Lab to Fab for R2R Thermal Nano- and Microimprinting

Raimo Korhonen[1], Jaakko Raukola[1], Petri Peltonen[1]

[1]Iscent Oy, Ylöjärvi, Pirkanmaa, Finland

ABSTRACT

Iscent makes large scale R2R thermal nano- and microimprinting production and production lines. Iscent has developed a seamless path from Lab to Fab to help researchers and companies to scale up their ideas of functional surfaces based on nano- and micropatterns. The cornerstones of this path are three levels of machines: laboratory, pilot and production machines that make R2R thermal nano- and microimprinting. For successful operation of the machines in-line measurements are essential. In this paper, temperature measurements and nanopattern analyses by a scatterometry camera system are described.
Keywords: imprinting, embossing, R2R manufacturing, Lab to Fab, nanopatterning, micropatterning.

1. BACKGROUND

Iscent is commercializing the approach for thermal nano- and microimprinting that was researched by VTT Technical Research Centre of Finland. Iscent is also a member of PrintoCent, VTT led community for industrialization of Printed Intelligence. Iscent utilized Finnish paper machinery know-how to scale up VTT research and developed a production machine that can run over 250 m/min (meters per minute) and the web width is over one meter. Iscent is developing, producing, marketing, and selling nano- and micropatterned foils and related production machinery.

In the process, the micro- and nanopatterns are copied from the surface of a heated imprinting cylinder to the surface of a moving foil, in the nip (contact area) that is formed by pushing a counter cylinder towards the imprinting cylinder. Many types of materials have been used in the process, coated papers, plastics like PET, OPP, COC, PC and PMMA and several bioplastics. The thickness of the foil has varied from 13 micrometers up to 500 micrometers.

Sustainability requirements have inspired more and more research to replace chemicals by nano- and micropatterning of surfaces to create surfaces with functional properties like self-cleaning, anti-bacterial or low friction. Iscent has developed a three-step Lab to Fab path for helping to scale up this kind of research.

2. MACHINES FOR LAB TO FAB

The path from Lab to Fab is based on three levels of R2R imprinting machines. The laboratory machine is used for initial tests utilizing a small imprinting tool. The right process parameters can be searched by the pilot machine before going to full scale production. The production machine is used for production test runs, production of material for market testing and finally for normal production.

2.1 Laboratory R2R Machine

The laboratory R2R thermal imprinting machine can process either rolls or sheets. The maximum width of the web is approximately 200 mm, and the speed is up to 30 m/min. The imprinting tool is attached around the electrically heated cylinder and the size of the tool is approximately 200 mm by 380 mm. Typically, the imprinting tool is made of nickel and even small pieces of nickel (like 5 cm by 5 cm) can be laser welded with dummy nickel to form the proper size tool. This machine is ideal for quickly testing of different designs of imprinting and different materials for substrates.

Figure 1: A photo of the lab machine with the cylinders.

2.2 Pilot R2R Machine

The pilot R2R machine can imprint, coat, gravure print and laminate plastic and paper foils. The web width can be up to 200 mm and the machine can run very slowly, like some tens of centimeters per minute, or very fast, like 120 m/min.

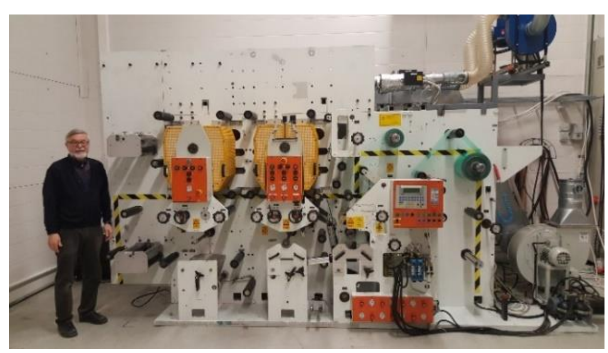

Figure 2: The pilot machine can be used for coating, imprinting and lamination.

The imprinting tool is based on nickel. It is laser welded to form a sleeve that is pushed on the imprinting cylinder.

Figure 3: Laser welded nickel plate forms a sleeve.

The imprinting cylinder is heated by oil up to 180 degrees Celsius and the substrate material can be preheated by infrared heaters. Different hardnesses and sizes of the pressure cylinder can be used to give the proper size for the nip. The length of the nip can be some millimeters when using a hard pressure cylinder and it can be increased over 10 millimeters with a soft cylinder. The pressure in the nip can vary from some MPa to over 20 MPa.

The pilot machine has two gravure printing units that can also be used for coating. If the base material is not thermoelastic and thus not suitable for thermal imprinting it can be coated by thermoelastic lacquer. A thin lacquer layer, for example 2 micrometers, is typically enough for nanopatterning.

There is flexibility for web guiding. The web can go directly to the imprinting nip and directly out. It is possible to have the web to stay on the imprinting cylinder after the nip. It is possible to rotate the imprinting cylinder in the counter direction and then the web can be preheated on the imprinting cylinder before the nip.

The pilot machine construction gives some mechanical flexibility. Units can be added to the machine. For example, if there is a need to test a special imprinting unit that is later delivered to a customer it can be added to the machine and the unwinder and the rewinder of the pilot machine can be used to guide the web through the imprinting unit. Also, different web inspection devices can easily be installed to the machine for testing purposes.

2.3 Production R2R Machine

The production machine has an unwinder, imprinting unit, slitting unit and a rewinder. A typical web width for the production machine is 700 mm but it can be even over one meter. The diameter of the imprinting cylinder is 300 mm. The imprinting speed depends on the substrate material and the imprinting design. It can be over 250 m/min for fast production.

The imprinting and pressure cylinders are heated by oil. Custom made imprinting machines can have preheating and after cooling cylinders. The web pass before and after the nip can be controlled.

Figure 4: The production machine, imprinting unit in the middle.

The production machines are using the sleeve technology, so nickel plates are laser welded to form large imprinting sleeves. The sleeve can easily be changed without taking the imprinting cylinder away from the machine. In addition, for applications needing high durability a thick steel shell can be used on the imprinting cylinder instead of a thin nickel sleeve.

3. MEASUREMENTS

Measurements, especially in-line measurements, are important for the quality of the production. Temperature, pressure, and contact time in the nip are important process parameters as well as infeed and outfeed tensions.

For the nip pressure it is enough to measure the input pressure for the cylinders that are pushing the pressure cylinder. The area of the nip is measured by nip testing paper. The nip pressure can be calculated using the input pressure and the nip area. The time in the nip can be calculated from the speed of the machine when the nip length is known. Tensions are measured using strain gauges.

The temperature of the imprinting cylinder is an important parameter. If it is too high, the substrate will melt on the cylinder and if it is too low, the imprinting will not be high enough.

Typically, the horizontal design is copied well in the imprinting process, but the critical issue is the height and the vertical shape of the result. These are analyzed off-line in the laboratory by atomic force microscopy (AFM). In-line measurements are challenging but scatterometry provides a promising opportunity for a nanoscale analysis.

3.1 In-line Temperature Measurement

The most straightforward way to measure the temperature of the imprinting cylinder surface is to use a non-contact IR sensor. The normal (wavelength range 8-14 micrometers) IR sensor is not able to measure shiny metal surfaces, even when the emissivity is adjusted. A painted black stripe is needed on the end of the cylinder to solve the problem.

The additional challenge is that the moving web takes away heat from the surface of the cylinder, so it is important to measure the temperature in the middle of the cylinder surface. For this purpose, we use a special IR sensor with low wavelength 2.3 micrometers. This kind of sensor can measure even shiny surfaces when the emissivity is adjusted.

Figure 5: Measuring the temperature of the black stripe at the end of the imprinting cylinder by an IR sensor (below middle on the photo).

3.2 Scatterometry

The in-line measurement of pattern depths under one micrometer has been developed in Eurostars project R2RMON [1]. Danish National Metrology Institute has long experience of scatterometry measurement technology and in R2RMON it is applied to measure moving nanopatterned webs. Danish company NILT has made test imprinting tools that have been used in the project. One of the test nanoscale grating covers periods from 700 nm to 1400 nm in steps of 100 nm, with two different orientations perpendicular to each other. The gratings are 50/50 gratings and height of 230 nm. Iscent has been responsible for in-line test arrangements with different R2R machines.

A schematic of the measurement setup is in Figure 6. Light from a fiber-coupled white LED is going through the web. It is polarized along the direction of the motion of the web. The polarizer increases the image contrast between fields with grating orientation parallel- and perpendicular to the light polarization. The transmitted light is focused onto an aperture to eliminate uncollimated light and light originating from higher diffraction orders. So, only the 0^{th} order transmission from the sample is used. Light goes to a spectrograph and the diffracted light is finally collected by a camera.

A spectrum is acquired to each pixel in a line perpendicular to the web moving direction. To reconstruct the surface structure of the web from this optical fingerprint, we use inverse modelling. Knowing that the nanoimprinting process copies well horizontal structures, the horizontal parameters can be taken from the tool design. A library with different heights is calculated to be used for a fast in-line analysis.

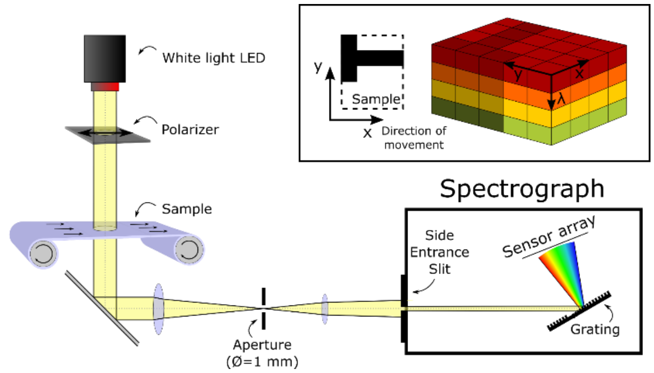

Figure 6: The measurement setup for scatterometry [1].

In one trial, the speed of the laboratory machine was 10 m/min. The height of the nanopatterns on the tool were 230 nm and the heights on the web were from 160 nm to 190 nm based on the in-line scatterometry measurements. When compared to the AFM measurements there was a good match within 10 nm.

4. CONCLUSION

A seamless path from Lab to Fab was presented for thermal R2R nano- and microimprinting. Lab to Fab approaches typically have two levels: lab level and pilot level. In this presentation we have expanded to three levels: lab, pilot, and production. This three-level approach gives a low risk cost efficient route for scaling up manufacturing of innovative nano- and/or micropatterned foils. We emphasize the importance of in-line measurements for successful scale up work.

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