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Letter

Gate-modulation imaging of organic thin-film transistor arrays: Visualization of distributed mobility and dead pixels

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A B S T R A C T

We report on the application of the gate-modulation (GM) imaging technique in rapid and collective inspection of organic thin-film transistor (OTFT) array operations. The method allows visualizing charge carriers accumulated in the OTFT array by time-translational differential image sensing with the use of a charge coupled device (CCD) sensor. The feature makes it possible to visualize the dead pixels, broken channels, or distributed device performance in the OTFT array. We discuss how to correlate the spectroscopic information of GM signal with the device performance and how to use this technique in the collective inspection of OTFT arrays.

1. Introduction

Organic thin-film transistors (OTFTs) are being intensively investigated as potential key components for next-generation electronics that have large area, light weight, and mechanically flexible characteristics [1]. A possible future role of these devices is in so-called "ubiquitous electronics," in which any plastic surfaces are decorated electronically by arraying a large number of OTFTs to function as active backplanes for displays or sensors [2–5]. In practice, the number of pixels, each of which is composed of one or two OTFTs, should exceed 10^6–10^7 (e.g., it reaches 7×10^6 in the case of a 20 inch backplane with 200 ppi resolution). This feature now raises the additional challenge of developing a rapid and collective inspection technique for OTFT arrays composed of such large numbers of devices, as their inspection may take an extremely long time if conventional electrical measurements are used. This issue is particularly important for OTFTs because the development of an innovative solution-based manufacturing process is currently a crucial issue for manufacturing OTFT arrays [6,7], so that their rapid inspection is indispensable for process optimization. Infrared thermography is known as a non-contact optical inspection technique to locate defective areas in two-dimensional array devices. This technique can visualize thermal images due to Joule heating of short circuits by an infrared image sensor [8–11], but it is not able to detect dead pixels or distributed characteristics in OTFT arrays. Charge-modulation spectroscopy (CMS) is known as a technique to optically detect accumulated charge carriers in OTFTs [12]. This method involves observing slight changes in the optical absorption spectrum due to the charge accumulation by the lock-in technique with applying an AC gate bias. The obtained CMS spectra can provide microscopic information on the carrier states [13–15]. Recently, the use of a charge-coupled device (CCD) area image sensor was introduced into CMS [16,17], thus adopting the lock-in technique for each pixel detection. It has been demonstrated that this technique enables two-dimensional spatial mapping of charge carriers accumulated in an OTFT within a realistic time scale of about 10 min. However, this technique has not yet been applied to the collective inspection of OTFT arrays to find dead pixels or to investigate distributed device characteristics.

Here we report on the application of the non-contact CMS technique in rapid and collective inspection of OTFT array operations. We successfully imaged time-developing and equilibrium charge carriers by time-differential image sensing with the use of a CCD area sensor. By the observation of the equilibrium charges, it is possible to visualize the dead pixels or broken channels. We also demonstrate that the serial images for the time-developing charge images allow correlating the response time of the OTFTs with the field-effect mobility, thus enabling inspection of the distributed device performance of OTFT arrays. We discuss how to correlate the spectroscopic information from CMS with the device

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performance and how to use this technique in the collective inspection of OTFT arrays.

2. Experiment

Fig. 1a presents a schematic image of the experimental setup of gate-modulated (GM) imaging of an OTFT array. The measurements were conducted for the OTFT array fabricated on a quartz glass substrate. The device with bottom-gate bottom-contact (BGBC) configuration was composed of successive layers of semi-transparent Al (1 nm)/Au (6 nm)/Cr (1 nm) as the gate electrode, fluoropolymer (400 nm) (Asahi glass Co., Ltd., CYTOP CTL-809M) as the gate insulator, Au (30 nm)/Cr (1 nm) as the source/drain electrodes, and poly(3-hexylthiophene-2,5-diyl) (P3HT, 60 nm) as the channel semiconductor layer. Cr was used as an adhesion layer between the Au gate electrode and the quartz glass substrate. Al was used as an adhesion layer between the Au gate electrode and the fluoropolymer gate insulator. The gate and source/drain electrodes were patterned by vacuum sublimation with stencil masks. Thin-film formation of the P3HT on the hydrophobic fluoropolymer surface was conducted by the push-coating technique [6], in which a 1,2,4-trichlorobenzene solution of P3HT with a concentration of 0.1 wt% was dropped on the fluoropolymer surface and was compressed by a viscoelastic poly(dimethylsiloxane) (PDMS)-based stamp. The P3HT thin film was annealed at 373 K for 30 min after thin-film formation. The capacitance of the gate insulator was determined to be 4.1×10^{-9} F cm^{-2} from the capacitance measurement. For the measurements of GM images, the arrays were illuminated by using a halogen lamp with an optical band-pass filter as the light source, and the transmitted light was captured as an image by a CCD area sensor. Square-wave bias modulation (alternation between 0 V and V_G at 15 Hz) was applied at

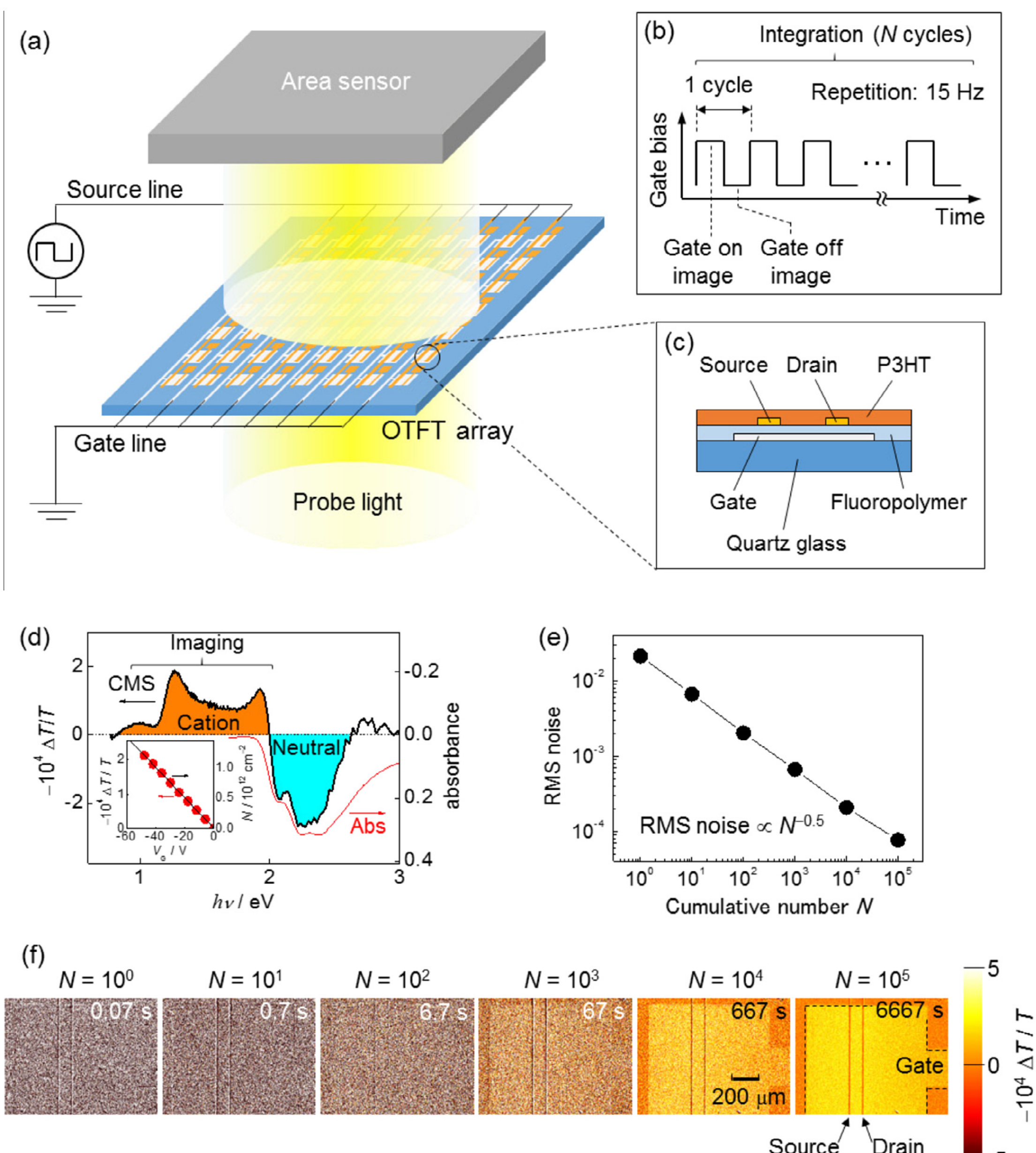

Fig. 1. Schematic of (a) experimental setup for GM imaging of an OTFT array, (b) gate-bias modulation applied for the array, and (c) cross section of each device in the array. (d) CMS (black line) and photoabsorption (red line) spectra measured for a P3HT OTFT. The inset shows the CMS signal at $h\nu$ = 1.24 eV plotted as a function of gate bias voltage. (e) RMS noise of a GM image plotted as a function of cumulative number N. (f) GM images at respective N. The area surrounded by the broken line in the image corresponds to the gate-electrode area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)