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High-Speed Micron-Scale Gravure Printing Nip Visualization

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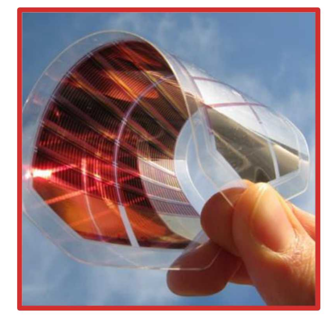
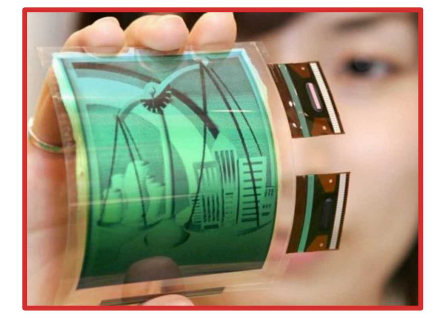
Printing Flexible Electronics

- Gravure printing has been a workhorse in the production of newspapers, magazines, and bank notes and new developments enable its use for future applications like flexible displays and organic photovoltaics.
- Poised to be an ideal manufacturing technology to print flexible electronics at high throughput over wide areas with a wide gamut of materials capable of depositing sub-5 µm features at speeds greater than 1 m/s.
- New developments that push the limits of gravure printing rely on understanding the process in order to avoid defects that are common to most coating and printing methods such as particle aggregation, pin holes, ribbing, etc.

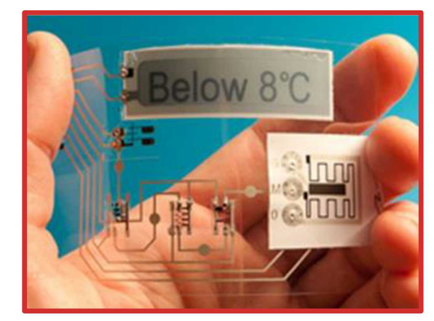


ORGANIC PHOTOVOLTAICS



FLEXIBLE SCREENS

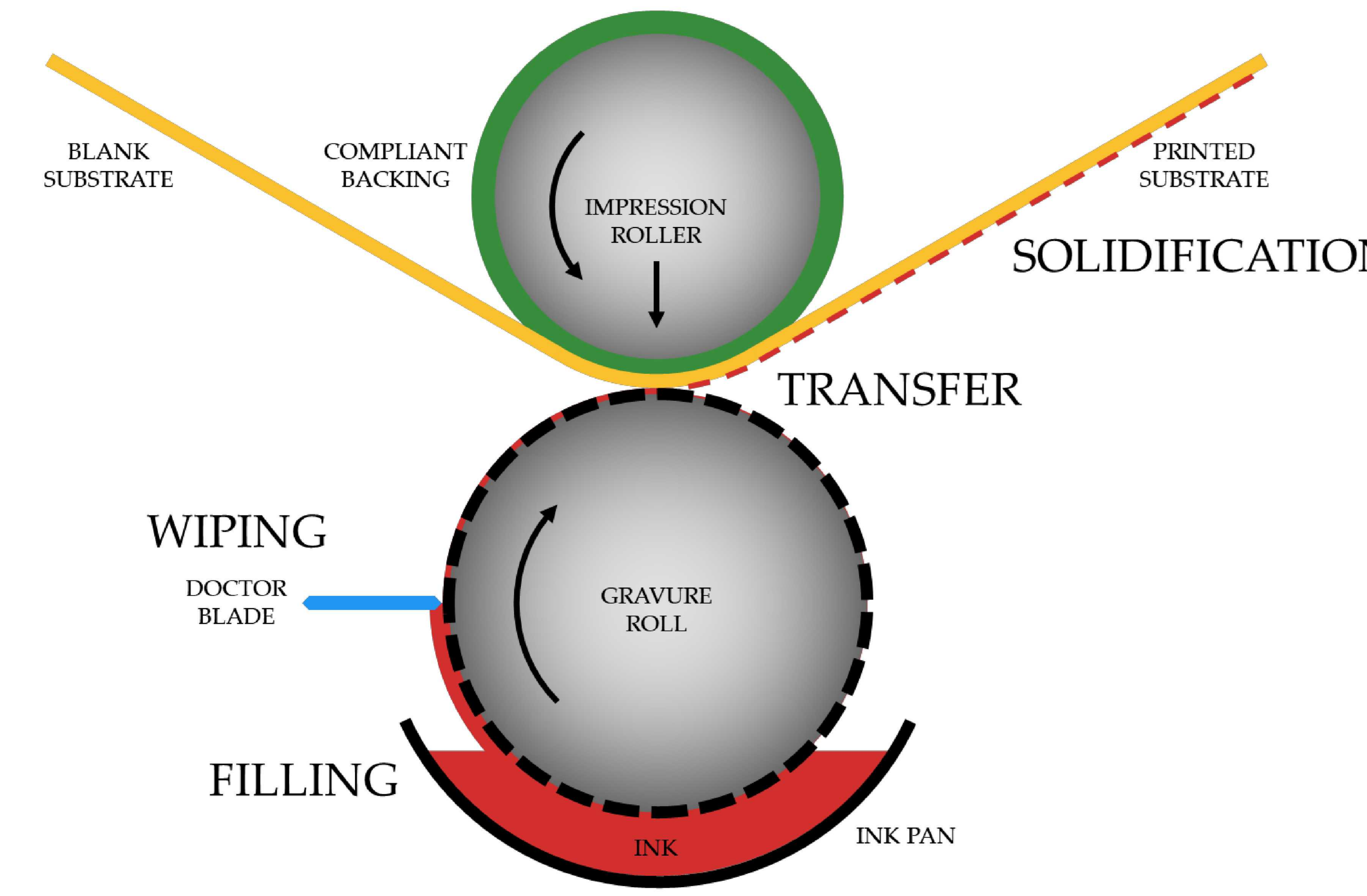
SOLID STATE LIGHTING



PRINTED ELECTRONICS

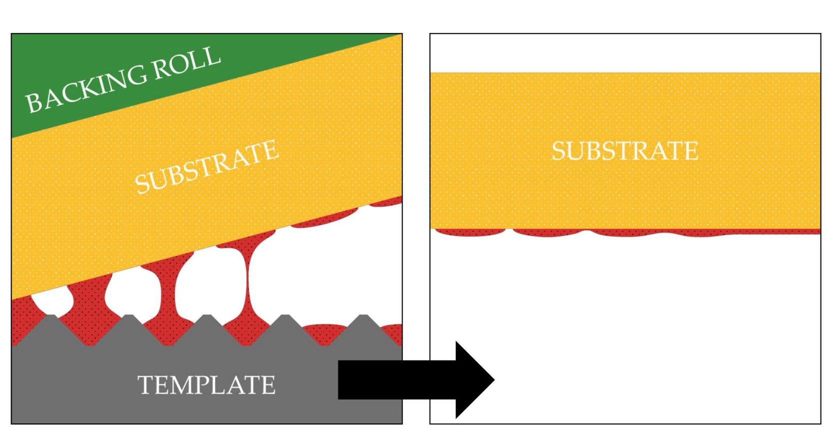
Gravure Printing

- Printing process is a factor of 4 steps:
  - Filling
    - Cells submerged in ink
    - Ink flows into cells
    - Excess flows out and back
  - Wiping
    - Excess wiped away by flexible blade
    - Pressure applied to blade
  - Transfer
    - Substrate pressed against patterned roller with matched speed
    - Ink wets substrate and spreads
    - Ink transferred as substrate is separated
  - Solidification
    - Ink solidifies via drying, curing, phase change, sintering, or densification

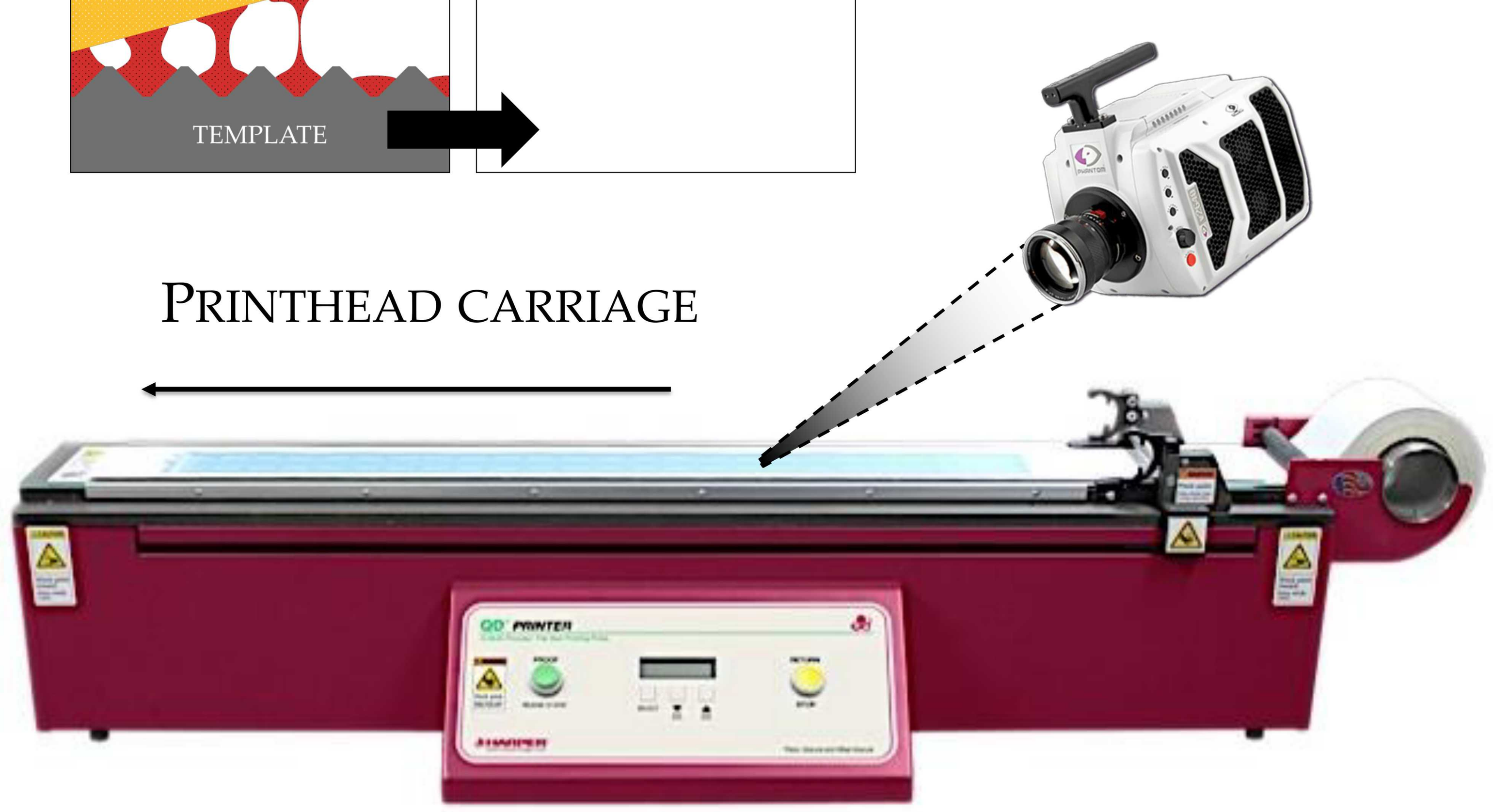


Visualization Setup

- Visualization of the meniscus shape during the transfer step can help reveal the hydrodynamic origin of defects but literature regarding visualizations of the transfer nip at the micron-scale and high-speeds with a wide field of view is little.
- This study, which accompanies the work presented in "Underpinning Physics of Defect Formation in Gravure Printing and Defect Prediction via Machine Learning", utilizes micron-scale, high-speed flow visualization to help understand the underpinning physics of defect formation in gravure printing. Careful configuration of camera, optics, and mounting system enables continuous high-speed capture of the gravure printing nip with a field of view of several tens of gravure cells at a resolution of about 1 µm per pixel.

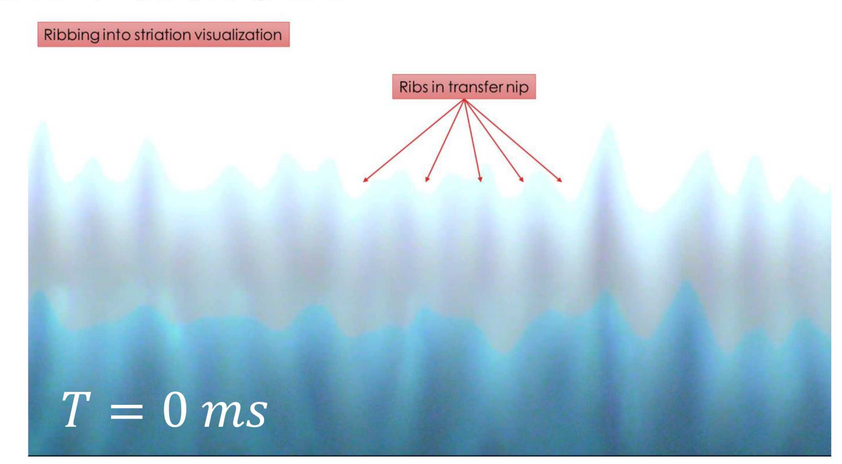


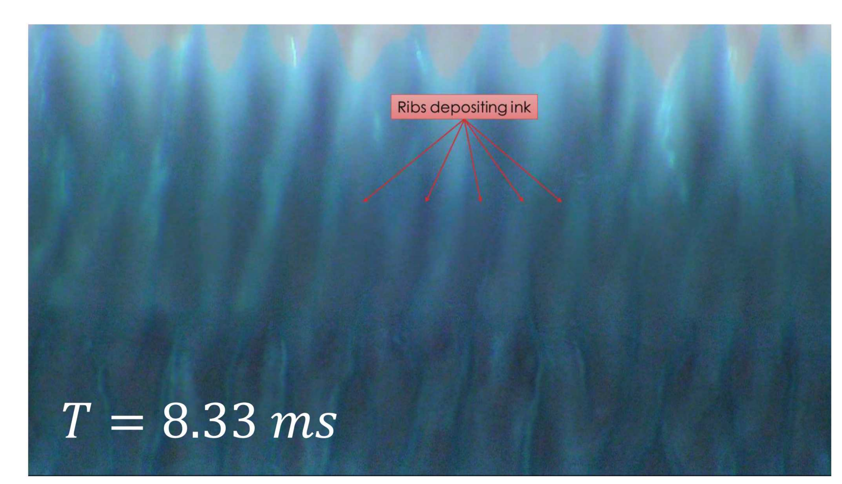
DO THE STRIATIONS INDEX TO RIBBING?

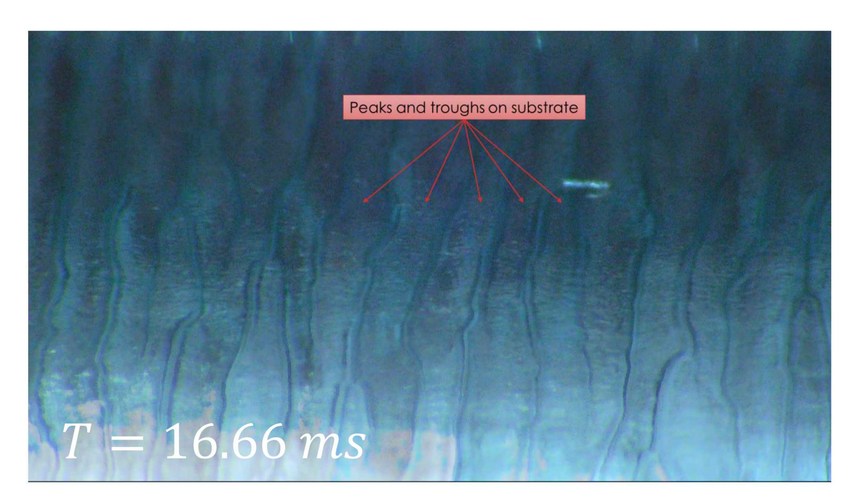


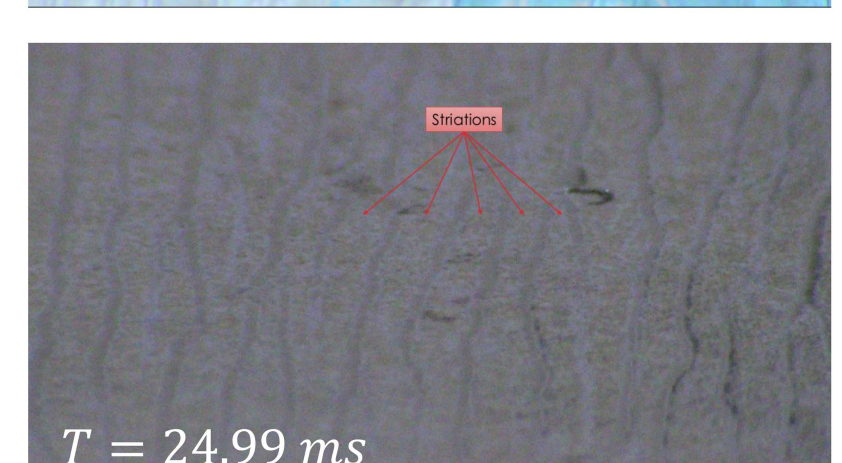
Continuous Observation

- Single position observed continuously as transfer nip translates over the substrate and deposits the film which subsequently dries
- First image: $T = 0\ ms$ Transfer nip in view
- Second image: $T = 8.33\ ms$ Transfer nip moving away at top of image with deposited film on substrate in view at bottom
- Third image: $T = 16.66\ ms$ Deposited film has peaks and troughs from the ribbing instability
- Fourth image: $T = 24.99\ ms$ Peaks and troughs dried quickly leaving behind the striation pattern



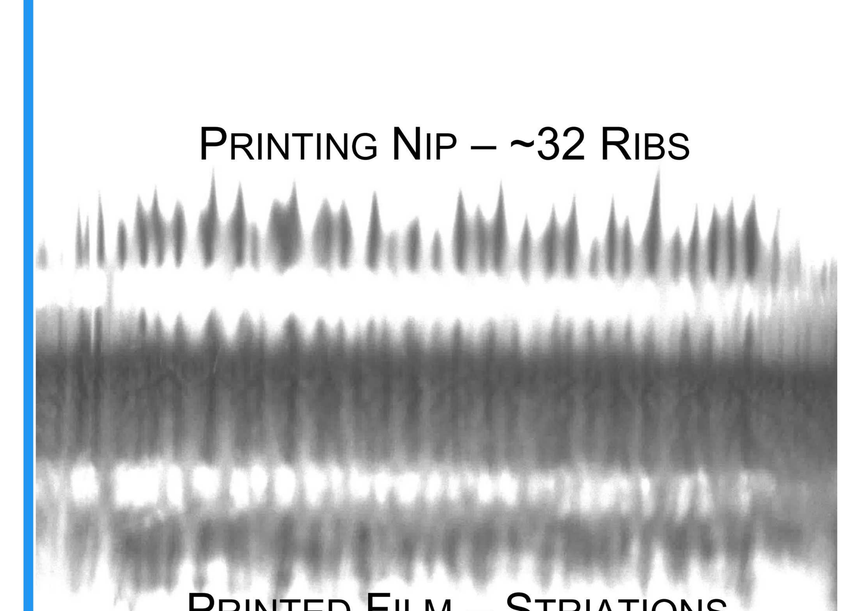


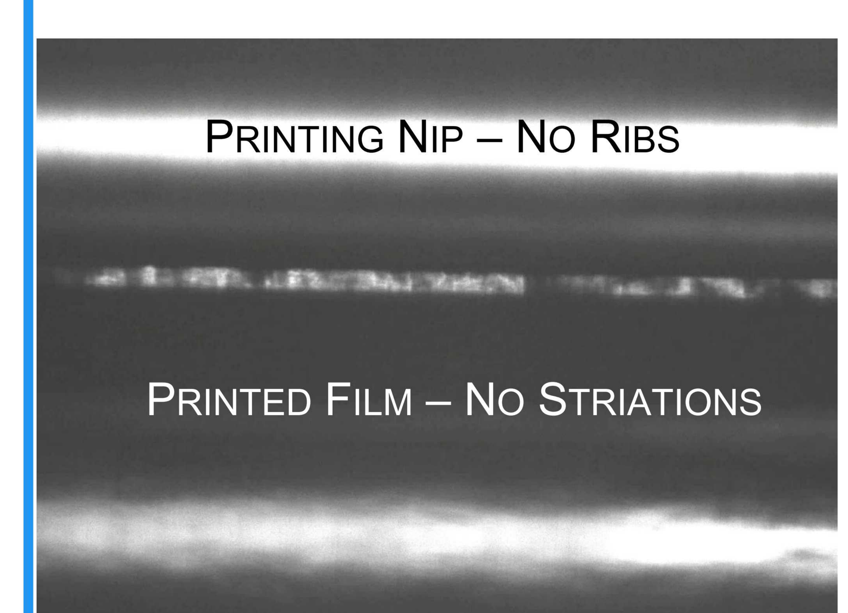


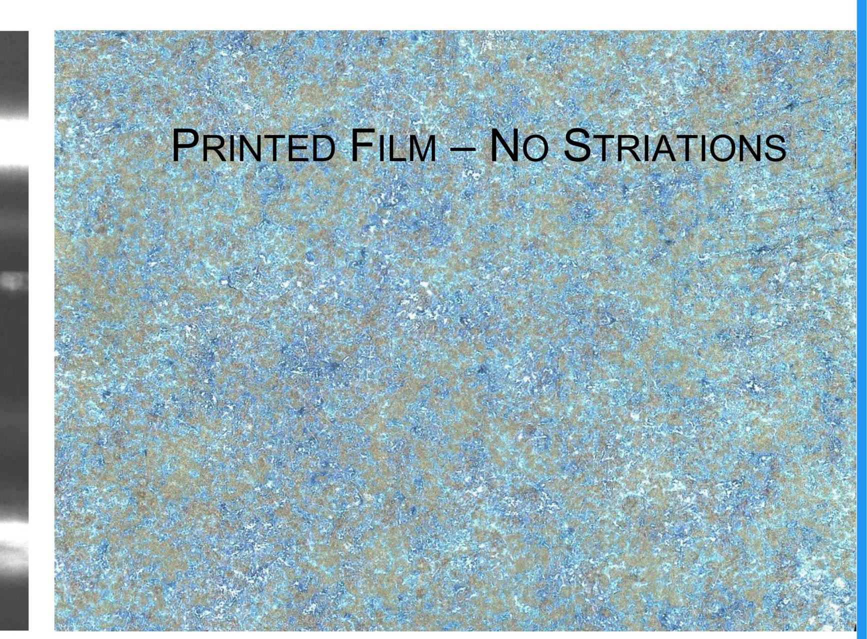


Ribbing Indexes Striations

- The visualizations coupled with the aforementioned Machine Learning Defect Prediction model provide a connection between the complex capillary-hydrodynamics at play and the root-causes of printing process defects.







- Count and positions of ribbing instabilities match count and positions of striations pattern
- Ribbing instability key mechanism in striation generation

Acknowledgements

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