May, 2008

Phil will be at the SID conference in Los Angeles the week of May 19. Please contact him, pbos@lci.kent.edu, if you are interested in receiving the latest information on any particular topic.

CLEANROOM NEWS

Process Spotlight: Spincoating, Part 1
Thin film deposition is a fundamental part of LCD fabrication. While vacuum techniques such as sputtering are still widely used for some layers, such as transparent conductors and the multiple layers of thin film transistors, such techniques are generally expensive and require large capital investment. Even with such equipment, solution-based coating steps are still required for photolithography processing, and generally for alignment layers.

The most common techniques for application of wet coatings in displays are spincoating, roller coating, offset printing, and slot die coating. Inkjet technology holds great promise to simplify processing by allowing for direct patterning of films (similar to offset printing), but is not yet in wide use for production. LG Philips introduced inkjet printing of color filter arrays in 2005, and has developed processes including nanoimprinting to fabricate TFTs; a complete roll-processed TFT display will be shown at SID this month.

This month we will discuss the simplest wet coating process, spincoating.

Basic Concepts

Spincoating in the simplest sense is comprised of three steps: dispensing, spinning, and drying.

![Spincoating Diagram](image)

Figure 1: basic spincoating configuration—liquid solution is dispensed onto substrate, which is mounted to spin chuck (image: Brewer Science)

To spincoat a material, it is first dissolved in a solvent, then dispensed onto a substrate. Dispensing can be done manually with a syringe and filter, or automatically with metering pump and filter. Static dispensing refers to dispensing material onto a stationary substrate, then beginning spinning; dynamic dispensing refers to dispensing onto a rotating substrate.
The substrate is then rotated at high speed (generally several thousand RPM) to generate a thin uniform film. At first glance, this does not seem like a good way to achieve a uniform coating, since radial forces continue to push material toward the edges of the substrate. In fact, if the substrate dries during spincoating, the result is usually less than uniform film. The key to successful spincoating is inhibiting drying of the film. For this reason, solvents used in spincoating are not highly volatile; common solvents for polyimide materials are NMP (n-methyl-pyrollidone), gamma butyrolactone, and butyl cellosolve. Solvents such as chloroform evaporate much too quickly to generate uniform films.

Spinning is generally a multistep process, with a low speed spread step (to allow the material to completely coat the surface of the substrate) followed by a higher speed spin step that is primarily responsible for controlling final film thickness.

Each spincoater holds a substrate on a spin chuck, which is attached to a motor shaft. The chuck is surrounded by an enclosure, or bowl, which will protect the user and environment from potential harm, and which will inhibit drying of the film. The bowl is typically connected to an exhaust line, which will draw out solvent vapors; the exhaust may be shut off during spinning to prevent premature flash off of the solvent. Most spinners have a microprocessor control to allow programming of multistep speed profiles.

Spin chucks can be simple discs or complicated fixtures to hold specific size substrates. Simple disc chucks, which are generally smaller than the substrate, generate the most turbulent air flow, and thus give the least uniform results. Recessed chucks, which contain a cutout within a large chuck for small substrates, eliminate much of this problem. Most chucks use vacuum to hold the substrate.

Drying of the substrate is generally accomplished after spinning is complete. The substrate is transferred to a hotplate or oven to flash off the remaining solvent. Drying temperature is determined by the flash point of the solvents being used.

Theory

Spincoating is actually a very complicated process to model (see resources at end), as it is dependent upon not only the concentration of the material in solution and spin speed of the chuck, but also upon evaporation rate, temperature, and time. For actual mathematical models of the spincoating process, please refer to the sources at the end of this article. Numerical methods are necessary to accurately fit process data.

A major difficulty in attempting to model the process is variability in equipment. Since evaporation rate plays a large role, the exhaust system for a machine / facility can change results dramatically, as the information from source 8 below shows:

<table>
<thead>
<tr>
<th>Film thickness is indirectly proportional to the spin speed:</th>
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<tbody>
<tr>
<td>[ H \sim N ]</td>
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<tr>
<td>Where ( H ) is the film thickness and ( N ) is dependent on solvent evaporation.</td>
</tr>
<tr>
<td><strong>Case 1:</strong> No Evaporation – film thickness varies with spin speed and time:</td>
</tr>
<tr>
<td>[ H \sim t^{1/2} ]</td>
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<tr>
<td><strong>Case 2:</strong> Constant Evaporation Rate:</td>
</tr>
<tr>
<td>[ H \sim t^{2/3} ]</td>
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<tr>
<td><strong>Case 3:</strong> In most applications, the evaporation rate varies with the square root of the spin speed:</td>
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<tr>
<td>[ H \sim t^{1/2} ]</td>
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</table>
Practical considerations

In practice, it is common to generate spin curves to determine film thickness for a given spin speed. Plots of final thickness vs. spin speed are generated for a fixed concentration of material. At low speeds, the thickness changes quickly, and process control is difficult. Ideally, processes are set in an area where the curve begins to flatten out (see example curves for Rohm & Haas S1800 series resist below—each curve is for S18xx where xx is the concentration in weight percent or photoresist). If a suitable thickness cannot be obtained in this way, it is best to change the concentration. Spin speeds for small (<4”) substrates may be 4000 rpm or higher, but generally are much lower for larger substrates. This is mostly due to the much higher inertia generated by larger plate/chuck combinations, making them much more susceptible to vibration and imbalance (which can lead to thickness nonuniformities or, worse, substrate breakage).

![Spin curves for Rohm & Haas S1800 series resist](from R&H data sheet)

Figure 2: Spin curves for Rohm & Haas S1800 series resist (from R&H data sheet)

Next month we will discuss spincoating defects and their causes, and how to set up a spincoating process.

EQUIPMENT AT THE LCDRF

The LCI has several spincoaters: the Solitec spincoater and Brewer Cee spinner for small (less than 7”) substrates, and the Headway and Brewer GX100 spinners for glass up to 14” in size. If you are interested in access to these machines, or would like more information about spincoating, please contact Doug Bryant at the LCI.

Some resources to learn more about spincoating:


EQUIPMENT UPDATE

Several tools in the LCDRF will be undergoing maintenance and upgrades, or have recently completed maintenance:

The arc lamp on the Oriel Mask Aligner was replaced in March. Some improvements to the substrate stage still need to be made. The alignment cameras have been optimized for multilayer coatings, and have subsequently been used to align patterned layers to within 3 microns.

The MRC 603III sputter coater had its CPU board replaced in early April. The MFCs have also been recalibrated to improve performance.

The Technics PlanarEtch II plasma etcher is currently down. No work is planned on this machine in the next month. If you have interest in using this machine, please contact Doug Bryant; if there is a need for it, we can bump this up in priority.

The Clean Air Systems Wet Bench has been gutted and is being rebuilt for maximum efficiency in working with 6” and 7” glass. Kevin Ballard, and undergraduate cleanroom assistant, has nearly completed replumbing of the bench. A new work surface is on order, and the machine will be installed in the cleanroom when this arrives, likely in mid June.

LCI NEWS

Videos on the web
As IPP members, you can now access a members-only area of the IPP web site that features over 80 videos (and growing) of recent LCI Seminar research talks and conference presentations at the Liquid Crystal Institute. To access the videos from the IPP web site, simply click on the "Members only" button on the bottom of the IPP home page: http://www.lci.kent.edu/ipp/07 . From there, you can click on "Videos" and you will be prompted to enter your company login id and password.

'Smart' Greenhouse Research Partnership Unveiled
The LCI and Cleveland Botanical Garden officially launched a pioneering research project to explore the potential of liquid crystal technology for creating more sustainable, energy-efficient greenhouses. At an event held on Wade Oval, the garden and the university unveiled the two greenhouses that will be used in the first phase of the project. One contains liquid crystal panels and the other, a control, has plain glass. A demonstration revealed how the panes “switch” to manage the amount of sunlight that enters the greenhouse. The results from the experiment will be collected throughout the next several years. Through this research, the garden and the university aim to create a fully automated “smart” greenhouse that is easily programmed to provide the ideal growing environment for a variety of plants.

Cleveland Botanical Garden is the country's first urban garden center, (a nonprofit garden) and0o a national leader in urban horticulture and botanical education. From its 10-acre campus in University Circle to three inner-city learning gardens and dozens of outdoor classrooms at area schools, the garden has introduced the benefits of gardening to thousands of people of all ages, interests, backgrounds and abilities. Since its founding in 1930, education has been the core of the garden’s mission, guiding expansion in recent years to include urban outreach, school programs that support national academic
Nastyshyn recognized with KSU Provost's International Scholar Award
Dr. Yuriy Nastyshyn, currently a visiting scientist with Dr. Oleg Lavrentovich, is the 2008 recipient of the Kent State University Provost International Scholar Award. He accepted the award at the 21st Annual International Awards and Induction Ceremony presented by the Kent State University Beta Zeta Chapter of Phi Beta Delta on April 9.

Nastyshyn is the head of the research sector on Biological Optics and Optics of Liquid Crystals at the Institute of Physical Optics of Ukraine. This is his fourth visit to the Liquid Crystal Institute at Kent State University.

“This time, Dr. Nastyshyn brought his expertise to help us in the studies of the so-called chromonic lyotropic liquid crystal,” Lavrentovich said. These materials can be used in a number of applications, from sensors of harmful bacteria such as anthrax and E. Coli to thin films with unique optical properties, such as polarizers. His studies are focused at the optical and elastic properties of these materials; he collaborates with researchers at the LCI and at the Department of Physics (Prof. Sam Sprunt's group).

Besides his expertise in chromonic lyotropic liquid crystals, he has extensive contributions in the areas of optics, defects, and rheology of liquid crystals, anchoring in nematic liquid crystals, phase transitions in surfactant lyotropic liquid crystals and the growth and optical studies of biocrystals.

Upcoming Presentations
May 18-23, 2008, SID International Symposium, Los Angeles
Mitya Reznikov, Bentley Wall and Philip J. Bos, “Mono-domain alignment of the SmC liquid crystalline phase for analog display applications”
E. Dorjgotov, A. Bhowmik, P. Bos, “Liquid crystal etalon device for reflective display”
Yi Huang, K.H. Kim, J.K, Jang, H.S. Kim and Philip Bos, “Dynamic simulation of Pi-cell liquid crystal displays with transverse field”

Recent Presentations
April 2008: Physics Colloquium, Univ of Memphis
R. Selinger, "Rubber That Moves: Modeling Liquid Crystalline Elastomers"

Recent LCI Seminars
April 2, 2008
Prof. Vladimir M. Agranovich, The NanoTech Institute, The University of Texas at Dallas, and Institute of Spectroscopy, Russian Academy of Science, "Negative refraction, polaritons and negative group velocity"
April 9, 2008
Prof. Sasha Govorov, Department of Physics, Ohio University, “Optical properties of coupled semiconductor and metal nanocrystals: Exciton-plasmon interaction and nonlinear effects”
April 16, 2008
Prof. Matthew A Glaser, Department of Physics, University of Colorado, “Nanophase segregation and frustration: chirality, splay, and curvature in bent-core smectics”
April 30, 2008
Prof. Paul Goldbart, Department of Physics, University of Illinois at Urbana-Champaign, Title: "Chemical gels and their structural and elastic heterogeneity: A simple, Landau-type picture"
May 7, 2008
Prof. Robert Austin, Department of Physics, Princeton University, Title: "DNA in Tight Places: Connecting Nanochannels with Evolution"