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ROLL TO ROLL MANUFACTURING

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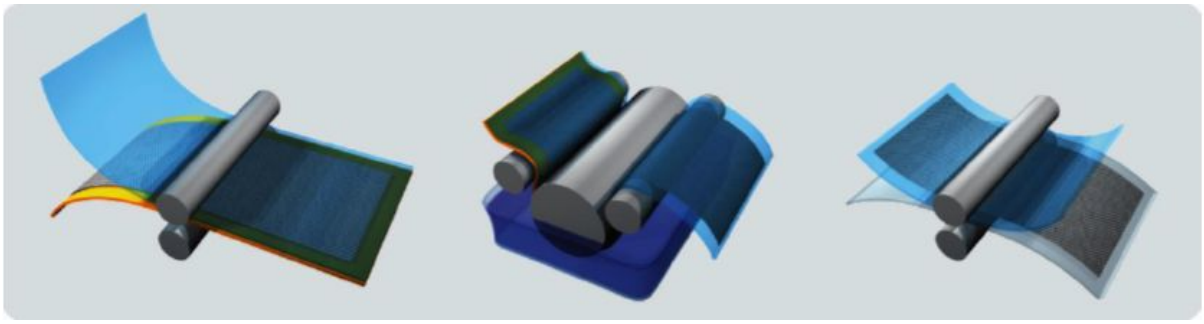
ABSTRACT

Roll to roll manufacturing (commonly referred to as R2R manufacturing) is a family of manufacturing technique which involves deformation of a substrate which is put between two moving rollers of a hard material. It consists of a number of processes that when put together produce high quality end products with a high production rate. Its high production rate and mass production are its key features.

Keywods:- *R2R Manufacturing, Manufacturing etc.*

I. INTRODUCTION

Though the initial setup can cost a moderate amount, the production process is very time efficient and cheap which gives it an upper hand over other similar techniques. Though it mostly involves moving rollers, roll to roll manufacturing also has other variants such as sheet to sheet manufacturing, roll to sheet manufacturing and sheet on shuttle manufacturing. These processes provide the manufacturer huge freedom to build continuous products by using both additive as well as subtractive manufacturing.



R2R Processing

Roll to roll manufacturing has a huge array of application which includes mechanical and electronic device production. It can be used to manufacture large area electronic devices, flexible batteries solar panels as well as mechanical device such as metal foil, metallic sheets etc. It has medical application too and can be used to manufacture medical products and membranes.

The substrate is generally flexible and paper, plastic sheets or metal foils are the ones that are mostly used. Stainless steel is also used sometimes as it provides durability and high temperature tolerance.

Much research is being done to decrease the energy consumption by R2R processing. The cost and environment effects of this process are also being optimized. Once the energy consumption, cost and pollution effects are optimized to a minimal level, R2R processing would be one of the most useful manufacturing techniques. Since R2R employs mass production, the tool efficiency is already quite high which leads to low cost. Deposition can be made even more efficient which will further decrease the energy consumption and hence the cost.

II. MECHANISMS INVOLVED IN PROCESS:

R2R processing has a huge application when it comes to 2 dimensional, large area products such as solar cell, thin film batteries etc. There are a variety of processes that are used in R2R processing to obtain the necessary shape and size of the products. A brief description of few processes are discussed below:

1. **Deposition:** R2R processing employs various kinds of deposition processes too. Chemical vapour deposition (CVD) is a commonly used process in R2R. Evaporation and sputtering are also used. A vacuum chamber is present during the CVD and sputtering process to facilitate the process since

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vacuum conditions are more preferable than normal conditions. Multilayer sputtering is highly employed to achieve high deposition rate. However, vacuum facility might be a bit difficult since reactive gas chambers are required in the process.

2. **Gravure**: This is a kind of printing process. An image is engraved to an image carrier. In R2R, the image is engraved on the rollers which is then completely dipped into ink. The extra ink is removed and the roller is brought in contact with the impression cylinder. This setup is then used to transfer the impression from the roller to the substrate using the ink and rolling movement.
3. **Flexographic Printing:** This is also a kind of printing technique which instead of impression cylinder, employs a flexible relief plate. Instead of dipping the whole cylinder into the ink, a part of the plate is covered which is then used to engrave the image onto a substrate. One of the key feature of this process is that it can be to engrave image onto non-porous material.
4. **Soft lithography:** This technique (also known as Imprint) employs multiple mask levels which are imprinted as single three dimensional structure. This process involves heating, curing and etching of the substrate to produce the required product. The substrate is heated above the transition temperature so that it can easily flow into the crevices. Crevices are present in a stamp which along with the liquid substrate is cured with ultraviolet (UV) light. This results in the hardening of the substrate which is then etched. The end result is the high quality pattern on the substrate.
5. **Offset Printing**: A blanket cylinder is used to bridge a plate cylinder and the substrate. The image impression is transferred from the cylinder to the blanket cylinder which is then transferred to the substrate.
6. **Substrates**: R2R processing involves a variety of substrates. These substrates vary according to the process parameters and can also be transparent. Stainless steel foils may be used for high temperature applications since they have high temperature tolerance but they lack transparency. Processes which require transparency employ plastic films which provide high strength and flexibility but cannot be used at high temperatures. In few special cases, other metal foils such as copper and aluminum can also be used for R2R processing.

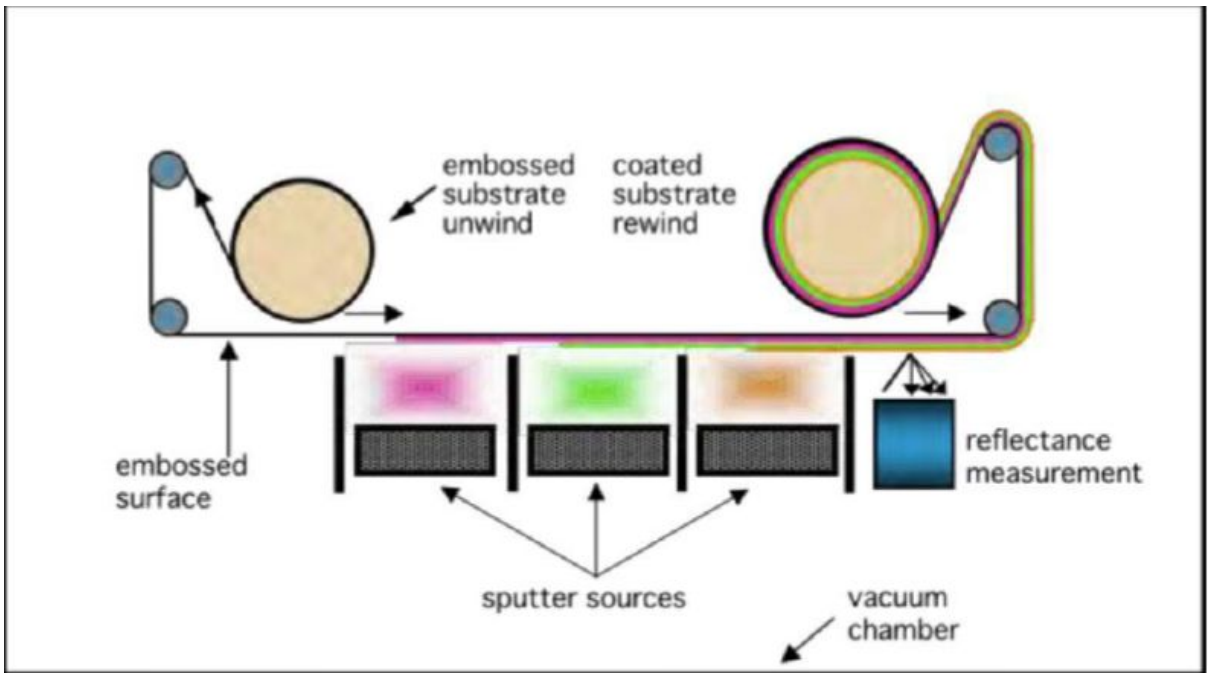

Diagram showing different processes involved in R2R Processing

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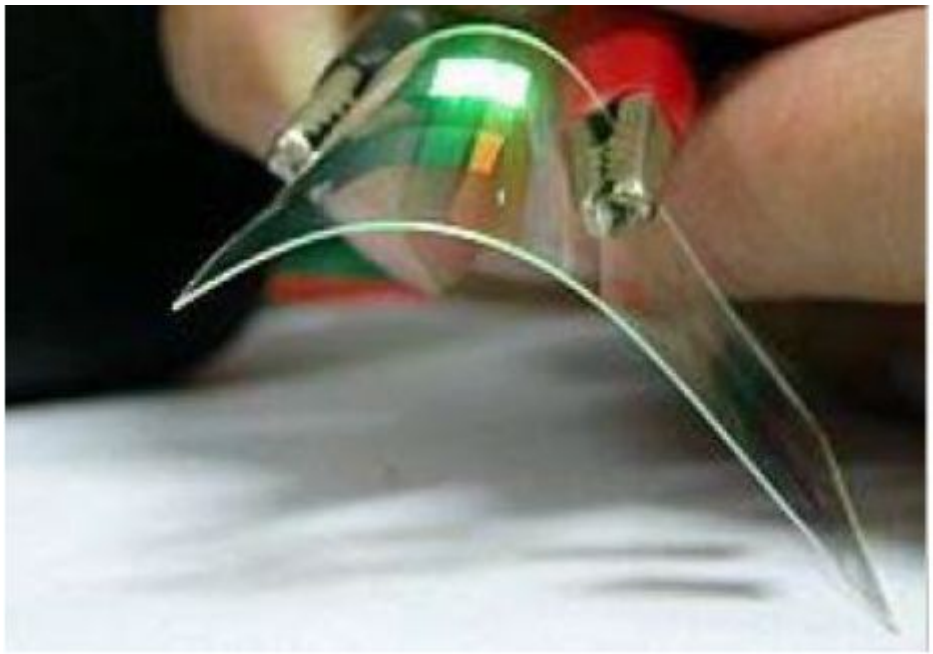
III. CHALLENGES TO R2R PROCESSING

Though R2R processing has a huge area of applications, it faces several major challenges which we need to overcome to make the process viable. Few of these challenges are listed below-

1. The cost of R2R processing is quite high. For making process a success, huge reduction in cost is needed.
2. The processed in R2R processing are fixed for a specific set of products which cannot be altered during the production. This results in the limited variety of products that can be manufactured using R2R processing.
3. The process can be cost justified only if mass production of the products is carried out. This leads to another challenge to the process which is requirement of large facility to store and operate mass production. Any such process which is carried out in small scale would incur high cost.
4. Standards have not yet been fixed for all the involved processes in the R2R processing. This results in delay since material may vary from one production facility to another. The equipment tolerances and process parameters are also not the same.

IV. APPLICATION OF ROLL TO ROLL MANUFACTURING

1. **Production of Membranes-** Thorough R2R manufacturing, we can produce high pressure "ceramic" membranes, indoor air quality and dehumidification membranes for applications in buildings, gas separations for natural gas processing and CO2
2. **Advanced Deposition Processes-** Very high quality and pure deposition rates are needed for such processes. R2R can provide for such applications. Investigations/development will focus on tools to feed solutions and slurries at high rates while controlling solution theologies.
3. **Flexible Electronics-** R2R finds extensive application in Flexible electronics as it helps in production of OLED(Organic Light Emitting Diodes). This has been described in extreme detail in the coming sections.



Demonstration of a flexible OLED device. Photo: General Electric

4. **Photovoltaics-**Scalable, ambient atmosphere roll-to-roll manufacture of encapsulated large area, flexible organic tandem solar cell modules

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5. **Battery Technology-** Including existing agency investments and commercial development results, work should focus on a 1004 wide range of battery chemistries, i.e. Li-ion, Zinc-polymer, Li/CFx, Vanadium Redox Flow (VRF) systems, 1005 and advanced alkaline systems.

V. RISK AND UNCERTAINTY, AND OTHER CONSIDERATIONS ASSOCIATED WITH R2R MANUFACTURING-

R2R processes, in general, are energy efficient and environmentally friendly. However, as with any type of manufacturing, there are 1158 associated risks and uncertainties.

Mentioned below are some of the risks associated with R2R manufacturing-

1. **High Start-up Costs** –R2R manufacturing processes have very high initial start-up cost due to expensive material and low availability of tool material. "For example, setting an organic light-emitting diode (OLED) substrate line amounts to roughly $177 per square foot. The cost of tooling a passive-matrix polymer light-emitting diode (PLED) line is far less, at $45 per square foot." .[energy.gov/.../QTR%20Ch8%20 20Roll%20To%20Roll%20**Process**ing...]
2. **Speed of High Volume/Large Area Process vs. Low Volume/Small Item Stand-Alone Process-** The speed of R2R manufacturing process is dependent on various factors, such as material requirement and other variables. These variables play a huge role in determining the speed and production rate from R2R processes. "For example, processes such as lithography, etching and sputter deposition are used in the R2R process, and 1000-feet by two -feet rolls of polymeric substrate are used to make a final product of 3.25-inch by 3.25-inch LED display, then the ***cost per square foot of active and passive matrix displays are expected to decline with increases of volume***." Source- .[energy.gov/.../QTR%20Ch8%20 Roll%20To%20Roll%20**Process**ing...]
3. **Material Variations/Tolerances/Lot Variations/Scrap –** Variation in material and quality of substrate plays a major role in determining the efficiency of R2R processes
4. **Metrology-** As discussed in the previous sections, efficiency of R2R process depends heavily upon the quality of raw material and other such factors. So metrology is needed to address the defects present in the raw material and final products produced.
5. Both in line and off line quality control is needed for proper inspection of products produced.
6. **Proprietary Information and Intellectual Information-** Successful implementation of R2R processes within the manufacturing industry will require information exchange, resource partnering, and open discussion of ideas, discoveries, and best practices.

VI. ADVANCED PROCESSES

Organic Solar Cells

R2R printing and coating machine for organic solar cells with (A) unwinder, (B) edge guide, (C) web cleaning, (D) corona treatment, (E) flexo printing unit, (F) slot-die station, (G) hot-air dryer, (H) rotary screen printing unit, (I) hot-air dryer, and (J) re-winder .Organic solar cells are the emerging technology in solar energy generation. They are multi-layered devices with each layer having a specific role in operation of the cell.

Various function of the layers-

1. Conductive Electrode
2. Light Absorbing active layer
3. Charge Generation

Furthermore each of the layer in cell has different process parameters like drying time and layer thickness. Each ink for layer has to be optimised for that layer only so because of this we need various deposition processes each having its different parameters. This can be easily and conveniently accomplished through R2R manufacturing.

Two variants of R2R can be used in solar cell manufacturing-

Discreet Processing- In this process, there is discreet addition of a layer to the cell at separate workstations. Fabrication method, ink, speed, drying and other such process parameters are optimized for each of the layer. A

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machine can be optimized to a specific layer and the required conditions or vice versa. Discrete processing is the most favourable workflow for research purposes.

Inline Processing- The ultimate fabrication scenario is inline processing of all layers in one machine and at the same time. The order of printing unit and dryer length would be tailored to a specific device stack while the maximum processing speed is limited by the slowest single process. A process failure in one of the layers can lead to a malfunction of the full device stack. The advantage of full inline processing is the minimized bending stress inside the R2R machine, reduced handling, and potentially much faster device completion.

An intermediate workflow method is used which is a combination of inline and discreet methods can be used. In this method, some inline workstations are used in an overall discreet setup. Subsequent printing and coating steps with similar speed ranges and drying requirements can be combined.

Application- R2R fabrication technique has been proved very helpful for fabrication of ITO-free organic solar cells, where front silver grids and PEDOT:PSS was inline printed, and ZnO and active layer was inline slot-die coated in one run.

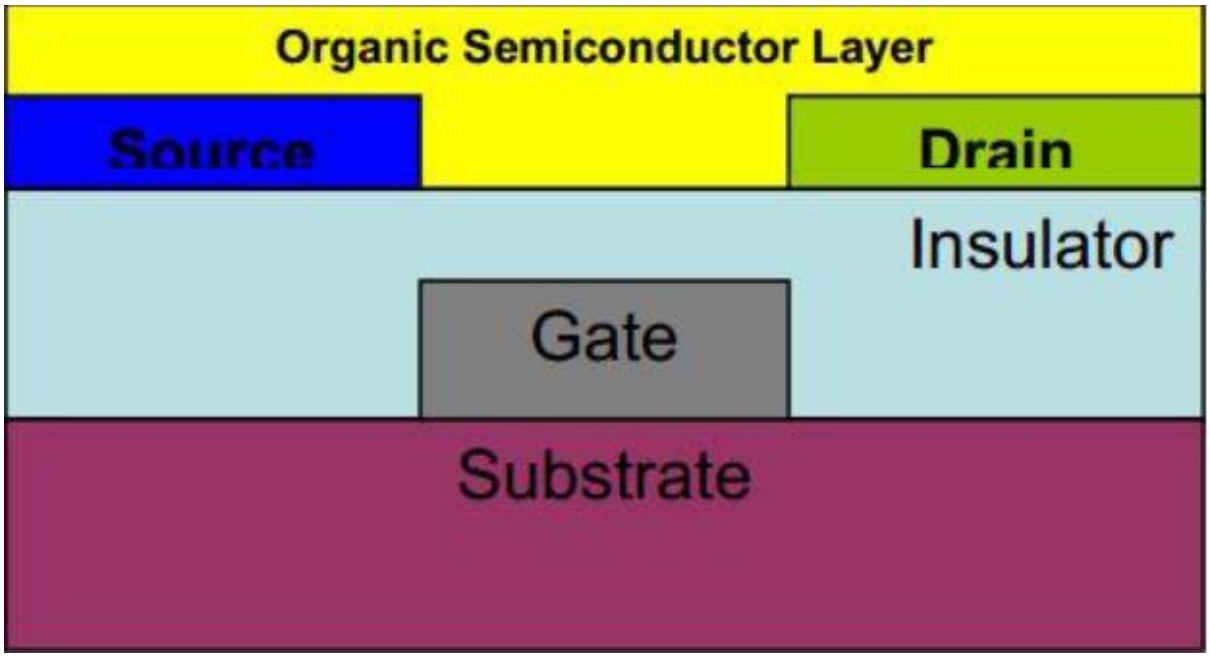
VII. ROLL TO ROLL PROCESSING FOR FLEXIBLE ELECTRONICS

To see the realistic approach of this processing and how should be overcome those problem. Main focus upon the need of new substrate, innovative patterning method and impermeable barrier layer. Industry point of view the cost of the product and their requirement should be optimal. In today's scenario electronics devices become more portable because of use of chip, circuit and battery. In this technology is photolithography is used. This process is high expensive and give more resolution but can pattern only on small area. So industry now prefer use of flexible substrate that would have lower profile, lighter weight and be more rugged than silicon substrates.

A Typical R2R Process Flow:-

The creation of thin film transistor is the typically flexible electronics process.

There are three step involves in the R to R processing- (i) Deposition (ii) Patterning (iii) Packaging



As in the figure shown of transparent conducting oxide layer is deposited on the top of the flexible substrate. So this is acting as gate electrode for the TFT (thin film transistor).

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Because of ultimate stability environmental, low electrical resistivity (1 to 3x10-4Ohm-cm) and high transparency to visible light, the ITO (Indium Titanium Oxide) is more preferably is used.

In subsequent patterning steps we first a thin insulating dielectric film of SiO2 and the metallic source and drain electrodes are made and then printed the organic semiconductor layer.

Soft lithography methods, laser ablation, and inkjet printing methods seem like promising technologies for large area flexible displays are used rather than conventional photolithography way.

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