Local Structures of Co in Co-Doped HfO_2 Studied by EXAFS

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The high-k oxide HfO_2 has been considered one of the most promising insulators useful for resolving the tunneling problem in semiconductor devices. Thin films of HfO_2 are also reported to exhibit ferromagnetism without magnetic dopants, as well as enhanced magnetic moment when doped with Co atoms. It is conceivable that novel spintronic devices can be developed using the HfO_2 system. In addition to the potential applications, the mechanism underlying the reported novel physical properties in these materials also deserves a detailed investigation.

To understand the novel magnetic behavior of the HfO2:Co system, the location of Co impurity atoms in the HfO2 host oxide is an important prerequisite. The possibility of cobalt cluster formation may mislead the data interpretation in magnetic measurements and therefore has to be ruled out. We have employed the extended x-ray absorption fine structure (EXAFS) technique to probe the local structures around Co atoms in Co-doped HfO2 of different Co concentration grown by molecular beam epitaxy (MBE) at different temperatures. Since the Co dopant atoms in general lack long-range structural order, the short-range-order EXAFS method was used for this purpose.

Thin films of HfO2:Co with a thickness of 120 nm were grown by MBE on Yittrium stabilized Zirconia (YSZ) substrates at a high temperature 700ºC and a low temperature 100ºC. The Co concentration was estimated to be 1- 20 at. % for the high-temperature-grown samples and 10 at. % for the low-temperature-grown sample. All the samples investigated in this work are ferromagnetic at room temperature. The average short-range-order structures around the magnetic Co dopants were probed by Co K-edge EXAFS. The x-ray absorption measurements were performed in part at beamline BL01C of National Synchrotron Radiation Research Center (NSRRC) using a single-element Si(Li) detector for fluorescence mode measurements.

Our EXAFS data has indicated formation of Co clusters in high-temperature-grown HfO2:Co. On the other hand, low-temperature MBE growth can indeed lead to nearly Co-cluster-free HfO2:Co films. As revealed by our x-ray results, the seemly inevitable formation of Co clusters under regular MBE growth mode with a growth temperature ~700ºC can indeed be deterred to achieve cluster-free HfO2:Co films by using a much lower growth temperature ~100ºC. The low-temperature-grown films are ferromagnetic diluted magnetic oxides with great potential in spintronic applications.

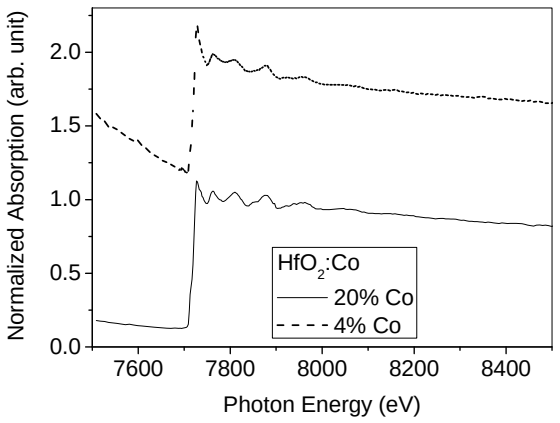

Figure 1. Co EXAFS data obtained at Beamline 01C.