Organic Photodetector Focal Plane Arrays Fabricated on Hemispherical Substrates by Three-Dimensional Stamping

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Abstract—We demonstrate a new approach to print organic photodetector arrays on 3D transparent plastic substrates. A 15×15 matrix with a feature size of 500 μm is fabricated, with dark current density is 3.1 μA/cm² at -1V.

Current imaging systems require complex, heavy and expensive compound lenses to project an object onto a flat focal plane array. In contrast, biological systems, as typified by the human eye, employ a hemispherical image plane, thus considerably simplifying the imaging optics. Unfortunately, printing high density focal planes on such curved surfaces with resolutions consistent with the demands of modern imaging systems has proven to be problematic using brittle and fragile semiconductors commonly used in focal plane arrays (FPAs). However, organic materials offer both high performance and the potential for low cost while being compatible with flexible or deformable substrates [1-4]. Hence, in this work, we demonstrate a novel stamping technique to pattern a 15×15 passive matrix array of organic photodetectors onto transparent hemispherical glycolised polyester (PETg) substrates.

Previously, cold welding has been demonstrated as a means to stamp metal contacts onto organic electronic devices [5]. Patterned, soft polymer (e.g. poly(dimethylsiloxane) -- PDMS) stamps and the substrates were pre-coated with the organic active material layers and capped by a thin metal “strike” layer of similar composition to that on the stamp. The two metal surfaces are brought into an intimate contact forming a metallic bond. Once the stamp is removed, the patterned metal is left behind, and the underlying strike layer is removed by exposure to an Ar plasma.

Here, we apply cold welding to 3D hemispherical surfaces. Masters with line-patterns of 50μm and 500μm feature sizes were generated using conventional photolithography. Fig. 1(a) showed a master formed on a silicon wafer using a negative-tone UV photoresist. A curing agent and PDMS prepolymer were mixed and placed in vacuum to remove bubbles. Then the prepolymer was poured onto the Si master and cured at 100°C to form an elastomeric stamp with line patterns duplicated from the master (Fig. 1). The mold held the PDMS stamp with line-patterns in a hemispherical shape by vacuum (Fig. 2). The PETg substrate was heated and deformed into a hemispherical shape by applying vacuum to a similarly shaped, second metal mold, followed by cooling to freeze the shape in place. 100Å-thick and a 50Å-thick Au layers were deposited onto the stamp and the deformed PETg substrate, respectively. When the two 3D surfaces are brought into contact, the vacuum is released from the mold holding the PDMS stamp, allowing the PDMS to relax. By this method, the stamp makes conformal contact with the substrate surface, thereby transferring the metal from stamp to substrate. The continuous metal strike layer on substrate was then removed in an Ar plasma. Fig. 3(a) shows 15 Au lines patterned on a PETg dome by this method. The line width of the sample is 500μm. A scanning electron microscope (SEM) image with 50μm feature size is shown in Fig. 3(b).

To complete the organic photodetector array on the preshaped substrate, we next deposited by vacuum thermal evaporation, organic photodetector materials onto the entire PETg surface. The photodetector employs an organic semiconductor heterojunction structure is as follows: anode/copper phthalocyanine 200Å (CuPc) donor/400Å C₆₀ acceptor/ 100Å bathocuproine exciton blocking layer/ 100Å Ag cathode [6, 7]. The 3D stamping technique was applied once more to pattern the top Ag cathode rows.
orthogonal to Au anode columns. In fabricating the full array, both the Ag and Au strike layers, as well as the intervening organic are etched in a single 5 min step as above. As shown in Fig. 3(c), a $15 \times 15$ array has a single device pixel area of $(500 \mu m)^2$. The dark current density at -0.5V is $1.1 \mu A/cm^2$, increasing to $3.1 \mu A/cm^2$ at -1V (Fig. 4). This leakage is comparable to that obtained to a CuPc/C$_{60}$ device of similar area fabricated on a flat ITO substrate using conventional shadow mask patterning [7]. Further device characteristics such as quantum efficiency and speed of response will be discussed.

In conclusion, we reported a new stamping technique to fabricate organic photodetector arrays on 3D plastic substrates. By utilizing a hemispherical focal plane that is, in principle, matched to the image plane of a spherical lens, most of the current imaging systems with flat FPAs can be considerably simplified. A $15 \times 15$ photodetector matrix with 500$\mu$m feature size has been demonstrated in this paper. Based on the patterning result of a single layer of metals, the approach has been shown to result in organic focal plane with feature sizes as small as 50$\mu$m.

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Fig. 1. Fabrication of a PDMS stamp from a silicon master with line-patterns.

Fig. 2. The procedures of patterning metal by 3D stamping technique. (a) An elastomeric PDMS stamp is held by the mold when applying vacuum. Same metal films are deposited on both stamp and deformed substrate. (b) After transferring metal from stamp to substrate and argon plasma etching, the metal has been patterned on the deformed substrate with designed features.

Fig. 3. (a) Picture of a PETg dome with 15 Au lines patterned. The width of a single line is 500$\mu$m and the spacing is 400$\mu$m. (b) SEM image for 50$\mu$m-wide Au lines. (c) Picture of a $15 \times 15$ matrix on a dome with feature size of 500$\mu$m.

Fig. 4. Dark current-voltage property of an organic photodetector on domed substrates (reverse bias).