[Supporting Information]

Atomic Layer Deposition of Tin Oxide with Nitric Oxide as an Oxidant Gas

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Growth temperature. The thermal stability of the Sn(II) precursor has not been investigated in detail since the early study in combination with 50 wt.% H_2O_2 was focused on low temperature growth lower than 200 ^oC.[1] In order to determine the starting temperature of precursor decomposition, growth conditions without any NO pulse were repeated at three different substrate temperatures of 250, 280, and 310 ^oC. Fig. S1 shows XRF spectra for these samples where characteristic Sn $L_{\alpha 1}$ (3.443 keV) and $L_{\beta 1}$ (3.662 keV) peaks are monitored. The background spectrum as a control was collected on a SiO_2/Si substrate. It is clearly seen from the Fig. S1 that the spectrum for

250 ^{o}C is almost overlapped with the standard spectrum; however the one for 280 ^{o}C shows small increase in intensity for both peaks, which is a sign of partial decomposition of the precursor. When the temperature is further increased up to 310 ^{o}C, the spectrum obviously shows more intense tin peaks. Based on these observations, it appears that this Sn(II) precursor is stable up to 250 ^{o}C and its decomposition starts at ~280 ^{o}C. If not mentioned otherwise, the film growth and characterization were done on films grown at temperatures of 250 ^{o}C or less.

Optical properties. Fig. S2a shows the optical transmission and reflection spectra of a ~110 nm-thick SnO_2 film deposited at 250 ^{o}C on a quartz substrate. The average transmission in the visible region from 400 to 700 nm was 87.2%, which is comparable to other reports for ALD-grown SnO_2.[1, 2] The Fig. S2b shows a plot appropriate for a direct transition of $(\alpha h\nu)^2$ versus photon energy, where α is the absorption coefficient and $h\nu$ is the incidence photon energy. Linear behavior is found at photon energies over 4.2 eV. The estimated band gap of the SnO_2 film was 4.23-4.27 eV. This band gap is wider than the value ~3.6 observed for undoped SnO_2.[3, 4] This widening is known as the Burstein-Moss shift, which is due to the high carrier concentration in the conduction band.[5]

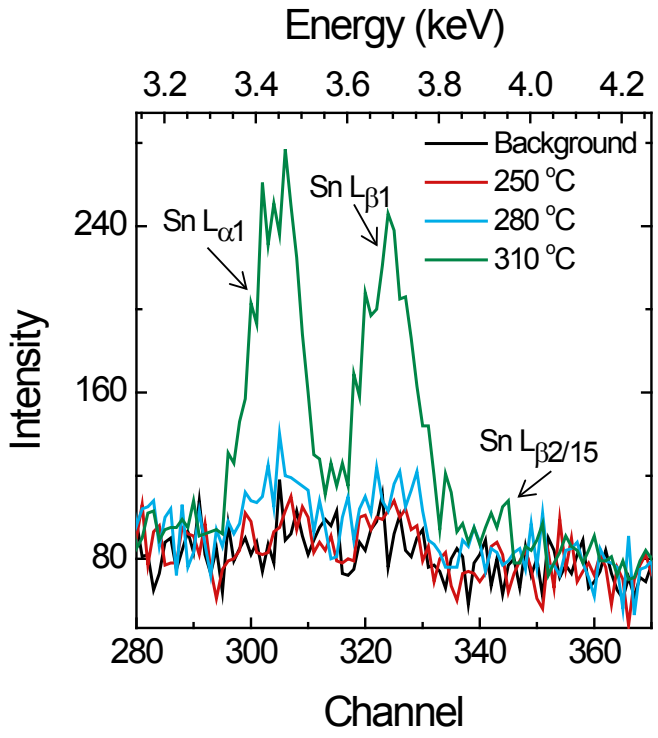

Fig. S1 XRF spectra for samples deposited at various temperatures. The background spectrum was obtained from a SiO_2/Si substrate. Three samples were exposed to Sn precursor vapor (250 cycles) without any oxidant pulse. Increases in the peak intensities of Sn L lines are noted for the 280 and 310 ^{o}C samples, which suggests thermal decomposition of the Sn(II) precursor.

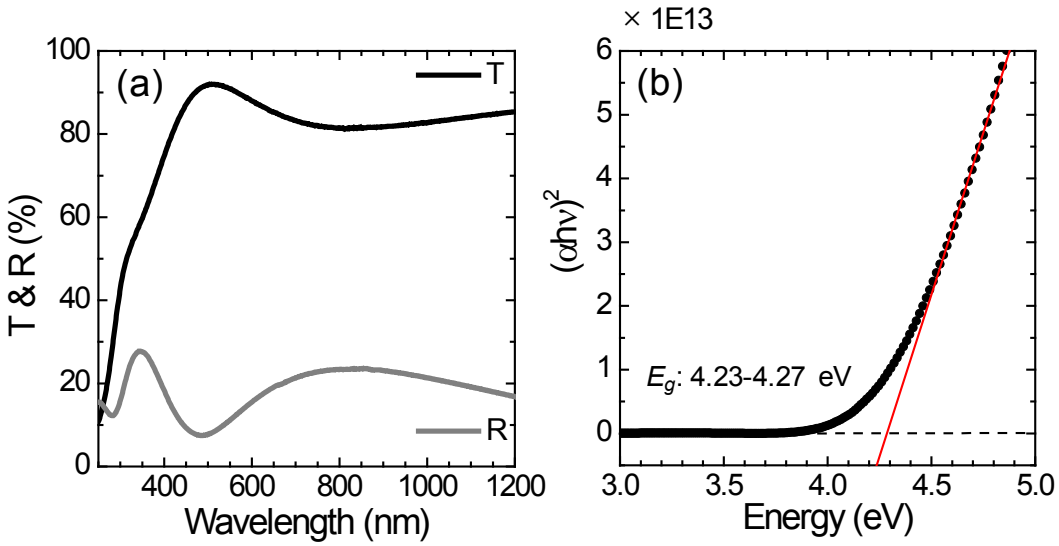

Fig. S2 (a) Transmission and reflection spectra for ~110nm-thick SnO_2 film grown at 250 ^oC. (b) Corresponding direct band gap plot.

References

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