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Mechanism analysis of photoleakage current in ZnO thin-film transistors using device simulation

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We analyzed the photoleakage current (Ilek) in ZnO thin-film transistors using device simulation. The dependences of Ilek on the location of light irradiation and drain voltage are reproduced by considering a Schottky barrier at the source contact using a two-dimensional device simulation. First, carrier generation is induced by light irradiation, the generated holes accumulate near the source contact, and some of these are captured in the donor traps. Next, the Schottky barrier becomes narrow, and electron injection increases via a tunneling effect. This discussion also suggests that the off-current is exceedingly low because the Schottky barrier prevents electron injection. © 2010 American Institute of Physics. [doi:10.1063/1.3502563]

Oxide-semiconductor thin-film transistors (TFTs), such as ZnO TFTs1 and amorphous In–Ga–Zn–O (a-IGZO) TFTs,2 are promising as next-generation giant microelectronic elements because they are transparent devices, exhibit high performances, and can be fabricated on plastic substrates at low temperatures. Therefore, ZnO TFTs have been actively studied and extensively developed for not only flat-panel displays3,4 but also image sensors5 and transparent electronics.6,7 However, ZnO TFTs are not completely transparent devices even in the visible spectrum from the viewpoint of electrical influences, and a photoleakage current (Ilek) is observed upon blue-light irradiation.8 The large value of Ilek cannot be explained using simple physics of the carrier generation and should be deeply discussed.9

In this research, we analyzed the mechanism of Ilek in ZnO TFTs using device simulation. The dependences of Ilek on the location of light irradiation and drain voltage are reproduced by considering a Schottky barrier at the source contact using a two-dimensional (2D) device simulation. First, carrier generation is induced by light irradiation. Then, the generated holes accumulate near the source contact, and some of these are captured in the donor traps. Next, the Schottky barrier becomes narrow, and electron injection increases via a tunneling effect. This discussion also suggests that the reason the off-current (Ioff) in ZnO TFTs is exceedingly low is because the Schottky barrier prevents electron injection even if the electron density is relatively high in ZnO films.

The device structures of the ZnO TFTs with light-shield layers to analyze the mechanism of Ilek are shown in Fig. 1.5 First, a Cr film is deposited as a gate electrode on a glass substrate, a SiNx film is subsequently deposited as a gate insulator using plasma-enhanced chemical-vapor deposition (PECVD) of SiH4 and NH3, and a SiOx film is sequentially stacked using PECVD of SiH4 and N2O. Next, a ZnO film is deposited as a channel layer using radio frequency magnetron sputtering at 150 °C, a SiNx film is sequentially stacked to protect the channel layer, and both films are simultaneously patterned using photolithography and dry etching. Afterwards, a SiNx film is further deposited as an interlayer insulator, an ITO film is deposited as source-drain electrodes, and a SiNx film is again deposited as an encapsulation insulator. Finally, a Cr film is deposited as a light-shield layer to restrict light irradiation within the channel layer. Three types of the light-shield layers are formed, where the entire, source-half, or drain-half regions of the channel layer are exposed to light irradiation. Here, the thickness of each film and gate width (W) and length (L) are indicated in Fig. 1.

The dependences of Ilek on the irradiation location and drain voltage (Vd) measured using actual ZnO TFTs are

![FIG. 1. (Color online) Device structures of the ZnO TFTs with light-shield layers to analyze the mechanism of Ilek.](image-url)

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shown in Fig. 2. The wavelength and power of light irradiation are 370 nm and 200 μW cm−2, respectively. Compared to the Si-based TFTs, an outstanding feature is that Ileak for the source-half irradiation is larger than that for the drain-half irradiation, as shown in Figs. 2(a) and 2(b). Another feature is that Ileak for the source-half irradiation increases as Vds increases, whereas that for the drain-half irradiation does not increase very much even if Vds increases as shown in Fig. 2(b).

The 2D device simulation is executed with carrier generation and tunneling effect models to analyze the mechanism of Ileak. Here, we assume a Schottky barrier at the source-half irradiation becomes narrower as Vds increases, whereas that for the drain-half irradiation is larger. Moreover, the Schottky barrier for the entire irradiation is narrower than that for the source-half irradiation, which is also narrower than that for the drain-half irradiation, whereas that without irradiation is terribly high. Moreover, the Schottky barrier for the source-half irradiation becomes narrower as Vds increases.

The mechanism of Ileak deduced from the measured and simulated results is shown in Fig. 6. First, carrier generation is induced by light irradiation. In the case of the source-half irradiation, generated holes are gathered and accumulate at the lower insulator interface near the source contact because the hole mobility is very low, and some of these are captured in the donor traps. Next, the positive charge lowers the energy band, the Schottky barrier becomes narrow, and electron injection is subject to a tunneling effect. Therefore, Ileak for the source-half irradiation is larger. Moreover, the Schottky
The effect is enhanced. Therefore, the leakage current for the source-half irradiation is smaller. Moreover, the electron injection via thermal excitation depends only on the height of the Schottky barrier and not the width. Therefore, the increase in $I_{\text{leak}}$ for the drain-half irradiation is small even if $V_{\text{ds}}$ increases.

This discussion also suggests that the reason $I_{\text{off}}$ in ZnO TFTs is exceedingly low is because the Schottky barrier prevents electron injection even if the electron density is relatively high in ZnO films. The Schottky barrier may become wider and prevent electron injection by applying a negative gate voltage ($V_G$) before the electron density is sufficiently reduced in ZnO films.

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11. See supplementary material at http://dx.doi.org/10.1063/1.3502563 for some questions about the mechanism of $I_{\text{leak}}$. The authors would like to thank Silvaco International and Silvaco Japan. This research is partially supported by a research project of the Joint Research Center for Science and Technology of Ryukoku University, a grant for research facility equipment for private universities from the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), a grant for special research facilities from the Faculty of Science and Technology of Ryukoku University, and a grant from the High-Tech Research Center Program for private universities from the MEXT.