A.8: Probing growth mode of epitaxial NiO on Al_2O_3 substrate

Nickel oxide (NiO) is an important wide band gap (3.7-4.0 eV) semiconductor with p-type conductivity which is mainly because of nickel vacancies. Additionally, it is antiferromagnetic with Neel temperature of 523 K, and has found various applications such as in gas sensors, resistive switching random access memory devices, and p-type transparent conducting oxide. UV light emitting diodes (LEDs) based on heterojunctions of NiO with several other n-type semiconductors such as GaN and ZnO have been fabricated primarily due to its p-type conductivity. Sometimes, an insulator of a relatively higher band gap, such as MgO and Al_2O_3, is introduced in between p-n heterojunctions as an electron blocking layer, which improves the device characteristics. Hence, understanding of growth mode of NiO on high band gap materials like Al_2O_3 substrate is quite essential.

To probe the growth mode, epitaxial NiO layers were deposited on Al_2O_3 (0001) oriented substrate using pulsed laser deposition (PLD) technique. A KrF excimer laser (~248 nm) beam of energy density ~1 J-cm^{-2} was focused on an in-house prepared high purity (99.999%) ceramic NiO target for ablation. Two samples consisting of NiO of thicknesses ~1.5 nm and ~12 nm were deposited on Al_2O_3 substrate at 500°C in a partial pressure of ~1x10^{-3} mbar of oxygen gas. Crystalline quality of the deposited NiO layers was assessed from x-ray diffraction (XRD) measurements performed at the Angle dispersive x-ray diffraction (ADXRD) beamline (BL-12) of Indus-2 synchrotron source (λ≥0.8 Å). The growth mode was studied by observing the behaviour of Ni $2p_{3/2}$ core level peak, which was determined from photo-electron spectroscopy (PES) experiments performed with a laboratory source of Al K_α (~1486.6 eV) installed at the ARPES beam line at Indus-1.

Figure A.8.1(a) shows ω/2θ scan from thick layer sample measured by the synchrotron beam of wavelength of ~0.8 Å, where both (111) reflection of NiO layer and (0006) reflection of Al_2O_3 substrate are observed at 2θ values of ~19.1° and ~21.4°, respectively. It is to be noted that Pendellosung oscillations corresponding to the thickness of NiO layer are clearly observed around the Bragg peak of NiO, which indicates a good interface at NiO layer and Al_2O_3 substrate and good crystalline quality of the NiO layer. The thickness of ~12 nm, determined from the period of Pendellosung oscillations, is in corroboration with that obtained from the hard x-ray reflectivity measurements. Figure A.8.1(b) displays Ni $2p_{3/2}$ core level spectrum from thin layer (~1.5 nm) of NiO deposited on Al_2O_3 substrate. The core level of Ni $2p_{3/2}$ is fitted to three features, which are related to the bulk component, the surface component, and a satellite. The main feature observed at ~853.45 eV is related to the bonding of Ni atoms coordinated octahedrally with O atom in the bulk of NiO. A nearby feature noted at ~854.78 eV is due to the bonding of pyramidally coordinated Ni atoms with O atoms at the surface of NiO layer. The third feature observed at 860.27 eV is the satellite of the main feature. The Ni $2p_{3/2}$ peak (Fig. A.8.1(c)) from ~12 nm thick NiO layer deposited on Al_2O_3 substrate is also fitted to three features at 852.68 eV, 855.49 eV and 860.70 eV, which are related to the bulk, surface, and satellite features respectively. However, the intensity of surface related feature as compared to the bulk feature is quite different in both the samples.

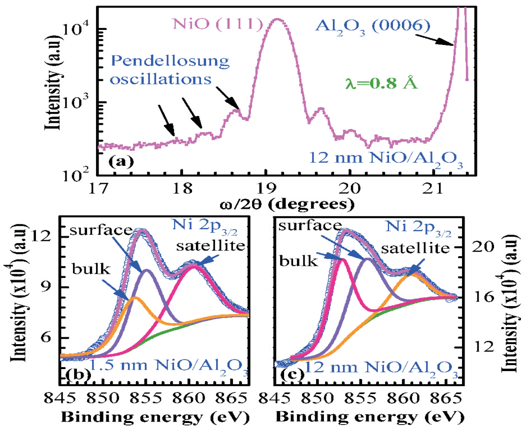

Fig. A.8.1: (a) ω/2θ scans from ~12 nm thick NiO layer deposited on Al_2O_3 substrate. The Ni $2p_{3/2}$ core level spectrum for (b) ~1.5 nm (c) ~12 nm thick NiO layers.

It has a value of 1.1 and 0.9 for ~1.5 nm thick and ~12 nm thick NiO layers, respectively. This observation suggests that the surface related feature is present in a larger extent for the thin layer of NiO as compared to the thick layer. This may be related to the growth process of NiO on Al_2O_3 substrate, in which initial growth is in the form of islands because of the large lattice mismatch (~7%) between NiO and Al_2O_3. As the growth proceeds, these islands merge with each other to form NiO layer for larger coverage.

In conclusion, NiO layers of good crystalline and interfacial qualities can be deposited on Al_2O_3 substrate. However, the initial growth is in the form of islands, which merge to from continuous layer for higher coverage of NiO (For more details, please refer to S. D. Singh et al., J. Appl. Phys. 119, 165302, 2016).

Reported by:
S. D. Singh (devsh@rrcat.gov.in) and Tapas Ganguli