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Editorial

Applications of Thin Films in Microelectronics

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Due to their versatility, thin films, which can be formed through many different approaches, are being used in various applications in microelectronics (e.g., transistors, sensors, memories, energy devices, coatings). Furthermore, the electronics industry has become the greatest beneficiary of thin-film technology, which contributes to the development of microelectronics by reducing the sizes of semiconductor devices. These thin-film devices are designed with outstanding mechanical deformability, sensitivity to multifunctional responses, and intelligent control capabilities.

This Special Issue consists of fourteen papers, highlighting the materials synthesis, fabrication processes, and emerging applications that address recent breakthroughs in microelectronic systems.

As alternative channel materials for thin-film transistors (TFTs) in the field of displays and transparent electronics, metal oxides have emerged due to their attractive electrical properties, strong oxidizing power, good chemical inertness, low cost, nontoxicity, and large surface area. The studies in references [1–3] suggested the use of indium-gallium-tin oxide (IGTO) for TFTs. They demonstrated relatively high mobility through various approaches compared to indium-gallium-zinc oxide (IGZO) TFTs, widely used as the backplanes of large-area flat-panel displays. Jeong et al. [1] investigated the effects of different annealing environments on the electrical performance and stability of IGTO TFTs; O_2 gas is the most suitable environment for the heat treatment of IGTO TFTs to maximize their performances. Cha et al. [2] also improved the electrical characteristics of IGTO TFTs using an oxidized aluminum capping layer (with a thickness of 3 nm), which can selectively remove the weakly bonded oxygen species acting as sub-gap tail states within the IGTO. Additionally, Kim et al. [3] examined that the 15 nm-thick (optimized thickness for positive bias stress (PBS) and the negative bias illumination stress (NBIS) stability) IGTO TFT exhibited the best electrical characteristics.

Furthermore, as a method of forming a functional thin film, solution-based sol–gel technology has attracted interest in various fields for state-of-the-art developments due to the accessibility of advanced materials with "tailor-made" functionalities through inexpensive and environmentally viable processing routes. One of the reasons for the continued advancement of sol–gel technology is the ease of control of the nanoarchitecture of the resultant materials and the plethora of different material constructs that can be developed. The method's versatility lies in the comfort of integrating sol–gel technologies with other forms of processing, allowing multidisciplinary approaches to occur with minimal effort. Hence, many efforts have been made to apply metal oxide materials, especially SnO_2 and ZrO_2, by sol–gel processing to maximize each material's advantages [4–9]. Lee et al. [4] showed the effect of annealing ambient on the electrical performance of SnO_2 TFTs fabricated by a sol–gel method. The annealing process plays a critical role in improving device performance because the formation of defect sites is determined according to the annealing condition. Hence, the authors showed that the SnO_2 films annealed in the air had the smallest crystalline-grain size but exhibited the highest field-effect mobility. This is because the free carrier concentration played a more critical role in realizing high-performance

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devices than the boundary-scattering minimization. In addition to the annealing process, electrical performance improvements can also be obtained through various doping; the researchers presented this possibility with magnesium (Mg) [5], yttrium (Y) [6], and lithium (Li) [7] doping, respectively. These dopants can successfully control free carrier concentration by suppressing oxygen vacancy formation inside SnO_2 thin films due to lower electronegativity and standard electrode potential (SEP). In addition, due to the nature of the sol–gel process, device performance can be influenced by the thickness and roughness of the active channel layer. From this point of view, Kim et al. [8] optimized the thickness of sol–gel-processed SnO_2 TFTs. The authors found that the precursor concentration affected the thickness and roughness in this study and identified the optimal condition through this result. Thus, in order to fabricate TFTs with good performance, the concentration of the precursor must be considered in addition to the annealing and doping conditions. Ha et al. [9] presented research results for a next-generation memory device; they fabricated and demonstrated resistive random-access memory (RRAM) using sol–gel-processed ZrO_2 thin films. RRAM is considered a promising candidate for next-generation memory cells because it has various advantages: low-power operation, a simple structure, and strong endurance and retention. Additionally, to fabricate an RRAM cell, the selector is required to solve the sneak path issue. A ZrO_2 thin film, which has been employed to increase field-effect mobility by improving the interface quality, was used for the selector of the RRAM device. These led to a decrease in leakage current and an increase in the resistance ratio of the high-resistance state (HRS)/low-resistance state (LRS) and successfully improved non-volatile memory properties, such as endurance and retention characteristics.

In addition, various studies using organic thin-film materials were conducted. Due to their versatile properties and simple preparation method, organic materials have been used in organic electronics, biological sensors, and renewable energy. Vergara et al. [10] investigated an organic semiconductor based on zinc 8-hydroxyquinoline (ZnQ_2) and tetracyanoquinodimethane (TCNQ), which can be used as a photoactive layer. They also demonstrated a flexible photo device using these organic films. Additionally, Park et al. [11] proposed a new perspective on designing polymer electronic devices. The authors fabricated high-performance TFTs using highly aligned nanowires of a diketopyrrolopyrrole (DPP)-based donor–acceptor-type copolymer (poly (diketopyrrolopyrrole-alt-thieno [3,2-b] thiophene), DPP-DTT). Moreover, a simple patterning technique using a polydimethylsiloxane (PDMS) mold was introduced to align polymer backbones in the desired orientation to achieve high-performance polymer electronic devices. Note that charge carriers are mainly transported along the chain backbones of polymers; thus, highly aligned polymer molecules are preferable to enhance the charge transporting properties. As a result, highly aligned polymer TFTs exhibited more than five times higher charge carrier mobility than spin-coated film-based devices.

Other exciting studies on ferroelectric thin films were carried out, as follows. Lee et al. [12] developed flexible ultraviolet (UV) photodetectors (PDs) for minimizing risk and damage from UV exposure in work and daily life activities. The authors designed simple, reproducible, and air-stable solution-processed hybrid organic PD devices on flexible substrates. These devices consist of a very thin ferroelectric co-polymer interlayer (a poly (vinylidene fluoride-co-trifluoroethylene)) between the optical active layer and cathode (a poly (9-vinyl carbazole)/zinc oxide nanoparticle). The proposed structure of the devices enhanced their charge-transfer performance via the ferroelectric–poling interface layer. The ferroelectric co-polymer also displayed a memory effect, resulting in a spontaneous input-to-output signal display. Song et al. [13] reviewed ferroelectrics based on HfO_2 film. This review mainly discussed critical points about the fabrication (e.g., atomic layer deposition (ALD), physical vapor deposition (PVD), pulsed laser deposition (PLD), and chemical solution deposition (CSD)) and applications (e.g., negative capacitor, ferroelectric random-access memory (FeRAM), ferroelectric tunnel junction (FTJ), and ferroelectric field-effect transistor (FeFET)) of ferroelectric HfO_2 films.

Additionally, Al_2O_3/GaN interfaces were assessed for power switching components with a high breakdown field, direct wide bandgap, radiation hardness, high electron mobility, and high saturation velocity [14]. In this research, the authors showed that the electrical conduction in GaN Schottky diodes improved with the application of post-deposition annealing, mainly due to the formation of positive surface polarity at both gate and surface areas in addition to the passivation ability of Al_2O_3 on the surface area.

As thin films technology is a multidisciplinary field, thin films studies have directly or indirectly caused the advancement of many new research areas. They will continue to play increasingly important roles in studying various problems of fundamental and technological importance. Therefore, by interacting with diverse perspectives, knowledge of the nature, functions, and new properties of thin films can be used to develop new technologies for future applications in microelectronics.

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