

Evaluating Non-Pyrophoric Aluminium Precursor for Industrial Application on Silicon Solar Cells

Chang-Yeh Lee¹, Rong Deng¹, Tian Zhang¹, Shuo Deng¹, Kean Thong Khoo¹ and Bram Hoex¹

¹ *Australian Centre for Advanced Photovoltaics, School of Photovoltaic and Renewable Energy Engineering, University of New South Wales, Sydney, NSW 2052, Australia*
E-mail: justin.lee@student.unsw.edu.au

Typically, trimethyl aluminium (TMA) is used as the Al precursor in atomic layer deposition (ALD) or plasma enhanced chemical vapour deposition (PECVD) for Al₂O₃. However, the pyrophoric nature of TMA is a showstopper for some potential users. An alternative nonpyrophoric Al-precursor, dimethylaluminum isopropoxide (DMAI), has been used to deposit Al₂O₃ films, and the Al₂O₃ films yield a similar level of surface passivation on both *p*- and *n*-type c-Si wafers when using plasma-enhanced (PE) ALD. However, the level of surface passivation provided by thermal ALD Al₂O₃ films is generally significantly lower than those synthesised by PE-ALD. As thermal ALD is the preferred method in the industry, there is a strong incentive to improve the performance of the thermal ALD process to allow for the application of this intrinsically safer Al₂O₃ deposition process.

Before Al₂O₃ deposition, the FZ *p*-type c-Si wafers received a standard Radio Corporation of America (RCA) cleaning process, and a thin chemical SiO_x is created on the Si surface (pre-oxidized). Part of the wafers receive an HF (1 %) dip to remove the surface oxide and leave Si-H on the surface (H-terminated). The Al₂O₃ was deposited by thermal and PE-ALD, followed by a post-deposition annealing after the deposition. Figure 1 (a) and (b) show the injection-dependent minority carrier lifetime plots, and the difference of c-Si surface condition show a substantial impact on the thermal ALD samples. For PE-ALD samples the difference is negligible. In Figure 1 (c) the FTIR absorption spectrum of the Si-O longitudinal photon vibrational mode is shown which is used to identify the interfacial SiO_x formation. For PE-ALD sample, both H-terminated and pre-oxidized surface show distinct Si-O peak is located at ~1235 cm⁻¹. For thermal ALD samples, the low intensity of the Si-O peak indicates the SiO_x layer is absent compared to the pre-oxidized sample, and this could explain the low level of surface passivation.

To apply DMAI in industrial manufacturing of c-Si solar cells, the high-temperature stability of the Al₂O₃ film is one of the primary interests because this high-temperature process is used for contact formation. The Al₂O₃/SiN_x stack is expected to improve the thermal stability of Al₂O₃ and to reduce the required thickness of the underlying Al₂O₃ layer. Therefore, the stability of the ALD Al₂O₃/PECVD SiN_x stack is tested by post-deposition anneal at 400 °C and a firing process of a peak temperature of 850 °C in a belt furnace, as shown in Figure 2. For thermal ALD Al₂O₃ capped by SiN_x layer, the as-deposited stack shows a high-level of surface passivation. After thermal annealing and firing process, the effective carrier lifetime degrades. In contrast, the as-deposited stack by PE-ALD shows a low level of surface passivation, and the post-deposition annealing process is necessary to activate the passivation. In Figure 2 (c) and (d), the results of ALD films grown using TMA are shown and a similar trend of degradation was observed after thermal processing. *iV*_{OC} over 700 mV and effective minority carrier lifetimes over 1 ms are obtained after conventional firing process.

To identify the cause of the degradation, an injection-dependent lifetime spectroscopy analysis was employed on thermal ALD AlO_x/PECVD SiN_x sample to separate the influence of the bulk and surface recombination, as shown in Figure 3. According to Figure 3 (b), the fitted *J*₀ decreases after the post-deposition annealing step and the firing process, from 20.1 to 13.2 and 9.52 fA/cm², respectively. It indicates that the degradation of the effective lifetime is mainly due to the activation of bulk defects in the FZ wafer during the thermal process. This shows the importance to consider the bulk Si degradation when examining the thermal stability.

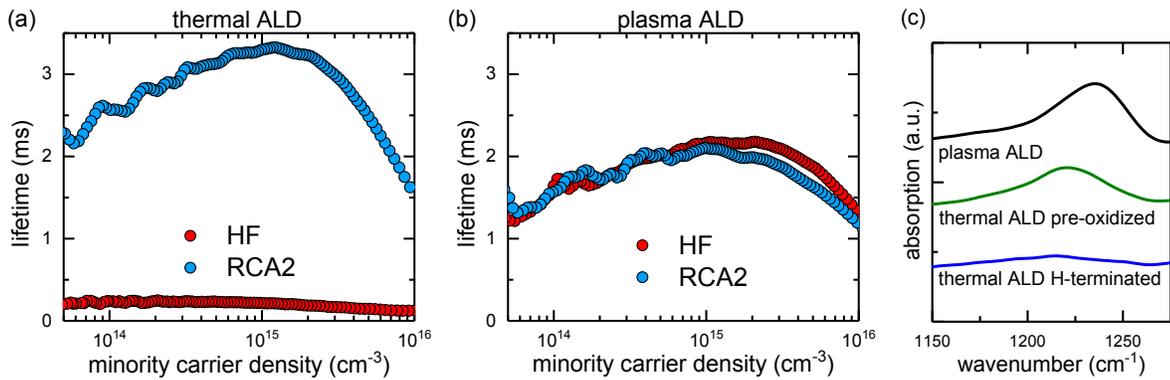


Figure 1. Injection-dependent effective minority lifetime for Al₂O₃ deposited on HF and RCA2 c-Si surface by (a) thermal (b) plasma-enhanced ALD using DMAI precursor. (c) FTIR absorption at Si-O region.

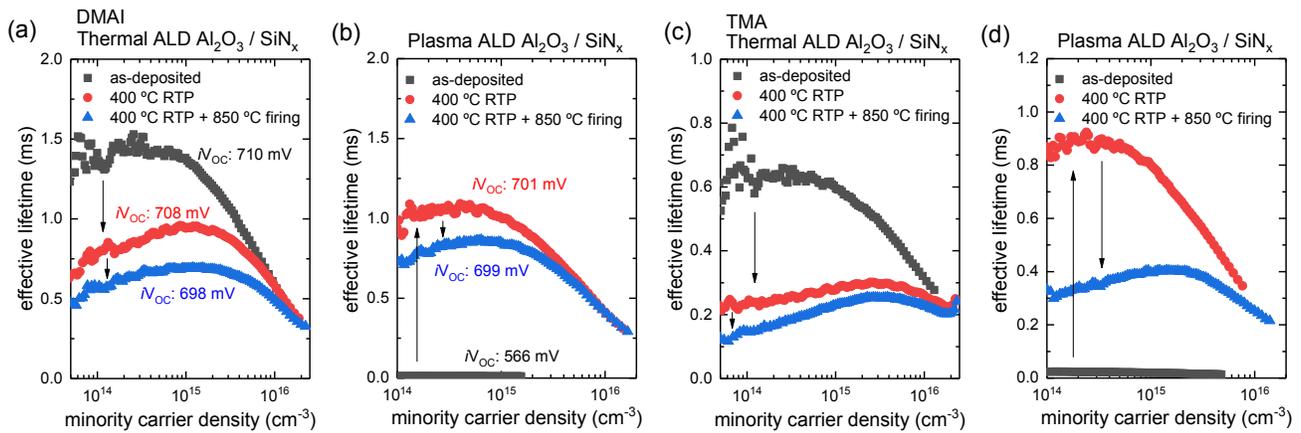


Figure 2. Thermal stability of thermal and PE-ALD Al₂O₃ / SiN_x stack using DMAI, (a) and (b), and TMA, (c) and (d), as the Al precursor.

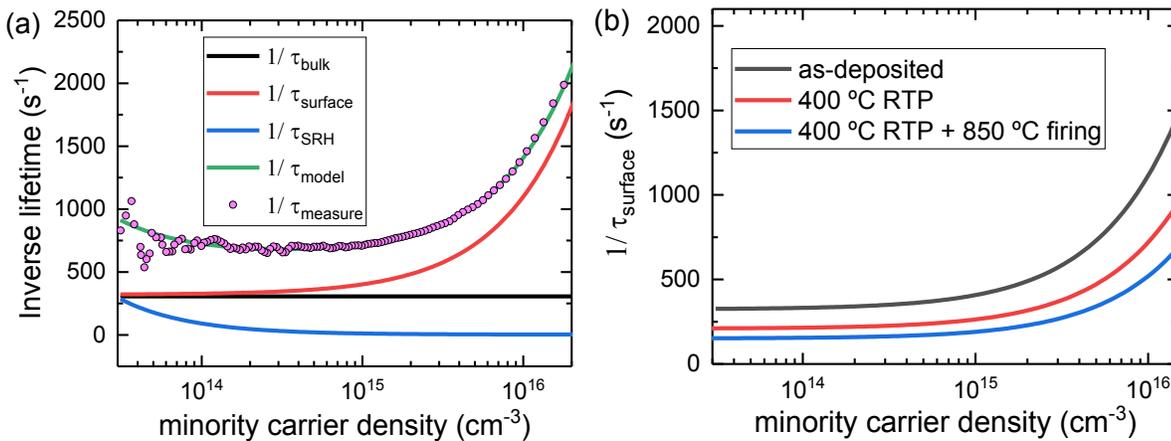


Figure 3 Auger-corrected injection dependent lifetime spectroscopy of the as-deposited thermal ALD AlO_x/SiN_x sample ($1/T_{\text{measure}}$) and the modelled inverse lifetime ($1/T_{\text{model}}$) including the inverse saturation current lifetime ($1/T_{\text{surface}}$), inverse bulk lifetime ($1/T_{\text{bulk}}$) and an inverse Shockley-Read-Hall (SRH) lifetime ($1/T_{\text{SHR}}$).