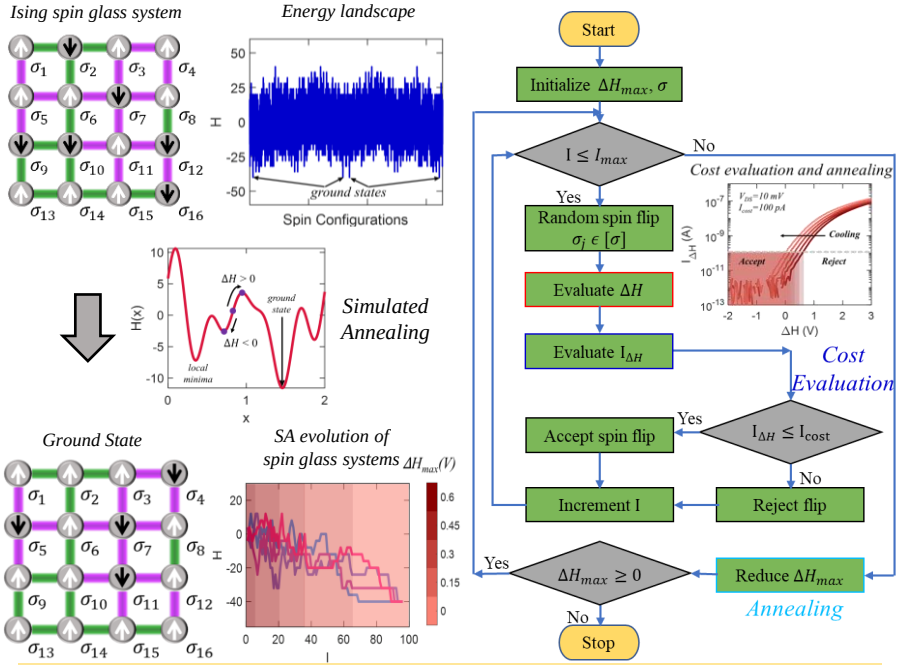
Annealing Accelerator for Ising Spin Systems using 2D FETs

Amritanand Sebastian, Sarbashis Das, Saptarshi Das (2DCC, Penn State)

Project Summary: Metaheuristic algorithms such as simulated annealing (SA) has been implemented for optimization in combinatorial problems, especially for discreet problems. SA employs a stochastic search, where high-energy transitions ("hill-climbing") are allowed with a temperature-dependent probability to escape local optima. Ising spin glass systems have frozen ferromagnetic and antiferromagnetic interactions and the spins must be flipped to obtain the ground state. However, these systems exhibit high number of metastable states and ground-state degeneracy. We exploit subthreshold Boltzmann transport in complementary two-dimensional (2D) field effect transistors (FETs), i.e., n-type MoS_2 and p-type WSe_2, integrated with analog, non-volatile, and programmable floating-gate memory stack to develop in-memory computing primitives necessary for energy and area efficient hardware acceleration of SA for the Ising spin systems. We experimentally demonstrate > 800X search acceleration for 4×4 ferromagnetic, antiferromagnetic, and a spin glass system using SA compared to an exhaustive search using brute force trial at miniscule total energy expenditure of ~120 nJ. Our hardware realistic numerical simulations highlight the astounding benefits of SA in accelerating the search for larger spin lattices. Published in *Advanced Materials* **34**, 2107076 (2022) and selected as Editor's Choice.

2DCC Role: Our demonstration uses large-area high-quality MoS_2 films grown using metal organic chemical vapor deposition (MOCVD) from Prof. Joan Redwing's group, which was developed through 2DCC. The development of such films is extremely valuable to the 2D community as it allows greater scalability and demonstration of circuits using 2D FETs.



SA algorithm is used to identify the ground state of a Ising spin glass system. In the SA flowchart, evaluation of change in energy (ΔH), cost evaluation and annealing are performed with the aid of MoS_2 FETs (MoS_2 obtained from 2DCC).