Thin Films
Room 329 - Session TF-TuA

Transparent Conducting Oxides
Moderator: G. Ockenfuss, OCLI - JDS Uniphase

2:00pm **TF-TuA1 Enhanced Conductivity in Post Deposition Annealed Spinel Oxide Films**, *G.J. Exarhos,* Pacific Northwest National Laboratory*;* ***R.R. Owings***, University of Florida*; C.F. Windisch,* Pacific Northwest National Laboratory*; P.H. Holloway,* University of Florida

Infrared transparent nickel cobalt spinel oxides exhibit p-type polaron conductivity that is highly dependent on the content of nickel in the structure. In this system, the relatively high covalency of nickel and the distribution of cation oxidation states among the available tetrahedral and octahedral lattice sites act to promote polaron formation. The nature of the polaron formed and its mobility are very much dependent upon composition and lattice parameter which, in turn, can be altered by choice of deposition parameters and post deposition treatment. Film conductivity is affected directly by post deposition annealing and can be enhanced or degraded reversibly upon rapid quenching or slow cooling to produce a set of recoverable conductivity values. The addition of lithium into the nickel cobalt system promotes enhanced conductivity as well, if included in small enough amounts. As the nickel concentration in the film increases, less lithium is required to produce a conductivity increase. Lithium containing films also exhibit the same recoverable conductivity behavior when subjected to heat treatment. Electrical property measurements are correlated with vibrational and electron spectroscopy results. Structural nuances are characterized by means of HRTEM. Perturbations to the conductivity are thought to arise from the presence of chemisorbed species such as carbonate and cation partitioning among available sites in the lattice.

2:20pm **TF-TuA2 Reactive-Environment, Hollow Cathode Sputtering: Basic Characteristics and Application to Al@sub 2@O@sub 3@ and Doped ZnO**, ***A.E. Delahoy***, *S.Y. Guo,* Energy Photovoltaics, Inc.

A novel method for thin film deposition by reactive sputtering has been studied. The method is based on metal sputtering in a hollow cathode configuration with supply of a reactive gas to the vicinity of the substrate. The working gas and entrained sputtered atoms exited the cathode through a slot having an aspect ratio of 8:1. The reactive gas is thereby largely prevented from reaching the target. The basic operation of the cathode was studied using a Cu target. These studies included lateral and longitudinal film thickness profiles, the dependence of deposition rate on power, pressure, and flow rate, and film resistivity as a function of substrate temperature and low energy ion bombardment. Al and Zn targets were used to prepare Al@sub 2@O@sub 3@ and ZnO films in a reactive environment of oxygen. Using quartz crystal rate monitoring it was demonstrated that only a very small amount of oxygen passing through the cathode will oxidize (poison) the target, whereas large quantities of oxygen supplied externally to the cathode need not affect the target at all. A very stable plasma discharge and ease of Al@sub 2@O@sub 3@ formation was realized in this latter mode. Using a Zn target, the method was then applied to the preparation of transparent, conductive films of ZnO doped with Al and B. The Al was introduced by co-sputtering, and the B from B@sub 2@H@sub 6@. The dopant concentrations were measured by ICP. The film resistivity was found to depend strongly on oxygen flow rate. Low film resistivities (0.49 x 10@super -3@ ohm-cm) and high deposition rates (a dynamic rate of 17 nm m/min) were achieved.

2:40pm **TF-TuA3 Transparent Electronics: An Overview of Materials, Devices, and Applications**, ***J.F. Wager***, *H.Q. Chiang, D. Hong, B.J. Norris, J.P. Bender, M.M. Valencia, C.-H. Park, J. Anderson, J.Y. Jeong,* Oregon State University*; D.A. Keszler,* Oregon State University, U.S.A*; H. Yanagi, M. Price, J. Tate,* Oregon State University*; R.L. Hoffman,* Hewlett-Packard Company **INVITED**

The objective of transparent electronics is to fabricate invisible electronic circuits. Part of the motivation for the development of transparent electronics is the recent availability of p-type transparent conductive oxides (TCOs). With the emergence of p-type TCOs, in addition to conventional n-type TCOs such as indium-tin oxide, tin oxide, and zinc oxide, fabrication of transparent bipolar electronic devices becomes feasible. This presentation will emphasize four topics. First, a brief overview of conventional n-type TCOs will establish the context for the pursuit of transparent electronics. Second, recent work on the development of p-type TCOs, as well as other non-oxide transparent conductors, will be reviewed. Third, the fabrication and performance of a novel ZnO-based transparent thin-film transistor will be described. Fourth, transparent electronic applications such as transparent select transistors for active-matrix liquid-crystal displays and transparent back-plane electronic drivers for transparent displays will be discussed.

3:20pm **TF-TuA5 Expanding Thermal Plasma Deposition of Textured ZnO: Plasma Processes and Film Growth**, ***R. Groenen***, *I.M. Volintiru, M. Creatore, M.C.M. van de Sanden,* Eindhoven University of Technology, The Netherlands

Zinc oxide (ZnO) is a transparent conducting oxide (TCO) of considerable technological interest. Recently, the utilization of an expanding thermal plasma (ETP) created with a cascaded arc is demonstrated for low temperature textured ZnO deposition.@footnote 1@ The remote configuration of the ETP technique allows for separate control of plasma production, gas phase chemistry and substrate surface treatment and is suitable for large area deposition. Films are deposited on glass substrates from oxygen, diethylzinc and for doped material additionally trimethylaluminum. A controllable, rough surface texture which is essential for application as a front electrode in thin film solar cells, is inherently obtained during deposition. Here, a fundamental study of the plasma processes and film growth is presented. Complementary in-situ diagnostics (e.g. Langmuir probe, quadrupole mass spectrometry, optical emission spectroscopy and spectroscopic ellipsometry) are used to correlate plasma composition, film growth and material properties. Film growth appears to be dominated by molecular (i.e. background) instead of atomic oxygen. The relation between detected species and the observed texture development allows for further improvement of the material light trapping properties. @FootnoteText@@footnote 1@R. Groenen, et al., Appl. Surf. Sci. 173 (2001) 40.

3:40pm **TF-TuA6 Transparent Conducting Amorphous Zn-Sn-O Films Deposited by Simultaneous DC Sputtering**, ***T. Moriga***, *Y. Hayashi, K. Kondo, K. Matsuo, H. Fukumoto, K. Murai, K. Tominaga, I. Nakabayashi,* The University of Tokushima, Japan

The films of ZnO-SnO@sub 2@ system were deposited on glass substrates by simultaneous DC magnetron sputtering apparatus, where ZnO and SnO@sub 2@:Sb (Sb@sub 2@O@sub 5@ 3wt% doped) targets were faced each other. The substrate temparature were maintained at 150 and 250°C. As an experimental parameter, current ratio @delta@, ZnO target current divided by the sum of ZnO and SnO@sub 2@:Sb target currents, was adopted. Monophasic amorphous transparent films appeared for Zn/(Sn+Zn)=0.50-0.73. At Zn/(Sn+Zn)=1/2 (@delta@=0.62), 2/3 (@delta@=0.73) and any other ratio in as-deposited films, neither crystalline ZnSnO@sub 3@ nor Zn@sub 2@SnO@sub 4@ was obtained. Minimum resistivity was found at @delta@=0.50, whose composition was approximately SnO@sub 2@ZnSnO@sub 3@. Amorphous tin oxide coexisting with amorphous zinc stannate ZnSnO@sub 3@ would have an important role to reduce the resistivity. Resistivity increased linearly with an increase of the current ratio, until the composition reached the zinc stannate Zn@sub 2@SnO@sub 4@.

4:20pm **TF-TuA8 Highly Transparent and Conductive ZnO:Al Thin Films Prepared by Vacuum Arc Plasma Evaporation**, ***T. Miyata***, *S. Ida, Y. Minamino, T. Minami,* Kanazawa Institute of Technology, Japan

Recently, we reported preparation of undoped and impurity-doped ZnO thin films on large area substrates by a newly developed vacuum arc plasma evaporation (VAPE) method using oxide fragments as a low-cost source material. Resistivities on the order of 10@super -4@@ohm@cm were obtained in Ga- or F-doped ZnO thin films. However, doping Al into ZnO films was very difficult because of the large difference in decomposition energy (vapor pressure) between Al@sub 2@O@sub 3@ and ZnO. In this paper, we describe the preparation of Al-doped ZnO (AZO) thin films by a newly developed VAPE method using ZnO fragments and a gas source Al dopant. The film depositions were carried out under the following conditions: substrate, large area glass; substrate temperature, RT to 450@super o@C; oxide fragments, sintered ZnO; pressure, 0.08 to 1 Pa; Al dopant gas pressure (flow rate), 0.01 to 0.5 Pa; Ar and O2 gas flow rates, 20 and 0 to 20 sccm; and cathode plasma power, 4.5 to 10 kW. A low resistivity on the order of 10@super -4@@ohm@cm and an average transmittance above 85% in the visible range were obtained in AZO thin films. In addition, a deposition rate of 150 nm/min as well as a uniform distribution of resistivity and thickness on the substrate surface was obtained. It was found that the Al content in AZO films was altered by varying the partial pressure (or flow rate) of the Al dopant gas. It is

concluded that the newly developed VAPE method, using both oxide fragments and gas sources as source materials, is very effective for the preparation of multicomponent oxide thin films.

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