Preferential Electrospray Deposition onto Interdigitated Electrodes

CNF Project Number: 3109-23
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Primary Source(s) of Research Funding: SUNY Binghamton IEEC Grant

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Primary CNF Tools Used: AJA Sputter System(s), Heidelberg DWL2000, Hamatech Wafer Processor(s), SUSS MA6-BA6 Contact Aligner, YES Image Reversal Oven, YES Vapor Prime Oven, DISCO Dicing Saw, Photoresist Spinners/Hotplates

Abstract:

Electrospray deposition is an additive process that uses strong electric fields to atomize a liquid solution into a fine spray of charged microdroplets. Solute material dispensed in the liquid will be contained in the droplets, which undergo rapid in-flight solvent evaporation until dry particles of solute remain and are deposited on a surface to create a film. In this work, we investigate the preferentiality of electrospray deposition onto substrates with conductive and insulative components. Micro-scale devices were fabricated at the Cornell NanoScale Facility (CNF) that consisted of interdigitated metal electrodes on glass substrates. Fluorescent nano-particles were electrospray-deposited onto the devices and imaged with fluorescent microscopy to evaluate the preferentiality of deposition onto the conductive electrodes versus the insulative glass substrate.

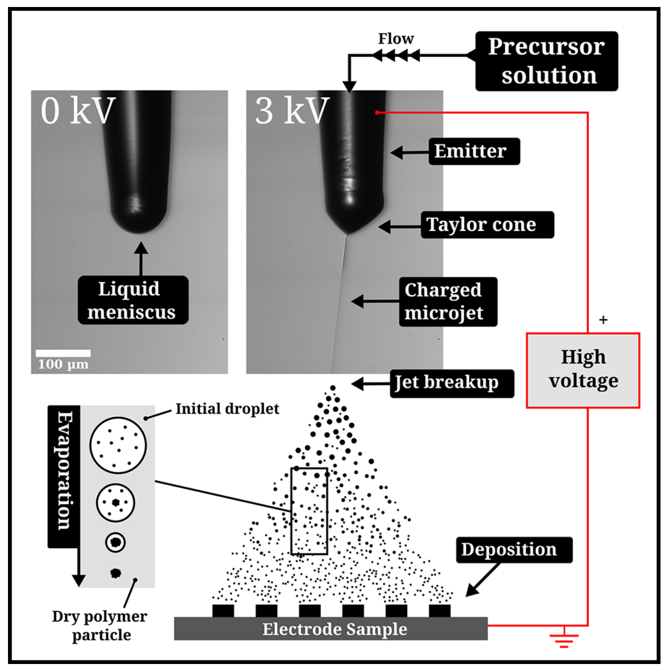

Figure 1: Schematic of electrospray deposition.

Summary of Research:

In this work we investigated the preferentiality of electrospray-deposited polymer films on multi-material substrates (i.e., substrates with conductive and insulative components). Figure 1 contains a schematic of the electrospray deposition process, which begins from a precursor solution composed of a solute material (polymer) in a volatile carrier solvent. The precursor solution is pumped through an emitter and charged with a high electric potential (3-5 kV) causing the liquid meniscus at the tip of the emitter to deform into a cone (Taylor Cone). A charged microjet is emitted from the tip of the conical meniscus which breaks up into a spray of nano- and micro-sized droplets. The volatile carrier solvent rapidly evaporates from the droplets, rendering a spray of dry (solvent-free) solute particles that are delivered to the substrate to create a film.

The deposition pattern of an electrospray is governed by the electric field formed between the emitter and the substrate. The charged droplets/particles follow the electric field lines to the target which preferably terminate on grounded conductive surfaces, allowing for preferential deposition of material onto conductive surfaces (versus neighboring insulative surfaces). In this work, we probed the geometric limits of preferential electrospray deposition by fabricating micro-scale devices at the CNF that were composed of interdigitated metal electrodes on glass substrates.

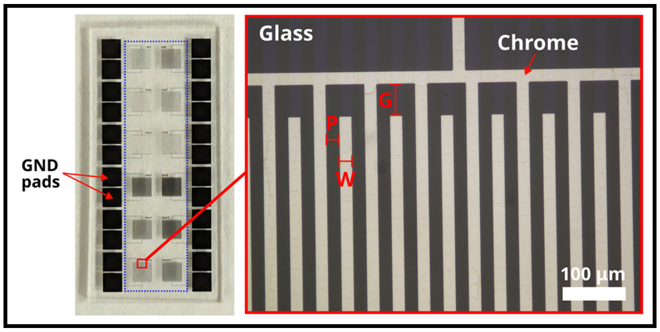

Figure 2: Optical and microscopic images of the electrode devices fabricated at CNF.

Figure 2 contains a photo and microscope image of a single device with 12 arrays of interdigitated chrome electrodes on a glass substrate. Each array on the device had a different electrode width (W) and pitch (P), with widths of 2, 5, 10, 20 μm and pitches of 5, 10, 20 μm. The microscope image outlined in red shows the 20 x 20 μm (WxP) array. All arrays used a uniform channel gap (G) of 50 μm. The interdigitated electrode devices were fabricated at the CNF.

The electrode pattern was designed using a python GDSII library (phidl) and converted to a mask using the mask writer at the CNF. Following mask fabrication, the device fabrication process was as follows: (1) sputter deposition of chrome (200 nm) onto glass substrate, (2) photoresist (S1805) spin-coating and baking, (3) expose with contact aligner, (4) NH3 image reversal, (5) flood exposure and develop, and (6) wet-etch chrome to reveal pattern.

The preferentiality of deposition onto the electrodes was evaluate by electrospraying fluorescent polystyrene nanoparticles (~ 100 nm diameter) and imaging with fluorescent microscopy. Figure 3 contains fluorescent microscope images of polystyrene deposition onto the electrodes. The image on the left is of the device that was fabricated (at CNF) using soda-lime (SL) glass as the substrate, and the device in the right image was fabricated on Borofloat (BF) glass. Notably, there is a significant difference in the deposition on the SL glass versus the BF glass. The device with SL glass (left) received a significantly greater amount of material on the glass substrate (the black area) compared to the device with BF glass (right) which received a minimal amount of material on the glass. The deposition onto the glass of the SL device (left) results in decreased coverage on the electrodes (outlined in red), as material is "lost" to the glass substrate. In contrast, the device with BF glass (right) has much greater coverage on the electrodes since less material was delivered (lost) to the glass substrate.

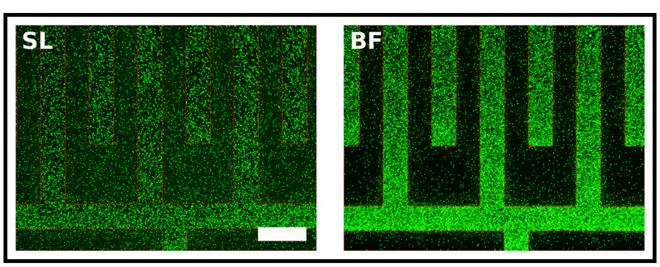

Figure 3: Fluorescent microscopy images showing the effect of glass substrate on preferentiality of electrospray deposition. Soda-lime glass is denoted by SL and Borofloat glass is denoted by BF. Scale bar in 40 µm.

Figure 4 plots the preference ratio (ratio of deposition onto electrodes vs. glass) versus metallization ratio (ratio area of electrodes vs. glass). Larger metallization ratios equate to electrodes with less glass area, resulting in preference ratios near or exceeding 0.9 (90%). Over all metallization ratios, the devices with BF glass substrate have greater preferentiality than those with SL glass. The difference in preferentiality between the SL and BF glass can be attributed differences in their dielectric properties. Electrospray deposition is highly sensitive to the electrical properties of the target material. For dielectric materials, the rate of charge decay governs the deposition onto the substrate. For preferential deposition, dielectrics with low rate of charge decay (BF glass) are beneficial as charge that is delivered (from the charged particles of the electrospray) to the surface of the dielectric will remain for a longer period of time and inhibit other charged particles from landing. Deposited charge will dissipate faster on dielectric with high charge decay (SL glass), resulting in greater accumulation of material on the glass.

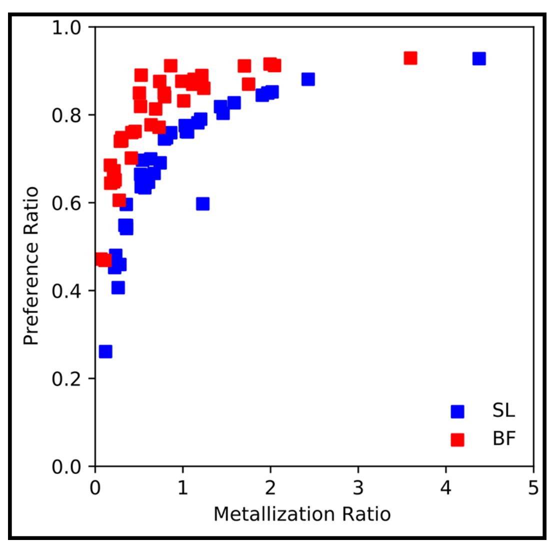

Figure 4. Plot of preference ratio vs. metallization ratio for SL glass (blue) and BF glass (red) substrates.