Low Temperature and High-Quality Neutral Beam Enhanced Atomic Layer Deposition of Hafnium Dioxide

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Introduction: As the continuous scaling down of the SiO_2 film as the gate oxide layer in CMOS technology in recent years was reaching its limit in terms of the size and the gate leakage current [1]. Hence, many alternative dielectric materials were investigated, the insulator with a higher dielectric constant was proposed to replace the SiO_2. Among them, the hafnium dioxide (HfO_2) with high enough k-value, thermal stability, kinetic stability, reasonable energy gap, and good interface quality with Si make it one of the most promising candidates [2,3]. Neutral beam enhanced atomic layer deposition (NBEALD) method is a novel deposition technique, using the neutral beam to replace the plasma in the irradiation step of plasma enhanced (PE)ALD method. The inherent problems in the plasma process such as UV photon irradiation damage and charge-up damage could be overcome in the NBEALD process [4]. In addition, for the manufacture of integrated circuits, each film has its own deposition temperature, it is difficult to maintain the integrity of the formed part if the film is constantly stacked on top of each other, unless the deposition temperature is reduced [5]. Therefore, in this study, the high-k $HfO_2/SiO_2/Si$ stacked film was continuously formed by using NBEALD system at room temperature 30°C.

Experimental: The interface SiO_2 film and HfO_2 film were deposited on 2-inch silicon wafers in a large-radius neutral beam source reactor which consists of an ALD reaction chamber and an inductively coupled plasma (ICP) source. About 1nm SiO_2 interface layer was fabricated on the cleaned Si substrate by neutral beam oxidation (NBO) method, for SiO_2/Si with better interface properties compared with the direct-contact HfO_2/Si. To form the HfO_2 film, Tetraethyl methyl amino hafnium (TEMAH) was used as a Hf precursor, O_2 neutral beam was used as oxidants. Ar gas was, used as a carrier gas and purge gas. TEMAH precursor cylinder was heating to 70°C, the precursor gas line was maintained at 100°C, and the chamber wall was maintained at 120°C to prevent condensation. The stage temperature was controlled at 30°C. The NBEALD cycle consists 5 steps: TEMAH feed, TEMAH purge, O_2 gas injection, O_2 NB irradiation, O_2 NB purge. Chemical components and film density were investigated by X-ray photoelectron spectroscopy (XPS) and X-ray diffraction (XRD). Root-mean-square (RMS) roughness on the surface was obtained by Atomic Force Microscope (AFM).

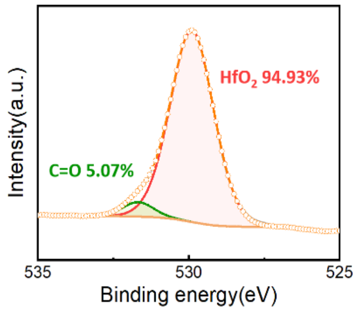

Figure 1. XPS O1s spectra of the HfO_2 film.

Results and discussion: Figure 1 shown the XPS spectra of O1s of the HfO_2 film grown 60 cycles. The film was sputtered by Argon gas prior to the XPS measurement to eliminate the surface C contaminations in the atmosphere. O1s peak are divided into two components, a signal associated with HfO_2 at 529.9 eV and an additional small peak associated with carbon and oxygen at 531.7 eV. As a result, HfO_2 thin film deposited by NBEALD, both carbon (2.7%) and nitrogen (3.9%) contamination ratio were low, even at low temperature 30°C. The O/Hf ratio was 2.03, which almost the same as thermal oxidation HfO_2. Therefore, we succeeded to growth the low contamination $HfO_2/SiO_2/Si$ stacked film at 30ºC by using NBEALD.

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