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Formation of high electron mobility indium oxide film by high-power impulse magnetron sputtering

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An indium oxide (InO_x) is a metal oxide material with high electron mobility because its conduction band is mainly formed by the 5s orbitals of indium and spreads spherically and overlaps. So far, high-mobility transparent conductive oxide (TCO) or high-mobility thin film transistor (TFT) using InO_x films as a channel layer have been reported [1][2]. The mobility increases due to polycrystallisation of InO_x or an increase in domain size.

High-power impulse magnetron sputtering (HiPIMS) is an ionized sputtering method that applies high voltage pulses with a short pulse width of several tens of microseconds to the target, generating a high-density plasma (10^{12} - 10^{13} cm^{-3}). The high-density plasma promotes the ionization of sputtered metal and noble gas atoms in the gas phase. The ion bombardment effect is expected to enhance the crystallization of InO_x thin films. In addition, the pulse duty ratio is below several %, which enables the low-temperature deposition.

In this study, InO_x films were deposited by HiPIMS and the effect of post-annealing was investigated. The crystallinity of the InO_x films and the electrical properties were evaluated.

The 3-inch In_2O_3 target was used and a pulsed voltage with pulse width of 20 μs and a frequency of 500 Hz was applied to the target. The peak power density, which is the multiplication of the peak target current density and the target voltage, was 0.1 kW/cm^2. The total flow rate of Ar/O_2 mixture gas was 10 sccm, the oxygen gas flow rate ratio ($O_2/Ar+O_2$) was 1 %, and the gas pressure was 0.5 Pa. InO_x films with a thickness of 30 nm were deposited on an alkalifree glass substrate (Eagle XG). The 60 min post-annealing was performed at 250 °C in a nitrogen (N_2) gas atmosphere.

Figure 1 shows the X-ray diffraction (XRD) pattern of InO_x thin films. No XRD peak was observed for the as-deposited InO_x film. The XRD peak at 2θ = 30.5°, corresponding to the (222) planes of the cubic bixbyite structure, were observed from the post-annealed InO_x film. The sharp crystalline peak indicates that high crystallinity and a large crystal grain size.

Figure 2 show SEM images of as-deposited and post-annealed InO_x films. Small crystal grains were observed in the as-deposited InO_x film. The grain size of the InO_x crystallites was increased to be approximately 100 nm by the post-annealing.

The electrical properties of InO_x films was evaluated by Hall effect measurements using the van der Pauw method. The hole mobility increased from 14.8 cm^2 /Vs to 41.6 cm^2 /Vs by the post-annealing since the electron scattering at grain boundaries was suppressed due to an increase in crystallite size.

Acknowledgements
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References

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[2] Y. Magari, et al., Nat. Commun., 13, 1078 (2022).

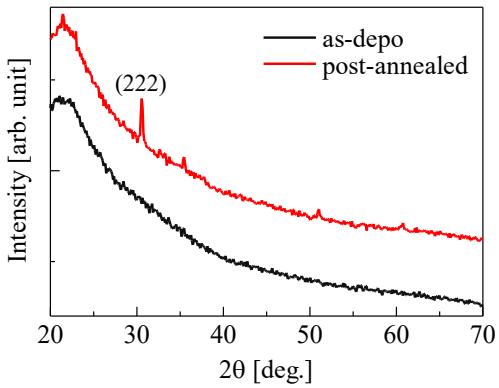

Figure 1. XRD patterns of InO_x films.

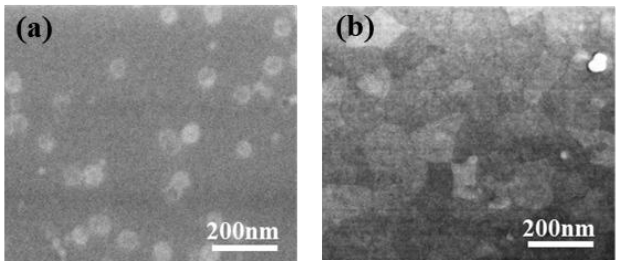

Figure 2. SEM images of (a) as-deposited and (b) N_2 gas post-annealed InO_x film.