Study on the thermal-diffusion-type Ga-doping in ZnO nanoparticles aiming for TFT channel application

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Using semiconductor nanoparticles (NPs) is one of the attractive techniques to obtain channel layer of thin-film transistors (TFTs) [1], because of its exceptional properties. Recently, by using the ZnO-NPs synthesized in our laboratory [2], not only n-channel but also p-channel back-gate TFTs on Si/SiO_2 substrates were successfully demonstrated by using the simple and easy spraying method [3], providing high expectation to realize complementary logic circuits using ZnO-based NP-layers. However, the resistivity of NP-layer was too high, preventing the progress of TFT performance. In this study, the thermal-diffusion-type Ga-dopings in n-type ZnO-NPs were investigated with different ambient gases to obtain low resistive NP-layers aiming for TFT channel application.

ZnO-NPs were synthesized using an arc-discharge-mediated gas evaporation process. For synthesizing of n-type ZnO-NPs, conditions with a chamber pressure of 610 Torr and the arc current of 20 A was used. The Ga-doping was carried out by mixing 0.2 g of ZnO-NPs with 0.06 g of Ga_2O_3-NPs (Sigma-Aldrich Co Ltd.) and thermally treated in the ambient of open-air, N_2 and O_2 atmosphere with the temperature of 800 °C for 60 min. Particles were dispersed in pure water by ultrasonic homogenizer with the power of 150 W for 3 min. 7 ml of dispersions with a median size of 240 nm were sprayed onto heated quartz substrate (hot plate temperatures was 500 °C) with 5 s intervals for ~15 min. A basic illustration of the spray method showed in Fig. 1.

Fig.2 shows the XRD pattern showing well-known (100), (002) and (101) peaks were observed for all samples. The calculated crystallite sizes by Scherrer's equation in (100) spectra are 41 nm, over 100 nm, 42 nm and 54 nm from the bottom in Fig. 2. The electrical resistivity (Fig. 3) of the ZnO-NP layers falls to a minimum value of approximately 200 Ω/sq by thermal treatment in air, while it decreased only a little in N_2 or increased in O_2. One possible reason for the dramatic reduction of resistivity by thermal treatment in air is the decrease of the grain boundary density. From XRD, a noticeable increase of crystallite size was detected only from the NPs thermally treated in air. Another possible reason is Ga incorporated into ZnO-NPs with substituting for Zn; i.e. Ga-doping was achieved effectively. In increasing the crystallite, it needs the movement of atoms. Due to the similarity of the atomic radius between Ga and Zn [4], it can be presumed that the substitution of Zn and Ga occurred with higher possibility than others. Details are not cleared yet, but it was investigated that the existence of moisture in the ambient gas tended to cause Zn-related defects making a substitution with Ga easier [5].

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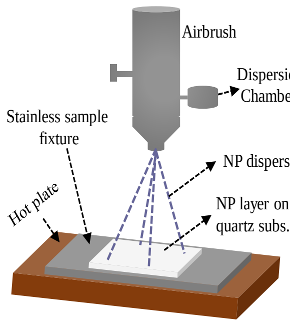

Fig. 1 Illustration of physical spraying process.

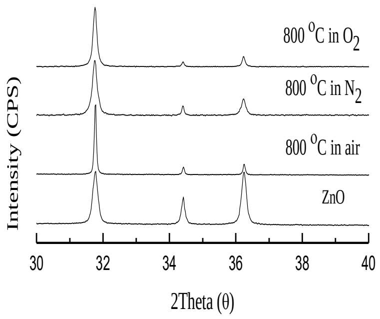

Fig. 2 XRD patterns for thermally treated ZnO NPs films

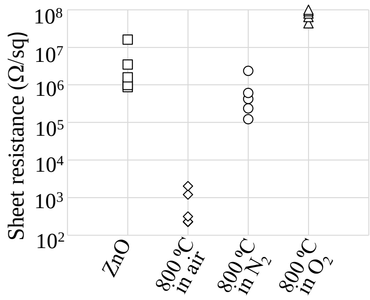

Fig. 3 Resistivity distribution curve for each sprayed NPs layers

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