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Nanomagnetic Logic in Focused Ion Beam Engineered Co/Pt Multilayer Films

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Abstract

Magnetic field-coupling promises a paradigm shift in nanoscale computing: information is propagated and processed by magnetic interaction of single-domain ferromagnetic particles. It is a novel way for rad-hard, nonvolatile, dense and highly parallel digital information processing. The feasibility of such structures, also referred to as nanomagnetic logic (NML), has already been demonstrated experimentally by a magnetic majority gate, lithographically fabricated from Permalloy dots.

By contrast, the objective of this work is the experimental demonstration of NML devices based on ion-beam patterned magnetic multilayers with special focus on their microelectronic integration. Ferromagnetic building blocks for NML devices in Co/Pt multilayer stacks are experimentally demonstrated and their correct function substantiated by calibrated micromagnetic modelling. Detailed magnetic force microscopy imaging and Hall-effect measurements show that the characteristics of the nanomagnets are well-controlled. This raises hope for realizing complex field-coupled structures with a nanomagnetic dot density of up to $2.5 \cdot 10^{11}$ cm^{-2} (20 nm $\times$ 20 nm islands). That means in turn, that an ultimately scaled, programmable NAND gate would fit in a 100 nm $\times$ 100 nm area, by simultaneously superseding metallic interconnects to the individual computing elements. As-grown, thermally annealed and homogeneously ion irradiated films are investigated and compared for a broad temperature range. They are proven to keep their ferromagnetic characteristics up to more than 80 °C.

Special focus is put on the design and fabrication of electrical inputs/outputs and an integrated clocking system. Submicron-scale electrical wires, buried under the magnetic layers, provide electrical input to field-coupled nanomagnets. Selective switching of single-domain dots by means of electrical current pulses is demonstrated and backed by analytical models to predict both temperature as well as time dependent switching fields. Furthermore, electrical output is demonstrated by means of a sub-micron extraordinary Hall-effect sensing element, utilizing a split-current geometry and allowing for undisturbed field-coupling to the device under test. The nanomagnetic state is directly sensed and details of the hysteretic switching are recorded. The application of angular dependent Hall probing gives a deeper insight in the reversal mechanism of Co/Pt films and dots. The fabrication of the magnetic computing components is compatible with silicon technology and is promising to enhance the functionality of microelectronic systems by future hybrid CMOS/NML implementations. It will pave the way for complete field-coupled computing systems implemented in ferromagnetic films.

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