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Electrical characterization of sputtered ZnO:Al films with microprobe technique

Andrea Crovetto(1), Daniel Kjær(1,2), Dirch H. Petersen(1), Jørgen Schou(3) and Ole Hansen(1,4)

(1) DTU Nanotech, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark
(2) CAPRES A/S, Scion-DTU, DK-2800 Kgs. Lyngby, Denmark
(3) DTU Fotonik, Technical University of Denmark, DK-4000 Roskilde, Denmark
(4) CINF, Center for Individual Nanoparticle Functionality, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark

Tel.: +45 4525 5845; fax: +45 4588 7762; email: ancro@nanotech.dtu.dk

Determination of sheet resistance, carrier density and mobility in transparent conductive films is typically done with the van der Pauw technique, a rather destructive macroscopic method requiring special sample geometry or dedicated sample patterning. In this work a miniaturized non-destructive four-point measurement system developed at CAPRES A/S is employed to evaluate the electrical properties of transparent conductive ZnO:Al films, with high spatial resolution, accuracy, and speed of measurement. n-type ZnO:Al films are deposited on fused silica substrates by DC magnetron sputtering using a ZnO/Al_2O_3 ceramic target (98/2 wt%). The process temperature is varied between room temperature and 250°C. Process pressure and oxygen content in the Ar-based sputtering atmosphere are varied in the range 3-8 mtorr and 0-2% respectively. Resulting film thicknesses are between 80 and 400 nm. Films deposited at room temperature are characterized before and after an additional annealing step in air, whereas films deposited at elevated temperatures are characterized as deposited. In this way the effect of deposition temperature is compared to the effect of temperature and duration of the post-deposition annealing step. We focus in particular on the determination of electrical properties by means of a semi-automatic system utilizing a microscopic Hall-probe with collinear cantilever electrodes placed parallel to, and within a few µm from a sample edge. By combination of multiple 4-point measurements obtained in one location the electrical properties are extracted and the resulting measurement errors are below 1% for sheet resistance and 4% for carrier density and Hall mobility. Such a setup eliminates the need for *ad-hoc* sample geometries and allows line scans along a cleaved edge of the sample for determination of the electrical properties of interest with a spatial resolution below 100 µm. This can be useful in characterizing spatial electrical non-uniformities in the films, often arising in correspondence to the erosion pattern on the sputtering target. Another advantage is that the film is only marginally affected by the contact with the micro-probes. The electrical properties measured by the microprobe system are compared to ordinary four-point probe measurements and to spectroscopic ellipsometry fits in the spectral region of free-carrier absorption. To complement the electrical analysis, optical properties are characterized by spectroscopic ellipsometry and UV-vis-NIR transmission spectroscopy; composition is evaluated by X-ray photoemission spectroscopy (XPS); grain size and morphology are investigated by scanning electron microscopy (SEM); and surface topography is characterized by atomic force microscopy (AFM). The most appropriate choice of deposition and post-deposition process parameters is discussed for application of ZnO:Al films as window layers in thin-film chalcogenide solar cells, where film resistivity should be minimized while maintaining a high transmittance in the spectral region of strong solar irradiance.