PHYSICS COLLOQUIUM

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SUPERPARAMAGNETIC TUNNEL JUNCTIONS FOR PROBABILISTIC COMPUTING

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130 HAHN HALL NORTH

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Interacting nanomagnets with low thermal stability have been proposed for probabilistic computing, which has potential uses in low power sensing and logic, encryption and decryption, and integer factorization [1]. The similarities and differences between superparamagnetic nanoparticles and electronically controlled superparamagnetic tunnel junctions will be reviewed, including a comparison of the Stoner-Wohlfarth asteroid and its tunnel junction equivalent. Next the differences between deterministic and probabilistic logic will be discussed. Boltzmann machines based on interacting spins, and how they achieve the lowest energy states with greatest statistical probability are described. By controlling the interaction strengths, probabilistic logic gates can be realized. Superparamagnetic tunnel junctions (SP-MTJs) are an ideal type of nanomagnet because their time-averaged magnetization of the free layer can be programmed with a voltage or current [2, 3]. Fabrication of hard-wired magnetic tunnel junctions (MTJs) and incorporation in hybrid CMOS circuits are described. Experimental results for two example logic gates will be discussed: first the simple NOT gate formed from two coupled MTJs, and then a more complex AND gate made from three coupled MTJs. The feedback for the NOT gate leads to very high anti-correlations (~95%) and is nearly deterministic in behavior. With the AND gate, we start with a theoretical discussion of the feedback weightings, and corresponding Boltzmann factors for the probabilities of different microstates. The effect of pinning the output on invertibility of the logic gates is shown in terms of energy levels and probabilities. A metric based on pairwise comparison of microstate probabilities is proposed to quantify the performance of hardware-based probabilistic logic gates. This metric is applied to experimental results for our AND gate, and the impact of variations in MTJ performance is discussed.

1. K. Y. Camsari, et al., Phys. Rev. X 7, 031014 (2017).
2. M. Bapna and Sara A. Majetich, Appl. Phys. Lett. 111, 243107 (2017).
3. B. Parks, A. Abdelgawad, T. Wong, R.F. L. Evans, and S. A. Majetich, Phys. Rev. Applied 13, 014163 (2020).

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