Round Robin Test (RRT) of the thickness of nano-scale HfO_2 thin film using XRR (X-Ray Reflectometry)

Chang Soo Kim[a*], Minhyuk Choi[a], In-young Jung[a], Seungwoo Song[a], Yasushi Azuma[b], Yunsan Chien[c], and Lingling Ren[d]

[a] Korea Research Institute of Standards and Science (KRISS), 267 Gajeong-ro, Daejeon, 305-340, South Korea
[b] National Institute of Advanced Industrial Science and Technology(AIST), National Metrology Institute of Japan (NMIJ), 1-1-1 Higashi, Tsukuba, 305-8565 Japan
[c] Center for Measurement Standards (CMS), Industrial Technology Research Institute, Kuangfu Rd. 30011, Hsinch City, Taiwan
[d] National Institute of Metrology (NIM), Bei San Huan Lu, Chaoyang District, Beijing 100013, China
* Correspondence email: kimcs@kriss.re.kr

As the gate length of CMOS device is scaled down, thinner gate oxide is required to reduce the short channel effect. Because of the leakage current due to the reduced gate oxide thickness, a gate oxide material with high dielectric constant is required. HfO_2 is one of the most promising gate dielectrics with high dielectric constants, allowing us to increase the physical thickness while keeping the EOT (equivalent oxide thickness) constant, and the HfO_2 thickness should be controlled with high precision.

Nano-scale HfO_2 thin films with nominal thicknesses of 1.2, 2.5 and 5.0 nm were prepared, respectively, on silicon substrates (coded as specimens 1, 2, and 3) by atomic layer deposition method and used as specimens for thickness measurement of an international round robin test (RRT). The thicknesses of the films were measured by using XRR, which is a powerful technique for film thickness determination nondestructively.

Four NMIs (National Metrology Institutes) from TCMM (Technical Committee of Materials Metrology) of APMP (Asia Pacific Metrology Program) and 10 laboratories from Korea (including Samsung Electronics and SK Hynix) were participated in the comparison. Aims of the comparison were to measure and compare the thicknesses of nano-scale HfO_2 thin films, and to confirm international consistency and equivalence regarding HfO_2 thickness.

Specular X-ray reflectivity curves were measured for the HfO_2 films. The curves were analyzed by simulation and fitting procedures, and the thicknesses were determined. Thickness uncertainties as well as thicknesses for the films were reported from four NMIs, and only the thickness results were reported from 10 laboratories. Using the results comparison reference values (CRV) and standard uncertainties were determined by the uncertainty-weighted mean method. The standard uncertainties for the film thicknesses were very small, i.e., 0.003, 0.007 and 0.012 nm, which correspond to the relative uncertainties of 0.85, 0.97 and 0.88% for specimens 1, 2 and 3, respectively. In addition, the thickness results for each specimen from different laboratories were included in each expanded uncertainty range (95% confidence level) of the corresponding specimen, which determined by the CRV ± expanded uncertainty. The facts reveal that for nano-scale HfO_2 thin films, thicknesses determined by XRR from different laboratories are consistent with each other within the uncertainty limit. Furthermore, the results show that XRR is an appropriate and accurate measurement method for the thicknesses of nano-scale HfO_2 thin films.