Production of metal oxide thin film transistors using a back channel etch process

Introduction

The demands for active matrix liquid crystal displays has to rise continuously. High resolutions of 3840 × 2160 pixels, frame rates of 240 Hz and sizes of 70 inches has to be achieved [1]. As a result, high performance thin film transistors are needed for a functional display. A major problem is the insufficient charge carrier mobility of semiconductors. The required mobility of \( \mu = 3 \text{ cm}^2/\text{Vs} \) is not reached by most of the materials, making them retire for display production [2]. For this reason, amorphous metal oxide semiconductors are of particular interest. This material has a sufficiently high charge carrier mobility of \( \mu > 10 \text{ cm}^2/\text{Vs} \) [2]. Further advantages are the large-area-deposition and the possibility to deposit from the liquid phase [3]. This work deals with the development of a process for amorphous metal oxide thin film transistors in the back channel etch structure. Thereby a metal oxide semiconductor called iXenic® S is used. The material iXenic® S based on indium oxide and is deposited from the liquid phase.

Experimental details

During testing of the process three different process variants have been developed, which are titled with process A, B and C. First Process A will be explained.

The used substrate is a boron-doped p-silicon wafer, which has a 200 nm thick thermally oxidized layer of silicon dioxide. The cleaned substrate is subjected to UV-ozone treatment, to remove organic residues, and to improve the adhesion. Then 100 µl of iXenic® S1201 are applied by spin coating (3000 RPS, \( t = 30 \text{ s} \)). The precursor is heat-treated for 10 min at 260 °C to carry out a pre-annealing. An etching mask is made by photolithography, for which the positive resist AZ1515H is used. Then the semiconductor structure is etched with oxalic acid (\( c = 1 \text{ mol/l} ,T = 40 ^\circ \text{C} \)). At a temperature of 350 °C the precursor is converted into metal oxide (\( t = 1 \text{ h} \)). The next step contains the deposition of two metal layers by DC sputtering. On a 36 nm thick molybdenum layer (\( \rho = 3 \cdot 10^{-4} \text{ torr} ,P = 1000 \text{ W} \), \( t = 60 \text{ s} \)), a 45 nm thick indium tin oxide layer is deposited (\( \rho = 5 \cdot 10^{-4} \text{ torr} ,P = 500 \text{ W} \), \( t = 112 \text{s} \)). The source and drain contacts are formed by photolithography. The etching process with aluminum acid should be carried out with caution, since the metal oxide may be damaged after
the molybdenum layer has been corroded by the acid. Finally, the sample is post-annealed \((t = 30 \text{ s}, \ T = 350 \ ^\circ \text{C})\). While producing samples with process A the conversion temperature has been increased from 350 \ ^\circ \text{C} to 370 \ ^\circ \text{C} and 400 \ ^\circ \text{C} in order to study their influence.

Basically Process B includes a lot of identical steps to process A. The difference between the processes is the way of annealing. After the deposition, the precursor is completely converted into the metal oxide \((T = 40 \ ^\circ \text{C}, \ t = 1 \text{ h})\) without a pre-annealing-step. Thereafter, the process will continue as usual. After the patterning of the metal oxide, the metal layers are applied by sputtering. Finally, the structuring of the contacts and the post-annealing takes place.

Process C is based on Process B, whereby the order is changed. After the coated metal oxide has been converted, the metal layers are deposited and patterned instead of structuring the metal oxide. Furthermore, an extra annealing step before metal structuring is added to make the ITO more stable against the oxalic acid. In contrast to Process A the last step is the patterning of the metal oxide.

Results and discussion

During the preparation of samples with the two-stage annealing step (process A), the influence of the conversion temperature should be studied. It is found that the variation of the temperature during the conversion has significant effects on the turn-on voltage, the current flow and motility. Jeong et al suggest the rise of oxygen vacancies with the conversion temperature [4]. By an increased concentration of oxygen vacancies, an increase in carrier concentration is caused. The greater charge carrier concentration leads to a shift in negative direction of the turn-on voltage and an increase in mobility [5]. Figure 1 shows the transfer characteristics of samples of different conversion temperatures and reflects the assumed trend. By the increase in charge carrier concentration, the increased current flow with the conversion temperature can be
Another approach suggests that parts of the amorphous phase of the metal oxide can be converted at a higher temperature in crystalline states [6,7]. The increased stability during contact patterning could cause less damage to the metal oxide and so permit a higher current flow. An ideal conversion temperature of 370 °C was determined for this BCE process.

In Figure 2 a transfer characteristic of a sample that has been made with one-stage annealing step is shown. Note the insufficient electrical properties. In addition, a AFM recording after the metal structuring was taken. On the image impurities are visualized, which are probably photoresist residues. In the production of a second sample, an additional purification step is added after the metal structuring, whereby the residues are reduced and electrical characteristics improved. A relationship between current flow and photoresist residues is suspected. Photoresist residues can cause deep defect levels in the band gap of the metal oxide, whereby charge carriers are captured. The impurities in the metal oxide-molybdenum boundary layer can thus lead to a deterioration of the charge carrier path, resulting in low current flow. Consequently, it is necessary to remove the photoresist completely after the metal structure while producing with Process A and B.
In the preparation of samples with process C the sequence of the structuring has been changed. The transfer characteristic shows an improvement of the electrical properties. The influence of the process sequence may be due to the different degree of coverage of the metal oxide with photoresist. A directly deposited Molybdenum layer on the converted metal, creates a metaloxide-molybdenum boundary layer without impurities. Photoresist residues are not present in this area, because the patterning of the metal oxide is carried out after the structuring of the electrodes. It is believed that the carrier path is not affected by non-existing impurities, whereby the increased current flow occurs.

The comparison of process A and B shows that a one-stage annealing process has advantages over the two-stage annealing. The metal oxide is already fully converted in Process B during patterning. Thus, it is more stable when the photoresist is removed with acetone. When using process A, however, the metal can be damaged by the acetone, which can cause a lower electrical performance. For this reason, the one-stage annealing step is preferable. In addition, the importance of structuring sequence by comparing Process B Process C has been proved.

In this work, important information about the production of metal oxide transistors in the backchannel etch structure could be obtained. The advantages of the one-stage annealing step were identified. In addition, an ideal conversion temperature of 370 °C was observed. If the metal oxide is first patterned and then the electrode, a complete removal of the photoresist is very important. If the metal layers are structured before
the metal oxide a pure molybdenum-metal oxide boundary layer can be achieved, causing a better electrical performance.

References


