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The effect of sputter growth conditions on the charge transport and stability of In-Ga-Zn-O semiconductors

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ABSTRACT

Thin film transistors (TFTs) incorporating high mobility In-Ga-Zn-O (IGZO) semiconductors were fabricated and evaluated. The Ar:O_2 gas flow rates were varied during the sputter growth of IGZO layers, which had a substantial influence on the device performance and stability under negative bias stress (NBS) and negative bias illumination stress (NBIS). As the Ar gas flow rate is increased, the TFTs exhibit inferior performance and stability. Thin film analyses indicate that the relative content of oxygen deficient sites in IGZO increases with increasing Ar gas flow rate, which is accompanied with more pronounced device degradation under bias stress. Relatively high oxygen deficiency usually leads to the generation of excess free carriers in oxide semiconductors, which normally results in high field effect mobility. However a counter-intuitive decrease in mobility is observed in this work, which is suggested to originate from the overall decrease in IGZO film density as a result of elevated sputtering pressure at high Ar gas flow rates. It is conjectured that disruptions of conduction paths occur in low density IGZO layers, owing to the lack of overlap between metal 5s orbitals.

1. Introduction

The advent of thin-film transistors (TFT) based on oxide semiconductors such as indium gallium zinc oxide (In-Ga-Zn-O or IGZO) has allowed the recent commercialization of high resolution flat panel displays [1–4]. The types of product include active matrix liquid crystal display (AMLCD) and active matrix organic light emitting diode (AMOLED) panels that are incorporated in televisions, monitors, tablets and cell phones. TFT devices based on oxide semiconductors generally exhibit field effect mobility values near 10 cm^2/Vs in practice, while only 1 cm^2/Vs is obtained at best with conventional hydrogenated amorphous silicon (a-Si:H) [5,6]. Oxide semiconductors thus offer a higher degree of freedom regarding the design of displays with high pixel density (>200 ppi) operating at high frame rates (>120 Hz), and several industrial manufacturers are investing in the development of novel applications based on this technology, including mechanically flexible platforms [7,8].

While low temperature polycrystalline silicon (LTPS) is currently the material of choice for the fabrication of high mobility TFT backplanes (>50 cm^2/Vs) for high resolution mobile AMOLEDs, the manufacturing costs are relatively elevated owing to the use of expensive laser crystallization equipment. Also, the presence of grain boundaries and laser footprints makes it difficult to realize large area panels with uniform image quality. However, the high device performance allows the integration of gate driver circuits in the periphery of the display area, leading to the achievement of narrow bezels.

In this regard, the successful development of amorphous oxide TFTs with field effect mobility comparable to LTPS devices will provide a cost effective way to fabricate high resolution display matrices, which will also expedite the integration of driver circuitry in the backplanes especially for large size applications. The deposition of oxide semiconductors is routinely carried out by simple sputtering methods and the preservation of an amorphous structure over large substrate areas is a prime advantage of this class of material [9–11].

The present work consists of a study on the properties and stability of high performance TFTs based on amorphous indium gallium zinc oxide (In-Ga-Zn-O or IGZO), with respect to the sputter deposition conditions. While field effect mobility values of approximately 20 cm^2/Vs are achieved at relatively low Ar:O_2 gas flow rate ratios, the performance and stability under negative bias stress (NBS) and negative bias illumination stress (NBIS) are compromised as the Ar flow rate increases. The relatively high content in oxygen deficient sites results in

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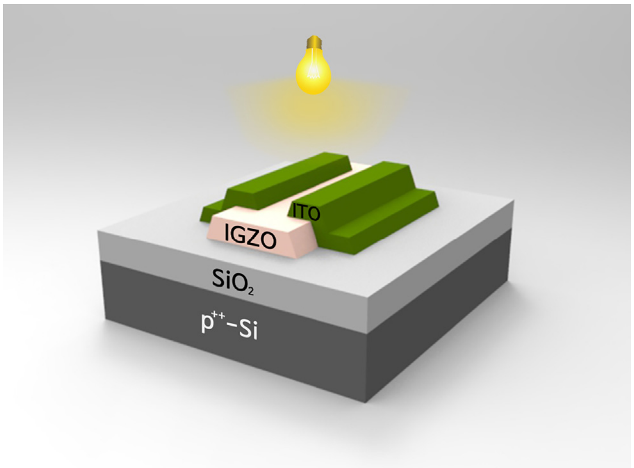

Fig. 1. Schematic diagram of the TFT structure used in this work.

inferior device stability, however the drastic decrease in field effect mobility appears to originate from the decreasing IGZO film density.

2. Experimental procedure

TFT devices were fabricated on highly doped p-type Si substrates with a thermally grown 100 nm-thick SiOx dielectric, which is used as the gate insulator. IGZO films were then sputter deposited to a thickness of 30 nm, using a 2-in. IGZO target with an atomic composition ratio of In:Ga:Zn = 2:1:2. The Ar:O_2 gas flow rate ratio was varied, of which the values were 3:5, 15:5, 30:5 and 45:5 sccm. The corresponding working pressure values were 4, 8, 12 and 16 mTorr, respectively. The active islands were formed using shadow masks. Indium tin oxide (ITO) films were then sputter deposited to form the source-drain electrodes, again using shadow masks. The final devices were annealed at 250 °C for 1 h. The initial TFT transfer properties were evaluated using a Keithley parameter analyzer. The devices were then subjected to NBS and NBIS. The gate voltage (V_G) and drain voltage (V_D) applied for the negative bias stresses were −20 V and + 10 V, respectively. For NBIS, a light source with a luminance of 1500 lx was used on top of the devices. Fig. 1 depicts a cross-sectional schematic diagram of the final device structure.

The chemical bonding states of oxygen in the IGZO layers grown under different Ar:O_2 ratios were examined by X-ray photoelectron spectroscopy (XPS, K-Alpha model, Thermo Fisher Scientific) with a pass energy of 50 eV was performed in order to study the chemical bonding states of nitrogen and oxygen anions, using a monochromatic AlKα X-ray source. Before performing the XPS analyses, the surface of each film was sputtered with a low energy Ar^+ ion beam (200 eV) for 30 s in order to minimize any possible contamination. A relatively small amount of carbon was intentionally left so that the peak position could be calibrated with respect to the C 1s peak, of which the standard binding energy is about 284.5 eV. This amount of carbon does not affect the XPS analysis of the elements of interest. An electron flood gun was used to neutralize the positive charge from the Ar^+ ions.

The IGZO film microstructure and density were evaluated for each growth condition by X-ray diffraction (XRD) and X-ray reflectometry (XRR) using a D8 Discover Super Speed (Bruker AXS) [12].

3. Results and discussions

Fig. 2 consists of the initial transfer characteristics of the IGZO devices, with the semiconductor layer grown under different Ar:O_2

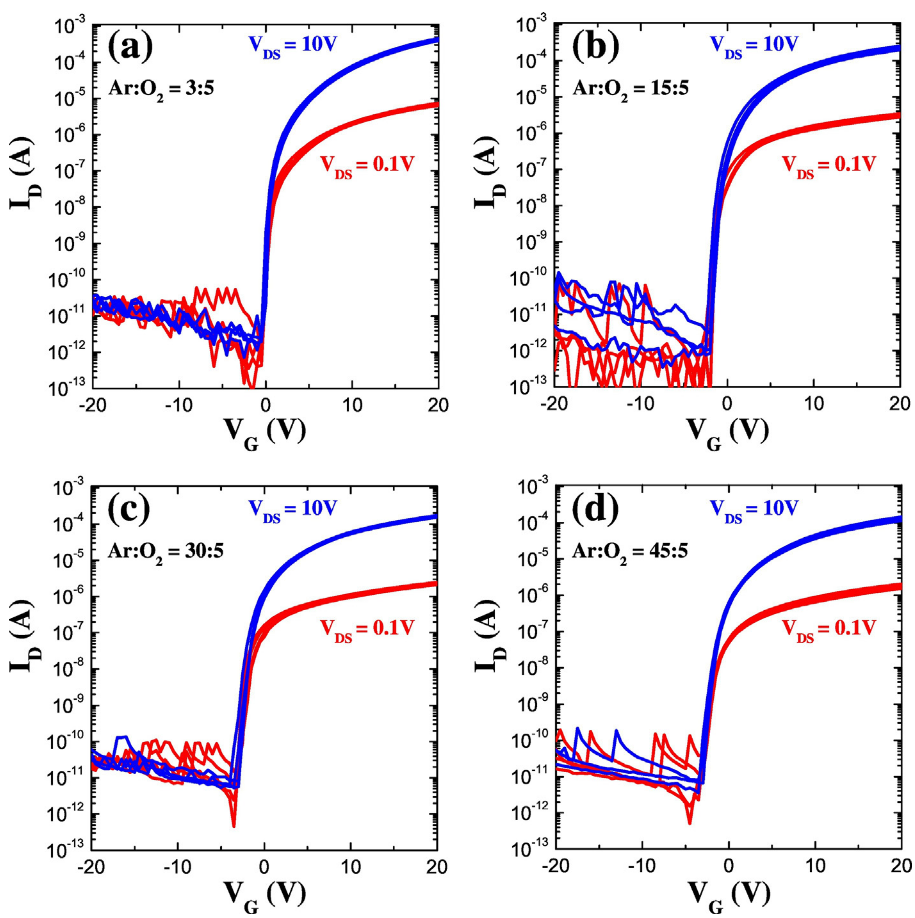

Fig. 2. Initial transfer characteristics of the TFTs with the IGZO layer grown with (a) Ar:O_2 = 3:5, (b) Ar:O_2 = 15:5, (c) Ar:O_2 = 30:5, and (d) Ar:O_2 = 45:5 sccm.