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**Moore et al.**

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(54) **PRINTING DEVICE AND METHOD OF USING THE SAME**

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(52) **U.S. Cl.**
CPC .................................. *B41J 11/002* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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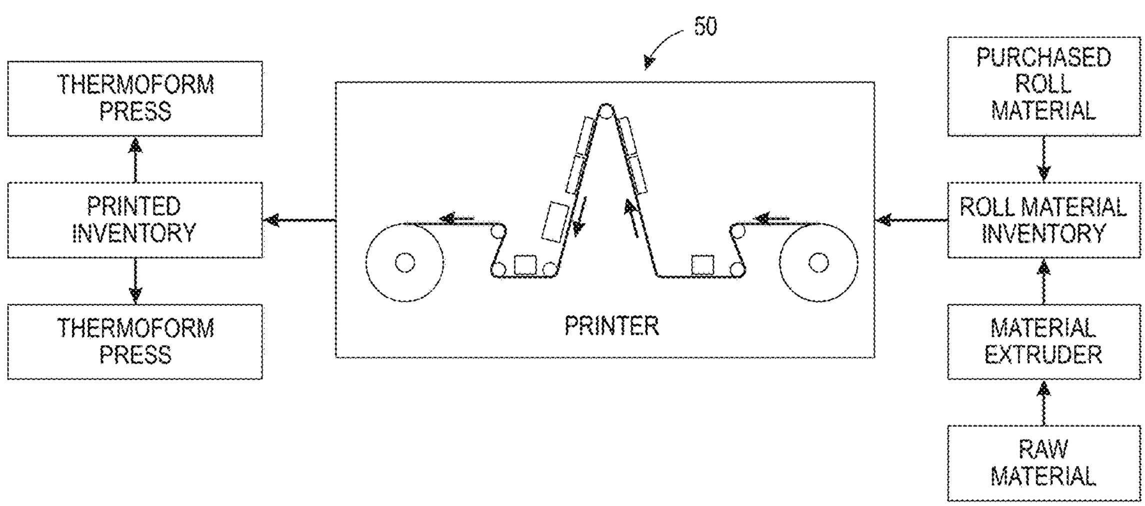
(57) **ABSTRACT**

A system for printing at least one stretchable ink on a thermoformable substrate including an unwinder arranged to feed the thermoformable substrate from a first roll into a web drive subsystem, a surface energy modification device arranged to alter a substrate surface energy to enhance wetting and adhesion of the at least one stretchable ink to the thermoformable substrate, at least one full width printhead array arranged to deposit the at least one stretchable ink on the thermoformable substrate, at least one radiation curing device arranged to cure the at least one stretchable ink on the thermoformable substrate, a full width array sensor arranged to monitor the at least one stretchable ink on the thermoformable substrate, and a rewinder arranged to receive the thermoformable substrate and to form the thermoformable substrate into a second roll.

**11 Claims, 5 Drawing Sheets**



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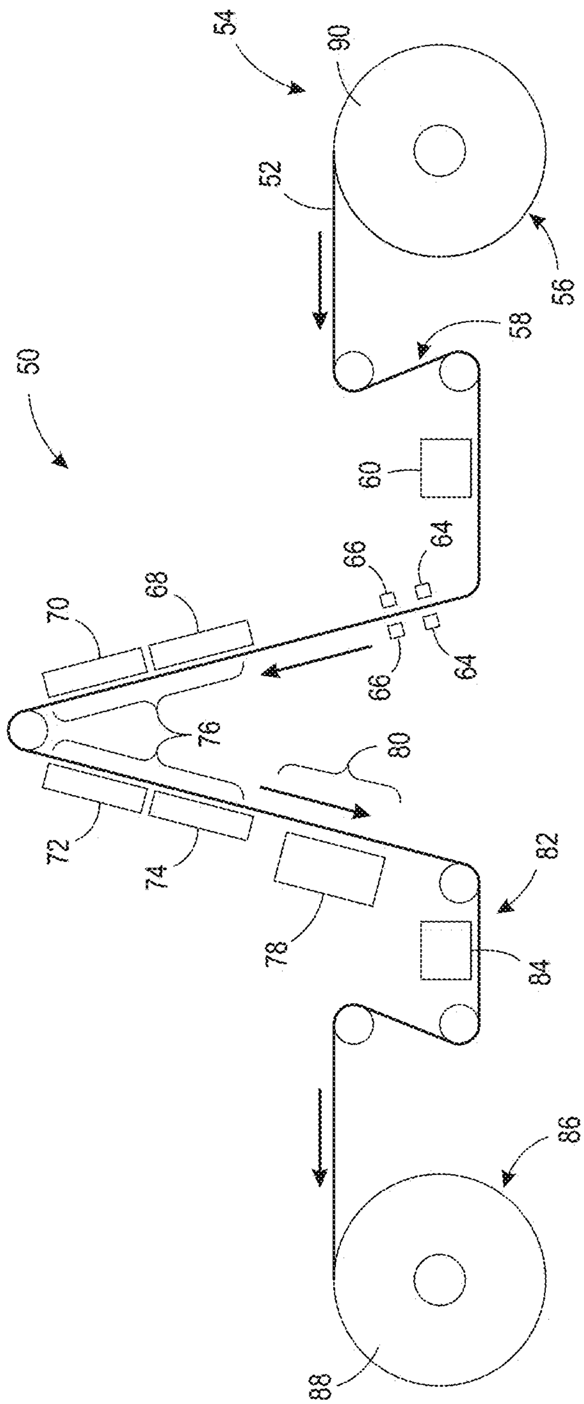


FIG. 1

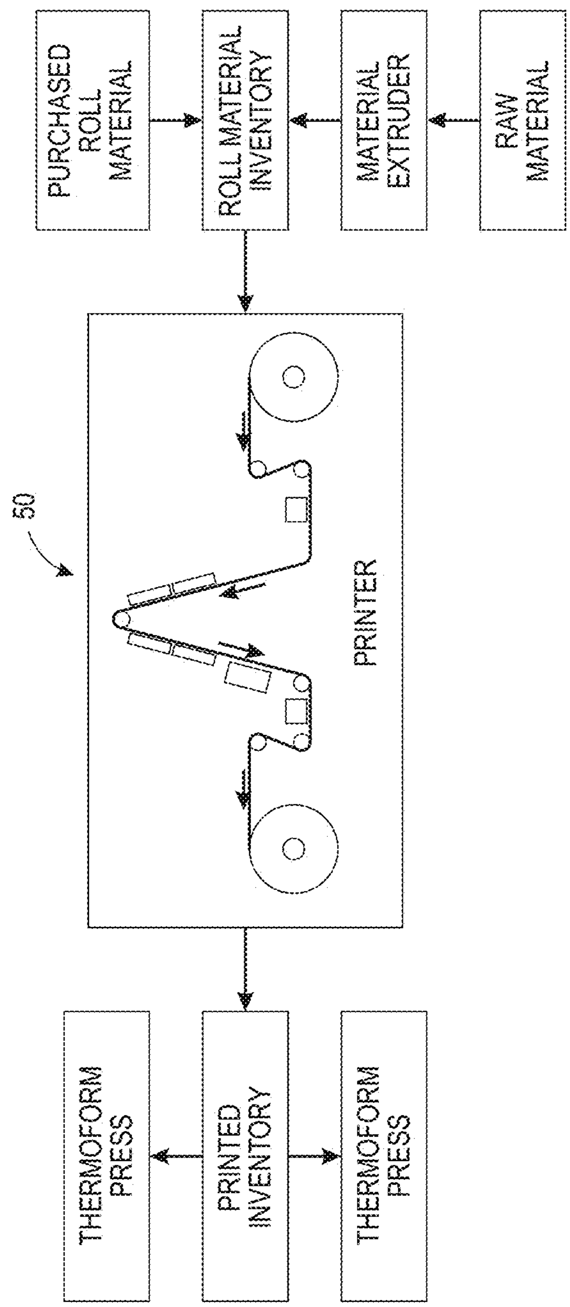
PURCHASED ROLL MATERIAL
ROLL MATERIAL INVENTORY
MATERIAL EXTRUDER
RAW MATERIAL
50
PRINTER
THERMOFORM PRESS
PRINTED INVENTORY
THERMOFORM PRESS

FIG. 2

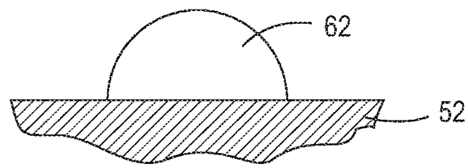


FIG. 3

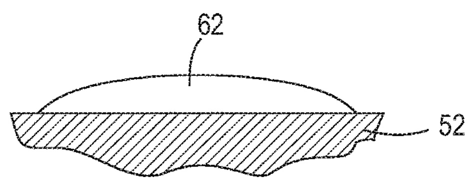


FIG. 4

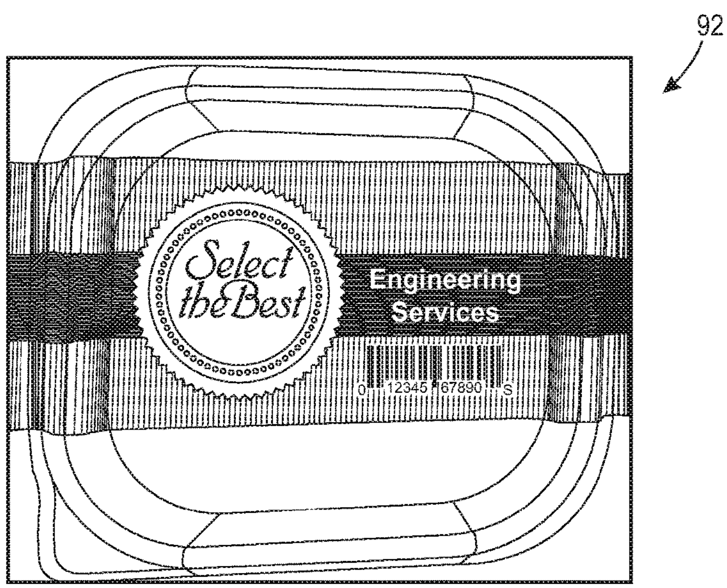


FIG. 5

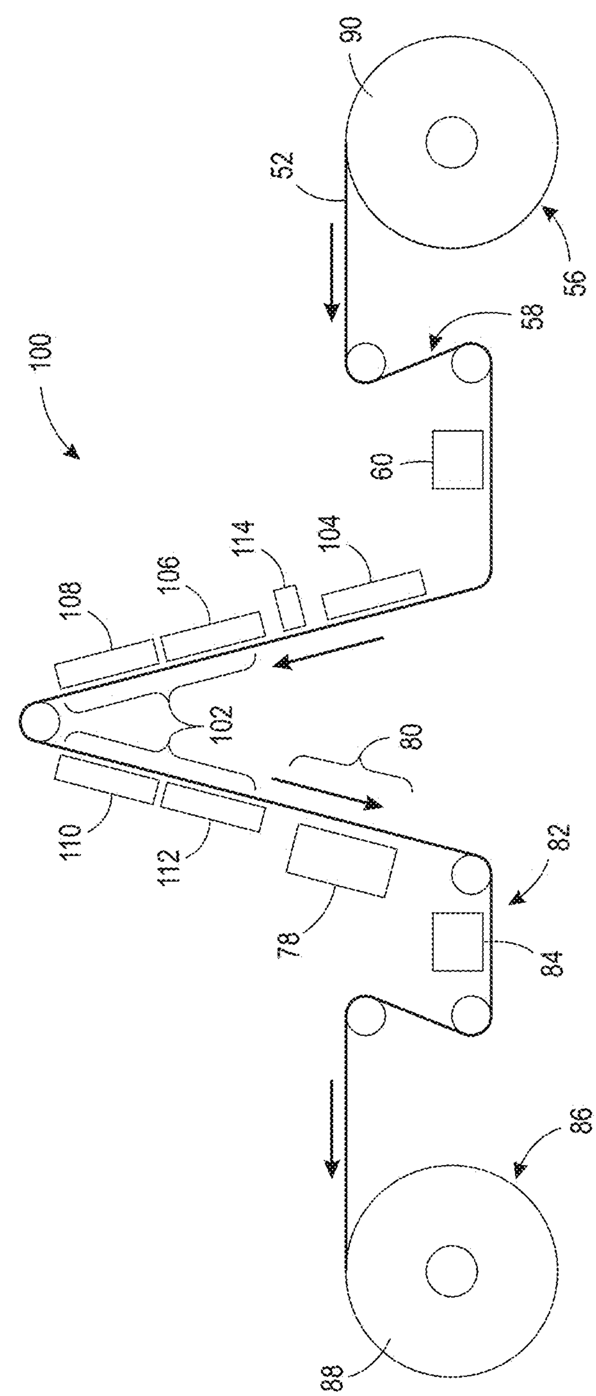


FIG. 6

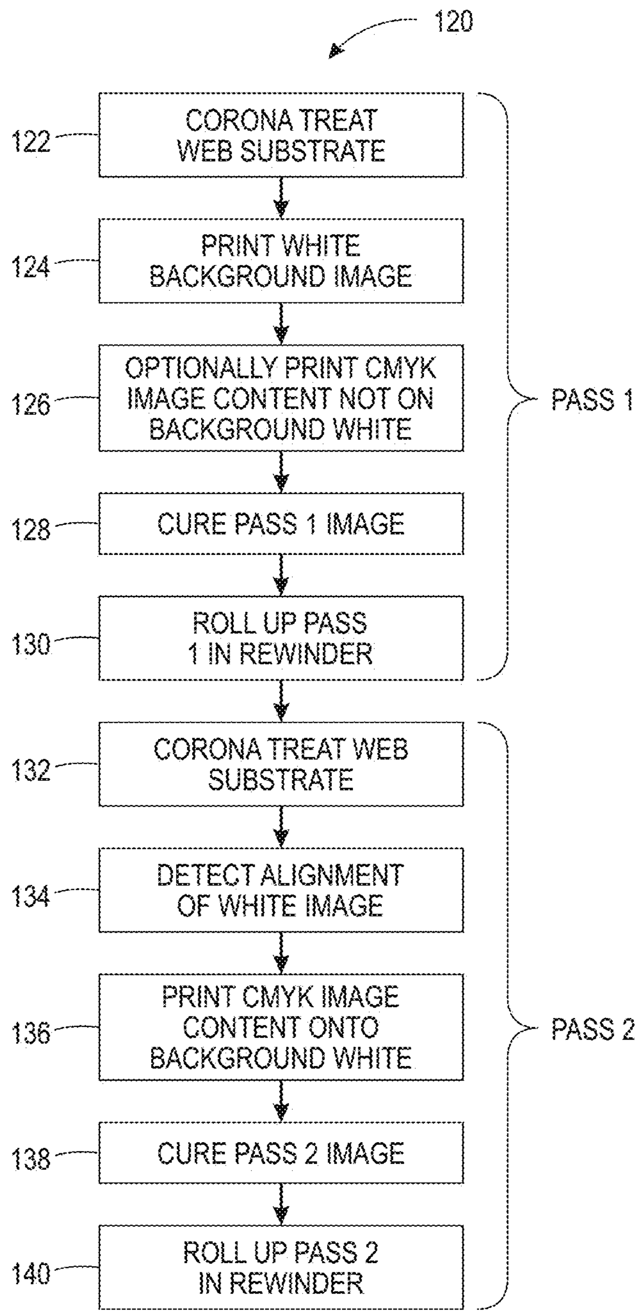
120
122
CORONA TREAT WEB SUBSTRATE
124
PRINT WHITE BACKGROUND IMAGE
126
OPTIONALLY PRINT CMYK IMAGE CONTENT NOT ON BACKGROUND WHITE
128
CURE PASS 1 IMAGE
130
ROLL UP PASS 1 IN REWINDER
PASS 1
132
CORONA TREAT WEB SUBSTRATE
134
DETECT ALIGNMENT OF WHITE IMAGE
136
PRINT CMYK IMAGE CONTENT ONTO BACKGROUND WHITE
138
CURE PASS 2 IMAGE
140
ROLL UP PASS 2 IN REWINDER
PASS 2

FIG. 7

# PRINTING DEVICE AND METHOD OF USING THE SAME

## TECHNICAL FIELD

The presently disclosed embodiments are directed to providing a printing system for use with depositing or printing stretchable and/or radiation curable inks on thermoformable substrates and methods of using the same.

## BACKGROUND

Print processes compatible with thermoforming processes are known in the art. Conventional digital printers operate by scanning an array of printheads repeatedly across the media web while indexing the travel of the web, i.e., similar to the raster like functioning of traditional ink jet printers. This conventional print process is extremely time consuming in a manufacturing environment in which printed rolls must be delivered to one or more thermoforming presses. Often, the time required to print greatly exceeds the time necessary for thermoforming.

The following are two examples of printing systems used with thermoformable materials. Electronics For Imaging's VUTEk GS Pro-TF Series digital inkjet printer can allegedly produce custom formed signs, packaging, POP displays, vending panels and other thermoforming applications. Similarly, FUJIFILM's Acuity Advance Select is a flatbed inkjet printer used to produce printed thermoforms. Unfortunately, both systems suffer from the drawback of utilizing a scanning printhead which severely limits system throughput, e.g., FUJIFILM's system advertises throughput up to only 32 $m^2$/hr.

Further complicating the process of printing on thermoformable material is the optical characteristics of that material. Many thermoformable materials are transparent, which is a desirable characteristic when being used to hold product that consumers wish to see prior to purchase, e.g., strawberries in a clear plastic container. Clear materials pose a challenge for printing conventional CMYK images (cyan, magenta, yellow and key (black)) since incident light will transmit through the ink. To improve visibility, it is common to print a CMYK image onto a white background having high reflectance. In order to maximize the usefulness of a printing system and minimize costs, preferably the white background is created using the same printing process used for CMYK printing. However, if white is printed on the substrate immediately before the CMYK color separations, the color inks may bleed into and mix with the white, causing unacceptable print quality.

The present disclosure addresses a system and method for high throughput printing on thermoformable substrates without unacceptable color bleed or mixing.

## SUMMARY

Broadly, the present printing system is intended for use with curable inks, e.g., radiation curable inks. In some embodiments, the printing system is intended for digitally preprinting labels onto thermoformable grade plastic which is subsequently thermoformed into a useful object such as a container. It has been found that when printing with a UV curable CMYKW ink set that it is necessary to treat the white ink differently than the CMYK inks.

From a productivity perspective, i.e., throughput, it is desired to provide a system in which the three primary components are independent of each other: a) extrusion of raw material into web form; b) printing on to the web; and, c) formation of the web into the end articles, such as containers. Such a system can provide greater flexibility and can deliver higher uptime than a system in which these components are integrated in an in-line manner. The foregoing system requires a printing architecture that can accept a roll of thermoforming grade plastic, print digitally on the plastic with suitable inks, and then deliver the printed roll for later conversion to thermoforms.



Broadly, an embodiment of a printing system arranged to provide a printed thermoformable web includes: a) a web unwinder; b) a treatment station to modify the substrate surface energy; c) a conventional web drive and tracking subsystem; d) one or more full-width arrays of printheads; e) an ink delivery subsystem; f) a radiation-curable ink set capable of stretching by at least 400% during thermoforming; g) one or more radiation curing devices; h) an in-line sensor to monitor print quality on the web; and, i) a web rewinder.

In view of the foregoing, an embodiment of the present system for printing at least one stretchable ink on a thermoformable substrate includes an unwinder arranged to feed the thermoformable substrate from a first roll into a web drive subsystem, a surface energy modification device arranged to alter a substrate surface energy to enhance wetting and adhesion of the at least one stretchable ink to the thermoformable substrate, at least one full width printhead array arranged to deposit the at least one stretchable ink on the thermoformable substrate, at least one radiation curing device arranged to cure the at least one stretchable ink on the thermoformable substrate, a full width array sensor arranged to monitor the at least one stretchable ink on the thermoformable substrate, and a rewinder arranged to receive the thermoformable substrate and to form the thermoformable substrate into a second roll.

Broadly, an embodiment of the above described printing system performs the following steps: a) treating a substrate with a first corona; b) printing a white background layer; c) fully curing the white background layer; d) treating the cured white background layer with a second corona; e) printing a CMYK image onto the cured white background layer; and, f) fully curing the CMYK image. In short, the foregoing method is a two pass printing method that can achieve the described printing process for UV curable inks. In the first pass, a white layer is printed and cured, while in the second pass, the white layer is corona treated and the CMYK inks are printed and cured.

Broadly, in view of the foregoing, another embodiment of the present method for applying an image on a thermoformable substrate includes: a) modifying a first surface energy of the thermoformable substrate with a surface energy modification device; b) depositing a background layer on a portion of the substrate with at least one full width printhead array, the background layer comprising at least one stretchable ink; c) curing the background layer to form a first printed substrate with at least one radiation curing device; d) modifying a second surface energy of the first printed substrate with the surface energy modification device; e) depositing a foreground layer on the background layer with at least one full width printhead array, the foreground layer comprising at least one stretchable ink; and, f) curing the foreground layer to form a second printed substrate with at least one radiation curing device.

Other objects, features and advantages of one or more embodiments will be readily appreciable from the following detailed description and from the accompanying drawings and claims.

## BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments are disclosed, by way of example only, with reference to the accompanying drawings in which corresponding reference symbols indicate corresponding parts, in which:

FIG. **1** is a schematic diagram of an embodiment of a present system for printing stretchable ink on a thermoformable substrate;

FIG. **2** is a schematic process flow diagram including an embodiment of a present system for printing stretchable ink on a thermoformable substrate;

FIG. **3** is a cross sectional view depicting the interaction of a stretchable ink with a thermoformable substrate having a low surface energy;

FIG. **4** is a cross sectional view depicting the interaction of a stretchable ink with a thermoformable substrate having a surface energy higher than the surface energy depicted in FIG. **3**;

FIG. **5** is a top plan view of an example thermoformed article manufactured using printed material from a present system for printing stretchable ink on a thermoformable substrate;

FIG. **6** a schematic diagram of another embodiment of a present system for printing stretchable ink on a thermoformable substrate including a radiation pinning device after the first printhead array; and,

FIG. **7** a flow diagram of an embodiment of a present method for applying an image on a thermoformable substrate.

## DETAILED DESCRIPTION

At the outset, it should be appreciated that like drawing numbers on different drawing views identify identical, or functionally similar, structural elements of the embodiments set forth herein. Furthermore, it is understood that these embodiments are not limited to the particular methodologies, materials and modifications described and as such may, of course, vary. It is also understood that the terminology used herein is for the purpose of describing particular aspects only, and is not intended to limit the scope of the disclosed embodiments, which are limited only by the appended claims.

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood to one of ordinary skill in the art to which these embodiments belong. As used herein, “full width”, e.g., “full width array sensor” and “full width printhead array”, is intended to be broadly construed as any structure that covers a significant width of the substrate. For example, in some embodiments, the length of a full width array sensor is approximately half of the width of the substrate which it inspects.

Furthermore, the words “printer,” “printer system”, “printing system”, “printer device” and “printing device” as used herein encompass any apparatus, such as a digital copier, bookmaking machine, facsimile machine, multi-function machine, etc. which performs a print outputting function for any purpose. Additionally, as used herein, “web”, “substrate”, “printable substrate” refer to, for example, paper, transparencies, parchment, film, fabric, plastic, photo-finishing papers or other coated or non-coated substrate media in the form of a web upon which information or markings can be visualized and/or reproduced, while a “thermoformable substrate” is intended to mean any substrate capable of being thermoformed after printing, i.e., capable of being shaped by the use of heat and pressure. As used herein, the term ‘average’ shall be construed broadly to include any calculation in which a result datum or decision is obtained based on a plurality of input data, which can include but is not limited to, weighted averages, yes or no decisions based on rolling inputs, etc.

Moreover, as used herein, the phrases “comprises at least one of” and “comprising at least one of” in combination with a system or element is intended to mean that the system or element includes one or more of the elements listed after the phrase. For example, a device comprising at least one of: a first element; a second element; and, a third element, is intended to be construed as any one of the following structural arrangements: a device comprising a first element; a device comprising a second element; a device comprising a third element; a device comprising a first element and a second element; a device comprising a first element and a third element; a device comprising a first element, a second element and a third element; or, a device comprising a second element and a third element. A similar interpretation is intended when the phrase “used in at least one of:” is used herein. Furthermore, as used herein, “and/or” is intended to mean a grammatical conjunction used to indicate that one or more of the elements or conditions recited may be included or occur. For example, a device comprising a first element, a second element and/or a third element, is intended to be construed as any one of the following structural arrangements: a device comprising a first element; a device comprising a second element; a device comprising a third element; a device comprising a first element and a second element; a device comprising a first element and a third element; a device comprising a first element, a second element and a third element; or, a device comprising a second element and a third element.

Moreover, although any methods, devices or materials similar or equivalent to those described herein can be used in the practice or testing of these embodiments, some embodiments of methods, devices, and materials are now described.

FIG. **1** depicts a schematic view of an embodiment of a present printing system, i.e., printing system **50**. Thermoforming grade substrate **52**, e.g., polyethylene terephthalate (PET) or polyvinyl chloride (PVC), is unwound at first end **54** of system **50** in unwinder **56**. Web **52** then passes through a conventional web drive and steering subsystem, i.e., subsystem **58**. Web **52** is exposed to surface energy modification device **60**, e.g., corona discharge, atmospheric plasma, or flame treatment. Surface energy modification device **60** enhances both the wetting and adhesion of ink **62** to web **52**. An example of a suitable surface energy modification device is a corona treatment device from Enercon of Milwaukee, Wis. with a typical output power of

$$0-100\frac{W\cdot\text{min}}{m^2}.$$

In some embodiments, printing system **50** may also include web cleaning stations **64** and static neutralization devices **66** to remove excess particles and static charge from the substrate. In some embodiments, stations **64** and devices **66** are located on both sides of web **52** between surface energy modification device **60** and printhead array **68**. Web **52** then passes by one or more printhead arrays, e.g., printhead arrays **68**, **70**, **72** and **74**. In some embodiments, each printhead array is composed of multiple piezo printheads arranged so that the full width of web **52**, other than inboard and outboard margins, can be addressed by at least one printhead without the need to move or scan the printhead. The foregoing arrangement of printheads allows for a 'single pass' print mode in which web **52** moves continuously through print zone **76**, i.e., the area where web **52** passes adjacent to printhead arrays **68**, **70**, **72** and **74**. It has been found that the foregoing embodiments can print over a speed range of 30-120 feet per minute. The full width printhead arrays of system **50** are stationary, i.e., not scanning transversely across web **52**, which enables much higher printing throughput than conventional printers.

FIG. **1** shows one printhead array for each of the four conventional colors, i.e., cyan, magenta, yellow and black, also commonly referred to as CMYK. The four printhead arrays are represented by arrays **68**, **70**, **72** and **74** for the CMYK colors, respectively. An additional array or a plurality of additional arrays can be included for a fifth color, e.g., white, or for a plurality of additional colors. The printhead arrays are responsible for adding digitally defined image content to substrate **52**, such as package graphics, instructions, and the like. The printhead arrays may also print non-image marks such as registration marks for subsequent thermoform processing, cutting operations, or other post printing processes that require alignment to the printed image.

It should be appreciated that corresponding ink delivery subsystems for each printhead array are not shown in the figures or discussed in detail herein as such subsystems are generally known in the art of liquid and solid ink printing. Each ink delivery subsystem supplies its corresponding printhead array with a radiation-curable thermoforming ink. It has been found that suitable inks should be formulated to allow for stretching of at least 400% elongation without cracking or losing adhesion to the substrate. However, the extent of necessary stretching is dependent on the thermoforming process and inks providing less than 400% elongation without cracking or loss of adhesion to the substrate may also be suitable for some applications.

After all ink has been deposited onto the substrate, the web then passes through a radiation curing zone, where such radiation source is selected based on the requirements for fully curing the ink. In some embodiments, multiple wide spectrum UV lamps provide curing of the inks, although other devices such as UV spectrum LED arrays may also be used, i.e., the necessary radiation output is dependent on the curing requirements of the ink. Thus, radiation curing device **78** may be selected from the group consisting of: an ultraviolet radiation source; an infrared radiation source; a visible light radiation source; and, combinations thereof, depending on the requirements of the stretchable ink. After web **52** passes through curing zone **80** it passes through sensing subsystem **82** which can be used to detect color-to-color registration, missing jets, and other print quality metrics. In some embodiments, sensing subsystem **82** comprises full width array sensor **84**. Web **52** then passes into rewinder **86** where printed web **52** is returned to a roll form, e.g., roll **88**. Printed roll **88** can be used in a thermoforming press and thereby converted into thermoformed objects, e.g., food packaging containers.

In some embodiments, web substrate **52** is 0.014 inch thick thermoforming grade PET, although other thermoformable plastics may also be used. In some embodiments, print resolution of 600 dots per inch (dpi)×600 dpi is acceptable, although other print modes may be used, e.g., 300 dpi×300 dpi.

In view of the foregoing, it should be appreciated that system **50** is capable of printing at least one stretchable ink on a thermoformable substrate, e.g., substrate **52**. In some embodiments, system **50** comprises unwinder **56**, surface energy modification device **60**, at least one full width printhead array, e.g., printhead arrays **68**, **70**, **72** and **74**, at least one radiation curing device, e.g., curing device **78**, full width array sensor **84** and rewinder **86**. Unwinder **56** is arranged to feed thermoformable substrate **52** from first roll **90** into web drive subsystem **58**. Surface energy modification device **60** is arranged to alter a substrate surface energy to enhance wetting and adhesion of the at least one stretchable ink to thermoformable substrate **52**. The full width printhead arrays are arranged to deposit the at least one stretchable ink on thermoformable substrate **52**. Radiation curing device **78** is arranged to cure the at least one stretchable ink on thermoformable substrate **52**. Full width array sensor **84** is arranged to monitor the at least one stretchable ink on thermoformable substrate **52**, and rewinder **86** is arranged to receive thermoformable substrate **52** and to form thermoformable substrate **52** into second roll **88**.

In some embodiments, each of the at least one stretchable ink is an ultraviolet radiation curable ink; however, other types of inks may also be used. Moreover, in some embodiments, thermoformable substrate **52** is selected from the group consisting of: polyethylene terephthalate; polyethylene terephthalate glycol-modified; polycarbonate; acrylic; polyvinyl chloride; acrylonitrile butadiene styrene; polypropylene; and, combinations thereof.

As described above, surface energy modification may be provided by a variety of devices. In some embodiments, surface energy modification device **60** is selected from the group consisting of: a corona treatment station; an atmospheric plasma treatment station; a flame treatment station; and, combinations thereof. In some embodiments, thermoformable substrate **52** comprises a first width and surface energy modification device **60** comprises a second width/length greater than the first width. Depending on system and printing requirements, it is also within the scope of the claims to have a surface energy modification device that is smaller/shorter than the width of thermoformable or printable substrate **52**.

Similarly, in some embodiments, each full width printhead array dispenses a unique stretchable ink. In other terms, each full width printhead array dispenses a particular color unique to that printhead array. Thus, a first full width printhead array **68** may dispense cyan ink, while a second printhead array **70** dispenses magenta ink, a third printhead array **72** dispenses yellow ink, and a fourth printhead array **74** dispenses black ink. In some embodiments, thermoformable substrate **52** comprises a first width and the at least one full width printhead array, e.g., arrays **68**, **70**, **72** and/or **74**, comprises a second width/length less than the first width. Depending on system and printing requirements, it is also within the scope of the claims to have printhead arrays that are equal to or greater than the width of the thermoformable or printable substrate. However, in embodiments having printhead arrays with widths/lengths greater than that of the thermoformable substrate, some piezo printheads must be turned off, i.e., the printheads falling outside of the substrate, to avoid waste of ink or damage to the overall system.

FIG. **2** depicts a schematic view of an embodiment of printer **50** within an example of a full thermoforming manufacturing process. The benefits of printing in a roll-to-roll mode are evident versus a fully integrated in-line system. For example, depending on throughput rates of extruders, printers, and thermoform presses, it is possible for a highly flexible and reconfigurable manufacturing process with high uptime if any one component is down for servicing or otherwise unavailable for its contribution to the overall process.

FIG. **3** depicts a cross sectional view showing the interaction of stretchable ink **62** with thermoformable substrate **52** having a low surface energy, while FIG. **4** depicts a cross sectional view showing the interaction of stretchable ink **62** with thermoformable substrate **52** having a surface energy higher than the surface energy depicted in FIG. **3**. Surface energy modification, e.g., corona treatment, increases the surface energy of a printable substrate to improve wettability and adhesion of inks and coatings. Some printable substrates, e.g., polymer films, have chemically inert and non-porous surfaces with low surface tensions that cause poor reception of printing inks and coatings. Surface tensions are indicative of surface energy which is also commonly referred to as dyne level. Surface treatment, such as corona treatment, increases the surface energy of the printable substrate, thereby improving print quality through improved wettability and adhesion of inks. Generally, it is believed that a substrate will be wetted if its surface energy is higher than the surface energy of the ink. The level of surface energy modification depends on a variety of factors, including but not limited to the type of treatment used, the substrate and the ink characteristics. Thus, the required intensity of treatment, i.e., the number of watts per minute per substrate surface area

$$\left(\frac{W \cdot \min}{m^2}\right),$$

is best determined for each combination of substrate and ink. The same determination should be made when using different production runs of the same substrate and/or ink to achieve optimal printing results.

FIG. **5** depicts a sample printed thermoform, i.e., thermoform article **92**, as would be produced using the above described process. In this example, after printing a thermoform substrate roll, the roll was used in a thermoforming process at a different location.

FIG. **6** depicts a schematic view of an embodiment of a present printing system for use in producing rolled printed thermoforming substrates, i.e., printing system **100**. System **100** is similar to system **50** described above, with several additional elements. Thermoforming grade substrate **52**, such as PET or PVC, is unwound in unwinder portion **56**. Web **52** then passes through conventional web drive and steering components, i.e., subsystem **58**. As the web drive and steering components are known in the art, they are not discussed in further detail herein. Web **52** is then exposed to surface energy modification device **60**. Suitable surface energy modification devices include but are not limited to a corona treatment station, an atmospheric plasma treatment station, and a flame treatment station. As described above, the purpose of device **60** is to enhance both the wetting and adhesion of ink **62** to substrate **52**. Both web cleaning stations and static neutralization devices to remove excess particles and static charge from the substrate may be included in system **100** but are not shown in this figure.

Web **52** then passes into printing zone **102** which is composed of multiple printhead arrays, i.e., printhead arrays **104**, **106**, **108**, **110** and **112**. Each printhead array is composed of multiple piezo printheads arranged so that the full width of web **52**, other than inboard and outboard margins, can be addressed by at least one printhead. This arrangement allows for a 'single pass' print mode in which web **52** moves continuously through print zone **102**. Within print zone **102**, web **52** passes first by printhead array **104**, which in this embodiment is associated with the color white, a common printed base layer. Array **104** prints a white background image. UV pinning device **114** is positioned after array **104** but before array **106** so that the ink deposited from array **104** is partially cured or 'pinned' to prevent subsequent mixing of inks with the background layer/image, e.g., the white background layer. It should be appreciated that as described above, the curing device or devices, as well as the pinning device, may emit radiation other than ultraviolet radiation, and such radiation is dependent upon the requirements of the ink. After passing by the pinning device(s), i.e., pinning device **114**, the pinned white background is overprinted by the CMYK printhead arrays, i.e., printhead arrays **106**, **108**, **110** and **112**. After all ink has been deposited onto the background layer/image and/or substrate **52**, web **52** then passes through curing zone **116**. In some embodiments, multiple wide spectrum UV lamps are used to cure the inks, although other devices such as UV spectrum LED arrays, or non-UV radiation sources are also suitable, depending on the requirements of the inks. After web **52** passes through curing zone **80** it passes through sensing subsystem **82** which comprises full width array sensor **84** to detect color-to-color register, missing jets, and other print quality metrics. Web **52** then passes into rewinder **86** where printed web **52** is returned to a roll form, e.g., roll **88**.

It has been found that systems **50** and **100** must be tuned for a particular ink, radiation source, etc. An optimal state of pinning cure for the background layer prior to CMYK overprinting must be determined. If the background layer is undercured, then color mixing occurs with objectionable defects. If the background layer is overcured, then its surface energy drops and the CMYK inks do not spread sufficiently to achieve an acceptable solid fill. Sensing subsystem **82** may be used to quantify the overall quality of printed web **52**, thereby facilitating tuning or optimization of systems **50** and **100**. Such optimization may include but is not limited to adjusting the web speed, tuning the surface energy modification, e.g., increasing or decreasing its input power, increasing or decreasing the quantity of printed ink, tuning one or more of the curing devices, etc.

In view of the foregoing need for process optimization, modifications to the present printing system have been made. The following embodiments of printing systems and methods may be used to accomplish the desired printed rolled thermoforming substrate with reduced process optimization. FIG. **6** shows a schematic view of printing system **100**, which example embodiment improves the overall printed results. As can be seen by a comparison of system **50** (FIG. **1**) and system **100** (FIG. **6**), system **50** does not include pinning device **114**, i.e., the pinning/curing device positioned immediately after the background layer/image printhead array. System **100** functions similarly to other embodiments described above. Web **52** is unwound by unwinder **56** and subsequently treated by exposure to surface energy modification device **60**. Web **52** then passes printhead array **104** where a background layer/image is deposited on web **52**. The background layer/image is fully cured in curing zone **80** by curing device **82**, the background image is inspected by sensing subsystem **82** and subsequently rewound into roll **88** by rewinder **86**. Roll **88** becomes the new roll **90** and is then refed though system **100** a second time. Web **52** having the background layer printed thereon is unwound by unwinder **56** and subsequently treated by exposure to surface energy modification device **60**. In this instance, surface energy modification device **60** alters the surface energy of both web **52** and the background layer/image cured thereon. Web **52** with the background layer/image cured thereon then passes printhead arrays **106**, **108**, **110** and **112**, i.e., printing zone **102**, where a CMYK image is deposited on web **52** and/or the background layer. The CMYK image is fully cured in curing zone **80** by curing device **78**, the completed image is inspected by sensing subsystem **82** and subsequently web **52** is rewound into roll **88** by rewinder **86**.

In short, the foregoing embodiments deposit or print CMYKW images via two independent passes of substrate **52** through printer system **100**, without the use of pinning device **114**. In other terms, a roll of material, i.e., a roll of thermoformable substrate, is sent through printer **100** twice. In the first pass, only the background layer/image is printed and then fully cured. It is within the scope of the present disclosure to print limited amounts of CMYK directly onto the substrate in order, for example, to create any registration marks or background layer other than white, and such printing can occur during the first pass through the printing system. The printed substrate resulting from the first pass is rewound into a roll and then reintroduced to the printing system for a second pass. During the second pass, the cured background layer/image is corona treated to enhance wetting of ink on its surface, i.e., the background layer/image is exposed to the surface energy modification device. The CMYK image content is aligned to any previously printed registration marks and is overprinted on the background layer/image and then fully cured. The substrate is rolled up a second time and is then in condition for installation onto a thermoforming press.

The foregoing printing process is depicted in FIG. **7** as printing process **120**. Web **52** is fed into printing system **100** at unwinder **56** from roll **90**. Web **52** is treated with surface energy modification device **60** at Step **122**. A background layer/image, e.g., a white background, is printed on web **52** by printhead array **104** at Step **124**. Optionally, CMYK image content may be printed on web **52** by printhead arrays **106**, **108**, **110** and **112** at Step **126**. Such content may include but is not limited to fiducials, alignment marks, image content falling outside the background layer/image, etc. The collective printed image on web **52** from the first pass through printing system **100** is cured by curing device **78** at Step **128**. Web **52** is then rewound by rewinder **86** into roll **88** at Step **130**. Roll **88** then becomes the new roll **90** which is again fed into unwinder **56** of system **100**. Web **52**, now including the background layer/image and any CMYK first pass image(s), is treated with surface energy modification device **60** at Step **132**. The position of the background layer/image is directly detected or detected via the position of alignment marks with position detection or sensing system **82** at Step **134**. A CMYK image is printed on web **52** in whole or in part on the background layer/image by printhead arrays **106**, **108**, **110** and **112** at Step **136**. The CMYK image on web **52** from the second pass through printing system **100** is cured by curing device **78** at Step **138**. Web **52** is then rewound by rewinder **86** into roll **88** at Step **140**.

In view of the foregoing, it should be appreciated that in some embodiments the present method for applying an image on a thermoformable substrate comprises the following. First, the surface energy of thermoformable substrate **52** is modified with surface energy modification device **60**. Then, a background layer is deposited on at least a portion of substrate **52** with at least one full width printhead array **104**. The background layer comprises at least one stretchable ink, e.g., a white ink. Next, the background layer is cured with at least one radiation curing device **78** to form a first printed substrate. The foregoing steps, i.e., the first pass through system **100**, are now largely repeated, i.e., the second pass through system **100**. The surface energy of the first printed substrate is modified with surface energy modification device **60**. Next, a foreground layer is deposited on the background layer and/or substrate with at least one full width printhead array **106**, **108**, **110** and/or **112**. The foreground layer comprises at least one stretchable ink, e.g., cyan, magenta, yellow and/or black ink. Then, the foreground layer is cured with at least one radiation curing device **78** to form a second printed substrate.

In some embodiments, the foregoing method further comprises forming roll **88** of the first printed substrate using rewinder **86** after the first pass through system **100**. Similarly, in some embodiments, the foregoing method further comprises forming roll **88** of the second printed substrate using rewinder **86** after the second pass through system **100**.

The printing system disclosed above provides a high throughput digital thermoform printer. Various embodiments and combinations of embodiments of the printing system include: a web unwinder, a treatment station to modify the substrate surface energy; a conventional web drive and tracking subsystem; one or more full-width arrays of printheads; an ink delivery subsystem; a radiation-curable ink set capable of stretching, e.g., by at least 400%, during thermoforming; one or more radiation curing devices; an in-line sensor to monitor print quality on the web; and, a rewinder. Benefits of the present printing system include but are not limited to: high throughput digital manufacturing capability for thermoformable materials; a digital (variable) printed labels which eliminate the need for adhesive backed paper or resin based labels; ease of recycling; and, the surface energy modifier also removes contamination. The present printing system reduces the costs associated with the production of labeled thermoformable containers by eliminating the steps of producing and applying a label.

The present disclosure also includes a two-step process for printing on a web or substrate to be thermoformed. In the first pass, a background layer/image such as a white layer is printed and cured. In the second pass, the background layer/image is treated to alter its surface energy and the CMYK inks are then printed and cured. Benefits of these embodiments include that the method produces clearly improved results from alternative methods.

It will be appreciated that various of the above-disclosed and other features and functions, or alternatives thereof, may be desirably combined into many other different systems or applications. Various presently unforeseen or unanticipated alternatives, modifications, variations or improvements therein may be subsequently made by those skilled in the art which are also intended to be encompassed by the following claims.

What is claimed is:

1. A method for applying an image on a thermoformable substrate comprising:

a) modifying a first surface energy of the thermoformable substrate with a surface energy modification device;

b) depositing a background layer on a portion of the substrate with at least one full width printhead array, the background layer comprising at least one stretchable ink;

c) curing the background layer to form a first printed substrate with at least one radiation curing device;

d) modifying a second surface energy of the first printed substrate with the surface energy modification device;

e) depositing a foreground layer on the background layer with at least one full width printhead array, the foreground layer comprising at least one stretchable ink; and,

f) curing the foreground layer to form a second printed substrate with at least one radiation curing device.

**2**. The method of for applying an image on a thermoformable substrate claim **1**, further comprising:

c1) forming a roll of the first printed substrate using a rewinder.

**3**. The method of for applying an image on a thermoformable substrate claim **1** further comprising:

f1) forming a roll of the second printed substrate using a rewinder.

**4**. The method of for applying an image on a thermoformable substrate claim **1**, wherein the at least one stretchable ink is an ultraviolet radiation curable ink.

**5**. The method of for applying an image on a thermoformable substrate claim **1** wherein the thermoformable substrate is selected from the group consisting of: polyethylene terephthalate glycol-modified; polycarbonate; acrylic; polyvinyl chloride; acrylonitrile butadiene styrene; and, combinations thereof.

**6**. The method of for applying an image on a thermoformable substrate claim **1** wherein the surface energy modification device is selected from the group consisting of: a corona treatment station; an atmospheric plasma treatment station; a flame treatment station; and, combinations thereof.

**7**. The method of for applying an image on a thermoformable substrate claim **1** wherein the thermoformable substrate comprises a first width and the surface energy modification device comprises a second width greater than the first width.

**8**. The method of for applying an image on a thermoformable substrate claim **1** wherein each full width printhead array of the at least one full width printhead array comprises a plurality of piezo printheads.

**9**. The method of for applying an image on a thermoformable substrate claim **1** wherein each full width printhead array of the at least one full width printhead array dispenses a unique stretchable ink of the at least one stretchable ink.

**10**. The method of for applying an image on a thermoformable substrate claim **1**, wherein the thermoformable substrate comprises a first width and the at least one full width printhead array comprises a second width less than the first width.

**11**. The method of for applying an image on a thermoformable substrate claim **1** wherein the at least one radiation curing device is selected from the group consisting of: an ultraviolet radiation source; an infrared radiation source; a visible light radiation source; and, combinations thereof.

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UNITED STATES PATENT AND TRADEMARK OFFICE

# CERTIFICATE OF CORRECTION



PATENT NO. : 9,827,790 B1
APPLICATION NO. : 15/166874
DATED : November 28, 2017
INVENTOR(S) : Steven R. Moore et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page

Item (72) Inventors should read: Steven R. Moore, Pittsford, NY (US); Xin Yang, Webster, NY (US); Alexander J. Fioravanti, Penfield, NY (US); Paul J. McConville, Webster, NY (US); Vincent M. Williams, Palmyra, NY (US); David P. Lomenzo, Pittsford, NY (US); Michael F. Leo, Penfield, NY (US); Jason O'Neil, Rochester, NY (US); Wayne A. Buchar, Bloomfield, NY (US)

Signed and Sealed this
Twenty-sixth Day of November, 2019

Andrei Iancu
*Director of the United States Patent and Trademark Office*