Oxide Semiconductors for Flexible Electronics

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The attraction of flexible electronics on plastic substrates is the potential for lower manufacturing cost and a package that is thinner, lighter, more robust, portable and formable. Applications targeted include LCD, OLED, and electrophoretic displays, RFID tags, and inexpensive electronics in general. However, the challenge for flexible electronics is either to develop a plastic substrate to accommodate existing high-temperature processing or find new materials that are compatible with available low cost, more temperature-sensitive plastic substrates. In fact the properties needed for a high-temperature plastic substrate are formidable: dimensional stability (low shrinkage), low thermal expansion, high optical clarity (displays), high use-temperature (e.g., ~ 300° C for processing a-Si TFTs), and chemical durability. Further, because plastic substrates are highly permeable to air and water vapor, they will also need barrier and encapsulation technology. Even if such a substrate technology existed today, it would only be compatible with low temperature Si (amorphous and nanocrystalline) and organic semiconductors. But their mobility is typically < 1 cm^2/V-s, inadequate to meet the demands of future OLED displays and RFID tags. Both higher performance criteria for new applications and the goal of enabling flexible electronics on inexpensive plastic substrates have motivated us to search for alternative semiconductors. In particular we have focused on oxide semiconductors.

Oxide semiconductors typified by ZnO, In_2O_3, and SnO_2 are ubiquitous in electronics as transparent conducting electrodes [1]. Intrinsic defects, such as interstitial metal atoms or oxygen vacancies, render them n-type or electron conductors. Undoped oxide films with electron carrier concentrations greater than 10^{20} cm^{-3} can have mobility more than 50 cm^2/V-s [2], even though their structure is nanocrystalline or amorphous! However, the earliest attempts to demonstrate field effect TFTs in thin film SnO_2 or single crystal ZnO gave somewhat disappointing results [3,4] (μ ~1 cm^2/V-s), especially compared to CdS TFTs, popular at that time. Subsequently, with advances in Si-technology, research activity on oxides TFTs essentially stopped, that is, until recently.

Some of the renewed interest in oxide TFTs, especially ZnO [5,6,], has been motivated by its optical transparency. Transparent electronics, with as yet unspecified applications, is certainly captivating. However, transparency could prove to be a practical advantage in active matrix schemes to drive displays, where TFTs do reduce light output per pixel or the "aperture", in proportion to the fractional area that they occupy. In this regard a transparent ZnO TFT could increase the effective aperture and would be light-insensitive. This could be important in OLEDs, where the pixel design requires multiple TFTs for stable current operation [7]. Principally, our interest in these oxides is their compatibility with plastic substrates and their potential for superior performance. Although a number of different synthesis methods for ZnO TFTs are possible, we have chosen magnetron sputtering because of its excellent control, reproducibility, and ease of scale-up for manufacturing. All of our sputtered ZnO TFTs were on unheated substrates.

For sputtered ZnO, its film resistance can be controlled over ten orders of magnitude (10^{-2}-10^{8} ohm cm) by adjusting the partial pressure of oxygen metered with Ar during sputtering. For ZnO films with resistivity

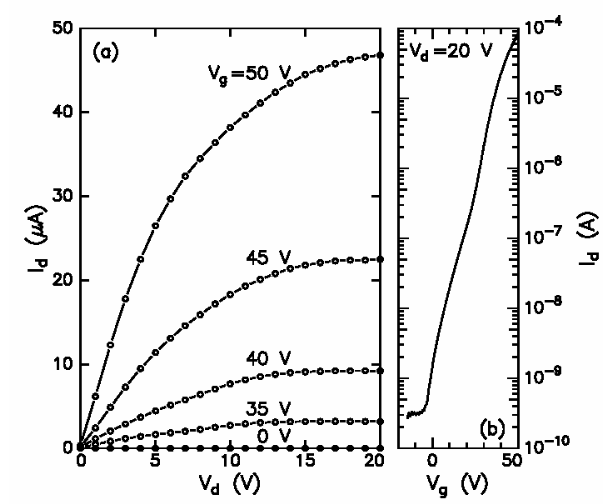

Fig. 1 ZnO transistor output and transfer charateristics for ZnO TFT on 100 nm SiO_2 gate oxide; W/L=10 with L=20 μm.

less than 1 ohm-cm, we measured Hall mobility of 10-25 cm^2/V-s. Because low device off-current is a performance requirement in a TFT, we fabricated our ZnO channel with a typical resistivtiy > 10^3 ohm cm. Fig.1 illustrates transistor characteristics for one of our earlier ZnO devices [6] on a thermally grown, SiO_2 gate dielectric. This particular device had μ=1.2 cm^2/V-s and on/off~10^6. While these performance parameters are better than or comparable to amorphous Si and organic TFTs, it is notable that this device requires a rather large gate voltage swing (~40 V) to switch from the off-state to ~ 10μA, needed, e.g. to drive an OLED pixel. A high threshold voltage, in the range 10-20V, is partly responsible.

To be attractive for current and future applications, ZnO TFTs must operate stably at lower voltage. This presentation will discuss progress that has been made in ZnO TFT performance with alternative gate dielectrics such as Al_2O_3, where threshold voltages ~ 1 V were attained with mobility exceeding 20 cm^2/V-s. Results for In_2O_3 and SnO_2 TFTs will also be discussed.

References

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