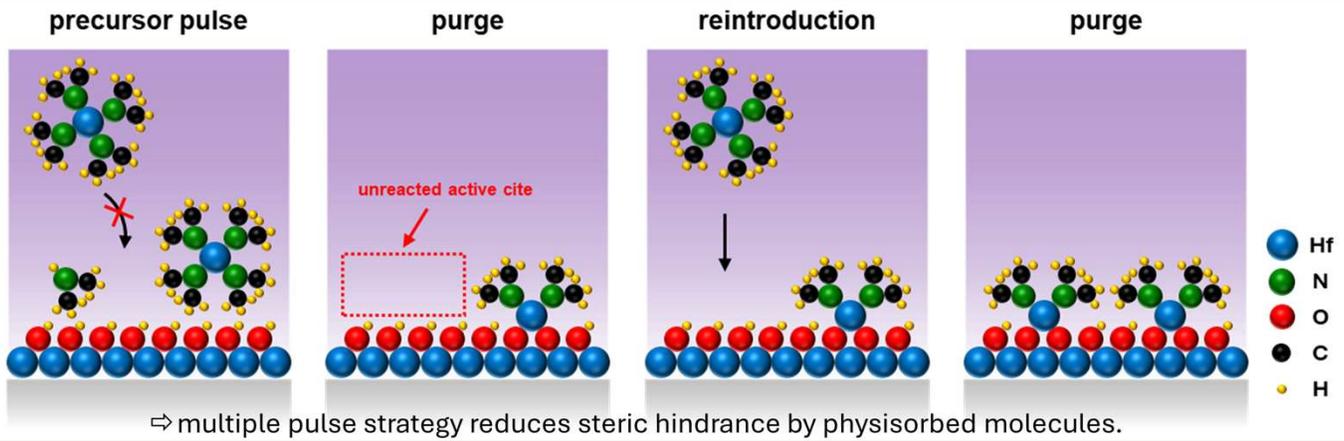
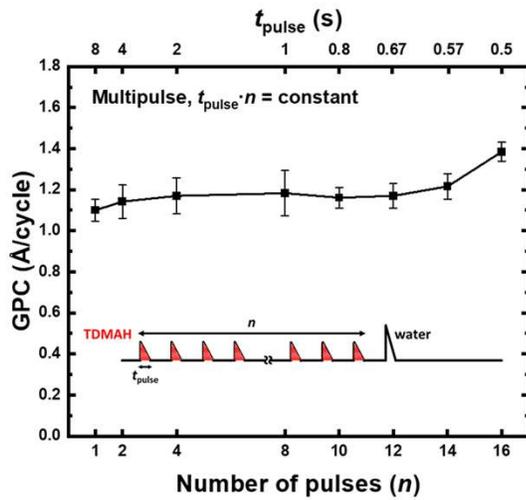


Schematic of the Multiple Pulse Sequencing Mechanism

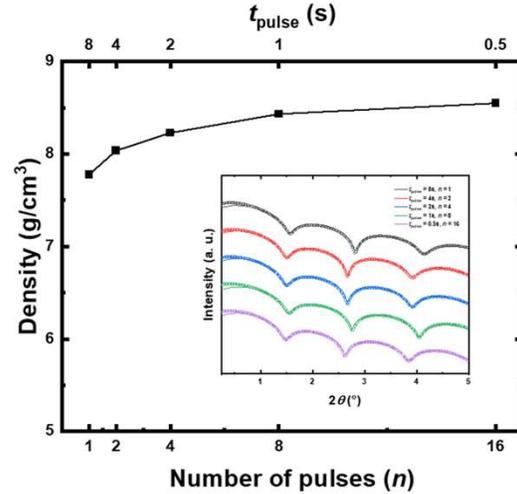


Enhanced Growth and Physical Properties of HfO₂

• GPC evolution



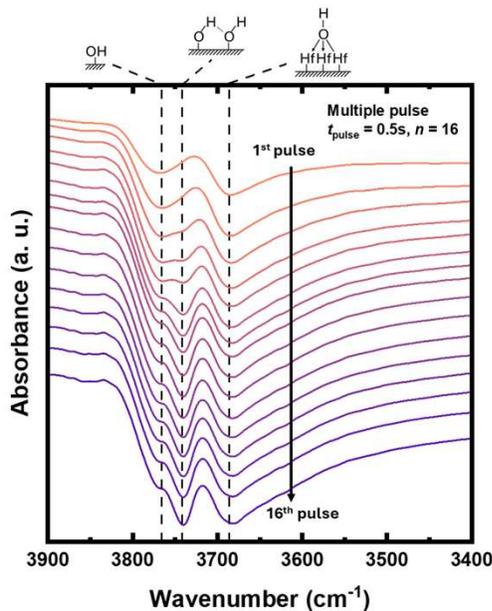
• Density improvement



⇒ higher GPC and density with multiple pulse ALD mode.

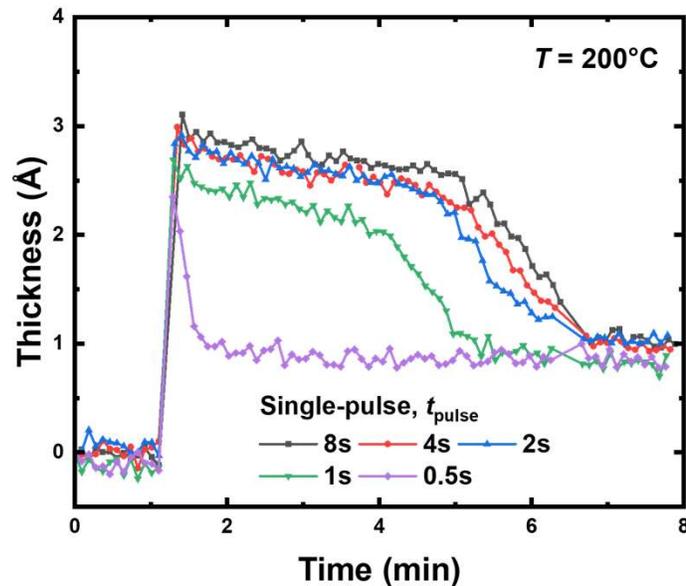
In situ Characterization of Surface Reaction/Adsorption

• Infrared spectroscopy



⇒ Incremental spectra reveal that sterically hindered and hydrogen-bonded hydroxyl groups become accessible and reactive through the multiple-pulse sequence.

• Spectroscopic ellipsometry



⇒ Lower precursor loading from shorter pulses mitigates surface crowding, facilitating rapid desorption kinetics compared to the saturated regime.