Development of Bulk Sputtered Metastable Tungsten for Use in Spin-Orbit Torque Random-Access Memory

Y. Ding, D. Sabrsula
Singh Center for Nanotechnology, University of Pennsylvania, Philadelphia, PA 19104
yijied@seas.upenn.edu

Spin-orbit torque magnetic random-access memory (SOT-MRAM) is a non-volatile memory technology offering numerous advantages, including high operating speed, superior endurance, and compatibility with CMOS processes, positioning it as a promising candidate for next-generation memory technologies.[1] This study investigates the optimal fabrication processes and device geometries for SOT-MRAM, with a focus on the process development of sputtering SOT films.

The operation of SOT-MRAM centers around the magnetic tunnel junction (MTJ), comprising three layers: a pinned ferromagnetic layer (PL), an insulating tunneling barrier, and a free ferromagnetic layer (FL). Digital information is stored by aligning the magnetic domains of the FL to parallel or anti-parallel to that of the PL resulting in low and high read resistance respectively.[2]

The domains of the FL are influenced by the spin Hall effect (SHE) during a write operation by inducing current into the SOT layer, which is in contact with the FL. The metastable β-phase tungsten (β-W) exhibits the strongest non-damping SOT efficiency but is prone to degrade to metallic W (α-W) once its thickness reaches above 12nm, losing SOT properties.[3]

Our process has successfully fabricated a 50μm size SOT-MRAM device with a 30nm β-W layer that exhibits controlled switching of states. The fabrication process at the Singh Center for Nanotechnology's QNF facility employed bilayer photolithography using direct laser writing, sputtering physical vapor deposition, and lift-off techniques for thin-film deposition. X-ray diffraction (XRD) measurements confirmed the β-phase of the tungsten layer. Future work includes reducing device size using electron beam lithography (EBL) and bulk β-W deposition research. These advancements aim to further SOT-MRAM's integration into high-performance computing and novel applications.

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[1] V.D. Nguyen, S. Rao, K. Wostyn, *et al.* Recent Progress in Spin-orbit Torque Magnetic Random-access Memory, (2024).
[2] X. Fong, Y. Kim, *et al*. Spin-Transfer Torque Memories: Devices, Circuits, and Systems, (2016).
[3] A. Chattaraj, J. Asirvatham, G. Das, *et al.* Growth-dependent Structural Ordering and Stability in β-tungsten Films for Spintronic Applications, (2022).

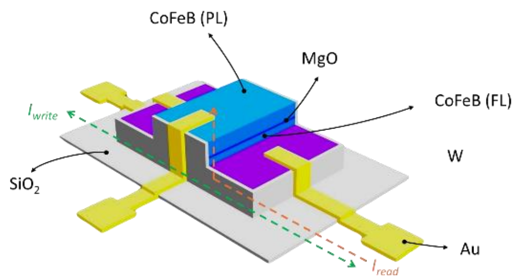

Figure 1: The Model of SOT-MRAM Device and Operation: Devices are deposited on silicon substrate. Silicon dioxide is deposited to avoid electrical paths touching the sidewall of devices.

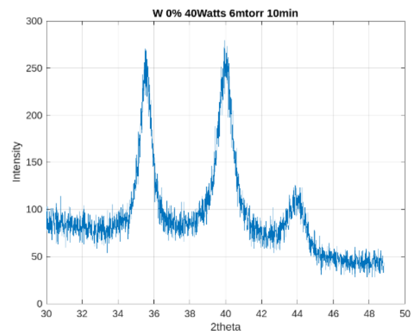

Figure 2: XRD 2θ Measurement of β-W: The three peaks pattern confirmed the metastable phase of tungsten.

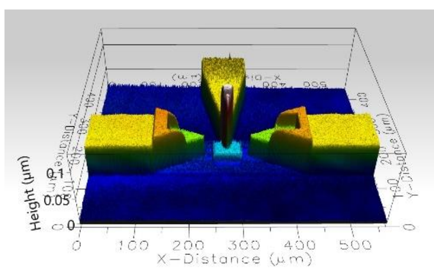

Figure 3: 3D Structure of a SOT-MRAM Device: Measured by white light interferometer.

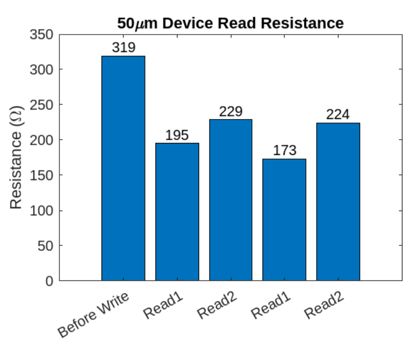

Figure 4: Electrical Testing Result of 50µm Device: Testing is conducted by read before any operations, read1 after writing in one direction, and read2 after writing in the opposite direction.