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Magnetoresistance and spin-transfer torque in magnetic tunnel junctions

Abstract

A magnetic tunnel junction (MTJ) consisting of a thin insulating layer (a tunnel barrier) sandwiched between two ferromagnetic electrodes exhibits the tunnel magnetoresistance (TMR) effect due to spin-dependent electron tunneling. Since the discovery of room-temperature TMR in the mid-1990s, MTJs with an amorphous aluminum oxide (Al–O) tunnel barrier have been studied extensively. Such MTJs exhibit a magnetoresistance (MR) ratio of several tens of percent at room temperature (RT) and have been applied to magnetoresistive random access memory (MRAM) and the read heads of hard disk drives. MTJs with MR ratios substantially higher than 100%, however, are desired for next-generation spintronic devices. In 2001, first-principle theories predicted that the MR ratios of epitaxial Fe/MgO/Fe MTJs with a crystalline MgO (001) barrier would be over 1000% due to the coherent tunneling of specific Bloch states. In 2004, MR ratios of about 200% were obtained for MgO-based MTJs [1]. MTJs with a CoFeB/MgO/CoFeB structure were developed for practical application and found to have MR ratios of above 200% and other practical properties [1, 2].

This lecture focuses on the physics of magnetoresistance and spin-transfer torque in MTJs and the application of MTJs to various spintronic devices such as magnetic sensors, spin-transfer-torque MRAM (STT-RAM or spin-RAM) with perpendicular magnetization, and novel spin-torque oscillators [3]. In addition, new types of MTJs such as spin-filter junctions with a ferromagnetic tunnel barrier will be discussed.

[1] S. Yuasa and D. D. Djayaprawira, J. Phys. D: Appl. Phys. 40, p.R337 (2007).

[2] D. D. Djayaprawira, K. Tsunekawa, M. Nagai, H. Maehara, S. Yamagata, N. Watanabe, S. Yuasa, Y. Suzuki and K. Ando, Appl. Phys. Lett. 86,092502 (2005).

[3] PDF file of the lecture slides can be downloaded from <http://unit.aist.go.jp/src/cie/ieee.html> with a password given at the lecture.

Bio

Dr. Shinji Yuasa received a PhD in Physics from Keio University in 1996. After receiving his doctorate, he served as a staff scientist at the Electrotechnical Laboratory (Tsukuba, Japan) where he worked on spin-dependent transport in metallic magnetic multilayers. Since 2001, he has been a staff scientist at the National Institute of Advanced Industrial Science and Technology (AIST),

working on the physics and device applications of MTJs. Since 2010, he has been a director of the Spintronics Research Center at AIST. He has published more than 100 peer reviewed papers and has given more than 80 invited talks at international conferences. For his achievement of the giant TMR effect in MgO-based MTJs, he has been awarded or co-awarded 20 prizes, including the Asahi Award in 2007. He is now serving as a program co-chair for the 2013 Joint MMM/Intermag Conference and is a member of the advisory committee for the MMM Conference and an editor of Applied Physics Express.