

Soft Magnetic Thin Film Applications at Radio Frequencies

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Development of new passive component technologies will enable a “More-than-Moore” paradigm leading to innovative application-specific compact systems [1]. Ferromagnetic thin film materials, having high permeability at (and above) radio frequencies, are candidate materials for use in inductive passive components that are available in the forms of vacuum-deposited and electro-deposited metallic alloys, chemically synthesized nano-particulate composites, and traditional oxides, among others. Using these materials, the development of CMOS integrated inductors and integrated electromagnetic noise suppressors for Long Term Evolution, or 3.9th Generation, cell phone RFIC and Point-of-Load one-chip DC-DC converters, is attracting great interest from both academic and industrial communities.

This lecture begins with a review of new soft magnetic thin film applications at radio frequencies for future system-in-package (SiP) and system-on-chip (SoC) technologies. Proposed in late 1970s, these thin film soft magnet applications have evolved from inductive read/write recording head technology to the frontiers of GHz frequency device applications. Discussions covered in this lecture include: (1) Development of international cross measurements of RF permeameters [2] to evaluate RF permeability and related FMR profiles of magnetic films; (2) small signal high permeable low loss applications to CMOS integrated inductors [3]; (3) small signal lossy application to CMOS integrated electromagnetic noise suppressor [4]; (4) small to medium signal applications as new metal/ferromagnetic multi-stack “conductors” to suppress skin effect utilizing negative permeability beyond the FMR frequency [$\mu_r' < 0$, $\mu_r'' \approx 0$] [5]; and, (5) large current permeable application to Point-of-Load type one-chip DC-DC converters. The lecture will conclude with an outlook that provides a perspective on the future of on-chip RF magnetics.

[1] John P. Kent, and Jagdish Prasad, “Microelectronics for the Real World: ‘Moore’ versus ‘More than Moore’,” IEEE 2008 Custom Integrated Circuits Conference, 15-4-1 (2008).

[2] M. Yamaguchi, Y. Miyazawa, K. Kaminishi and K.I. Arai, “A New 1 MHz-9 GHz Thin-Film Permeameter Using a Side-Open TEM Cell and a Planar Shielded-Loop Coil,” Trans. Magnetic Society of Japan, **3**, 137-140 (2003).

[3] Masahiro Yamaguchi, Keiju Yamada, Ki Hyeon Kim, “Slit Design Consideration on the Ferromagnetic RF Integrated Inductor,” IEEE Transactions on Magnetics, **42**, 3341-3343 (2006)

[4] Sho Muroga, Yasushi Endo, Wataru Kodate, Yoshiaki Sasaki, Kumpei Yoshikawa, Yuta Sasaki, Makoto Nagata Masahiro Yamaguchi, “Evaluation of Thin Film Noise Suppressor Applied to Noise Emulator Chip Implemented in 65nm CMOS technology,” IEEE Transaction on Magnetics, **48**, 4485 - 4488 (2011).

[5] Masahiro Yamaguchi, Yutaka Shimada, Takayoshi Inagaki and Behzad Rejaei, “Skin Effect Suppression in RF Devices Using a Multilayer of Conductor and Ferromagnetic Thin Film with Negative Permeability,” Microwave Workshop and Exhibition 2008 (MWE 2008), WS08-03 (Yokohama, 2008).

Biography - Masahiro Yamaguchi received the B.S., M.S. and Ph.D. (Dr. Eng.) degrees in electrical and communication engineering from Tohoku University, Sendai, Japan, in 1979, 1981, and 1984, respectively. Dr. Yamaguchi was an associate professor with the Research Institute of Electrical Communication, Tohoku University from 1991 to 2003. In 1995 he was a visiting associate professor at University of Wisconsin-Madison, the United States. Since 2003 he has been serving as professor in the Department of Electrical and Communication engineering, Tohoku University. He is also with the New Industry Creation Hatchery Center (NICHe), Tohoku University, since 2010. His research interest covers (1) RF permeability and FMR measurements for magnetic thin films, (2) RF magnetic field measurements for IC chips to analyze and countermeasure electromagnetic interference, and (3) application of soft magnetic materials for on-chip RF devices including thin film inductor, noise suppressor and skin-effect free multilayer conductor for telecommunication and micro power-conversion technologies. Prof. Yamaguchi established and served as the general chair for the International Workshop on High Frequency Micromagnetic Devices and Materials (MMDM, 2002-2008). He has served as the IEEE Magnetics Society Japan-Sendai Chapter Chair (2007), Co-editor-in-chief for the Magnetics Society of Japan (2007-2010), and board member of Japan Institute of Electronics Packaging (2008-2010). He is currently the chairman of the committees on On-Chip RF Magnetics of the Institute of Electrical Engineers of Japan (2011-2014).