Reduction of the Spin Hall Angle in Oxygen-Doped Beta Tungsten

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Primary CNF Tools Used: GCA 5x stepper, AJA sputtering tool, Veeco Icon AFM

Abstract:

Spintronic devices rely on spin currents that can be generated from charge currents flowing through certain non-magnetic metals. The spin Hall angle (SHA) is a measure of a materials' efficiency of this charge to spin current conversion. Tungsten is useful because the thin films have been shown to have a very large SHA of over 0.30, but only when the tungsten is ordered in the A15 structure (β-W) [1]. It has been previously shown that incorporation of oxygen into the tungsten during deposition can promote β-W growth and increase the SHA. Using spin-torque ferromagnetic resonance (ST-FMR) [2], we demonstrate that the SHA may actually decrease from over 0.30 to 0.10 or less as the oxygen concentration increases. We also show that the roughness of the tungsten films is approximately 0.19 ± 0.03 nm and is not significantly affected by the oxygen incorporation.

Summary of Research:

Thin film samples were deposited onto 100 mm silicon wafers using our magnetron sputtering system. The structure was $W(8)/Fe_{60}Co_{20}B_{20}(t_{FeCoB})/MgO(2)/Ta(1)$ with numbers in parenthesis representing the thickness of the layer in nanometers, and t_{FeCoB}, the thickness of FeCoB, was varied between 2 and 4 nm. Oxygen was incorporated only during the sputtering of tungsten, with the percentage corresponding to the relative amount of oxygen to argon. Stacks were then patterned into 20 × 5 μm^2 microstrips using photolithography with the 5X g-line stepper at CNF and etched using our own ion milling system. The contacts were made using the AJA sputtering system at CNF. An optical image of the microstrip is shown in Figure 1.

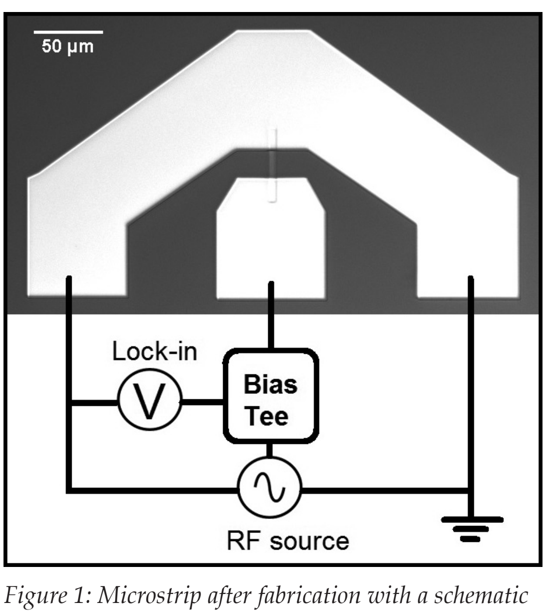

Figure 1: Microstrip after fabrication with a schematic of the ST-FMR measurement.

X-ray diffraction measurements were done on the tungsten thin films to verify that the sputtering techniques yielded β-W. Peaks were found corresponding to mostly β phase tungsten composition, and with some mixed phase α-W likely present. Resistivity measurements, using the van der Pauw method, also confirmed that the films were majority β phase, where β-W typically has a resistivity of between 100-300 $\mu\Omega\cdot cm$ [1]. Resistivities ranged from 127 $\mu\Omega\cdot cm$ for tungsten films with no oxygen incorporation to 329, 306, and 723 $\mu\Omega\cdot cm$ for tungsten with 1.6%, 2.4% and 4.0% oxygen respectively.

The spin hall angle (SHA) was determined using spin-torque ferromagnetic resonance (ST-FMR) with analysis described by Pai, et al., for determination of the SHA [2]. This technique works by driving a microwave frequency (RF) current through the microstrip, which induces magnetic precession in the ferromagnetic layer via the spin transfer torque. A magnetic field is swept from -3000 to 3000 Oe at 45° to the microstrip and the voltage

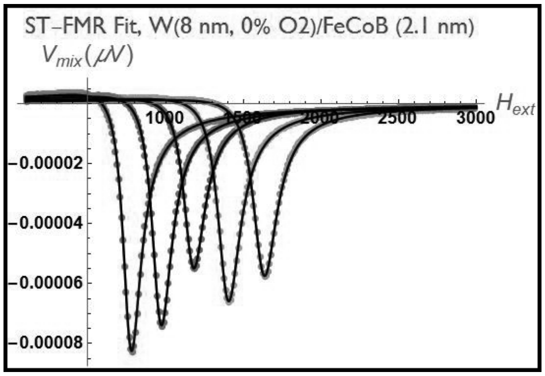

Figure 2: Voltage output from a magnetic field sweep from ST-FMR. Fits are also shown at 8, 9, 10, 11, and 12 GHz frequencies.

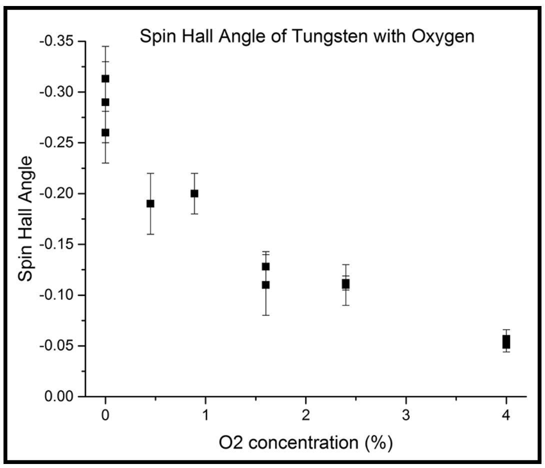

Figure 3: The spin hall angle (SHA) vs. oxygen incorporation in tungsten films.

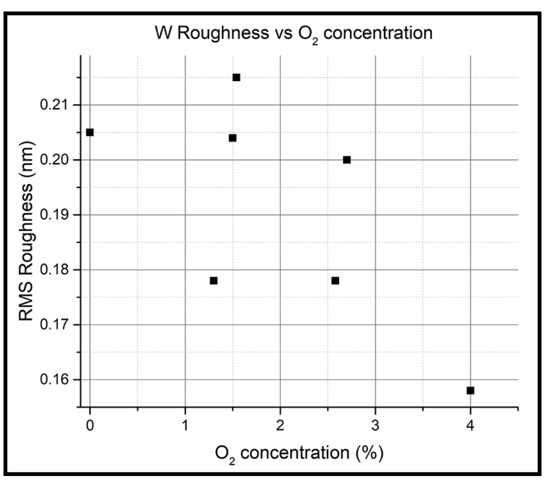

Figure 4: The roughness of tungsten films vs. oxygen incorporation shows no significant variation.

is measured by a lock-in amplifier, then the measurement is repeated for various frequencies. A lineshape analysis is done by fitting a Lorentzian function with symmetric (S) and antisymmetric (A) components as shown in Figure 2. The ratio of the prefactors S and A yield ξ_{FMR}, the spin torque efficiency. By fitting $1/\xi_{FMR}$ vs. $1/t_{FeCoB}$, the SHA is extrapolated.

For pure tungsten films with no oxygen incorporation, the SHA was found to be 0.31 ± 0.03. However, as oxygen incorporation increased, the SHA was found to decrease, with values of 0.13 ± 0.02 and 0.06 ± 0.01 for tungsten with 1.6% and 4.0% oxygen respectively. The results of the SHA vs. oxygen incorporation for several samples are shown in Figure 3. Despite resistivity data demonstrating potentially enhanced β-W growth, the SHA reduces as oxygen is incorporated. The roughness of pure tungsten films with varying oxygen concentration were measured using the Veeco Icon AFM at CNF and all films had an rms roughness of 0.19±0.03 nm, independent of oxygen concentration, as shown in Figure 4.

An explanation for the reduction in the SHA may be that the pure tungsten films were already grown in the β phase, and thus adding oxygen could not enhance the growth further. Rather, the oxygen may have only oxidized the tungsten which would also explain the increase in resistivity. This result contradicts the findings of K. Demasius, et al., which showed an enhancement of the SHA with oxygen incorporation [1].

References:

[1] Kai-Uwe Demasius, Timothy Phung, Weifeng Zhang, Brian P. Hughes, See-Hun Yang, Andrew Kellock, Wei Han, Aakash Pushp, and Stuart S.P. Parkin, Nat. Comm. 7, 10644 (2016).

[2] Chi-Feng Pai, Yongxi Ou, Luis Henrique Vilela-Leão, D.C. Ralph, and R.A. Buhrman, Phys. Rev. B. 92, 064426 (2015).