Optimization of Spacecraft Nano-Mechanical Memory

Elham Maghsoudi and Michael James Martin
Department of Mechanical Engineering, Louisiana State University, Baton Rouge, LA 70803, USA

The design of memory systems for space exploration is complicated by three constraints: limited available power, a harsh environment, and the need for increased reliability. The environmental constraints include high radiation levels, leading to the consideration of exotic memory systems for spacecraft applications. Buckling-beam memory uses an array of nano-fabricated beams, with each beam providing a single bit of memory. The data is "written" by thermally buckling the beams. A downward-buckled beam is a "1" and an upward-buckled beam is a "0". The initial, unbuckled beam is heated, either through a thin-film resistor, or a heated tip designed as a writing device, at a constant rate. After a time t_b, the thermal stresses in the axial direction will cause the force in the beam to exceed the force required for buckling, causing the beam to buckle down. If the heat is added to the bottom of the beam, it will buckle up which is corresponding to a "0". In this study, an integrated thermal-mechanical simulation of buckling in nano-mechanical memory is performed. The preliminary system is a silicon bridge with a length of 20 microns, a width of 1 micron, and a thickness of 300 nm, in air with a pressure of 5 kPa. Conduction along the bridge as well as convection between the beam and the gas are considered. The conduction and structural equations are solved numerically at each time step using a finite difference method. An implicit method which requires a matrix-inversion method is used to obtain an unconditionally stable solution. The simulations were run for 31×9×7 nodes in the 3D model. Grid independence was verified by repeating the simulations for 35×13×11, and 51×25×15. The results show that 35×13×11 is sufficient to obtain accurate results. High Performance Computing is required because of the high number of elements and corresponding high convergence iteration number at each time step. The finite-difference solver allows the temperature, materials, ambient conditions, heat load, and geometry to be changed easily. Using these results, a time-to-buckling t_b and a total energy for buckling Q for any given geometry and ambient conditions are computed. Longer structures will buckle faster, leading to a faster write time. The required energy will also decrease. The storage density is inversely proportional to the area occupied by each beam, so the ideal array would use the smallest beams possible. The current work suggests the length of 20 microns for the unit of the bridge to balance these constraints. As the thickness of the bridge increases, the energy consumption increases due to an increase of moment of inertia. The buckling time increases by increasing the thickness and the width. Simulations were repeated for silicon carbide, PMMA, and parylene. Among the beams with the fixed dimension, plastic materials show the fastest write time, with the lowest energy cost. To determine the effect of high-radiation environments, collisions with high-energy particles are simulated. The particle collision is modeled as a localized instantaneous heat addition. The study of high particle energy collision shows these particles do not cause fast undesired buckling for silicon and silicon carbide. The heat through collision dissipates in less than 10 *nsec* which is much smaller than the smallest buckling time for these materials. The heat through collision dissipates slowly in PMMA and parylene due to the small conductivity. It causes the device buckles for trapped electron of 1000 *Mev*. Simulation of a cold bit surrounded by heated bits show that an accidental buckling does not happen for the cold bit for all materials.