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High-Resolution Characterization of Josephson Junctions and Magnetic Multilayers for Low-Power, Superconducting Logic and Memory Devices

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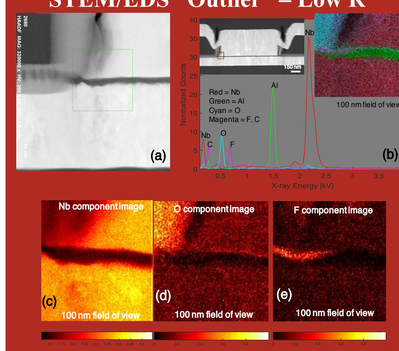
SCE for High-Performance Computing Presents a Significant Challenge to State-of-the-Art SCE Yield

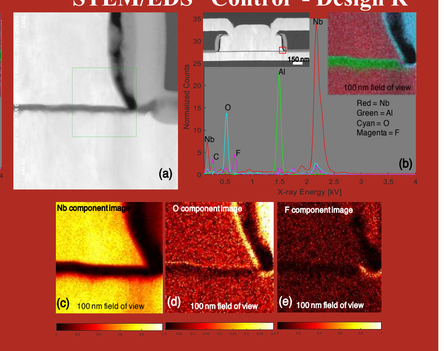
- Scaling of both logic and memory requires high yield fabrication and processing
- High yield requires uniform device characteristics
- Device characteristics depend upon properties of nanometer-scale thin films
- Microanalysis (structure, morphology, chemical composition) at these length scales can provide guidance to fabrication and processing
- Scanning transmission electron-beam microscopy **(STEM)** combined with energy dispersive x-ray spectroscopy **(EDS)** allows characterization of these parameters at the required length scales

Presence of contaminants in active area of Nb/Al-AlOx/Nb JJs correlate with electrical properties – compare "control to "outlier" JJ

STEM/EDS "Outlier" – Low R

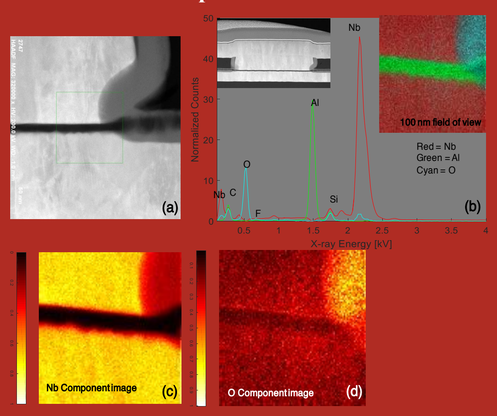


STEM/EDS "Control"- Design R



F observed in active JJ area correlates to low R for outlier JJs

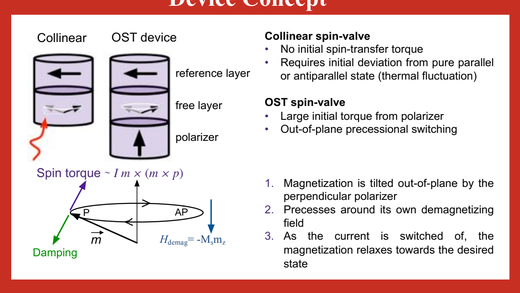
STEM/EDS reduced F process– no outliers on this wafer



No F observed in active JJ area or at interface with anodized sidewall

Template for Cryogenic Spin Transfer MRAM devices influences performance

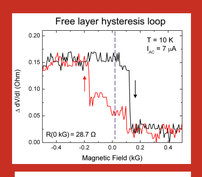
Device Concept

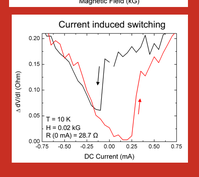


Collinear spin-valve
- No initial spin-transfer torque
- Requires initial deviation from pure parallel or antiparallel state (thermal fluctuation)

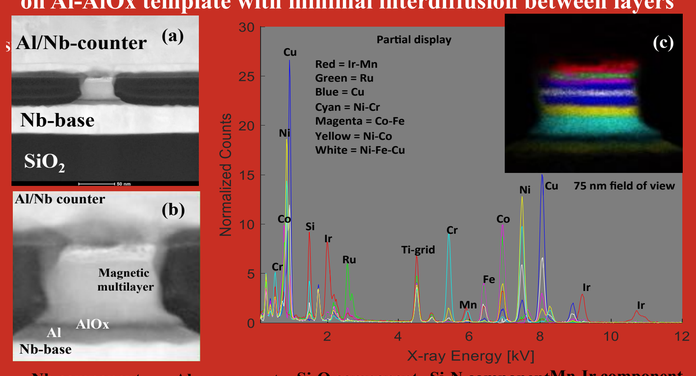
OST spin-valve
- Large initial torque from polarizer
- Out-of-plane precessional switching

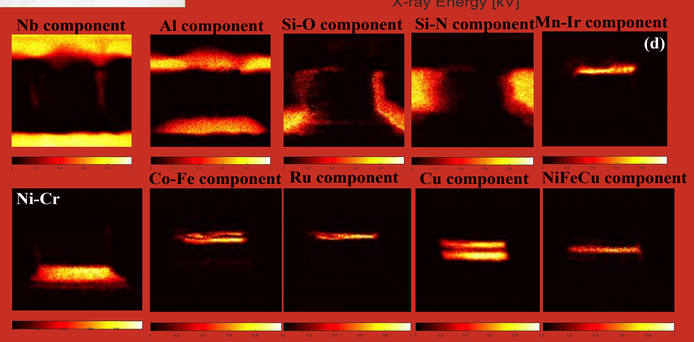
1. Magnetization is tilted out-of-plane by the perpendicular polarizer
2. Precesses around its own demagnetizing field
3. As the current is switched of, the magnetization relaxes towards the desired state





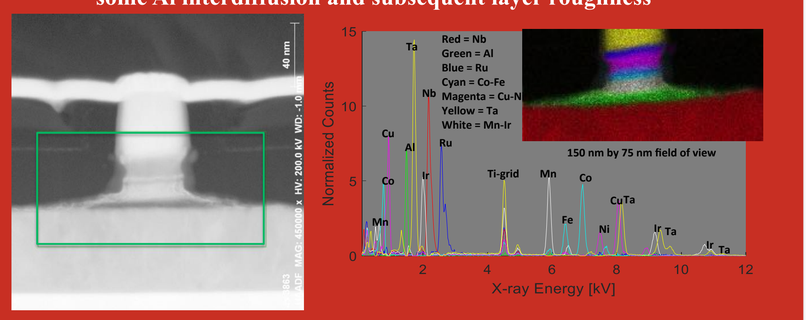
STEM/EDS : smooth, continuous, crystalline, nm-scale layers grow on Al-AlOx template with minimal interdiffusion between layers

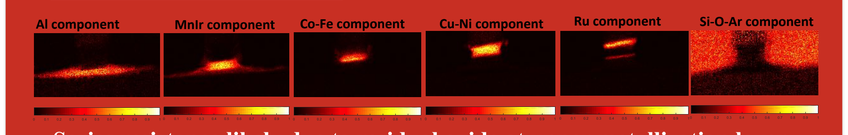




BUT: Thin AlOx adds problematic series resistance

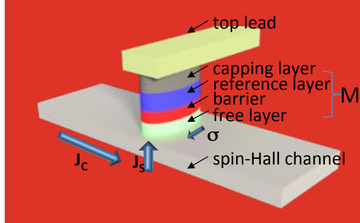
STEM/EDS: Absence of AlOx layer and alternative layer stack results in some Al interdiffusion and subsequent layer roughness





Series resistance likely due to residual oxide at upper metallization layer

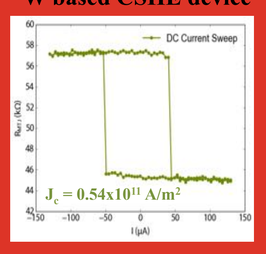
Template for Cryogenic Spin Hall Effect devices impacts layer roughness



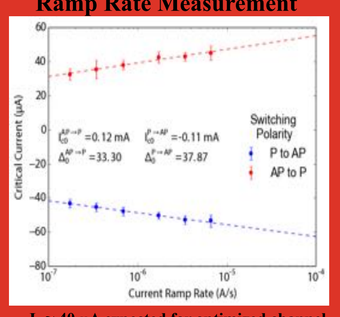
- **Three-terminal device: current-switchable 'free layer', whose state is read by using TMR across the 'reference layer'**
- **Switching is caused by the spin current incident on the free layer due to the spin-Hall effect in the bottom channel**
- **Read-out across the MTJ is enabled by third 'top lead'**

Liu et al., Science, 2012

DC spin torque switching curve for W based CSHE device

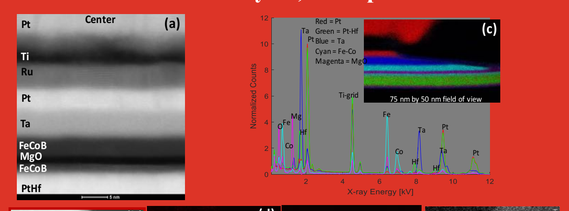


Ramp Rate Measurement

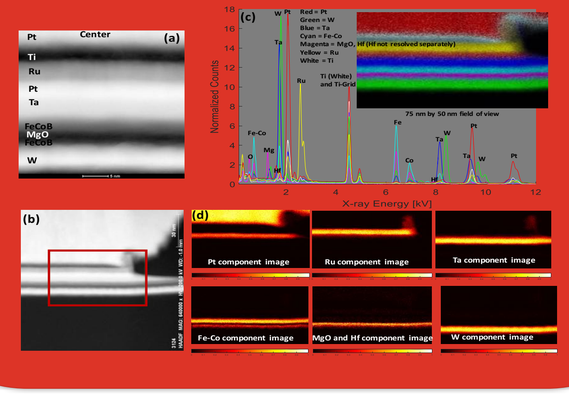


I_c ≈ 40 μA expected for optimized channel

STEM/EDS : smooth, continuous, crystalline, nm-scale layers grow with minimal interdiffusion between layers, some preferential side-wall etching



STEM/EDS : alternative W template introduces additional roughness to subsequent layers



Conclusion: FIB/STEM/EDS analysis of morphology, structure, chemical constituents can provide insight into variation in properties among specific devices and guide changes in fabrication and processing

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