Silicon Carbide Nanoelectromechanical Systems and Nanomechanical Logic

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Silicon carbide (SiC), an advanced polymorphic material of great technological importance, possesses a number of very attractive characteristics including wide bandgap, transparency from visible to near infrared, large refractive index, excellent thermal conductivity, very high elastic modulus and remarkable mechanical hardness and chemical inertness. These attributes make SiC highly interesting and promising for a wide spectrum of emerging and critical applications, ranging from high-temperature electronics, sensors and transducers enabled by micro/nanoelectromechanical systems (MEMS/NEMS), to photonics and quantum information processing.

In electronics, conventional transistors scaling is slowing down and facing severe power consumption challenges that are largely due to collective and increasing leakage issues persistent in each transistor scaled down to the nanoscale, dictated by fundamental thermodynamics and quantum mechanics. Among few candidates for alternative logic devices, nanoscale contact-mode logic switches (relays) have been actively explored for ultralow-power applications. NEMS switches offer compelling advantages including ideally abrupt switching with minimal off-state leakage, suitable for extreme environments, and small footprints. In pursuing these advantages, however, challenges remain: (i) all the high-performance mechanical switches recently demonstrated are still well in the MEMS domain and are orders of magnitude larger in size/volume than today's mainstream transistors. (ii) Most of today's truly nanoscale mechanical switches suffer from nanoscale contact issues and very short lifetimes.

We present our recent results in advancing SiC NEMS toward a scalable nanomechanical logic technology, and we demonstrate some clear advantages of SiC for enabling NEMS logic switches with robust nanoscale contacts and long lifetimes (in contrast to many other NEMS switches). Our nanocantilever-based SiC switches have all (but the length) dimensions in nanoscale, featuring motional volumes that are 10^4–10^5 times smaller than today's high-performance MEMS switches. For the first time, we experimentally record the time evolution of robust SiC NEMS switching events in ambient air, for at least $>10^6$ cycles *without failure* (devices still alive, high-speed accelerated tests needed), with high on/off ratios ($\sim10^4$), and with highly repeatable performance over days. The real-time recorded long switching cycles also give us a unique opportunity for studying the time evolution of the nanoscale contacts. We also report SiC NEMS switches and basic logic gates operating at high temperatures ($T\approx500$°C).