## Characteristics of TiAlO Nanocomposite Thin Films Prepared by Sol-Gel Method

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$TiO_2$ is a versatile material due to its stability, low cost, non-toxicity, and high dielectric constant. $TiO_2$ thin film also has been widely used as a transparent film due to its wide bandgap and high refractive index (***n***).[1] In solar cell applications, $TiO_2$ films mixed with $Al_2O_3$ (TiAlO) can be used as high-reflection or anti-reflection (AR) layers depending on thickness and ***n*** value. The ***n*** of TiAlO film can be easily varied by controlling $Al_2O_3$-content of the film. One of highly sophisticated deposition techniques to fabricate nanocomposite films such as TiAlO is atomic layer deposition (ALD).[1,2] However, the limitation of ALD is low deposition rate and the need for expensive vacuum equipment. In contrast, sol-gel method provides uniform thin films on large-area substrates and is highly cost-effective. The film composition can be easily controlled by adjusting the mixing ratio of precursors.

In this work, nanocomposite TiAlO films were investigated using sol-gel method. The characteristics of $TiO_2$ film prepared by sol-gel method were compared to those of $TiO_2$ film deposited by plasma enhanced ALD (PEALD).[1,2] The composition was analyzed using Auger electron spectroscopy. The optical characteristics of TiAlO films were studied using ellipsometry and UV-Vis spectroscopy.

For the fabrication of TiAlO films, $Ti(i\text{-}C_4H_9O)_4$ and $Al(i\text{-}C_4H_9O)_3$ were used as Ti- and Al-precursors, respectively. The diluted solution was spin-coated on Si or glass substrate. The films were fired at 420°C for 30 m. In this work, 1 ~ 2% solution was used in order to control the film thickness to be approximately 20 ~ 40 nm by single coating process. Then, the film thickness could be increased by repeating the coating and drying process. The thickness is proportional to the repetition number as shown in Fig. 1(a). Figure 1(a) also shows the average transmittance of $TiO_2$/Glass with respect to the number of coatings. In the wavelength region of 400 ~ 1000 nm that is important for the solar cell application, the average transmittance rather increases with increasing film thickness. The loss of average transmittance due to 131 nm-thick $TiO_2$ film was only 6.2% indicating that the sol-gel $TiO_2$ film is adequately transparent. Figure 1(b) illustrates the plot of sol-gel $TiO_2$ film extracting optical bandgap energy from the change of absorption coefficient ($\alpha$) with respect to photon energy. The optical bandgap of 87 nm-thick $TiO_2$ film is 3.45 eV, which is higher than reported values for $TiO_2$ film, 3.0 - 3.2 eV. Larger bandgap energy is more advantageous for solar cell applications requiring high transmittance of solar light.

The quality of sol-gel $TiO_2$ film (61 nm) was evaluated by comparing to PEALD-$TiO_2$ film (53 nm) deposited at 200°C. Table 1 shows the ***n*** value, composition ratio (O/Ti), C-content, and etch rate of sol-gel $TiO_2$ and PEALD-$TiO_2$ films. Although the highest temperature of sol-gel process was much higher than that of PEALD, the sol-gel film showed smaller ***n*** than the PEALD film. The ratio, O/Ti, was 2.17 for sol-gel $TiO_2$ and 2.27 for PEALD film. Carbon was detected only from sol-gel film. The 1.5 times higher etch rate of sol-gel film also indicates that the film density is lower than PEALD film. The existence of 2% C as impurity and the lower film density well explain the ***n*** value 15.5% smaller than that of PEALD-$TiO_2$ film.[3]

Figure 2 shows the ***n*** values of sol-gel TiAlO films with respect to $Al_2O_3$-content. The result clearly presents that ***n*** value proportionally decreases with $Al_2O_3$-content. Just as $TiO_2$, sol-gel $Al_2O_3$ shows ***n*** = 1.50 that is much smaller than that of ALD-$Al_2O_3$ (1.64 – 1.68).[3] Smaller ***n*** value is more adequate for the use as an AR-layer in solar cell application because sol-gel TiAlO films can be adjusted to have ***n*** = 1.5 ~ 2.0 which is larger than glass (1.40~1.45) and smaller than ZnO-based transparent electrodes (1.9~2.0).

In summary, TiAlO films of ***n*** values ranging from 1.5 to 2.0 can be easily fabricated by controlling $Al_2O_3$-content in cost-effective sol-gel process. The sol-gel TiAlO films would be very useful as AR-layers in solar cell applications.

**Acknowledgement**
This work was supported by New and Renewable Energy Development Project of Korea Ministry of Knowledge Economy.

**References**
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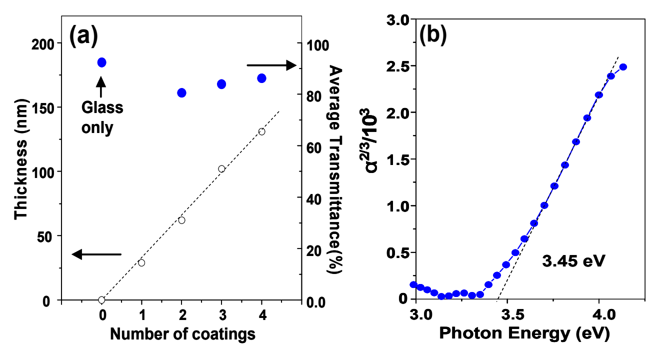


Figure 1. (a) $TiO_2$ thickness and average transmittance of $TiO_2$/glass vs the repetition number of coatings (b) optical bandgap energy of 87 nm-thick $TiO_2$ film

Table 1. Properties of PEALD- and sol-gel $TiO_2$ films

| Sample | *n* | O/Ti | C-content | Etch rate* |
|---|---|---|---|---|
| PEALD $TiO_2$ | 2.438 | 2.27 | 0 | 2 nm/m |
| Sol-Gel $TiO_2$ | 2.057 | 2.17 | ~ 2% | 3 nm/m |

*measured by Ar-ion sputtering

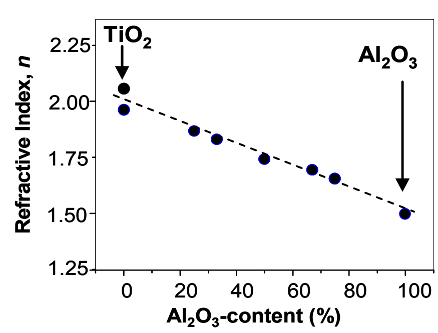


Figure 2. ***n*** values of sol-gel TiAlO films with respect to $Al_2O_3$-content.