In-situ Synchrotron Radiation Photoemission Spectroscopy Study of Property Variation of Ta$_2$O$_5$ Film during the Atomic Layer Deposition

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Atomic layer deposition (ALD) can be regarded as a special variation of the chemical vapor deposition method for reducing film thickness. ALD is based on sequential self-limiting reactions from the gas phase to produce thin films and over-layers in the nanometer scale with perfect conformity and process controllability. These characteristics make ALD an important film deposition technique for nanoelectronics. Tantalum pentoxide (Ta$_2$O$_5$) has a number of applications in optics and electronics due to its superior properties, such as thermal and chemical stability, high refractive index ($>$2.0), low absorption in near-UV to IR regions, and high-k. In particular, the dielectric constant of amorphous Ta$_2$O$_5$ is typically close to 25. Accordingly, Ta$_2$O$_5$ has been extensively studied in various electronics such as metal oxide semiconductor field-effect transistors (FET), organic FET, dynamic random access memories (RAM), resistance RAM, etc. In this experiment, the variations of chemical and interfacial state during the growth of Ta$_2$O$_5$ films on the Si substrate by ALD was investigated using in-situ synchrotron radiation photoemission spectroscopy. A newly synthesized liquid precursor Ta(N$^2$Bu$_2$(dmamp)$_2$ Me was used as the metal precursor, with Ar as a purging gas and H$_2$O as the oxidant source. The core-level spectra of Si 2p, Ta 4f, and O 1s revealed that Ta suboxide and Si dioxide were formed at the initial stages of Ta$_2$O$_5$ growth. However, the Ta suboxide states almost disappeared as the ALD cycles progressed. Consequently, the Ta$^{5+}$ state, which corresponds with the stoichiometric Ta$_2$O$_5$, only appeared after 4.0 cycles. Additionally, tantalum silicide was not detected at the interfacial states between Ta$_2$O$_5$ and Si. The measured valence band offset value between Ta$_2$O$_5$ and the Si substrate was 3.08 eV after 2.5 cycles.

Keywords: Atomic layer deposition, In-situ Synchrotron Radiation Photoemission Spectroscopy, Tantalum pentoxide (Ta$_2$O$_5$)