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Photo-Excited Charge Collection Spectroscopy

Probing the Traps in Field-Effect Transistors

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To the Lord Jesus and my wife Jihye

Seongil Im, 2013–01–10

Preface

Solid-state field-effect devices such as organic and inorganic-channel thin-film transistors (TFTs) have been expected to promote advances in display electronics based on low cost, high transparency, and flexibility. The operational stabilities of such TFTs are thus important, strongly depending on the nature and density of charge traps present at the channel/dielectric interface or in the thin-film channel itself. In particular, the illuminated display back panel is susceptible to the charge-trap-induced instability. As conventional tests for the device instabilities, gate-bias stress techniques are adopted in general, however, those appear limited in providing any satisfying information.

This book contains how to characterize these traps, starting from the device physics of field-effect transistor (FET). Unlike conventional analysis techniques which are away from well-resolving spectral results, newly introduced photo-excited charge-collection spectroscopy (PECCS) utilizes the photo-induced threshold voltage (V_{th}) response from any type of working transistor devices with organic-, inorganic-, and even nanochannels, directly probing on the traps. So, our technique PECCS has been discussed through more than ten refereed-journal papers in the fields of device electronics, applied physics, applied chemistry, nanodevices, and materials science, finally finding a need to be summarized with several chapters in a short book. In this book, Chap. 1 addresses the device physics of FET and the main principles of PECCS measurements, of which the detailed instrumentations are introduced in Chap. 2. From Chaps. 3 to 5 we address the applications of PECCS on organic, oxide, and nanostructure-based FETs while in the last Chap. 6 we discuss some weakness of PECCS and summarize the whole chapters as well. In the book, we distinguished the term TFT from FET, which may be a more extensive term including TFT, since we treated both thin-films and nanowires/or nanosheets for transistor fabrications and measurements.

Besides the coauthors, I acknowledge Dr. Kimoon Lee, presently at Tokyo Institute of Technology for his innovative initiations on PECCS, my graduate student Syed Raza Ali for the PECCS characterizations on ZnO nanowire-based field-effect transistors, Dr. Do Kyung Hwang, Dr. Ji Hoon Park, and Dr. Jiyoul Lee for the supports with their organic field-effect transistors, Dr. Jeong-Min Choi in Korean Intellectual Property Office for Patent examining.

Contents

Chapter 1
Device Stability and Photo-Excited Charge-Collection Spectroscopy

Abstract Important performance factors and basic device physics of organic or inorganic-channel thin-film transistors (TFTs) are addressed before introducing the photo-excited charge collection spectroscopy (PECCS), so that systematic and in-depth understanding on the device stability issues may be naturally drawn in focus. Device architecture, device physics, and general stability issues in TFT (or field-effect transistor) are thus introduced in the initial sections, and in the last section our photon-probing technique is explained along with its own device physics.

1.1 Thin-Film Transistor Architectures for Photon Probe Measurements

In general, there are four types of thin-film transistor (TFT) architectures: staggered, inverted staggered, coplanar, and inverted coplanar [1–4]. As shown below in Fig. 1.1, bottom gate TFTs with inverted staggered or inverted coplanar types are quite manageable for the photon probe measurements since they already have transparent windows above active semiconductor channels. In contrast, the top gate devices such as staggered or coplanar type need transparent gate electrodes for the photon measurements. In our experimentations of the following chapters, we usually take the inverted staggered type for bottom gate and the staggered type for top gate devices.

1.2 Device Physics and Equations for Thin-Film Transistors

1.2.1 Gradual Channel Approximation

As in the case of Metal–Oxide–Semiconductor Field-Effect Transistors (MOSFETs), TFTs have two different operational regimes depending on the drain voltage: linear

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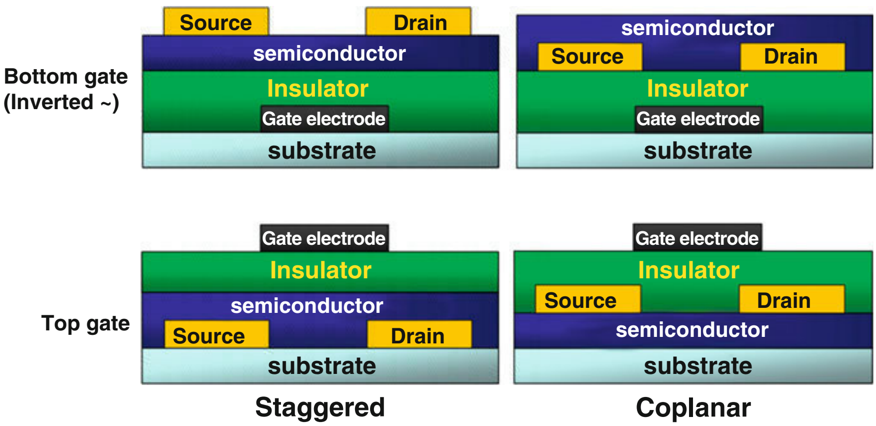
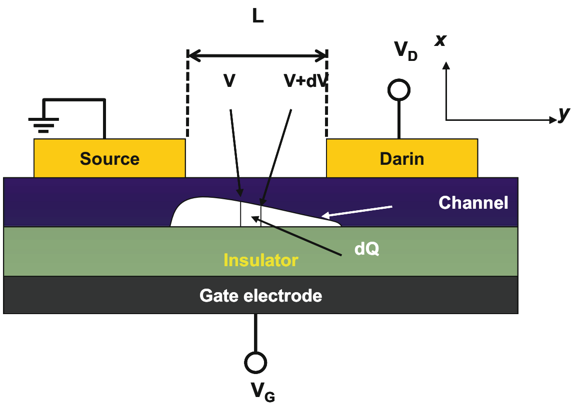


Fig. 1.1 The four types of TFT in device architectures: top gate and bottom gate (Inverted) types for staggered or coplanar TFTs

Fig. 1.2 Cross sectional view illustrating the gradual channel model



and saturation. A gradual channel approximation is assumed for the TFT channel, where y is the source-to-drain direction while z is the channel thickness direction perpendicular to the channel. The carrier density per unit area in the channel is the function of y-direction potential V_y caused by drain bias V_D. We illustrate the cross section of an inverted stagger type bottom gate TFT in Fig. 1.2 [5–7].

When the gate potential/voltage V_G overcomes the threshold voltage V_{th}, the accumulated mobile charge density Q_z is presented as the function of V_y and V_G in the following the formula

$$Q_z(y) = C_{ox}\left(V_G - V_{th} - V_y\right), \tag{1.1}$$

where C_{ox} is the capacitance per unit area of gate insulator (GI). Since the accumulated mobile charges are composed of majority carriers at/near the