

Towards Quantitative Comparisons of Bulk and Local Optoelectronic Properties of Emerging Solar Cell Materials with Interdigital Electrodes

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Primary CNF Tools Used: Hamatech Hot Piranha Cleaner, Class II Resist Spinners, Edge Bead Removal System, ABM

Contact Aligner, Hamatech Wafer Processor, Oxford Plasma Etchers (81 and 82), SC4500 Odd-Hour Evaporator, SC4500 Even-Hour Evaporator, Disco Dicing Saw

Abstract:

Gold interdigitated electrodes with varying electrode length and separation have been fabricated using a simple photolithography procedure. Fabricated electrodes were used in space charge-limited current experiments with a thin film of N,N'-Bis(3-methylphenyl)-N,N'-diphenylbenzidine embedded in a polystyrene matrix. Future work aims to combine such experiments with scanned-probe microscopy experiments to quantitatively compare bulk and local optoelectronic properties.

Summary of Research:

Gold interdigitated electrodes have been fabricated with a simple photolithography procedure, shown in Figure 1. Four-inch, standard-thickness quartz wafers were purchased from Mark Optics and were cleaned using the Hamatech hot piranha cleaner. Cleaned wafers were dehydrated at 180°C for 10 minutes and introduced to the spin coater, where they were coated with LOR resist. LOR was dispensed dynamically at 400 rpm for 4 seconds before coating at 4000 rpm for 45 seconds. The layer was soft-baked for 20 minutes at a wafer temperature of

180°C before S1805 resist was deposited statically with a coating speed of 4000 rpm for 60 seconds with an acceleration of 1000rpm/s. The film was soft-baked at 115°C for 3 minutes. The edge bead was removed with the edge bead removal system.

Figure 2 depicts the exposure array used to determine the optimum dose for wafer patterning. An octagonal mask with an opening was placed between the light source and the wafer on the ABM contact aligner. The experiment tested 8 distinct exposure conditions, varying the exposure time from 1 second to 4.5 seconds in 0.5-second increments. The wafer was developed with 726 metal ion-free developer sprayed in a single puddle for sixty seconds post-exposure. Optical microscopy

revealed that 3.5 seconds of exposure—corresponding to a dose of 41.7-53.6 mJ/cm²—was sufficient for producing the desired pattern and undercut.

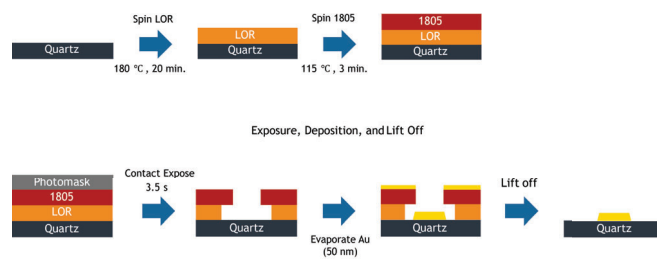


Figure 1: Schematic representation of the fabrication of gold interdigitated electrodes. Specific parameters are provided where possible.

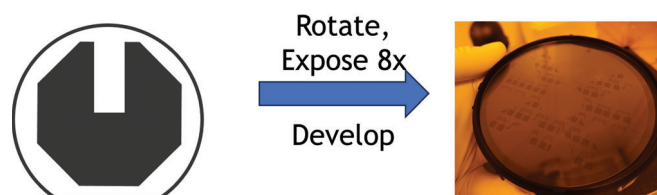


Figure 2: Schematic of the exposure array. Each region of the wafer was patterned using a distinct exposure dose. Determination of the ideal exposure dose was performed with optical microscopy.

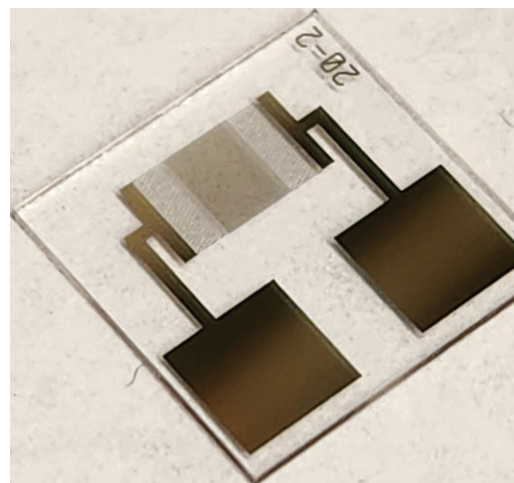


Figure 3: A successfully fabricated gold interdigitated electrode. The two numbers to the right of the electrode represent the separation of each digit in microns, while the second number signifies the length of each digit in millimeters.

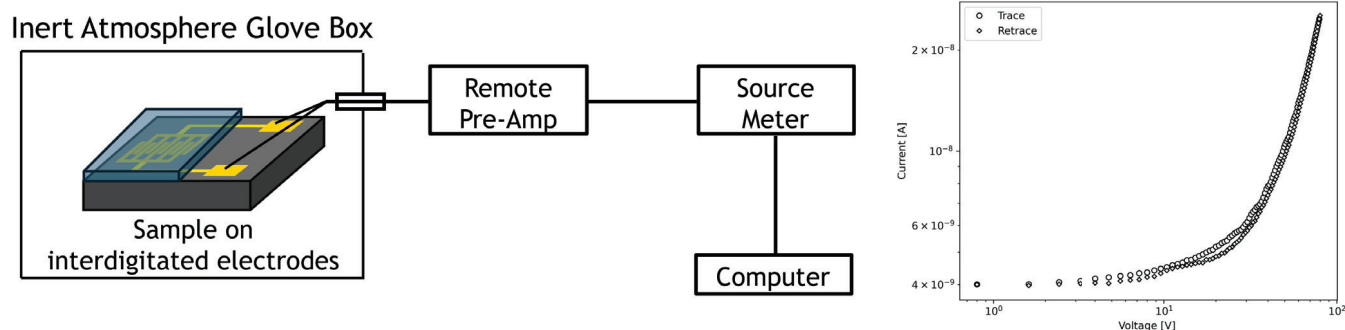


Figure 4: Block diagram of the space charge limited current experiment with a sample current voltage curve. The observed non-linearity in the current voltage curve is direct evidence of space charge-limited current injection.

Patterned wafers were placed in the Oxford 81 plasma etcher for a light oxygen plasma descum with a forward power of 50 mW for 45 seconds before being directly introduced into the Odd Hour Evaporator. When the bell jar pressure was $\sim 2 \times 10^{-6}$ Torr, 5 nm of chromium was deposited at a rate of ~ 1.4 Å/s, followed by the deposition of 50 nm of gold at a rate of 0.4 Å/s. The wafer was removed, and the metal was lifted off with Remover PG before being diced in the disco dicing saw. A representative electrode produced from the protocol is shown in Figure 3.

Electrodes were used in charge injection experiments involving the molecularly doped polymer system N,N'-Bis(3-methylphenyl)-N,N'-diphenylbenzidine in polystyrene. This system is known to produce space charge-limited current and provides a baseline for testing the electrodes¹. A block diagram of the charge injection experiment and current-voltage curve is shown in Figure 4. The non-linearity of the current-voltage curve is direct evidence of space charge-limited current injection into the thin film. The bulk charge mobility of the film can be determined from the current-voltage data and can be subsequently compared to local mobility values determined with scanned-probe microscopy experiments².

Conclusions and Future Steps:

Gold interdigitated electrodes were fabricated using a simple photolithography procedure. These were implemented in space charge-limited current experiments involving a molecularly doped polymer, where space charge-limited current was directly observed as a non-linearity in the current-voltage curve. Using an established theory for space charge-limited current injection, the bulk charge mobility in the film can be determined.

Future work aims to incorporate the current-voltage curve experiment into a scanned probe microscopy experiment, where an oscillating cantilever charged with a frequency and amplitude modulated AC voltage will be brought over conductive thin films deposited on interdigitated electrodes operating in the space charge regime. Measuring the frequency shift as a function of the frequency modulation frequencies will yield a spectrum that can be used to quantitatively extract the charge density, charge mobility, and conductivity of the film. By modifying the amount of voltage applied to the electrode, measurements can be taken when the electrodes are operating under ohmic and space charge-limited current conditions, allowing for a robust test of the theory used to quantitatively extract key local optoelectronic properties.

References:

- [1] Silveira, W. R.; Marohn, J. A. Microscopic View of Charge Injection in an Organic Semiconductor. *Phys. Rev. Lett.* 2004, 93 (11), 116104. <https://doi.org/10.1103/PhysRevLett.93.116104>.
- [2] Murgatroyd, P. N. Theory of Space-Charge-Limited Current Enhanced by Frenkel Effect. *J. Phys. D: Appl. Phys.* 1970, 3 (2), 151. <https://doi.org/10.1088/0022-3727/3/2/308>.