The dominant factors that determine carrier transport of less-than-10-nm thick W-doped In_2O_3 conductive films deposited on glass substrates by reactive plasma deposition with dc arc discharge

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ABSTRACT

Metal oxides are a group of materials that fulfil a wide variety of present application properties and also encourage evolution or development of near-future applications. In our laboratory, as well as the materials design, we also have been developing a technology of reactive plasma deposition with dc arc discharge which enables high film-deposition-rate ranging from 170 to 220 nm/min, low temperature of less than 200 ºC and low damage film growth to substrate surface. We, thereby, tailor electrical, optical and mechanical properties of highly transparent conductive oxide (TCO) films deposited on substrates with various sizes ranging from 10×10 to 200×200 cm^2. The TCO films are based from n-type doped ZnO- and In_2O_3-based films. We have been choosing several types of dopants suitable for achieving oxide films that meet the properties and functionals specific applications require. For achieving reliable solid devices, the use of dopants that have high oxygen affinity compared with host metal atoms is essential. For example, for In_2O_3 films, W and Ce atoms have advantages over the conventional Sn atoms.(1-3) This will suppress the generation of oxygen vacancies in the vicinity of the substitutional-type dopant sites. On the other hand, note that solid phase crystallization from amorphous to polycrystalline phase is an effective way for achieving high Hall mobility films. Recently, we reported Ce- and H-codoped In_2O_3 films (ICO:H) with a thickness of 100 nm showing high Hall mobility of 145 cm^2/(Vs). Incorporating ICO:H-based electrodes instead of Sn-doped In_2O_3-based electrodes improved the performance of Si heterojunction solar cells.(2,3)

We, recently, achieved high Hall mobility W(0.6 at.%)-doped In_2O_3 (IWO) films: 5-nm- and 30-nm-thick polycrystalline IWO films deposited on glass substrates show Hall mobility of 57.7 and 97.4 cm^2/(Vs), respectively.(1) We carried out the solid phase crystallization (SPC) under the condition of vacuum of 5×10^{-4} Pa for 30 min at 250 ºC. With decreasing thicknesses from 10 to 5 nm, we find classical size effects on electrical resistivity, especially Hall mobility: the decrease in thicknesses sharply reduce Hall mobility. Note that in such films, thicknesses are closely to electron mean free paths at any given thickness. The analysis of depth profile of In and O elements determined by Rutherford backscattering spectrometry (RBS) measurements reveals an increase in the density of O atoms in the vicinity of the surface and interface with the substrates compared with as-deposited amorphous IWO films. On the other hand, the postannealing changed from oxygen rich states to oxygen poor ones within the films. This implies that the charge transfer from In atoms to the oxygen interstitials that generate and form In–O chemical bonds due to SPC perturbs the surface and interface potential. This perturbation causes that the diffuse scattering affects carrier transport at the surface and interfaces, resulting in reduced Hall mobility thereby. In this talk, we elucidate the dominant factors that determine carrier transport of the ultra-thin films.

GRAPHICAL ABSTRACT

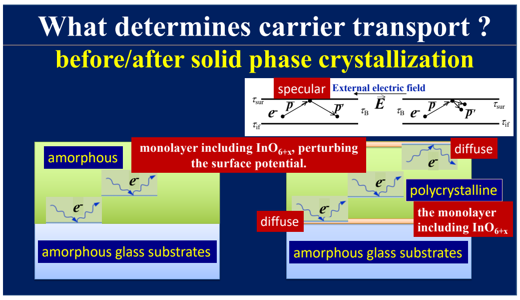

Figure Caption: free carrier scattering mechanism before and after solid-phase crystallization of IWO films deposited on glass substrates.

KEYWORDS

Transparent conductive films, In_2O_3, carrier transport, solid phase crystallization, classical size model

ACKNOWLEDGEMENT

The authors are grateful to Mr. Makoto Maehara, Dr. Yugo Okada, Mr. Hisashi Kitami, Mr. Toshiyuki Sakemi and Mr. Kimio Kinoshita of Sumitomo Heavy Industries, Ltd, for helpful discussions during this work. A series of R&D was supported by collaboration with Sumitomo Heavy Industries, Ltd (Patent:WO2017/014278A1, Sumitomo Heavy Industries, Ltd, 2017-01/26).

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BIOGRAPHY

Tetsuya Yamamoto obtained a Ph.D. degree (Theoretical physics of condensed matter, OSAKA University, Japan, 1997). He is a full Professor of graduate school, and also Director, Materials Design Center, Research Institute, Kochi University of Technology, 1999 – Present. Major research concerns materials design and device developments based on oxide semiconductors materials, and the development of film-growth deposition process together with apparatus. Many products with patents co-developed with industries thorough many national projects, where he was the supervisor, have been already commercial. Google scholar: h-index 35, i10-index 170 since 1991. He won the prize by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) for his work on ZnO-based TCO films for use in Liquid Crystal Display (LCD)-TV and thin-film solar cells in 2011.