A technique is presented for patterning the metal cathode of organic light-emitting diodes that allows for cathode engineering. The technique involves transferring pretreated and prepatterned metal on a substrate onto the surface of organic layers of the device by pressing, utilizing a difference in the adhesion strength of the metal between the substrate and the underlying organic layer. This cathode transfer technique is applied to fabricating a $20 \times 10$ passive matrix display with a pixel size of $250 \mu m \times 250 \mu m$. © 2002 American Institute of Physics.

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A significant reduction in the adhesion strength can result when a surface is treated with a SAM. For instance, it was reported\textsuperscript{11} that the work of adhesion is reduced from 20 000 to 3 \textmu J/m\textsuperscript{2} when the surface for a microelectromechanical system is treated with a SAM. For comparison purposes, the cathode was prepared by two different methods: the conventional thermal evaporation and the cathode transfer technique. In both cases, the aluminum thickness was 100 nm. The glass substrate with the cathode pattern was prepared by photolithographically patterning and then wet-etching the glass to a depth of 5–10 \textmu m to avoid unwanted contact due to glass deformation. The etchant was a 49% aqueous solution of HF diluted with a 25% aqueous solution of NH\textsubscript{4}F in a volume ratio of 1 to 16. The SAM used in the cathode transfer was tridecafluoro-1,1,2,2-tetrahydrooctyl-trichlorosilane (FOTCS). The treatment procedure is detailed in Choi et al.\textsuperscript{9} A significant reduction in the adhesion strength can result when a surface is treated with a SAM. For instance, it was reported\textsuperscript{11} that the work of adhesion is reduced from 20 000 to 3 \textmu J/m\textsuperscript{2} when the surface for a microelectromechanical system is treated with a SAM, a four orders of magnitude reduction. Aluminum was then deposited onto the treated glass. The aluminum-deposited substrate that had been patterned and treated with FOTCS was placed on the surface of the organic layers, and a pressure was applied by a hydraulic press to transfer the metal layer on the raised parts of the substrate to the organic surface. The applied pressure was 70 MPa at room temperature.

The device characteristics of the two types of OLEDs that had been fabricated identically, but with the cathode formed differently, are compared in Fig. 2 for the current-density–voltage characteristics. Also shown in the figure are the results of the device fabricated by cathode transfer (dark circle), compared to those of the device prepared with conventional thermal evaporation (open circle). The first type, indicated by open triangles, is due to the metal and the underlying Alq\textsubscript{3} surface. Shown in Fig. 3 for comparison is the emission spectrum of the luminescence. Here again, the spectra are nearly identical. These results show that the device fabricated with the cathode formed by the transfer technique is essentially the same as that fabricated with the cathode deposited by the conventional thermal evaporation. This conclusion opens the door to cathode engineering of OLEDs and other organic devices, such as organic transistors and lasers.

To apply the cathode transfer technique to a real display, we fabricated a passive matrix OLED with a pixel size of 250 \textmu m by 250 \textmu m. Twenty ITO anode lines, each 250 \textmu m wide, were formed by wet etching of ITO-coated glass, onto which the same organic layers as for the simple device described earlier were deposited successively. Ten cathode lines, each 250 \textmu m wide, were then formed by the cathode transfer technique. The passive matrix thus fabricated is shown in Fig. 4. The optical proximate photograph shows ten rows of aluminum cathode and twenty columns of ITO anode buried underneath the organic layers. Pixels are seen to be well-defined. Two types of defects are shown in the figure. The first type, indicated by open triangles, is due to the emitting OLED was fabricated using 4,4’-bis[2-(3-N-ethylcarbazolyl)vinyl]biphenyl BCyVBi codeposited with 4,4’-bis(2,2-diphenylvinyl)-1,1’-biphenyl DPVBi as emitting layer.\textsuperscript{10} ITO-coated glass (20 \Omega/\textsquare, 75 nm) panes were cut into 2.4×1.9 cm\textsuperscript{2} pieces and then cleaned successively by rubbing with a detergent, rinsing in deionized water, and cleaning by sonication in trichloroethylene, acetone, and then isopropyl alcohol. Onto the cleaned ITO glass, polyethylene dioxythiophene–polystylene sulfonate solution was spin-coated, followed by deposition of 4,4’-bis[N-(1-naphthyl)-N-phenyl-amino] biphenyl (NPB) by thermal evaporation to form the hole-transport layer, 50 nm thick. The emitting layer (50 nm thick) was then deposited, followed by the deposition of (8-hydroxyquinolinolino)aluminum (Alq\textsubscript{3}) for the electron-transport layer (20 nm thick).

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particles present in the ambient. Although all the layers were deposited in a glove box, the cathode transfer was carried out outside the glove box. The other type, indicated by filled triangles, was caused by uneven distribution of pressure. This latter type can be remedied if the pressure is equally distributed. The first type can be removed if the processing is carried out in a clean environment.

In summary, it has been shown that a device with a cathode formed by the transfer technique yields essentially the same device characteristics as the cathode formed by the conventional thermal evaporation. This fact opens the door to cathode engineering of organic devices such as OLEDs, organic transistors and lasers, which has been a long-standing key issue not yet resolved. It has been demonstrated that a passive matrix OLED display can be fabricated by the technique with individually addressable pixels. This simple and general patterning capability is an added feature of the cathode transfer technique, which allows for simultaneous cathode engineering and patterning. The essence of the technique lies in generating a large difference in the adhesion energy at two interfaces for efficient transfer of a metal onto an organic.