

EMBOSSING APPARATUS AND METHOD OF FABRICATING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[001] This application claims the benefit of priority of Singapore application No. 10201400094W filed February 20, 2014, the contents of it being hereby incorporated by reference in its entirety for all purposes.

TECHNICAL FIELD

[002] Various aspects of this disclosure relate to embossing apparatuses and methods of fabricating the same.

BACKGROUND

[003] In conventional roller thermal embossing or roll-to-roll thermal embossing of thermoplastic materials, patterns formation is based on polymer flow under high temperature and high pressure.

SUMMARY

[004] In various embodiments, an embossing apparatus may be provided. The embossing apparatus may include an input nip roller having an input nip roller axis. The embossing apparatus may also include a heating mechanism. The embossing apparatus may further include a middle roller having a middle roller axis substantially parallel to the input nip roller axis, the middle roller having a diameter at least substantially equal to a diameter of the input nip roller. The embossing apparatus may additionally include a cooling mechanism. The embossing apparatus may also include an output nip roller having an output nip roller axis substantially parallel to the input nip roller axis, the output nip roller having a diameter at least substantially equal to the diameter of the input nip roller. The embossing apparatus may be configured to receive a substrate so that the substrate is pressed between the input nip roller and the

middle roller and further pressed between the output nip roller and the middle roller. The input nip roller axis, the middle roller axis, and the output nip roller axis are in a common plane.

In various embodiments, a method of fabricating an embossing apparatus may be provided. The method may include providing an input nip roller having an input nip roller axis. The method may also include providing a heating mechanism. The method may further include providing a middle roller having a middle roller axis substantially parallel to the input nip roller axis, the middle roller having at least substantially the same diameter as the input nip roller. The method may include providing a cooling mechanism. The method may include providing an output nip roller having an output nip roller axis substantially parallel to the input nip roller axis, the output nip roller having at least substantially the same diameter as the input nip roller. The embossing apparatus may be configured to receive a substrate so that the substrate is pressed between the input nip roller and the middle roller and further pressed between the output nip roller and the middle roller; and wherein the input nip roller axis, the middle roller axis, and the output nip roller axis are in a common plane.

BRIEF DESCRIPTION OF THE DRAWINGS

[005] The invention will be better understood with reference to the detailed description when considered in conjunction with the non-limiting examples and the accompanying drawings, in which:

FIG. 1A is a schematic illustrating a roll thermal embossing system.

FIG. 1B is a schematic showing an embossed film with patterned microstructures.

FIG. 1C is a schematic illustrating a roll-to-roll (R2R) embossing system.

FIG. 1D is a schematic showing an embossed film with patterned microstructures.

FIG. 1E is a schematic illustrating an ultraviolet (UV) roll-to-roll (R2R) embossing system.

FIG. 2 is a schematic illustrating an embossing apparatus according to various embodiments.

FIG. 3 is a schematic illustrating an embossing apparatus according to various embodiments.

FIG. 4A is a schematic illustrating an embossing apparatus according to various embodiments.

FIG. 4B is a schematic illustrating the embossing unit of the apparatus shown in FIG. 4A according to various embodiments.

FIG. 4C is a schematic illustrating another embossing apparatus according to various embodiments.

FIG. 4D is a schematic illustrating a further embossing apparatus according to various embodiments.

FIG. 4E is a schematic illustrating another embossing apparatus according to various embodiments.

FIG. 4F is a schematic illustrating another embossing apparatus according to various embodiments.

FIG. 5A is a schematic illustrating an embossing apparatus according to various embodiments.

FIG. 5B is a photo of the embossing apparatus illustrated in FIG. 5A according to various embodiments.

FIG. 5C is a three dimension plot in the x, y and z directions of an embossed film formed by the embossing apparatus according to various embodiments.

FIG. 6 is a schematic illustrating a method of fabricating an embossing apparatus.

DETAILED DESCRIPTION

[006] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to

enable those skilled in the art to practice the invention. Other embodiments may be utilized, and structural and logical changes may be made without departing from the scope of the invention. The various embodiments are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments.

[007] In order that the invention may be readily understood and put into practical effect, particular embodiments will now be described by way of examples and not limitations, and with reference to the figures.

[008] It should be understood that the terms “on”, “over”, “lateral”, “top”, “bottom”, “down”, “side”, “back”, “left”, “right”, “front” etc., when used in the following description are used for convenience and to aid understanding of relative positions or directions, and not intended to limit the orientation of any device or structures or any part of any device or structure.

[009] FIG. 1A is a schematic 100a illustrating a roll thermal embossing system. FIG. 1B is a schematic 100b showing an embossed film with patterned microstructures. The system includes a first roller 102a and a second roller 102b. The first roller 102a includes a cylindrical surface with a mold template. A polymer film 104 is fed between the rollers 102a, 102b. In a roll thermal embossing, the bottom roller (roller 2) is used as a supporting roller. The film 104 is subject to high temperature before being fed between rollers 102a, 102b. A rigid supporting plate 106 is used in some cases for an effective thermal embossing.

[010] FIG. 1C is a schematic 100c illustrating a roll-to-roll (R2R) embossing system. FIG. 1D is a schematic 100d showing an embossed film with patterned microstructures. The system includes a first roller 112a and a second roller 112b. The first roller 112a includes a cylindrical surface with a mold template while the second roller 112b acts as a support. A film 114 may be fed between the two rollers 112a, 112b. The film 114 may be provided by roll 116a. The embossed film 114 may be

received by roll 116b. The film 114 may be heated by heated metal plates 118 prior to being fed between rollers 112a, 112b.

[011] Due to high temperature during and after thermal embossing, the heated polymer film 114 will become sticky and is hard to be demolded from the mold. During demolding, the embossed polymer film 114 will be stretched and/or wrinkled.

[012] FIG. 1E is a schematic 100e illustrating an ultraviolet (UV) roll-to-roll (R2R) embossing system. The embossing system includes rollers 122a-f. A coating unit 126 dispenses a photopolymer material onto a flexible substrate 124. An optically transparent belt mold 128 imparts a pattern onto the photopolymer and an UV light source 130 irradiates the pattern to cure and harden the pattern. The design and process method are not suitable for thermal embossing.

[013] In Roll-to-Roll thermal embossing, embossing of high aspect ratio microstructures needs higher pressure and high temperature. Conventional roll-to-roll thermal embossing may have the following problems:

(1) the polymer needs to be heated up-to or above its T_g (glass transition temperature) during thermal embossing. Due to high temperature during thermal embossing, the heated polymer film will become soft and sticky. The web tension will elongate the polymer film, causing deformation of microstructures; (2) the embossed polymer film is hard to be demolded while its temperature is around its T_g (this means that it is hard to separate the embossed film from the embossing mold that is fixed on an embossing roller; the embossed polymer film will be stretched and/or wrinkled during demolding; (3) conventional roll-to-roll thermal embossing lacks sufficient cooling before demolding and demolding without sufficient cooling will cause deformation of embossed film and/or collapse of embossed microstructures; and (4) conventional roll-to-roll thermal embossing lacks sufficient preheating, or the effect of preheating is reduced due to the distance between preheating device and embossing rollers.

[014] FIG. 2 is a schematic 200 illustrating an embossing apparatus according to various embodiments. The embossing apparatus may include an input nip roller 202

having an input nip roller axis. The embossing apparatus may also include a heating mechanism 204. The embossing apparatus may further include a middle roller 206 having a middle roller axis substantially parallel to the input nip roller axis, the middle roller 206 having a diameter at least substantially equal to a diameter of the input nip roller 202. The embossing apparatus may additionally include a cooling mechanism 208. The embossing apparatus may also include an output nip roller 210 having an output nip roller axis substantially parallel to the input nip roller axis, the output nip roller having a diameter at least substantially equal to the diameter of the input nip roller 202. The embossing apparatus may be configured to receive a substrate so that the substrate is pressed between the input nip roller 202 and the middle roller 206 and further pressed between the output nip roller 208 and the middle roller 206. The input nip roller axis, the middle roller axis, and the output nip roller axis are in a common plane 232.

[015] In other words, the embossing apparatus may include an input nip roller 202, a middle roller 206 and an output nip roller 210. The input nip roller 202, the middle roller 206, and the output nip roller 210 may have substantially the same diameter. The axes of the input nip roller 202, the middle roller 206 and the output nip roller 210 may be in the same plane 232. The embossing mechanism may be configured to receive a substrate so that the substrate is passed between the input nip roller 202 and the middle roller 206 and further passed between the output nip roller 208 and the middle roller 206 in a zig-zag manner. The embossing apparatus may further include a heating mechanism configured to heat the substrate and a cooling mechanism configured to cool the substrate.

[016] Various embodiments may help to address or mitigate the problems faced by conventional embossing systems. By receiving a substrate so that the substrate is between the input nip roller and the middle roller and further pressed between the output nip roller and the middle roller in a zig-zag manner, the amount of time to heat the substrate before embossing and/or the amount of time to cool the substrate

after embossing and before demolding may be increased.

[017] The embossing apparatus may be or may include a thermal embossing apparatus such as a roll-to-roll thermal embossing apparatus.

[018] The substrate may be or may include a film, such as a thermoplastic film. The thermoplastic film may also be referred to as a thermoplastic polymer film and/or sheet. The thermoplastic film may include a polymeric material. The thermoplastic film may become soft at temperatures above the glass transition temperature (T_g). The softened polymeric material may flow under applied pressure and may fill in cavities of a mold. After being cooled down, microstructures (corresponding to microstructures of the mold) may be formed. In other words, microstructures of the mold may be replicated on the thermoplastic film.

[019] The embossing apparatus may further include a feed-in mechanism. The feed-in mechanism may include the input nip roller 202 and a further input nip roller. The feed-in mechanism may be configured to receive the substrate between the input nip roller 202 and the further input nip roller so that the substrate is pressed between the input nip roller 202 and the further input nip roller. The embossing apparatus may further include an unwinding unit. The unwinding unit may be configured to unwind the substrate. The substrate may extend from the unwinding unit to the feed-in mechanism. The substrate may be received by the feed-in mechanism. The input nip roller and the further input nip roller may be configured to move a portion of the substrate between the input nip roller and the further input nip roller towards the embossing mechanism including the middle roller 206. The input nip roller 202 and the further input nip roller may be configured to move the substrate from the unwinding unit towards the embossing mechanism.

[020] The feed-out mechanism may include the output nip roller 210 and a further output nip roller. The feed-out mechanism may be configured to output the substrate between the output nip roller and the further output nip roller so that the substrate is pressed between the output nip roller and the further output nip roller. The

feed-out mechanism may be configured to receive the embossed substrate from the embossing mechanism. The embossing apparatus may further include a rewinding unit. The rewinding unit may be configured to wind the embossed substrate. The output nip roller and the further output nip roller may be configured to move the portion of the (embossed) substrate between the output nip roller and the further output nip roller towards the rewinding unit. The output nip roller and the further output nip roller may be configured to move the embossed substrate from the embossing mechanism towards the rewinding unit.

[021] The embossing mechanism may include a middle roller and a further middle roller. The substrate may be held or may be pressed between the middle roller and the further middle roller. The embossing mechanism may be configured to receive the substrate from the feed-in mechanism. The middle roller may have a cylindrical surface including a pattern for embossing onto the substrate. Additionally or alternatively, the further middle roller may have a cylindrical surface including a pattern for embossing onto the substrate. The middle roller and/or the further middle roller may be or may include a mold for imparting a pattern to the substrate. The embossing mechanism may be configured to move the substrate towards the feed-out mechanism after embossing. The substrate may extend from the unwinding unit to the feed-in mechanism, from the feed-in mechanism to the embossing mechanism, from the embossing mechanism to the feed-out mechanism and from the feed-out mechanism to the rewinding unit. The substrate may be pressed between the input nip roller 202 and the further input nip roller, may be pressed between the input nip roller 202 and the middle roller 206, may be pressed between the middle roller 206 and the further middle roller, may be pressed between the middle roller 206 and the output nip roller 210, and may be pressed between the output nip roller 210 and the further output nip roller.

[022] In various embodiments, the heating mechanism 204 may include one or more heating devices or thermal sources such as heaters, hot air nozzles (configured

to generate heated air), infra-red (IR) heating sources, and/or ultra-violet (UV) heating sources. The one or more heating devices/thermal sources may be provided between the feed-in mechanism and the embossing mechanism. Additionally or alternatively, the one or more heating devices/thermal sources may be provided in one or more of the input nip rollers and/or embossing rollers. The input nip roller 202 may include the heating mechanism 204. In various embodiments, one or both middle rollers may include one or more heating devices/thermal sources. In various embodiments, one or both middle rollers may include a further heating mechanism. The further heating mechanism may include one or more heating devices or thermal sources such as heaters, hot air nozzles (configured to generate heated air), infra-red (IR) heating sources, and/or ultra-violet (UV) heating sources. The one or more heating devices/thermal sources may be configured to provide unequal heating temperatures to the input nip rollers and the middle rollers. The one or more heating devices/thermal sources may be configured to provide unequal heating to the portion of the substrate contacted by the input nip roller motors and the portion of the substrate contacted by the embossing motors. Heating devices may also be referred to as pre-heating devices. The heaters may be or may include resistive heaters.

[023] In various embodiments, the cooling mechanism 208 may include one or more cooling devices such as nozzles for outputting cooled air. The one or more cooling devices may be provided between the embossing mechanism and the feed-out mechanism. Additionally or alternatively, the one or more cooling devices may be provided in one or both feed-out nip rollers. The output nip roller 210 may include the cooling mechanism.

[024] The embossing mechanism may include an embossing roller motor configured to drive at least one of the middle roller and the further middle roller. In various embodiments, the embossing mechanism 206 may include separate middle roller motors to drive each of the embossing rollers. The embossing roller motor(s) may be configured to rotate the middle roller(s). The embossing roller motor(s) may

be configured to emboss the substrate by rotating the middle roller(s). Rotating the embossing roller(s) may also move the substrate from the feed-in mechanism towards the feed-out mechanism.

[025] The feed-in mechanism may include a feed-in roller motor configured to drive at least one of the input nip roller and a further input nip roller. In various embodiments, the feed-in mechanism may include separate feed-in roller motors to drive each input nip roller. The feed-in roller motor(s) may be configured to rotate the input nip roller(s). The feed-in roller motor(s) may be configured to move the substrate from the unwinding unit towards the embossing mechanism by rotating the feed-in nip roller(s).

[026] The feed-out mechanism may include a feed-out roller motor configured to drive at least one of an output nip roller and a further output nip roller. In various embodiments, the feed-in mechanism may include separate feed-in roller motors to drive each input nip roller. The feed-out roller(s) may be configured to move the substrate from the embossing mechanism 206 towards the rewinding unit by rotating the feed-out nip roller(s).

[027] The embossing roller motor, the feed-in roller motor and the feed-out roller motor may be electrically coupled to the control mechanism 232. The embossing apparatus or embossing unit may include one or more electrical connections coupling the control mechanism 232 to the embossing roller motor, the feed-in roller motor and/or the feed-out roller motor.

[028] The embossing apparatus may further include a control mechanism electrically coupled to the feed-in mechanism, the feed-out mechanism and the embossing mechanism, the control mechanism configured to synchronize the feed-in mechanism, the feed-out mechanism and the embossing mechanism. For instance, the control mechanism may be electrically coupled to the embossing roller motor, the feed-in roller motor, and the feed-out roller motor. The control mechanism may be configured to control a first speed of rotation of at least one of the middle roller and

the further middle roller, a second speed of rotation of at least one of the input nip roller and the further input nip roller, and a third speed of rotation of at least one of the output nip roller and the further output nip roller. The control mechanism may be configured to synchronize the feed-in mechanism, the feed-out mechanism and the embossing mechanism by controlling a first speed of rotation of at least one of the middle roller and the further middle roller, a second speed of rotation of at least one of the input nip roller and the further input nip roller, and a third speed of rotation of at least one of the output nip roller and the further output nip roller. The first speed of rotation, the second speed of rotation and the third speed of rotation may be substantially equal. Alternatively, the first speed of rotation, the second speed of rotation and the third speed of rotation may be proportional to one another. Synchronization may be achieved by synchronizing the motor speed in addition to making the roller diameters at least substantially equal. For instance, rotation speeds of a embossing roller motor attached to the middle roller and a further embossing roller motor attached to the further middle roller may be measured using precision encoders. A fast motion controller may be used to ensure that the embossing roller motor and the further embossing roller motor are rotating at preset speeds with little deviations.

[029] The embossing mechanism may further include a flexible belt mold held at least by the middle roller. The cylindrical surface of the middle roller may be smooth, i.e. without patterns. Additionally or alternatively, the flexible belt mold may be held by the further middle roller. The cylindrical surface of the further middle roller may be smooth. The flexible belt mold may include a pattern for embossing the substrate. In other words, the flexible belt mold may be or may include a mold for imparting a pattern to the substrate.

[030] The flexible belt mold may be further held by at least one of an input nip roller and an output nip roller. The flexible belt mold may be held by the further input nip roller or/and the further output nip roller. The flexible belt mold may pass

between the input nip roller and the further input nip roller. The flexible belt mold may pass between the output nip roller and the further output nip roller. The flexible belt mold may pass between the middle roller and the further middle roller. The flexible belt mold may include a suitable metal.

[031] The embossing apparatus may further include a flexible belt mold support roller. The flexible belt mold may be further held by the flexible belt mold support roller.

[032] The embossing apparatus may further include a supporting belt coupled to the feed-in mechanism, the feed-out mechanism, and the embossing mechanism. The supporting belt may be a metallic belt. The supporting belt may include a suitable metal. The supporting belt may be configured to cooperate with the embossing mechanism to sandwich the substrate. The pair of middle rollers may be configured to receive the supporting belt. The supporting belt may pass through between the middle roller and the further middle roller. The supporting belt may be held by one of the middle roller and the further roller. The supporting belt may be further held by one of the input nip roller and the further input nip roller. The supporting belt may pass between the input nip roller and the further input nip roller. The supporting belt may be alternatively or additionally held by one of the output nip roller and the further output nip roller. The supporting belt may pass between the output nip roller and the further output nip roller.

[033] The feed-in mechanism, the feed-out mechanism, and the embossing mechanism may be laterally displaced. The embossing rollers may be laterally displaced from the input and output nip rollers.

[034] In various embodiments, the feed-in mechanism and the feed-out mechanism may define a low tension zone. The portion of the substrate within the low tension zone between the feed-in mechanism and the feed-out mechanism (i.e. between the input nip roller and the output nip roller) has a lower tension compared to portions of the substrate outside the low tension zone. The tension of the substrate in

the low tension zone may substantially be equal to zero.

[035] FIG. 3 is a schematic 300 illustrating an embossing apparatus according to various embodiments. The embossing apparatus may include a feed-in mechanism 302 configured to receive a substrate 312. The embossing apparatus may also include a heating mechanism 304 configured to heat the substrate 312. The embossing apparatus may further include an embossing mechanism 306 configured to emboss the substrate 312 after the substrate 312 has been heated by the heating mechanism 304. The embossing apparatus may additionally include a cooling mechanism 308 configured to cool the substrate 312 after the substrate 312 has been embossed by the embossing mechanism 306. The embossing apparatus may also include a feed-out mechanism 310 configured to output the substrate 312.

[036] The feed-in mechanism may include an input nip roller 302b having an input nip roller axis. The feed-in mechanism may further include a further input nip roller 302a having a further input nip roller axis. The further input nip roller axis may be parallel to the input nip roller axis.

[037] The feed-out mechanism may include an output nip roller 310a having an output nip roller axis. The feed-out mechanism may further include a further output nip roller 310b having a further output nip roller axis. The further output nip roller axis may be parallel to the output nip roller axis.

[038] The embossing mechanism may include a middle roller 306a and a further middle roller 306b. The middle roller 306a may include a middle roller axis. The further middle roller 306b may include a further middle roller axis parallel to the middle roller axis.

[039] The input nip roller axis, the middle roller axis, and the output nip roller axis may be in a common plane. The further input nip roller axis and the further output nip roller axis may be in a further common plane. The further middle roller axis may be in another common plane. The common plane may be between the further common plane and the other common plane.

[040] The embossing apparatus may further include a control mechanism electrically coupled to the feed-in mechanism 302, the feed-out mechanism 310 and the embossing mechanism 306, the control mechanism 312 configured to synchronize the feed-in mechanism 302, the feed-out mechanism 310 and the embossing mechanism 306.

[041] The substrate 312 may be or may include a polymer, such as a thermoplastic film.

[042] The embossing apparatus may include a thermal embossing unit. The thermal embossing unit may include the feed-in mechanism 302, the embossing mechanism 306 and the feed-out mechanism 310. The thermal embossing unit may further include a heating mechanism 304 and a cooling mechanism 308.

[043] The feed-in mechanism 302 may include an input nip roller 302b, i.e. R2, and a further input nip roller 302a, i.e. R1. The embossing mechanism 306 may include a middle roller 306a, i.e. R3, and a further middle roller 306b, i.e. R4. The feed-out mechanism 310 may include an output nip roller 310a, i.e. R5, and an output nip roller 310b, i.e. R6. In other words, the embossing unit may include at least a pair of input nip rollers (R1 302a, R2 302b) at a feed-in side, a pair of middle rollers (R3 306a, R4 306b) and a pair of output nip rollers (R5 310a, R6 310b) at a feed-out side.

[044] The feed-in mechanism 302 may be configured to receive the thermoplastic film 312 between the first input nip roller 302a and the second input nip roller 302b so that the thermoplastic film 312 is pressed or sandwiched between the input nip roller 302b and the further input nip roller 302a.

[045] The heating mechanism 304 may be or may include a heater. The heating mechanism may be configured to heat the thermoplastic film 312 so as to soften the thermoplastic film 312. The heating mechanism 304 may include one or more additional preheating devices. The preheating devices may be or may include hot air nozzles (configured to output heated or hot air), infrared (IR) based heating sources, ultraviolet (UV) based heating sources or any combination thereof. The heating

mechanism 304 may at least be partially embedded or included within the feed-in mechanism 302. For instance, the heater may be embedded within the second input nip roller 302b.

[046] The embossing mechanism 306 may include a middle roller 306a and a further middle roller 306b. One of the middle roller 306a and the further middle roller 306b may include a cylindrical surface comprising a pattern for embossing onto the thermoplastic film 312. In other words, a mold may be attached to or may be included on a surface of one of the middle rollers 306a, 306b. The mold may be attached to or may be included on either the top roller 306a or the bottom roller 306b. The mold is configured to impart a pattern onto the (heated) thermoplastic film 312 so as to emboss the (heated) thermoplastic film 312. One or both of the middle roller 306a and the further middle roller 306b may be coupled to or may include or may be embedded with a further heating mechanism (e.g. a heater), the further heating mechanism configured to heat the cylindrical surface during embossing. The heater may be configured to heat the top middle roller 306a and/or the bottom middle roller 306b for thermal embossing. One or both of the first middle roller 306a and the second middle roller 306b may be coupled to a motor. The motor may drive the top roller 306a and/or the bottom roller 306b.

[047] In one example, the input nip roller 302b may include a heater for pre-heating the thermoplastic film 312. The middle roller 306a may include a further heater to further heat the thermoplastic film 312.

[048] In various embodiments, the middle rollers 306a, 306b may include or may be embedded with separate heaters. The separate heaters may allow the rollers 306a, 306b to be set to different temperatures. For instance, if the top roller 306a includes an embossing pattern or mold, the temperature of the bottom roller 306b may be set higher than the temperature of the top roller 306a. In one example, the bottom roller 306b, R_4 , may be set to $(T_g + 20)^\circ \text{C}$ while the top roller 306a, R_3 , may be set to $(T_g - 20)^\circ \text{C}$, where T_g is the glass transition temperature of the polymer or

thermoplastic to be embossed.

[049] In various embodiments, the middle roller 306a may be coupled to a first motor and the further middle roller 306b may be coupled to a second motor. The middle roller 306a may be driven by the first motor while the further middle 306b may be driven by a second motor. The two middle rollers 306a, 306b may be synchronized to have substantially the same linear speed or rotational speed. The double-sided driven approach may help improve quality and fidelity of the embossed structures.

[050] The cooling mechanism 308 may be or may include a cooling device. The cooling device may be configured to cool the embossed thermoplastic film 312 by a suitable mechanism (e.g. air cooling). Cooling may improve the effective demolding of the embossed film 312.

[051] The feed-out mechanism 310 may be configured to output the thermoplastic film 312 between the output nip roller 310a, R5, and the further output nip roller 310b, R6, so that the thermoplastic film 312 is pressed between the first output nip roller 310a and the second output nip roller 310b.

[052] In one example, the output nip roller 310a may include a cooling device to cool the thermoplastic film 312 during and/or after demolding.

[053] The cooling mechanism 308 may include one or more additional cooling devices. The additional cooling devices may be used for cooling the embossed thermoplastic film 312 sufficiently for effective demolding. The cooling devices may be or may include air nozzles (configured to output cooled air).

[054] The further input nip roller 302a, R1, may be vertically above the input nip roller 302b, R2. The further middle roller 306b, R4, may be vertically below the middle roller 306a, R3. The further output nip roller 310b may be vertically above output nip roller 310a. The further input nip roller 302a, R1, may be lateral to the further output nip roller 302b, R6. The thermoplastic film 312 may pass between the input nip roller 302b and the further input nip roller 302a, to between the first middle

roller 306a and the further middle embossing roller 306b, to between the output nip roller 310a and the further output nip roller 310b.

[055] The further input nip roller 302a may be in contact with the input nip roller 302b or may be separated from the input nip roller 302b by a first predetermined gap. The output nip roller 310a may be in contact with the further input output roller 310b or may be separated from the further output nip roller 310b by a second predetermined gap. The middle roller 306a may be in contact with the further middle embossing roller 306b or may be separated from the further middle embossing roller 306b by a third predetermined gap. The first predetermined gap or second predetermined gap may be substantial equal to or more than a thickness of the unembossed film. The third predetermined gap may be substantially equal to a minimum thickness of the embossed film.

[056] The embossing apparatus may further include an unwinding unit 314 configured to provide the thermoplastic film 312 to the feed-in mechanism 302. The embossing apparatus may also include a rewinding unit 316 configured to receive the thermoplastic film 312 from the feed-out mechanism 310.

[057] The input nip roller pairs R1-R2 (302a, 302b) and output nip roller pairs R6-R5 (310b, 310a) may divide the embossing apparatus into three different tension zones, indicated by Zone 0, Zone 1 and Zone 2. The input nip roller pairs R1-R2 (302a, 302b) may divide Zone 0 and Zone 1. The output nip roller pairs R6-R5 (310b, 310a) may divide Zone 0 and Zone 2. The tension of the portion of the thermoplastic film 312 within Zone 0 may be lower than the tension of the portion of the thermoplastic film 312 in each of Zone 1 and Zone 2. The tension of the portion of the thermoplastic film 312 in Zone 1 may be substantially equal to the tension of the portion of the thermoplastic film 312 in Zone 2. The tension of the thermoplastic film 312 in Zone 0 may be reduced or minimized. In various embodiments, the tension of the thermoplastic film 312 in Zone 0 may be substantially equal to zero. By synchronizing the feed-in mechanism 302, the feed-out mechanism 310 and the

embossing mechanism 306, the tension of a portion of the thermoplastic film 312 in Zone 0 (between the input nip roller pairs R1-R2 (302a, 302b) and output nip roller pairs R6-R5 (310b, 310a) may be reduced or minimized.

[058] The embossing apparatus may further include a support roller 318. The support roller 318 may be configured to support the thermoplastic film 312 when the thermoplastic film 312 is fed into or received by the feed-in mechanism 302 including input nip roller pairs R1-R2 (302a, 302b). The embossing apparatus may also include a further support roller 320. The further support roller 320 may be configured to support the (embossed) thermoplastic film 312 when the thermoplastic film 312 is outputted from the feed-out mechanism (310a, 310b).

[059] FIG. 4A is a schematic 400a illustrating an embossing apparatus according to various embodiments. The embossing apparatus may include a feed-in mechanism 402 configured to receive a substrate 412. The embossing apparatus may also include a heating mechanism 404 configured to heat the substrate 412. The embossing apparatus may further include an embossing mechanism 406 configured to emboss the substrate 412 after the substrate 412 has been heated by the heating mechanism 404. The embossing apparatus may additionally include a cooling mechanism 408 configured to cool the substrate 412 after the substrate 412 has been embossed by the embossing mechanism 406. The embossing apparatus may also include a feed-out mechanism 410 configured to output the substrate 412.

[060] The embossing apparatus may further include a control mechanism electrically coupled to the feed-in mechanism 402, the feed-out mechanism 410 and the embossing mechanism 406, the control mechanism 412 configured to synchronize the feed-in mechanism 402, the feed-out mechanism 410 and the embossing mechanism 406.

[061] The embossing apparatus may include a thermal embossing unit. FIG. 4B is a schematic 400b illustrating the embossing unit of the apparatus shown in FIG. 4A according to various embodiments. The thermal embossing unit may include the

feed-in mechanism 402, the embossing mechanism 406 and the feed-out mechanism 310. The thermal embossing unit may further include a heating mechanism 404 and a cooling mechanism 408 which are not shown in FIG. 4B.

[062] The feed-in mechanism 402 may include an input nip roller 402b, i.e. R2, and a further input nip roller 402a, i.e. R1. The embossing mechanism 406 may include a first middle roller 406a, i.e. R3, and a second middle roller 406b, i.e. R4. The feed-out mechanism 410 may include an output nip roller 410a, i.e. R5, and a further output nip roller 410b, i.e. R6. In other words, the embossing unit may include at least a pair of input nip rollers (R1 402a, R2 402b) at a feed-in side, a pair of embossing rollers (R3 406a, R4 406b) and a pair of output nip rollers (R5 410a, R6 410b) at a feed-out side.

[063] The embossing apparatus illustrated in FIGS. 4A-B may be similar to the embossing apparatus except that instead of one of the middle rollers 406a, 406b including having a cylindrical surface including a pattern for embossing onto the thermoplastic film 412, the thermoplastic film 412 may be embossed via a flexible belt mold 422. The embossing mechanism may include the flexible belt mold 422. The cylindrical surfaces of middle rollers 406a, 406b may be smooth. The flexible belt mold 422 may be held by the middle roller 406a, the further input nip roller 402a and the further output nip roller 410b. The embossing apparatus may also include a support roller (may be also be referred to as a flexible belt mold support roller) 424. The flexible belt mold 422 may be further held by the support roller 424. The middle roller 406a may include or may be coupled to a motor. The flexible belt mold 422 may be coupled to active middle roller 406a. The flexible belt mold 422 may be driven by the middle embossing roller 406a. The flexible belt mold 422 may be driven around continuously and endlessly. The cooling period of the embossed film 412 may be extended since the starting point of demolding is behind the point between R5 and R6. In contrast, if the middle roller 406a including mold pattern is used instead of flexible belt mold 422, the starting point of demolding starts from the point between

R3 and R5. The flexible belt mold 422 may press the embossed film 412 onto the output nip roller 410a (R5) before demolding due to the controllable and adjustable tension of the belt mold 422. The belt mold may be used not only for embossing, but also (i) to maintain the pressing of the mold pattern into the film 412 and extending the cooling period, thereby providing sufficient cooling before demolding; and (ii) to enhance fidelity by pressing the mold onto the embossed film 412 before demolding.

[064] The feed-in mechanism 402, the feed-out mechanism 410, and the embossing mechanism 406 may be laterally displaced. The middle rollers 406a, 406b may be laterally displaced from the input and output nip rollers 402a, 402b, 410a, 410b. The input nip roller 402b and the output nip roller 410a may be arranged on a first lateral plane. The input nip roller 402b, the output nip roller 410a and the middle roller 406a may be arranged on a second lateral plane. The second embossing roller 406b may be arranged on a third lateral plane. The first lateral plane, the second lateral plane and the third lateral planes may be different lateral planes. The first lateral plane and the third lateral plane may be on opposite sides of the second lateral plane.

[065] FIG. 4C is a schematic 400c illustrating another embossing apparatus according to various embodiments. Alternatively, the flexible belt mold 422 may be held by the first embossing roller 406a, the further output nip roller 410b, and the support roller 424 as shown in FIG. 4C.

[066] FIG. 4D is a schematic 400d illustrating a further embossing apparatus according to various embodiments. The flexible belt mold 422 may be held (solely) by the first embossing roller 406a, the second output nip roller 410b.

[067] In general, the flexible belt mold 422 may be held by the middle roller 406a and/or the further middle roller 406b. The flexible belt mold 422 may further be held by at least one of an input nip roller and output nip roller. For instance, if the flexible belt mold 422 is held by the middle roller 406a, the flexible belt mold 422 may be further held by the further input nip roller 402a and/or the further output nip roller

410b. If the flexible belt mold 422 is held by the further middle roller 406b, the flexible belt mold 422 may be further held by the input nip roller 402b and/or the output nip roller 410a.

[068] FIG. 4E is a schematic 400e illustrating another embossing apparatus according to various embodiments. The embossing apparatus illustrated in FIG. 4E may be similar to the embossing apparatus illustrated in FIGS. 4A-B but may further include a supporting belt 426. The supporting belt 426 may also be referred to as a belt-type supporting carrier. The supporting belt 426 may be coupled to the feed-in mechanism 402, the feed-out mechanism 410 and the embossing mechanism 406. The supporting belt 426 may be configured to cooperate with the embossing mechanism 406 to sandwich the thermoplastic film 412. For instance, the supporting belt 426 may be configured to cooperate with the flexible belt mold 422 to sandwich the thermoplastic film 412. A portion of the thermoplastic film 412, i.e. the portion of the thermoplastic film 412 from the point between R1 and R2 to the point between R5 and R6 may be pressed between a portion of the flexible belt mold 422 and a portion of the supporting belt 426.

[069] The supporting belt 426 may be held by the input nip roller 402b (R2), the output nip roller 410a (R5). The supporting belt 426 may be further held by the first embossing roller 406a. The embossing apparatus or embossing mechanism may further include a flexible belt support roller 428. The middle roller 406a may be configured to exert a force in a first direction on the supporting belt 426 and the input nip roller 402b and the output nip roller 410a may be configured to exert a force in a second direction opposite the first direction on the supporting belt 426. The supporting belt 426 may be moved continuously and endlessly. The supporting belt 426 may be configured to carry the thermoplastic film 412 during embossing. The supporting belt 426 may protect the thermoplastic film 412 from suffering tension and elongation. The belt mold 422 and the supporting belt 426 may sandwich the polymer film 412 during and after embossing, extending the holding time of

pressing-mold-onto-film and providing sufficient cooling.

[070] FIG. 4F is a schematic 400f illustrating another embossing apparatus according to various embodiments. The embossing apparatus illustrated in FIG. 4F may be similar to the embossing apparatus illustrated in FIG. 4E but may be without the air cooling nozzles 408. The input nip roller 402b may include a heater. The heater may provide resistive heating with a closed loop control. Heating may be supplemented by forced hot air heating. The output nip roller 410a may include a cooling mechanism. Cooling may also be done using internally heated rollers by with a lower temperature. Cooling may be supplemented by forced ambient temperature air cooling.

[071] Controlled heating may be due to the substrate (e.g. plastic film) gradually absorbing heat from rollers 402b, 406a through the metal belt 426. The embossing of the substrate is controlled as the plastic is pressed onto the roller and sustain a peak force when the plastic passes through 406a, 406b. Controlled cooling may occur at 410a and beyond.

[072] The function of the metal belt 426 may include (1) to resist the applied tension force and shield the plastic from the tension force, which deforms the plastic; (2) assist or cooperate with the flexible belt mold 422 to emboss the substrate; (3) and/or provides wrapping to create a process length of sustained continuous pressure to form the features. A smooth continuous pressure may be generated as the plastic is wrapped around rollers in the layout. Continuous pressure may be preferred to form fine features.

[073] FIG. 5A is a schematic 500a illustrating an embossing apparatus according to various embodiments. FIG. 5B is a photo 500b of the embossing apparatus illustrated in FIG. 5A according to various embodiments. The embossing apparatus may include input nip rollers 502a, 502b, middle rollers 506a, 506b as well as the output nip rollers. The rollers 502a, 502b, 506a, 506b, 508a, 508b may be each mounted by a pin or axle to housing 530. The feed-in mechanism, the embossing

mechanism and the feed-out mechanism may be electrically coupled to a control mechanism 532.

[074] The control mechanism 532 may be or may include a control circuit. The control circuit may be embedded within or mounted on or attached to the housing 530.

[075] A "circuit" may be understood as any kind of a logic implementing entity, which may be special purpose circuitry or a processor executing software stored in a memory, firmware, or any combination thereof. Thus, in various embodiments, a "circuit" may be a hard-wired logic circuit or a programmable logic circuit such as a programmable processor, e.g. a microprocessor (e.g. a Complex Instruction Set Computer (CISC) processor or a Reduced Instruction Set Computer (RISC) processor). A "circuit" may also be a processor executing software, e.g. any kind of computer program, e.g. a computer program using a virtual machine code such as e.g. Java. Any other kind of implementation of the respective functions may also be understood as a "circuit" in accordance with various alternative embodiments.

[076] The control mechanism 532 may further include electrical connections or wirings from the circuit to the feed-in mechanism, the embossing mechanism and the feed-out mechanism.

[077] One of the feed-in nip rollers 502a, 502b may be attached or coupled to a feed-in roller motor. The feed-in roller motor may be configured to drive the one of the feed-in nip rollers 502a, 502b. Alternatively, both of the feed-in nip rollers 502a, 502b may be attached or coupled to separate feed-in roller motors. Each feed-in nip motor may be configured to drive a respective feed-in nip roller 502a, 502b. The feed-in mechanism may include the feed-in roller motor(s). The control mechanism 532 may be electrically coupled to the feed-in roller motor(s), e.g. via the electrical connections.

[078] One of the feed-out nip rollers 510a, 510b may be attached or coupled to a feed-out roller motor. The feed-out roller motor may be configured to drive the one of

the feed-out nip rollers 510a, 510b. Alternatively, both of the feed-out nip rollers 510a, 510b may be attached or coupled to separate feed-out roller motors. Each feed-out nip motor may be configured to drive a respective feed-out nip roller 510a, 510b. The feed-out mechanism may include the feed-out roller motor(s). The control mechanism 532 may be electrically coupled to the feed-out roller motor(s), e.g. via the electrical connections.

[079] One of the intermediate rollers 506a, 506b may be attached or coupled to an embossing roller motor. The embossing roller motor may be configured to drive the one of the embossing rollers 506a, 506b. Alternatively, both of the intermediate rollers 506a, 506b may be attached or coupled to separate embossing roller motors. Each embossing roller motor may be configured to drive a respective intermediate rollers 506a, 506b. The embossing mechanism may include the embossing roller motor(s). The control mechanism 532 may be electrically coupled to the embossing roller motor(s), e.g. via the electrical connections.

[080] The control mechanism 532 may be electrically coupled to one or both of the intermediate rollers 506a, 506b. The control mechanism 532 may be electrically coupled to one or both of the feed-out nip rollers 510a, 510b.

[081] FIG. 5C is a three dimension plot 500c in the x, y and z directions of an embossed film formed by the embossing apparatus according to various embodiments. The x and y directions are in millimeters (mm) and the z direction is plotted in micrometers (um). FIG. 5C shows a plurality of microstructures embossed on the film. The film may be a polypropylene film. The thickness of the film is about 0.18mm. The embossing is done at a temperature of about 140 ° C. The film feeding speed may be about 3 mm/s.

[082] FIG. 6 is a schematic 600 illustrating a method of forming an embossing apparatus. The method may include, in 602, providing an input nip roller having an input nip roller axis. The method may also include, in 604, providing a heating mechanism. The method may further include, in 606, providing a middle roller having

a middle roller axis substantially parallel to the input nip roller axis, the middle roller having at least substantially the same diameter as the input nip roller. The method may include, in 608, providing a cooling mechanism. The method may include, in 610, providing an output nip roller having an output nip roller axis substantially parallel to the input nip roller axis, the output nip roller having at least substantially the same diameter as the input nip roller. The embossing apparatus may be configured to receive a substrate so that the substrate is pressed between the input nip roller and the middle roller and further pressed between the output nip roller and the middle roller; and wherein the input nip roller axis, the middle roller axis, and the output nip roller axis are in a common plane.

[083] In other words, the method may include providing an input nip roller having an input nip roller axis, providing a middle roller having a middle roller axis substantially parallel to the input nip roller axis, and providing an output nip roller having an output nip roller axis substantially parallel to the input nip roller axis. The input nip roller, the middle roller and the output nip roller may have substantially the same diameter. The method may further include providing a heating mechanism and a cooling mechanism. The substrate may pass between the input nip roller and the middle roller, and between the middle roller and the output nip roller.

[084] A method of embossing the substrate may be provided. A method of using or operating the embossing apparatus may be provided. The method may include receiving the substrate using a feed-in mechanism. The method may also include heating the substrate. The method may additionally include embossing the substrate after the substrate has been heated using an embossing mechanism. The method may also include cooling the substrate after the substrate has been embossed. The method may further include outputting the substrate using a feed-out mechanism.

[085] The feed-in mechanism, the feed-out mechanism and the embossing mechanism may be synchronized by a control mechanism electrically coupled to the feed-in mechanism, the feed-out mechanism and the embossing mechanism.

[086] Heating the substrate may at least partially soften or melt the substrate. The partially softened or melted substrate may flow into the mold provided in or within the embossing mechanism. Heating may be carried out via a heating mechanism as described herein.

[087] Cooling the substrate may harden the substrate. Cooling the substrate when the partially softened or partially melted substrate is in contact with the mold may harden the substrate to preserve the pattern imparted by the mold on the substrate. The cooled substrate may more easily be demolded. Demolding may involve separating the embossed substrate (e.g. embossed thermoplastic film) from the mold (e.g. a flexible belt mold or the patterned surface of an embossing roller).

[088] Various embodiments may relate to a roll-to-roll thermal embossing apparatus, which includes (i) preheating mechanism, (ii) tension control for dividing the apparatus into different tension zones, (iii) cooling mechanism for effective demolding, (iv) belt-type mold for continuous embossing and sufficient cooling before demolding, supporting belt to minimize tension applied on polymer film and avoid elongation of polymer film during embossing, and/or (vi) combination of belt mold and supporting belt for low tension control and sufficiently cooling before demolding.

[089] Various embodiments may relate to a processing method for thermal embossing of microstructures on thermoplastic polymer films and/or sheets.

[090] Various embodiments may relate to a processing method for effectively embossing high aspect structures using effective preheating & sufficient cooling after embossing.

[091] Various embodiments may relate to a processing method for optimized tension control to minimize the elongation of embossed polymer films.

[092] Various embodiments may include a process method for roll-to-roll thermal embossing and apparatus performing the process. In the process, the web tension in the embossing zone may be minimized, or the tension may be set close to zero tension

by means of tension control or by means of a supporting carrier. Furthermore, the embossed film may be sufficiently cooled before demolding by means of cooling device or nip roller, or by means of combination of a belt mold and support belt which extend the cooling period.

[093] Various embodiments may include a nip roller used as preheating roller for heating up the polymer to be embossed, which may be synchronized with embossing roller.

[094] Various embodiments may include another nip roller is used as a cooling roller for cooling the embossed polymer film. The nip roller may be used for demolding as well, and synchronized with embossing roller.

[095] Various embodiments may be further include a properly arranged cooling device (air cooling, etc.) which may improve effective demolding of embossed film.

[096] Various embodiments may include two nip rollers in feeding-in side and feeding-out side to divide the embossing system (for polymer films) into three tension zones. By synchronizing the nip rollers with embossing rollers, the polymer film around the embossing roller may be kept at low tension or close-to-zero tension.

[097] Various embodiments may include tension control mechanism which reduces the web tension by a group of contacting rollers, or by a supporting belt to avoid elongation of polymer film.

[098] Various embodiments may relate to a design of belt mold and supporting belt guarantees minimized tension during embossing and sufficiently cooling before demolding.

[099] Methods described herein may further contain analogous features of any apparatus or device described herein. Correspondingly, apparatuses or devices described herein may further contain analogous features of any method described herein.

[0100] While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art

that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

CLAIMS

1. An embossing apparatus comprising:
 - a feed-in mechanism comprising an input nip roller having an input nip roller axis;
 - a heating mechanism;
 - an embossing mechanism comprising a middle roller having a middle roller axis substantially parallel to the input nip roller axis, the middle roller having a diameter substantially equal to a diameter of the input nip roller;
 - a cooling mechanism; and
 - a feed-out mechanism comprising an output nip roller having an output nip roller axis substantially parallel to the input nip roller axis, the output nip roller having a diameter substantially equal to the diameter of the input nip roller;

wherein the embossing apparatus is configured to receive a substrate so that the substrate is pressed between the input nip roller and the middle roller and further pressed between the output nip roller and the middle roller;

wherein the input nip roller axis, the middle roller axis, and the output nip roller axis are in a common plane;

wherein the feed-in mechanism further comprises a further input nip roller, the feed-in mechanism configured to receive the substrate between the input nip roller and the further input nip roller;

wherein the feed-out mechanism further comprises a further output nip roller, the feed-out mechanism configured to output the substrate between the output nip roller and the further output nip roller;

wherein the embossing mechanism further comprises a further middle roller so that the substrate passes through between the middle roller and the further middle roller;

wherein the embossing mechanism further comprises a flexible belt mold held by the further input nip roller and the further output nip roller, the flexible belt mold passing between the middle roller and the further middle roller, the flexible belt mold having a pattern for embossing the substrate; and

wherein the embossing apparatus further comprises a supporting belt held by the input nip roller and the output nip roller, the supporting belt passing between the middle roller and the further middle roller such that the supporting belt cooperates with the flexible belt mold to sandwich the substrate, the sandwiched substrate pressed between the input nip roller and the further input nip roller, between the middle roller and the further middle roller, and between the output nip roller and the further output nip roller, thereby embossing the substrate.

2. The embossing apparatus according to claim 1,
wherein the embossing mechanism comprises an embossing roller motor configured to drive at least one of the middle roller and the further middle roller.
3. The embossing apparatus according to claim 2,
wherein the feed-in mechanism comprises a feed-in roller motor configured to drive at least one of the input nip roller and the further input nip roller.
4. The embossing apparatus according to claim 3,
wherein the feed-out mechanism comprises a feed-out roller motor configured to drive at least one of the output nip roller and the further output nip roller.

5. The embossing apparatus according to claim 4,
a control mechanism electrically coupled to the embossing roller motor, the feed-in roller motor and the feed-out roller motor.
6. The embossing apparatus according to claim 5,
wherein the control mechanism is configured to control a first speed of rotation of at least one of the first middle roller and the further middle roller, a second speed of rotation of at least one of the input nip roller and the further input nip roller, and a third speed of rotation of at least one of the output nip roller and the further output nip roller.
7. The embossing apparatus according to claim 6,
wherein the first speed of rotation, the second speed of rotation and the third speed of rotation are substantially equal.
8. The embossing apparatus according to claim 1,
wherein the input nip roller comprises the heating mechanism and the output nip roller comprises the cooling mechanism.
9. The embossing apparatus according to claim 1,
wherein a distance between the input nip roller axis and the middle roller axis is at least substantially equal to the diameter of the input nip roller; and
wherein a distance between the middle roller and the output nip roller axis is at least substantially equal to the diameter of the input nip roller.
10. A method of fabricating an embossing apparatus, the method comprising:
providing a feed-in mechanism comprising an input nip roller having an input nip roller axis;

providing a heating mechanism;

providing an embossing mechanism comprising a middle roller having a middle roller axis substantially parallel to the input nip roller axis, the middle roller having a diameter substantially equal to a diameter of the input nip roller;

providing a cooling mechanism; and

providing a feed-out mechanism comprising an output nip roller having an output nip roller axis substantially parallel to the input nip roller axis, the output nip roller having a diameter substantially equal to the diameter of the input nip roller;

wherein the embossing apparatus is configured to receive a substrate so that the substrate is pressed between the input nip roller and the middle roller and further pressed between the output nip roller and the middle roller;

wherein the input nip roller axis, the middle roller axis, and the output nip roller axis are in a common plane;

wherein the feed-in mechanism further comprises a further input nip roller, the feed-in mechanism configured to receive the substrate between the input nip roller and the further input nip roller;

wherein the feed-out mechanism further comprises a further output nip roller, the feed-out mechanism configured to output the substrate between the output nip roller and the further output nip roller;

wherein the embossing mechanism further comprises a further middle roller so that the substrate passes through between the middle roller and the further middle roller;

wherein the embossing mechanism further comprises a flexible belt mold held by the further input nip roller and the further output nip roller, the flexible belt mold passing between the middle roller and the further middle

roller, the flexible belt mold having a pattern for embossing the substrate;
and

wherein the embossing apparatus further comprises a supporting belt held by the input nip roller and the output nip roller, the supporting belt passing between the middle roller and the further middle roller such that the supporting belt cooperates with the flexible belt mold to sandwich the substrate, the sandwiched substrate pressed between the input nip roller and the further input nip roller, between the middle roller and the further middle roller, and between the output nip roller and the further output nip roller, thereby embossing the substrate.