Abstract. Scanning gate microscopy (SGM) has been applied for a study of organic thin-film field effect transistor (OFET). In contrast to one-dimensional nano-material such a carbon nanonube or nano-structure such a quantum point contact, visualization a transport characteristic of OFET channel is basically rather difficult since the channel width is much larger than the size of the SGM tip. Nevertheless, Schottky barriers are successfully visualized at the boundary between the metal electrodes and the OFET channel at ambient atmosphere.

1. Introduction
There has been great interest in organic thin films as a key technology for new device applications, such as organic electro-luminescent display, and its drive transistors. However, there still exist many questions regarding the transport characteristics of these materials. For example, how the interface between the organic film and the metal electrode is connected electrically and/or where the carrier transport is restricted in the device. Such information is very important to understand the device characteristics, however a back gate, which covers the device entirely, is not sufficient to determine the local phenomena. In this study, we have applied a conductive cantilever of an atomic force microscope (AFM) as a “movable point gate” in a field effect transistor (FET) composed of an organic thin film. This technique is known scanning gate microscopy (SGM), however it is hardly applied for a transport study of organic materials.

SGM has been widely applied for investigations of semiconductor nano-structures such as quantum point contacts [1,2], quantum dots [3], and also carbon nanotubes [4]. Most of these studies have been carried in quasi-one dimensional systems since a restriction of current path is essentially important to obtain a SGM signal. However, we have applied the technique to two-dimensional organic-thin-film FET (OFET) so as to investigate the transport characteristics. In this paper, we have visualized an existence of Schottky barriers formed at the boundary between the metal electrodes and the organic material and also voltage drops in the channel simultaneously.

2. Experimental procedure
The sample consists of thin Au electrodes with 5 µm gap on a SiO₂/Si substrate. A copper phthalocyanine (CuPc) film of 250 nm thick is deposited by vacuum evaporator on the electrodes with a metal mask having an opening of 30 µm × 30 µm as shown in Fig. 1(a). Such a restriction of channel width is one of the important techniques for improving SGM response in a two-dimensional sample [5]. Moreover, this is also advantageous for reducing an photo-induced current because the
cantilever width can shadow the channel region from a radiation of a laser light used for AFM operation [5]. The schematic view of the electrical setting for SGM measurement is shown in Fig. 1(b). A PtIr-coated AFM tip was approached on the channel region. To obtain a SGM signal, we used interleave operation. A dc voltage \( V_{\text{tip}} \) is applied to the tip during interleave mode with lifting up the tip 30 nm from the surface and the tip scans a same trace of the sample surface. And then, a current across the channel \( I_{\text{sd}} \) is measured and stored in the AFM controller with changing the tip position. The SGM response is obtained by subtracting the current signals with and without \( V_{\text{tip}} \). A precise instrumentation of the measurement should be referred our previous paper [5].

![Schematic diagram of the experimental set up for the SGM observation.](image)

**Figure 1.** (a) Optical micrograph of the OFET sample. The CuPc was deposited on the thin Au electrodes using a metal mask. The channel region is emphasized by a dotted square. (b) Schematic diagram of the experimental set up for the SGM observation. The \( I_{\text{sd}} \) was stored in the controller during the scanning the tip over the channel. The back gate was grounded the measurement.

3. Results and discussion.

The CuPc-OFET showed normally on and \( p \)-type FET characteristics using the back gate as shown in Fig. 2. The field effect mobility is \( \sim 3 \times 10^{-4} \text{ cm}^2/\text{Vs} \) at ambient atmosphere [6]. The tip scanned across the source and the drain electrodes. A SGM line profile (top) and the corresponding AFM...
topography (bottom) are shown in Fig. 3. Since the SGM response in $I_{sd}$ was rather small comparable to the noise level, it was necessary to average the signal by 100-times repetition.

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{fig2}
\caption{The back-gate voltage dependence of the source-drain current. It suggests that the CuPc film shows normally on and $p$-type semiconductor.}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{fig3}
\caption{The line profiles of SGM signal (top), EFM response (middle) and the corresponding topography (bottom). The right electrode was biased +2V, and the left one was grounded. The SGM profiles are averaged with 100-times repetition. $V_{tip}$ of -10 V was applied during the interleave operation. The arrows indicate the corresponding vertical axis for the different curves.}
\end{figure}
The SGM response was obtained by subtracting the $I_d$ measured with and without applying the $V_{tip}$ in order to eliminate the photo-induced signal. Nevertheless, two large peaks are observed on the line profile of current variation ($\Delta I$). Comparing with the topographic profile, the positions of these peaks are corresponding to the edges of the Au electrode. Since the tip was biased a negative voltage, the electric field from the tip could modulate the local potential in the OFET channel. Considering the position of the peaks, it can be considered that the electrical field from the tip reduced a potential barrier at the interface between Au and CuPc [7]. Although such a boundary exists whole region on the Au electrode covered with CuPc film, it would be reasonable to consider that the carrier (hole) mainly injected from the narrowest region of the gap because of the large difference of conductivity between Au and CuPc. Therefore, these peaks result from the reduction of the Schottky barriers for both injection and emission of hole. Moreover, the peak height at the source (left) side is larger than the one at the drain (right) side. This means that the barrier height for the injection of holes into the channel is much larger than the height for the emission from the channel. It is also confirmed that the relationship is reversed with changing the polarity of the voltage on the right electrode [5].

The considerations are assisted by the electric force microscopy (EFM) response obtained during the SGM observation shown in the middle of Fig. 3. The EFM curve involves information of local voltage across the channel. Two large drops of EFM signal observed at the same positions of the peaks in SGM response. And then, the variation at the source (~50 %) is also larger than the one at the drain (~30 %). Consequently, the voltage dissipation inside the CuPc channel (~20 %) is smaller than the one at the CuPc/Au interface. Therefore, it becomes clear that the transport characteristics is mostly restricted by the Schottky barriers in the OFET.

4. Summary
An OFET consisting of a CuPc thin-film has been studied via SGM at ambient atmosphere. Two large peaks are obtained in the SGM line profile and the positions are corresponding to the edges of the Au electrodes. Moreover, large voltage drops are observed in the EFM response at the same positions. These results suggest that Schottky barriers at the interface between the Au and CuPc strongly restrict the hole transport in the OFET rather than the conduction of the CuPc film.

Acknowledgement
The authors would like to thank Prof. D. K. Ferry for help with the measurement techniques and Prof. J. P. Bird for kind discussion. This work was supported by the Sumitomo Foundation (060972), Graduate School of Science and Technology, Chiba University, and also supported in part by Chiba University 21COE program “Frontiers of Super-Functionality Organic Devices.”

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