Search for Magnetism in HfO$_2$ Thin Films

A. Suter$^1$, E. Morenzoni$^1$, T. Prokscha$^1$, H. Luetkens$^1$, G.J. Nieuwenhuys$^{1,4}$, Y. Krockenberger$^2$, and L. Alff$^3$

$^1$Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland
$^2$Correlated Electron Research Center, AIST Tsukuba Central 4, Tsukuba, Ibaraki, 305-8562 Japan
$^3$Institute for Material Science, Darmstadt University of Technology, D-64287 Darmstadt, Germany
$^4$Kamerlingh Onnes Laboratory, Leiden University, PO Box 9504, 2300 RA Leiden, The Netherlands

A recent intriguing report of the observation of unexpected and highly anisotropic ferromagnetism in the high-$\kappa$ dielectric oxide HfO$_2$ thin films [1] has stirred the scientific community. If validated, this discovery of $d^0$ ferromagnetism in a transparent oxide undoubtedly represents a major advance for the field of spintronics [2]. Interestingly, the high-$\kappa$ dielectric oxides such as HfO$_2$ are already under active consideration as gate dielectrics for next generation devices in semiconductor technology in view of the material compatibility with silicon [3]. Introducing a magnetic response in such dielectrics should enable an integration of complementary metal-oxide semiconductor (CMOS) with spintronic technology. The magnetic moment, derived from magnetization measurements, found by various groups in HfO$_2$ thin films is about 0.1 $\mu_B$ per formula unit.

From preliminary bulk studies [4] it was deduced that different muon states are present in HfO$_2$: $\mu^+$, Mu$^0_{\text{atomic}}$, and, for $T < 50$K, Mu$^0_{\text{shallow}}$. Differently to these findings, our preliminary low energy $\mu$SR (LE-$\mu$SR) study on HfO$_2$ thin films grown c-cut sapphire reveals a dominant $\mu^+$ signal (derived from ZF/TF measurements). A pronounced two component depolarization in the whole measured temperature range ($T = 4 \ldots 200$K) is observed. We attribute the fast depolarization as due to magnetism consistent with the macroscopic measurements (and not due to muonium depolarization/diffusion processes). We will discuss possible mechanisms which could lead to $d^0$ ferromagnetism.