Microstructure and Environmental Stability of Plasma-Enhanced ALD TiO_2/SiO_2 Multilayer Anti-Reflective Films on PMMA Substrates

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Results and Discussion

Plasma-enhanced atomic layer deposition (PEALD) has been utilized to deposit anti-reflective (AR) coatings on plastic substrates. At a deposition temperature of 70°C, it was found that the refractive index of TiO_2 and SiO_2 increased with higher plasma power due to enhanced precursor reactivity and film density, as shown in Figure 1,2. However, high-energy ion bombardment during multi-layer deposition caused cracks on the plastic surface, making 50W the optimal plasma power.

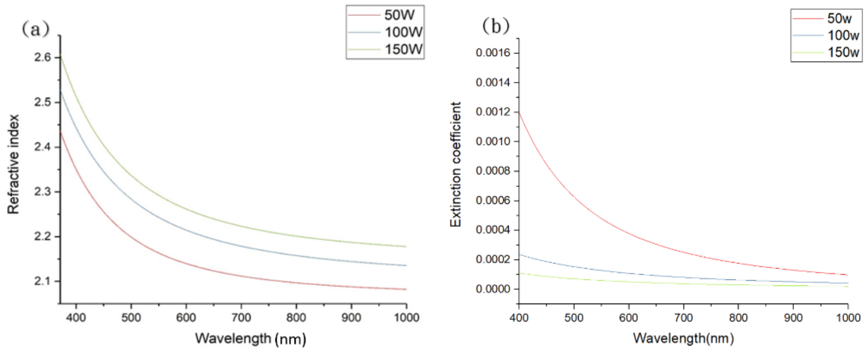

Figure 1. (a) refractive index (n) and (b) extinction coefficient (k) of TiO_2 under varying laser powers.

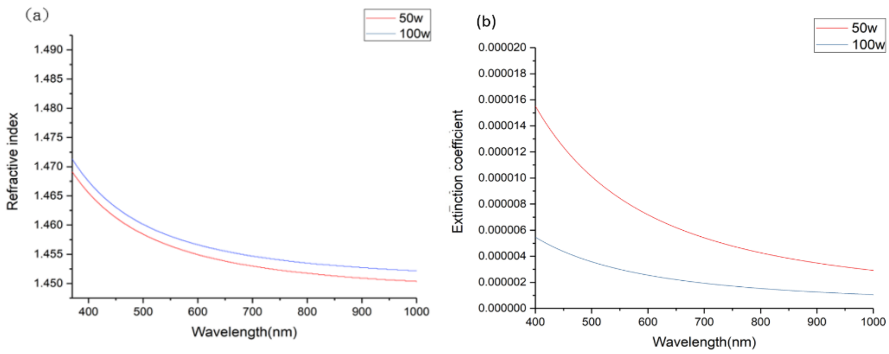

Figure 2. (a) refractive index (n) and (b) extinction coefficient (k) of SiO_2 under varying laser powers.

At low temperature (70°C) and low plasma power (50W), TiO_2 films showed no significant crystallization. Crystallinity strength increased slightly from 82 to 117 as film thickness increased, indicating a microcrystalline state, as shown in Figure 2(a). In figure 2(b), surface roughness remained low, around 0.28 nm, demonstrating very flat TiO_2 films suitable for AR coatings.

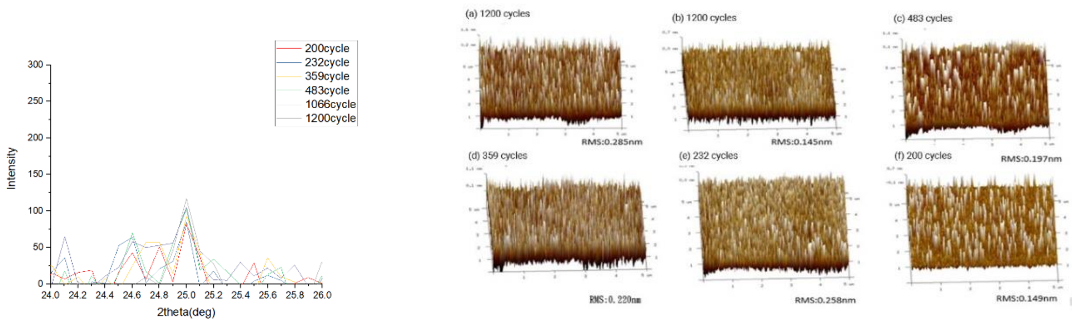

Figure 2. (a) Crystallization strength (b) Roughness of TiO_2 at different cycle times (film thickness).

Under harsh conditions (85°C, 85% RH), AR coatings without inhibition layers lasted up to 998 hours before cracking. Inserting 2 to 4 layers of 1.5 nm SiO_2 into TiO_2 reduced durability from 506 to 209 hours, indicating that more insertion layers weakened the film structure, as shown in Figure 3. Figure 4 depicts the TEM results of AR coatings with varying structural layers, incorporating 2 to 4 layers of 1.5 nm SiO_2 inserted into TiO_2. The decreased durability with SiO_2 insertion was attributed to lower TiO_2 thickness and density, making the films more susceptible to moisture penetration and erosion in high humidity.

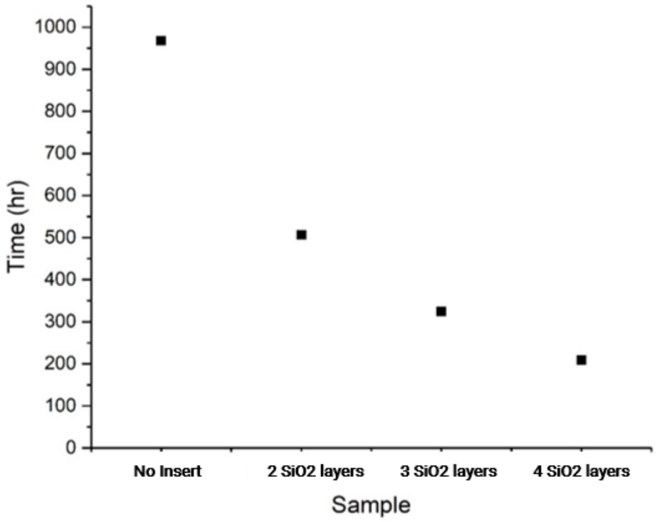

Figure 3. Impact of the numbers of SiO_2 Interlayer on AR Coating Durability (85°C, 85% RH).

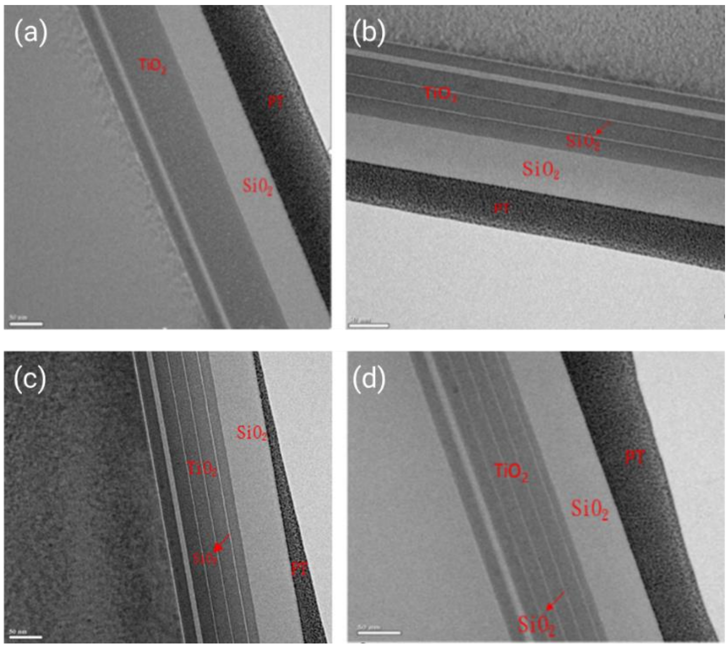

Figure 4. TEM results of different layer structures of AR films (a) Not intercalated (b) Inserted with 2 layers of SiO_2 (c) Inserted with 3 layers of SiO_2 (d) Inserted with 4 layers of SiO_2.

Thicker, denser TiO_2 films in non-inserted layers resulted in lower water vapor transmission rates (WVTR) and better durability under constant temperature and humidity testing.