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Physically-based simulation of zinc oxide thin-film transistors: Contact resistance contribution on density of states

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ABSTRACT

In this work, using a physically-based simulator, the density of states DOS is modeled to reproduce the experimental electrical characteristics of ZnO TFTs fabricated by Ultrasonic Spray Pyrolysis at 200 °C. The contact resistance was experimentally extracted from the ZnO TFTs and included into the simulation, in order to separate the metal–semiconductor interface contribution from the DOS. A comparison between the modeled DOS considering the contact resistance and disregarding it is also presented. It is proposed to consider the acceptor-like states and the tail-donor states, where the deep-acceptor states have approximately an exponential form and the distribution of tail-acceptor states are sharper than the distribution of tail-donor states. The simulated electrical characteristics reproduce very well the experimental data at different channel lengths. The use of physically-based simulation can be useful to model the DOS of Oxide semiconductor films in TFTs by reproducing the experimental data.

1. Introduction

Currently, oxide semiconductors have a wide application in Thin-film Transistors (TFTs) to enable low-cost electronics that replace the mature a-Si TFT Technology [1]. One of the bottlenecks in oxide TFT technologies is the material science and modeling of the devices. Since to modeling the electrical performance of the devices, it is necessary to know the approximated distribution of defects in the gap of the semiconductor (active layer), typically the so-called density of states (DOS) [2–5]. First of all, the material science in oxide semiconductors is still not completely understood. The role of impurities and defects distribution in electronic properties of most oxide semiconductors is still controversial [5–7]. Second of all, the calculation of the DOS in semiconductors materials is a complex work, since the extracted DOS reflects contributions of the main interfaces in the TFTs (metal–semiconductor and insulator–semiconductor). Typically, in order to extract a realistic DOS, the TFTs need to be free of parasitic effects related to low-quality interfaces (high contact resistance, gate leakage current effects, etc.) [2–4]. However, usually, having a metal-oxide semiconductor contact without interface states is difficult. Also, matching the semiconductor and metal work functions is nearly impossible [6]. It is important to say that the contact metallization technology in oxide semiconductors has not been explored extensively [6]. Finally, it is assumed that the DOS is homogenous throughout the active layer, there are no surface states and the DOS is constant through the time, however, in reality these are not true, making even more complex the DOS calculation [2–4]. Some methods have been reported to extract approximately the DOS, however, they require complex calculations or may introduce changes in the electrical characteristics of the Oxide TFTs. Also, they do not consider the contact resistance contribution on the DOS [5,8–14]. It is well-known, the contact resistance reduces the on-current, affects the off-current, the on/off-current ratio and masks the real value of the extracted electron mobility. Moreover, even some authors have reported higher values of subthreshold slope and a reduction in transconductance due to a high contact resistance [15–18]. Since the DOS is calculated from the electrical characteristics of the TFTs, for the above reasons, easily one can attribute some of the contact resistance effects to the DOS, resulting in an inaccurate modeled DOS and hence, an inaccurate modeled device.

The advantage of using physically-based simulators is that they provide information that is difficult or impossible to measure. Moreover, one can incorporate the necessary parameters in order to enable (simulate) the contribution of the different interfaces in the device (fixed oxide charge density, interface charge density, high contact resistance, etc.). The drawbacks of physically-based simulation are that it is necessary to know the relevant material parameters and device physics to be incorporated into the simulator, as well, numerical procedures must be implemented to solve the associated equations.

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