Dependence of the Noise Behavior on the Drain Current for Thin Film Transistors

Ya-Hsiang Tai, Chun-Yi Chang, Chung-Lun Hsieh, Yung-Hsuan Yang,
Wei-Kuang Chao, and Huan-Ean Chen

***Abstract*—In this letter, a noise formula is newly proposed to calculate the low frequency noise for the three kinds of amorphous silicon, low temperature polycrystalline silicon, and amorphous indium-gallium-zinc oxide (a-IGZO) thin film transistors (TFTs). It is found that the noise behavior of the TFT depends on its drain current in a simple manner. Based on the analysis, the ratios of drain current to the noise level for these TFTs are compared. It reveals that a-IGZO TFT is the best candidate to be used in the active pixel sensor.**

***Index Terms*—Thin-film transistor (TFTs), low frequency noise (LFN), amorphous indium-gallium-zinc oxide (a-IGZO), active pixel sensor (APS).**

I. INTRODUCTION

RECENTLY, active matrix flat panel technology based on thin-film transistors (TFTs) have gained considerable significance in large area flat panel digital imaging applications in view of their large area readout capability. The pixel architecture progresses from passive pixel sensor (PPS) [1] to active pixel sensor (APS) [2]. In the APS circuits, the TFT is used to amplify the sensing voltage at the gate to the drain current by its transconductance to be read out. In the mean time, the noise current of the TFT is also gathered by the external readout circuit. Thus, many reports studied on the low frequency noise (LFN) properties of TFTs [3]–[7], which include the most popular TFT technologies, namely, amorphous silicon (a-Si), low temperature polycrystalline silicon (LTPS), and amorphous indium gallium zinc oxide (a-IGZO). In these reports, the noise spectrum is expressed in a function of gate voltage V_G and drain current I_D as

$$S = \alpha_H q/f * WLC_{OX}\left|V_G - V_T\right|^{I_D^2} \tag{1}$$

where is Hooge parameter [8], q is the elementary electron charge, f is the frequency, W and L are the channel width and length, respectively, C_{OX} is the gate dielectric capacitance per unit area, and V_T is the threshold voltage. The Hooge parameter is a good index to characterize and discuss the noise properties for different materials. However, since I_D of the TFT depends on V_G and the dependence varies with material [9], it would be complicated when the noise in the operation of APS circuit is considered. Thus, we would like to propose a new expression of the noise formula only depending on I_D. Thus, we can determine the most suitable TFT technology to be adapted in the view point of signal-to-noise ratio (SNR).

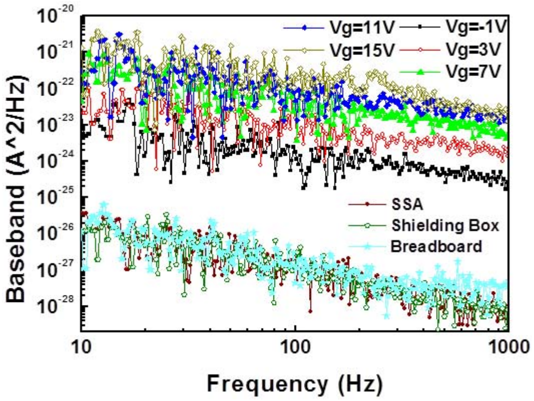

Fig. 1. Drain-current noise spectral densities of the a-IGZO TFTs and background noise measured at different V_G from −1 to 15 V and a constant V_D of 10 V.

II. EXPERIMENTAL PROCEDURE

The fabrication processes of the a-Si, LTPS, and a-IGZO TFTs in this letter are described elsewhere in [10], [11], and [12], accordingly. The channel widths of these TFTs are 20 μm, 15 μm, and 20 μm, respectively, and their channel lengths are all 5 μm. The gate and drain electrodes of the TFT are biased with lithium batteries in series and the source is virtually grounded by connecting it to the current preamplifier (Signal Recovery 5182) which converts I_D to a measurable voltage signal. The measurement setup, including breadboard that carries the device under test and the current preamplifier, is put in a shielding box to shield out the interference in environment. The voltage signal is linked out of the shielding box to a signal source analyzer (Agilent E5052B) with transmission lines.

III. RESULTS AND DISCUSSION

The LFN spectral densities for the a-IGZO TFT measured at different V_G from −1V to 15 V and a constant V_D of 10 V are shown in Fig. 1. It is observed that all the power noise spectrums follow the $1/f$ dependence. For the a-Si and LTPS TFTs, even though not shown here, the $1/f$ dependence of the

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Manuscript received October 18, 2013; accepted October 30, 2013. Date of publication January 2, 2014; date of current version January 23, 2014. This work was supported by the Industrial Technology Research Institute and National Science Council of China under Grant NSC 100-2628-E-9-21-MY. The review of this letter was arranged by Editor K. Uchida.

Y.-H. Tai is with the Department of Photonics and Display Institute, National Chiao Tung University, Hsinchu 30010, Taiwan.

C.-Y. Chang, C.-L. Hsieh, and Y.-H. Yang are with the Department of Photonics and Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu 30010, Taiwan (e-mail: kid78423.eo00g@nctu.edu.tw).

W.-K. Chao and H.-E. Chen are with the Display Technology Center, Industrial Technology Research Institute, Hsinchu 30010, Taiwan.

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Digital Object Identifier 10.1109/LED.2013.2291565

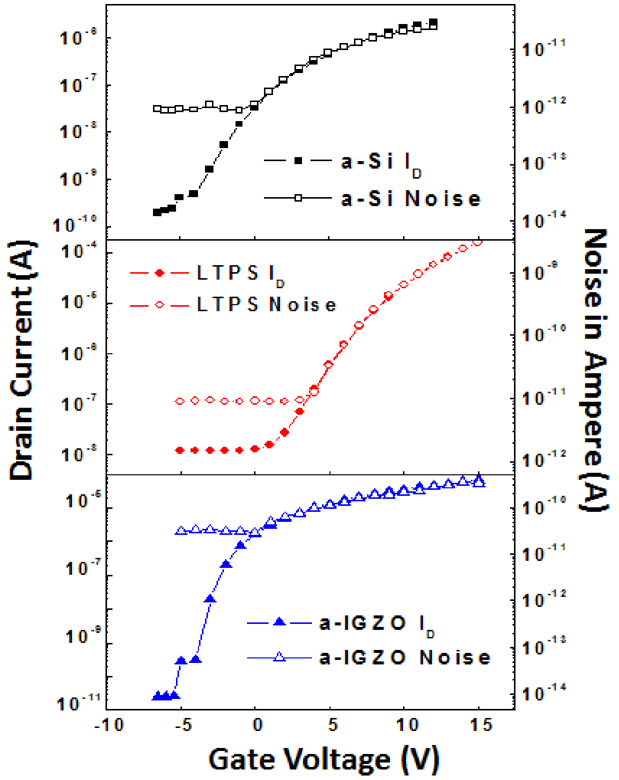

Fig. 2. Dependences of I_D and NiA on V_G for the a-Si, LTPS, and a-IGZO TFTs.

power spectrum and is also observed. The Hooge parameters α_H of the a-Si, LTPS, and a-IGZO TFTs are extracted to be 0.511, 0.595, and 0.00258, respectively, which are consistent with the previous reports [5]–[7]. According to these Hooge parameters, a-IGZO TFT is the device with the lowest noise, but how it can perform in APS is yet to be determined.

Here, we try to analyze the LFN behavior in another approach by integrating the noise power spectrum from 10Hz to 1 KHz and then taking the square root, as the following definition:

$$NiA = \sqrt{\int_{10Hz}^{1KHz} S df} \tag{2}$$

where *NiA* is a new index to represent the noise in ampere.

The noise spectrums at various V_G and V_D are measured, and the respective *NiA* are calculated and plotted against V_G together with I_D, as shown in Fig. 2. As can be seen, even though the graphs are in different scales, the curves of *NiA* coincide with the curves of I_D for all the devices, expect for the low V_G region where the measured noise level is limited by the noise background of the current preamplifier. It suggests the strong correlation between *NiA* and I_D.

Follow the Fig. 1, the background is lower the TFT noise. And thus, the measured noise above the background noise is discussed only. The background noise comproses the signal source analyzer (SSA), sheilding box and breadboad. And then, ignoring the noise background, the *NiA* and I_D are correlated in a simple manner of power-law dependence. In Fig. 3, the curves of I_D versus *NiA* are plotted in logarithmical scale for the three the TFTs. The linearity of the curves confirms that their correlation is universal for various TFTs, which is in the form of:

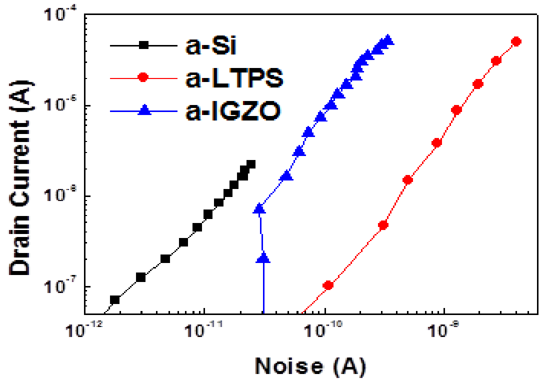

Fig. 3. NiA versus I_D with both axes in logarithmical scale for the three the TFTs.

$$I_D = K * NiA^m \tag{3}$$

where m and K are fitting parameters. The fitted values of m for the a-Si, LTPS and a-IGZO TFTs are 1.38, 1.69 and 1.77, respectively, and the fitted K values are 8.73×10^7, 7.59×10^9 and 2.61×10^{11}, accordingly.

Even the newly proposed expression describes the relation between *NiA* and I_D very well, we wonder if there is a theoretical ground for it. Thus, we compare the conventional noise expression in Eq. (1) with ours in Eq. (3). Putting the S in Eq. (1) into Eq. (2), the square of *NiA* can be written as:

$$NiA^2 = (\alpha_H q \ln(100)/WLC_{OX})(I_D^2/|V_G - V_T|) \tag{4}$$

Taking a close look at Eq. (4), the items in the first bracket are all constants for a device. Thus, as long as the $|V_G - V_T|$ in the second bracket is in the relation of power-law to I_D, *NiA* can be expressed by the only variable I_D on the right hand side of the Eq. (4). In this case, Eq. (4) can be reduced to the form of Eq. (3). Now the question comes to whether I_D versus $|V_G - V_T|$ is in the power-law relation. We assume that current of the TFT follows

$$I_D = 1/2\mu C_{OX} W\big/_L (V_G - V_T)^\beta \big/ V_{ref}^{\beta-2} \tag{5}$$

where μ is the field effect mobility and $V_{ref}^{\beta-2}$ is a constant and reference value. Substituting Eq. (5) into Eq. (4), we obtain:

$$NiA^2 = \left(\frac{\alpha_H q \ln(100)}{WLC_{OX}}\right) \times \left(\frac{1}{2}\mu C_{OX}\frac{W}{L}\right)^{1/\beta}\left(I_D^{2-1/\beta}\right) \tag{6}$$

Comparing Eq. (6) and the square of Eq. (3), the exponential term gives:

$$m = {}^{2\beta}\big/_{2\beta - 1} \tag{7}$$

The value of β plays an important role in the derivation above to get the m and K values of Eq. (3). They are extracted

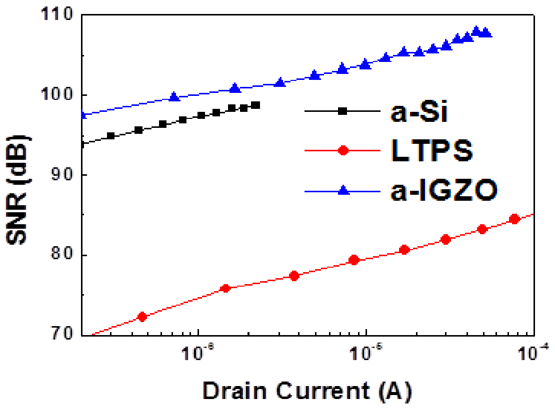

Fig. 4. The curves of SNR in dB scale versus I_D in logarithm scale.

from the $I_D - V_G$ curves of a-Si, LTPS, a-IGZO TFTs to be 1.38, 1.08, and 1.06, respectively, which correspond to the m values of 1.57, 1.86, and 1.89. These values are consistent with those values previously obtained from Fig. 3.

In the APS application, I_D of the amplifying TFT is measured to be the signal [2], while the noise current is also incorporated in the measurement. In this case, the best SNR that a TFT can provide is expected as the ratio of signal power to the noise power:

$$SNR = I_D^2/NiA^2 \tag{8}$$

Accordingly, we can transform Fig. 3 to Fig. 4, which shows the SNR in dB scale versus log (I_D) and provides us a better way to evaluate the noise behavior of the TFTs. As shown in Fig. 4, the IGZO TFT has SNR higher than 100dB, which corresponding to 16-bit of the analog-to-digital converter (ADC) system for the APS application. Furthermore, it is seen that a-IGZO TFT provides higher signal current to be more easily read out. As a result, the IGZO TFT is the best choice to be used in the active pixel sensor [13].

IV. CONCLUSION

In this letter, a new index for the noise behavior of TFTs is proposed to express the noise level in ampere. With this new index, the noise behavior can be described to be simple function of the drain current for the TFTs made of different materials. Considering both the current signal and noise levels, a-IGZO TFT is the most suitable device to be used in the APS applications.

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