Neuromorphic Computing and Ising Machines Using Spintronic Nano Oscillators

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Spintronic nano oscillators, like spin torque nano oscillators (STNO) and spin Hall nano oscillators (SHNO)), have been considered for various emerging computing applications because of their remarkable properties: oscillation frequency in GHz, low power and energy consumption, electrical tunability of frequency, synchronization characteristics, etc [1-3]. In the proposed invited talk, I will present the latest research contributions from myself and the students I have supervised in this regard [4-7]. I summarize the contributions here.

In [4] and [5], we have reported that the synchronization dynamics of dipole-coupled STNOs/ SHNOs is consistent with the physics-agnostic Kuramoto model, which is applicable across a wide range of oscillators. We have utilized this to show implementation of data classification tasks (used for neuromorphic computing) through these spin oscillators: different combinations of oscillators synchronizing and not synchronizing correspond to different categories into which the data can be classified (Fig. 1). We have also developed a training algorithm based on which frequencies of the oscillators can be tuned such that classification can be achieved with high accuracy. Data classification through these oscillators will be useful in edge AI applications where signals of very high frequency need to be categorized to draw inferences.

In [6] and [7], we have utilized the relative phase information of synchronized STNOs/ SHNOs to demonstrate their application as Ising machines, meant to solve combinatorial optimization problems which are useful for various applications (delivery scheduling, VLSI design, protein folding and drug discovery etc) but take exponential time to solve accurately on conventional digital computers. We show that while time to solution (TTS) of these problems grows quadratically with problem size even for approximation algorithms implemented on digital computers, TTS only grows logarithmically with problem size on oscillator Ising machines (Fig. 2). This high speed of computation is a major advantage of such oscillators.

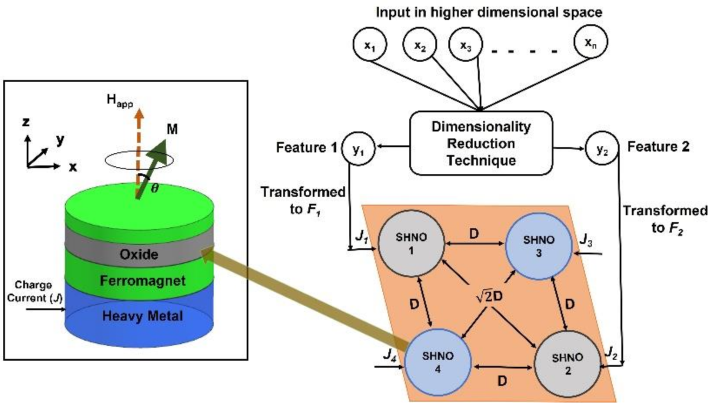

Fig. 1: Schematic of a single spin Hall nano oscillator (SHNO) at a device level and an array of four dipole coupled SHNOs, which carries out data classification, at a system level. SHNO1 and 2 are input oscillators, and SHNO2 and 4 are output oscillators. *Figure source, more details: [4] N. Garg et al, Neuromorphic Computing and Engineering, vol. 1, no. 024005, 2021.*

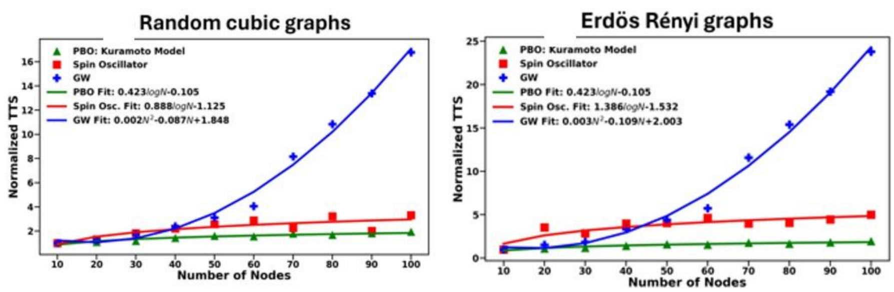

Fig. 2. Comparison of time to solution (TTS) for physics-agnostic phase binarized oscillators (PBOs), spintronic oscillators, and classical approximation algorithm (Goemans-Williamson, or GW) to solve the combinatorial optimization problem Max-Cut on different kinds of graphs up to 100 nodes. *Figure source, more details: [6] N. Garg et al, Nanotechnology vol. 35, no. 46 (465021), 2024*

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