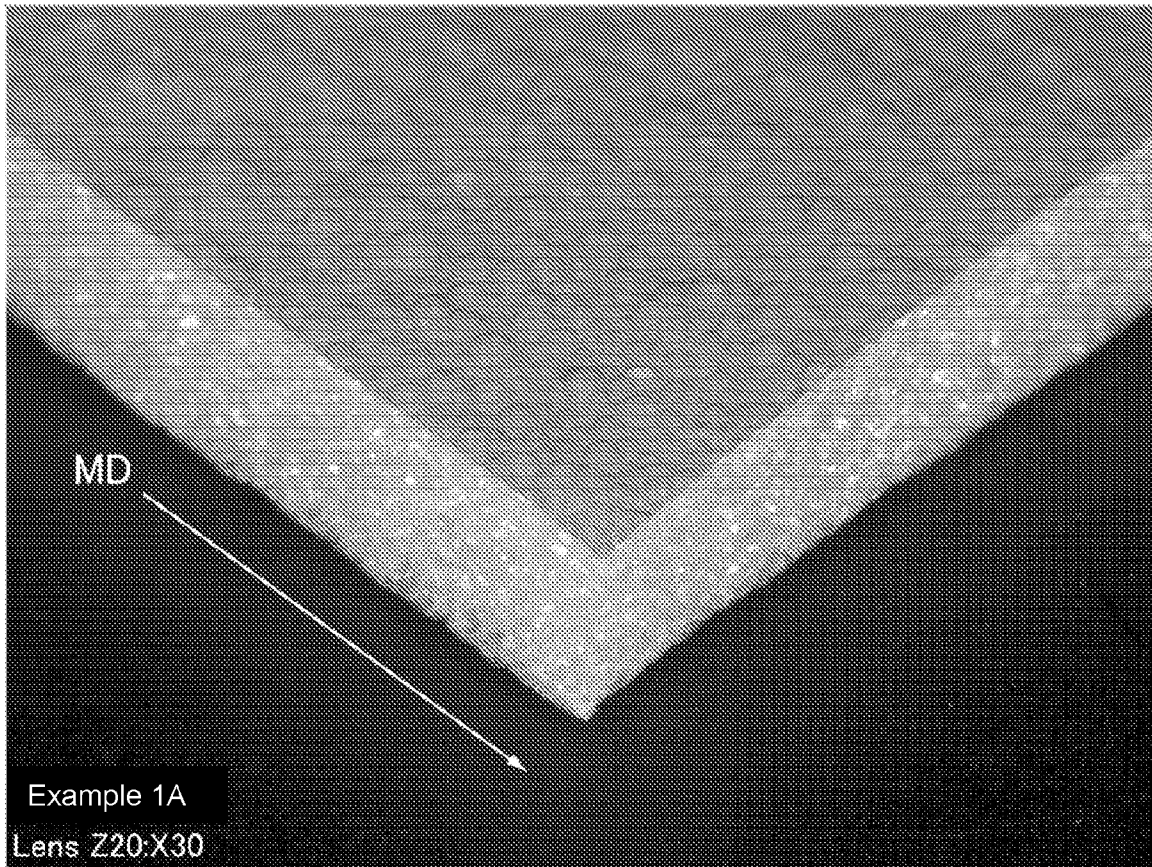


Figure 1A

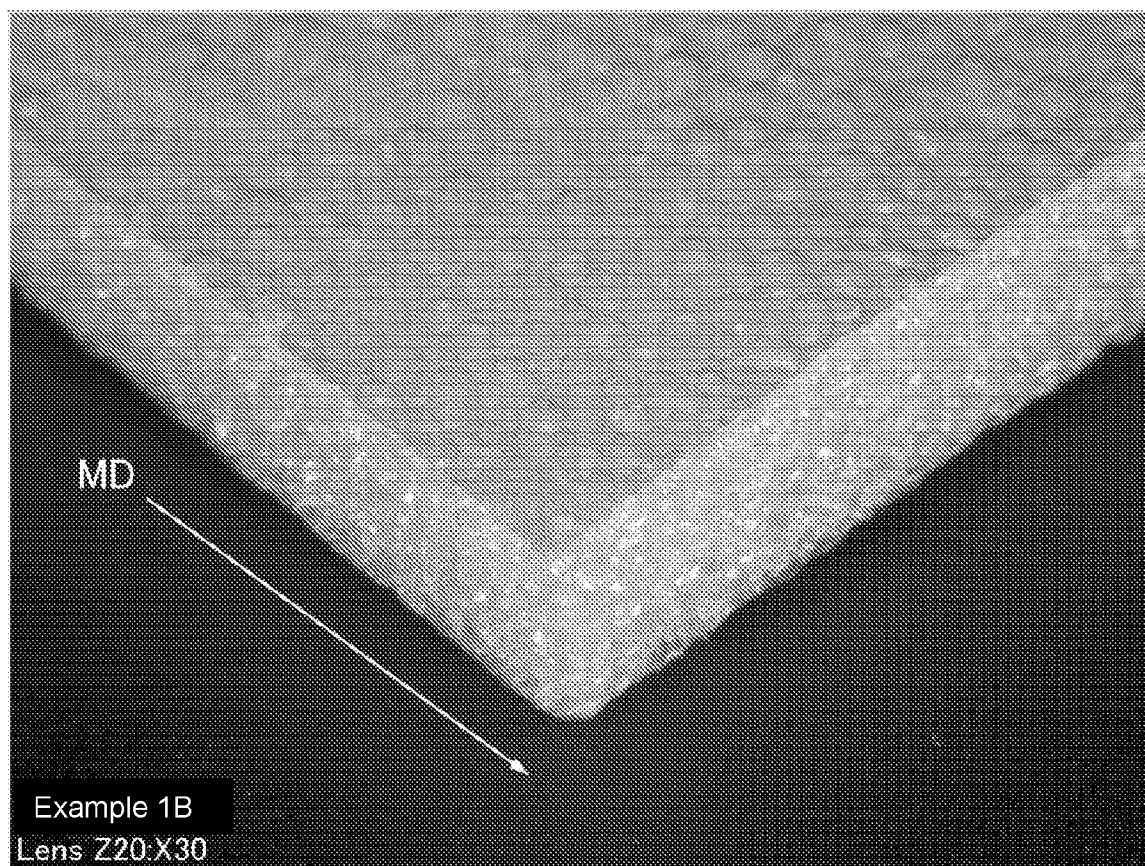


Figure 1B

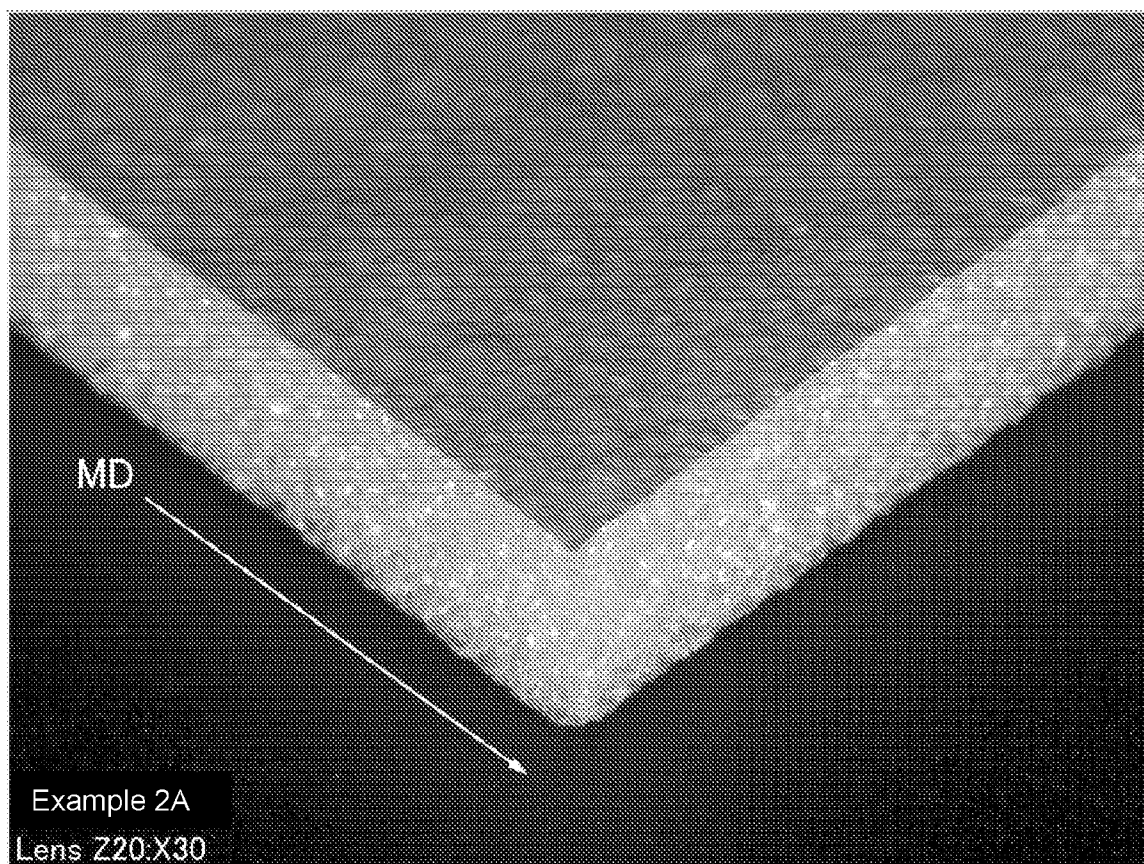


Figure 2A

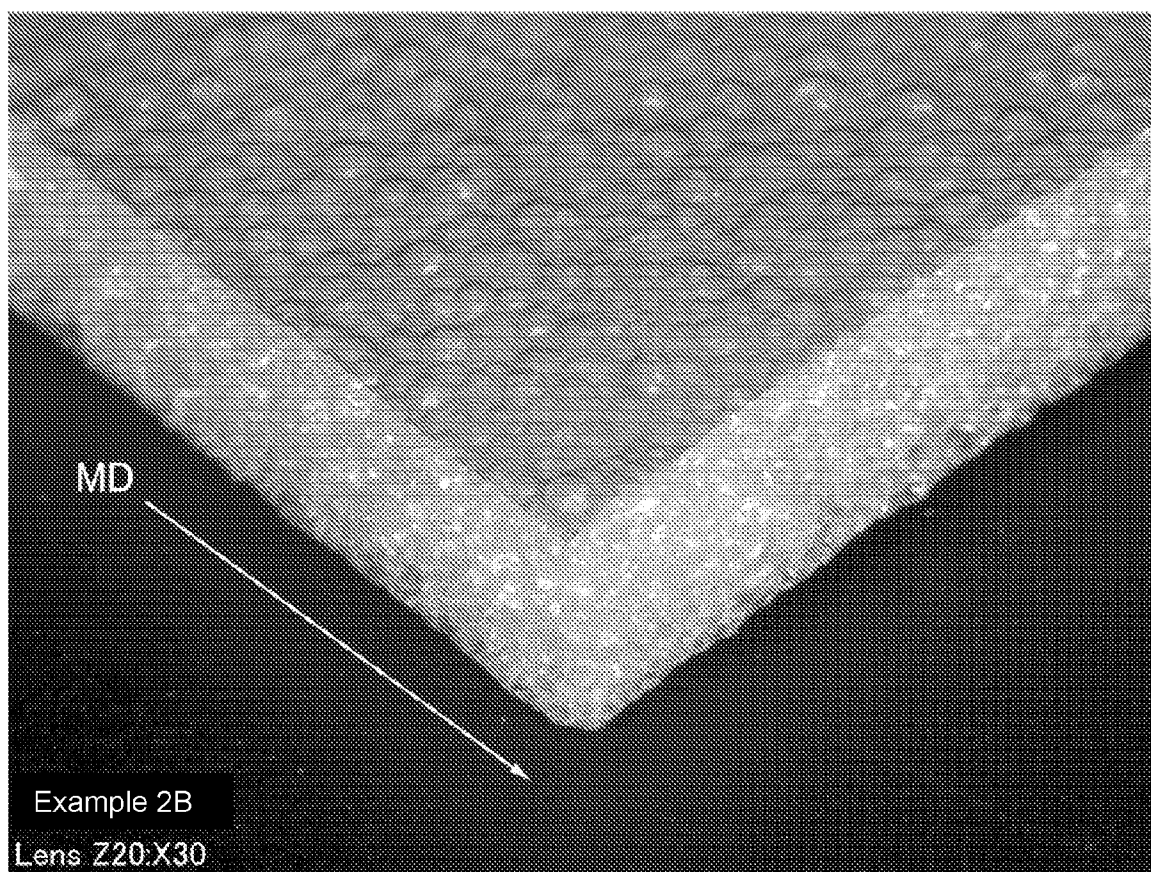


Figure 2B

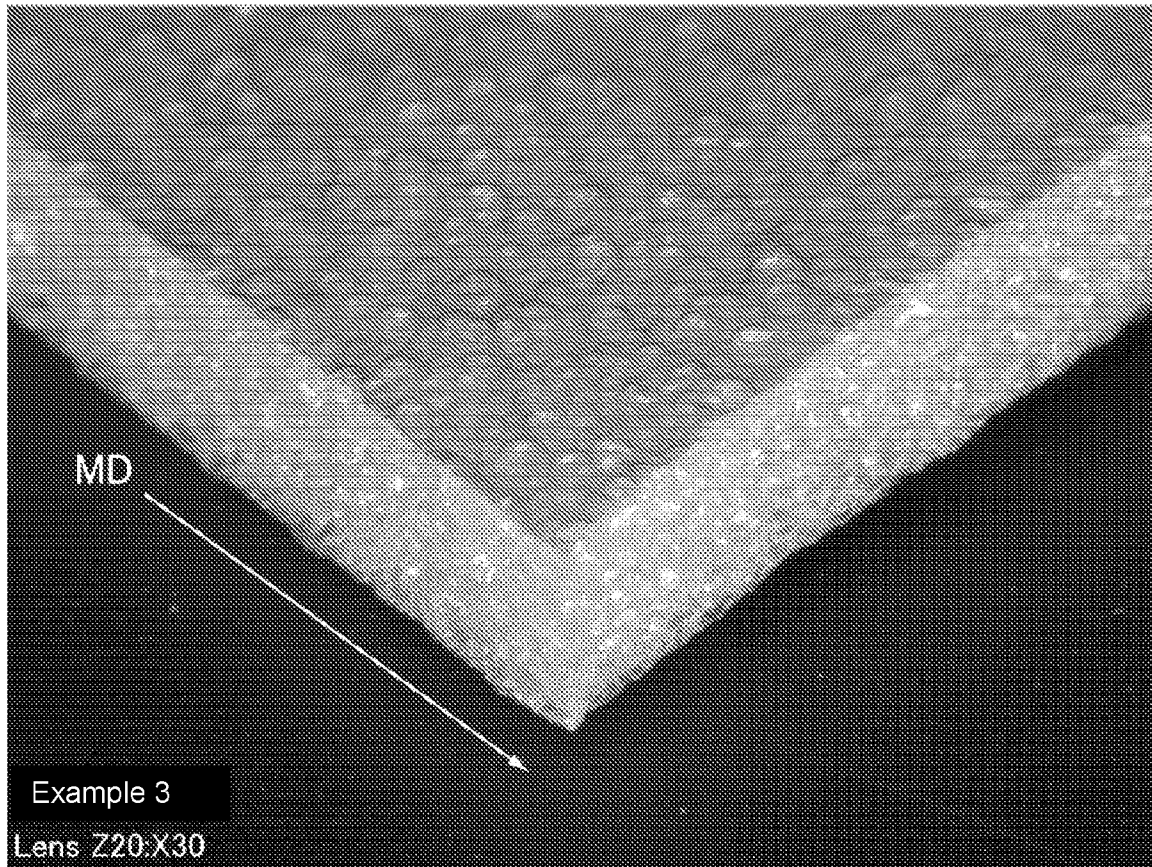


Figure 3

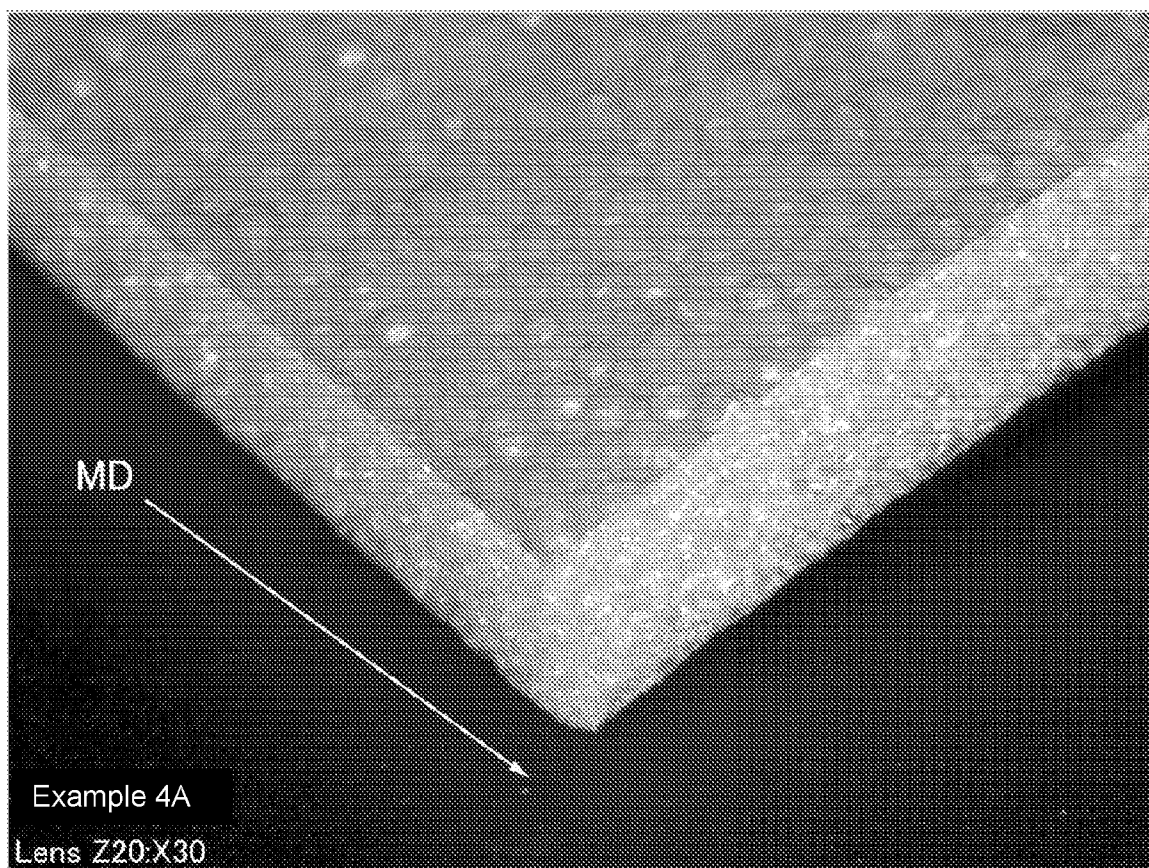


Figure 4A

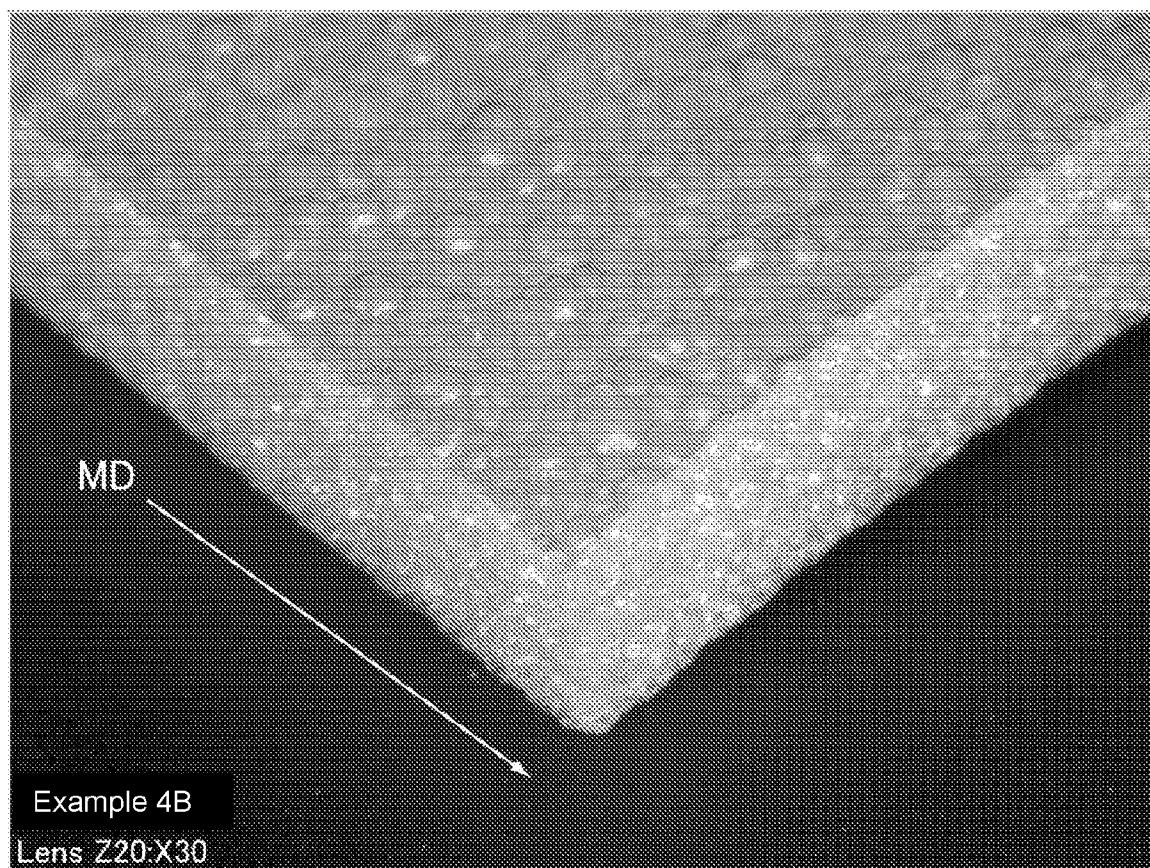


Figure 4B

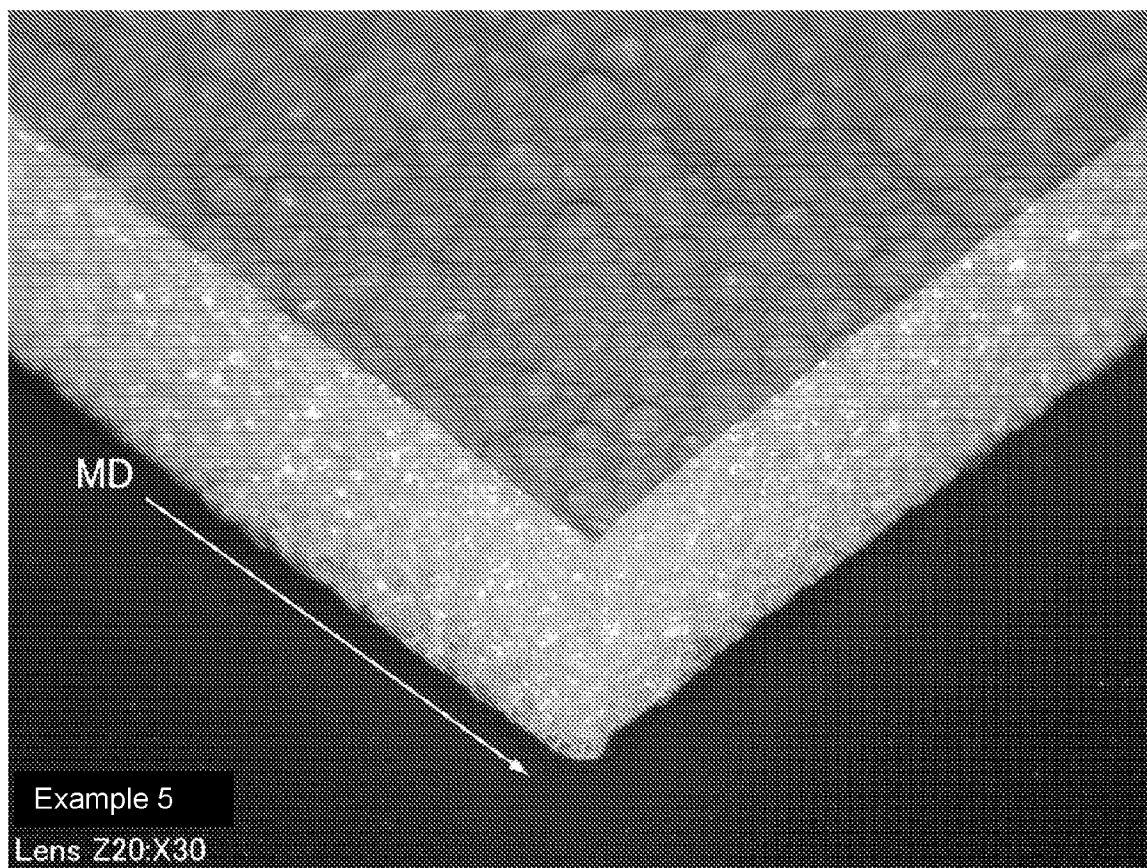


Figure 5

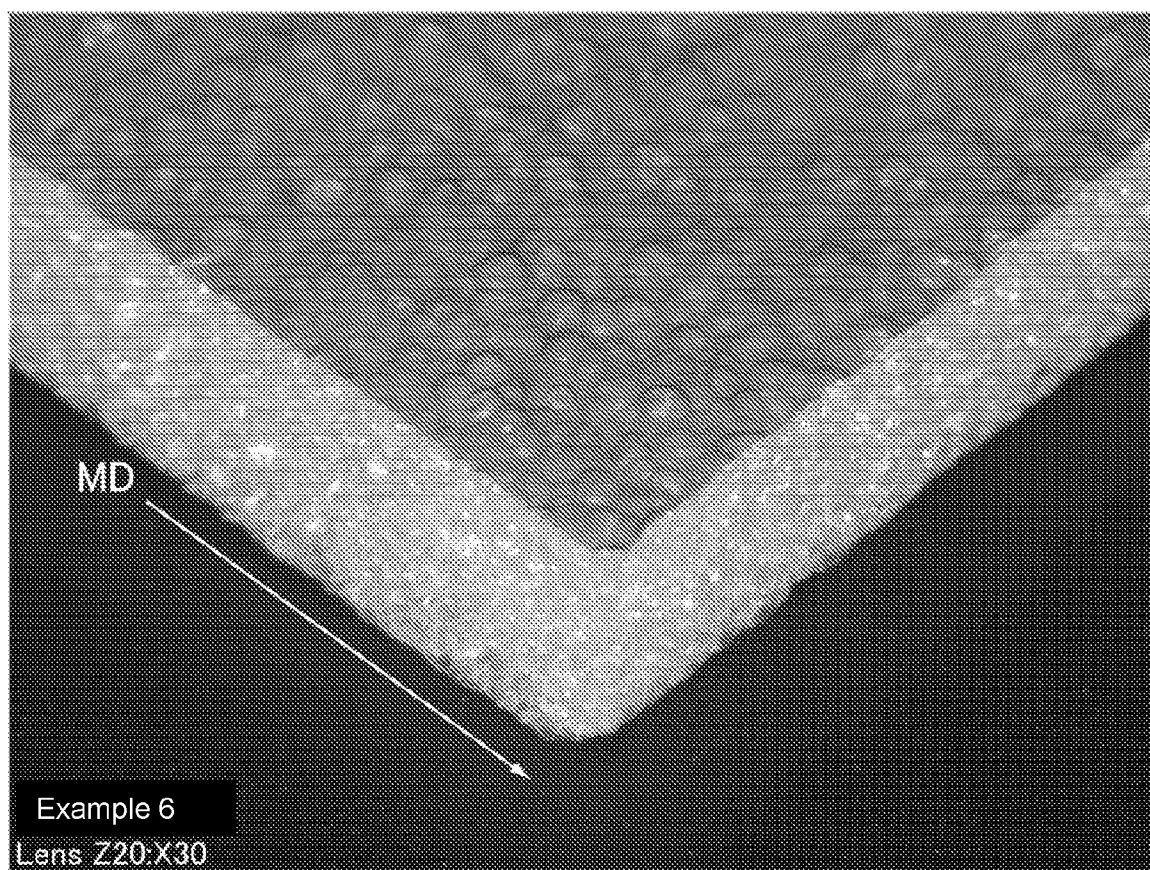


Figure 6

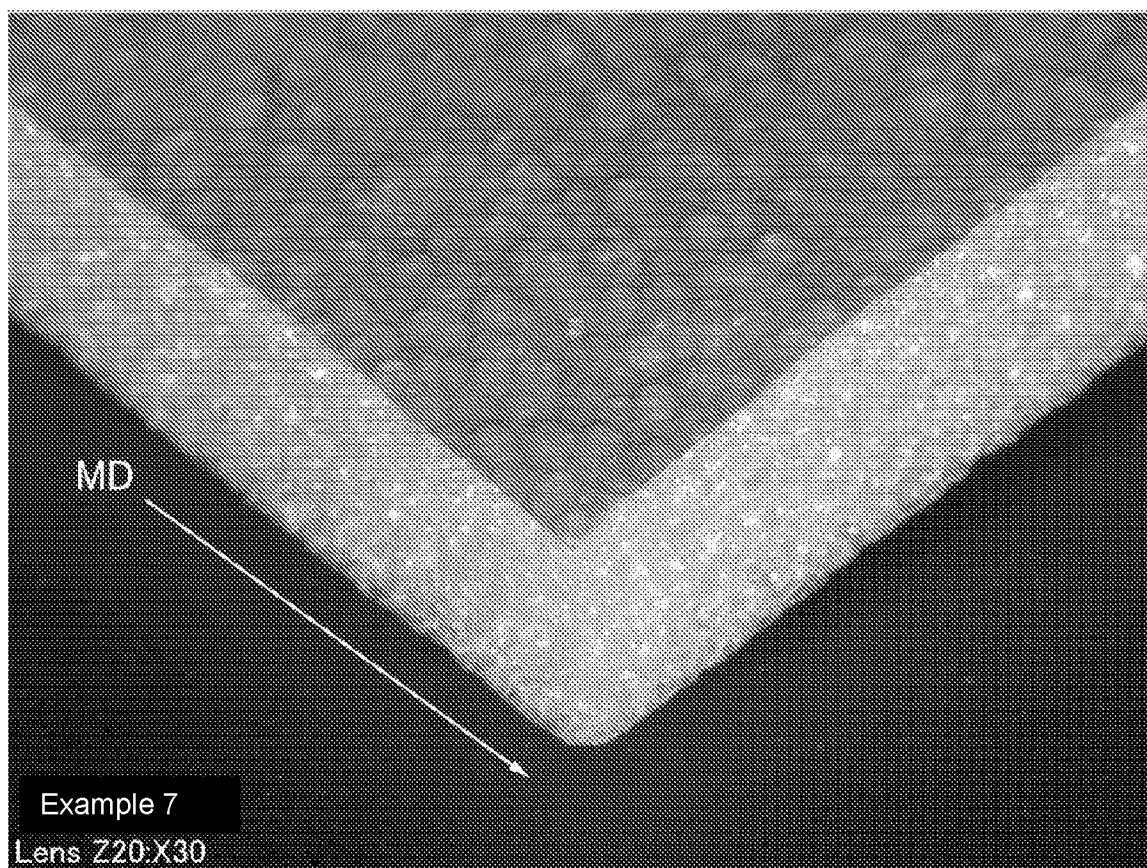


Figure 7

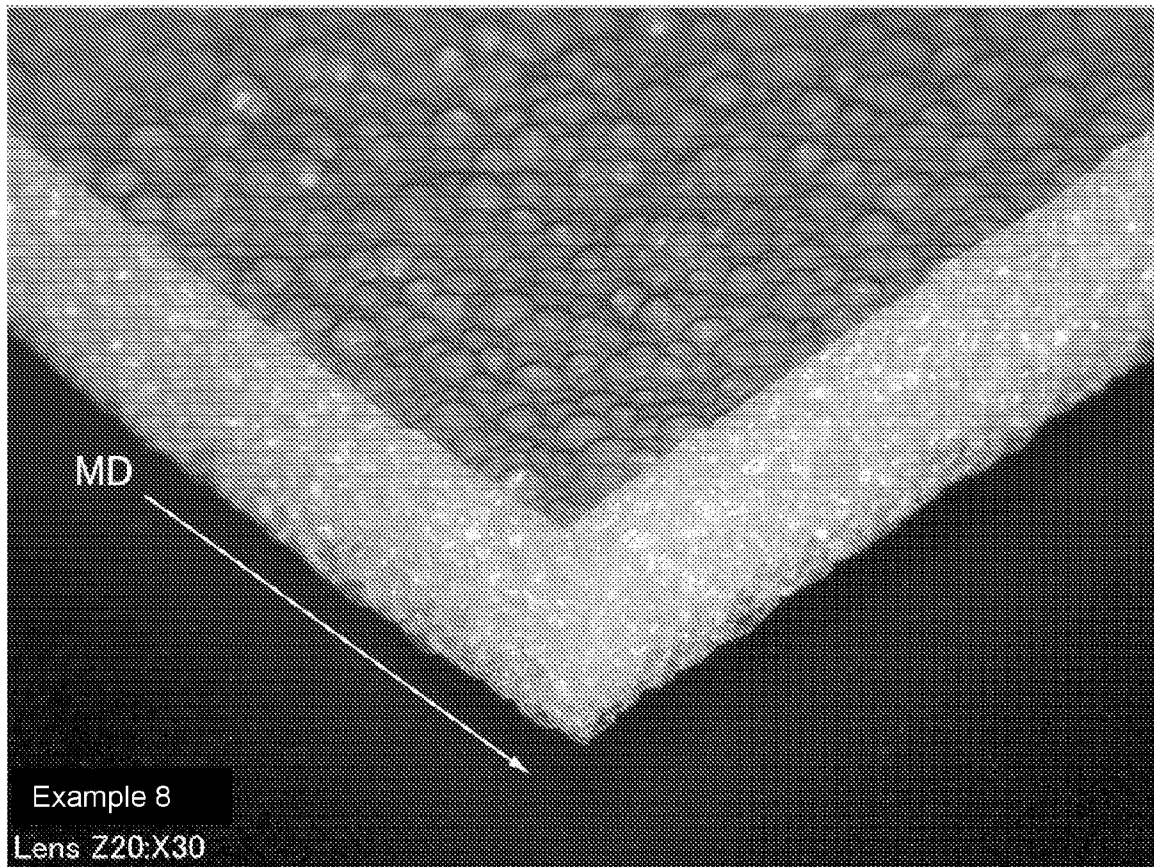


Figure 8

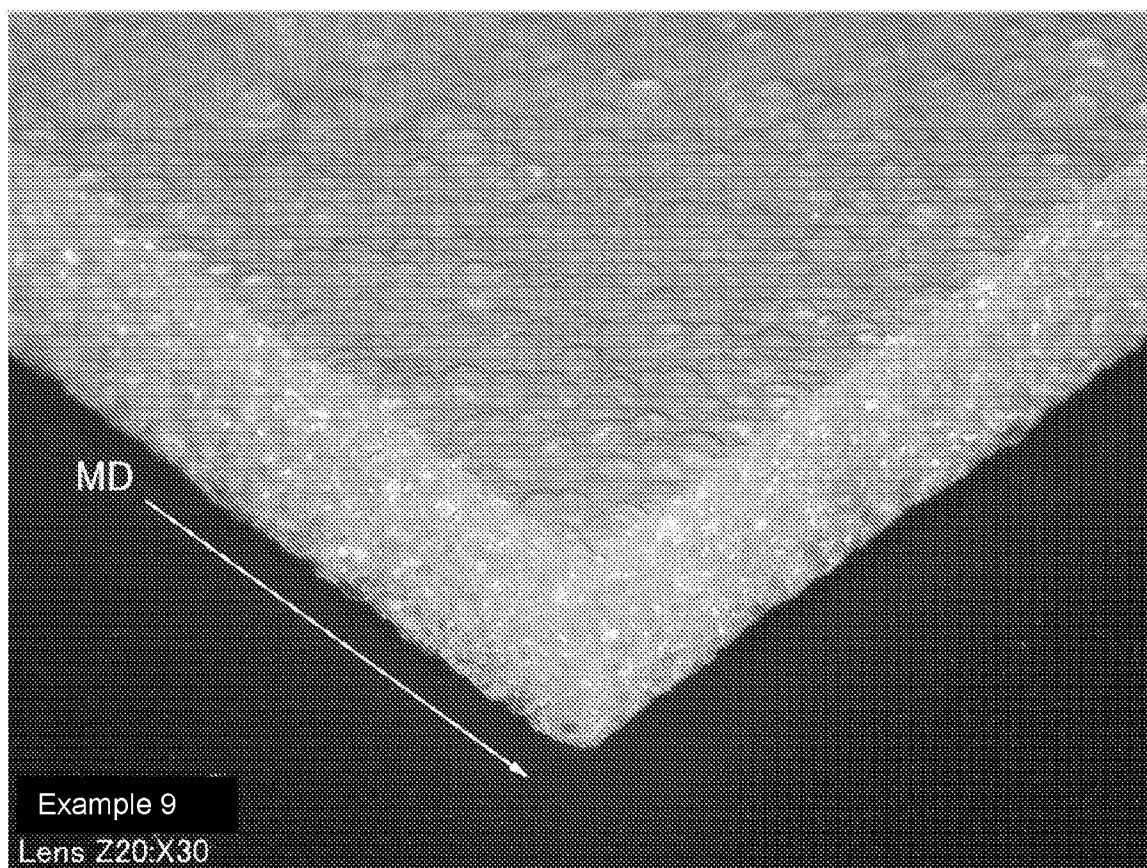


Figure 9

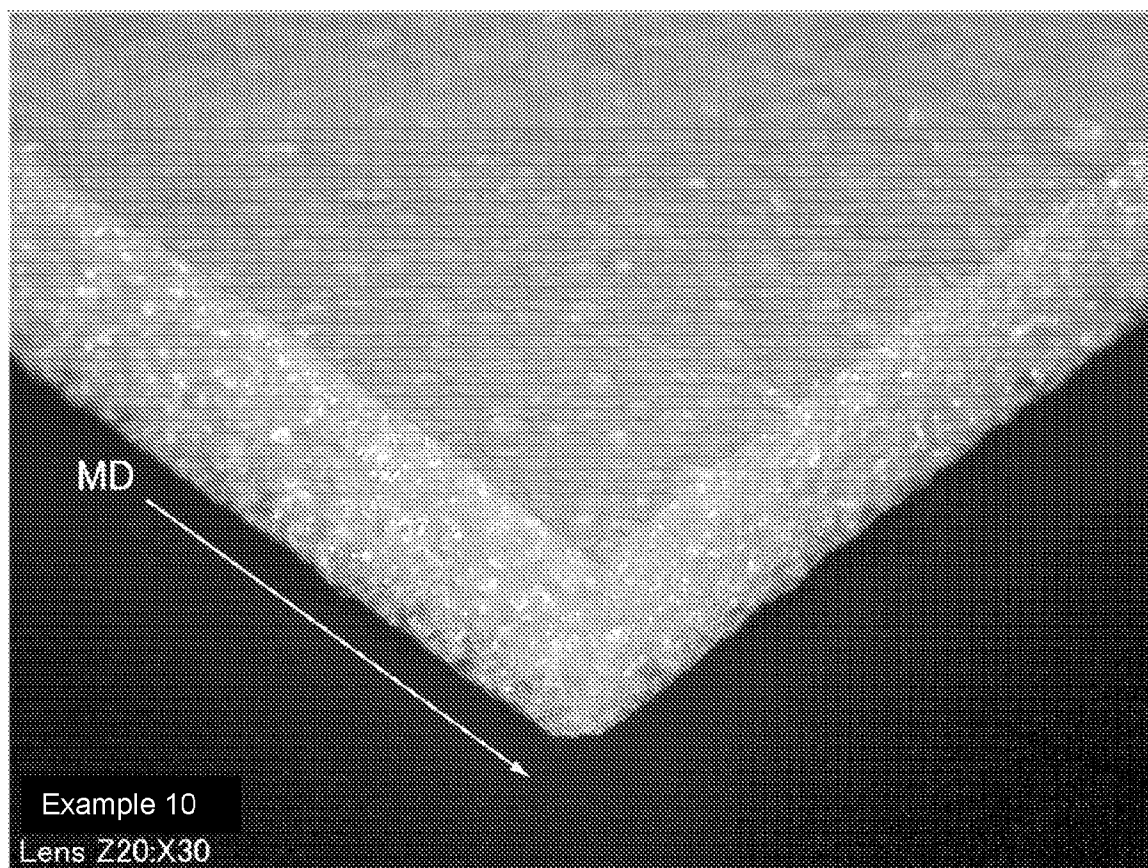


Figure 10

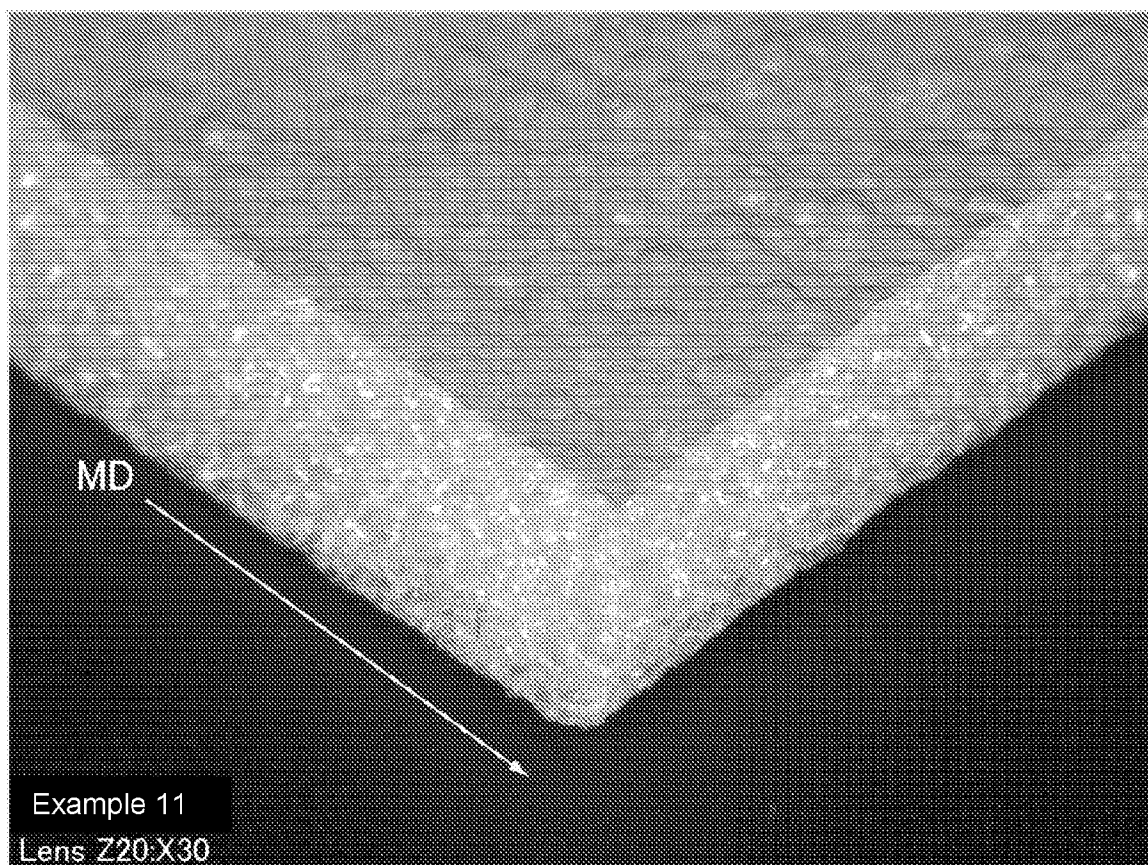


Figure 11

## INTERNATIONAL SEARCH REPORT

International application No

PCT/US2020/025480

## A. CLASSIFICATION OF SUBJECT MATTER

INV. B32B5/20 B32B27/28 B32B27/30 B32B27/32  
 ADD. B29C44/24 B29C48/21 C08J9/10 E04F15/10

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)

B32B B29C

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

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

EPO-Internal

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                 | Relevant to claim No.     |
|-----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| X         | JP H02 59335 A (SEKISUI CHEMICAL CO LTD)<br>28 February 1990 (1990-02-28)                                                                                                          | 1,3-8,<br>10-15,<br>17-20 |
| Y         | page 217, bottom-right column, lines 5 - 7<br>page 218, top-right column, line 1<br>- page 219, bottom-right column, line 16<br>-----                                              | 1-41                      |
| Y         | US 2016/185025 A1 (BALDWIN JESSE [US] ET<br>AL) 30 June 2016 (2016-06-30)<br>paragraph [0007] - paragraph [0010]<br>paragraph [0155] - paragraph [0165]<br>examples 1 - 4<br>----- | 1-41                      |



Further documents are listed in the continuation of Box C.



See patent family annex.

## \* Special categories of cited documents :

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

9 June 2020

Date of mailing of the international search report

18/06/2020

Name and mailing address of the ISA/

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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2020/025480

| Patent document<br>cited in search report |    | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
|-------------------------------------------|----|---------------------|----------------------------|---------------------|
| JP H0259335                               | A  | 28-02-1990          | NONE                       |                     |
| -----                                     |    |                     |                            |                     |
| US 2016185025                             | A1 | 30-06-2016          | NONE                       |                     |
| -----                                     |    |                     |                            |                     |