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Abstract

The silicon technology and the limits of computation

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Assuming with Feynman that single atoms can be used for storing information, a planar arrangement would allow a maximum density of the order of 10^{15} cm^{-2}. If the chemical composition of the surface is fixed and the information is stored simply as a conformation (between two possible ones) of any given surface atom, the above density would allow the storing up to just 1 Pbit cm^{-2}—the peta scale integration (PSI). The manipulation of atoms, however, is achieved through macroscopic-scale apparatuses (e.g., the scanning tunneling microscope), which operates on a few atoms at a time. Contrariwise electrons, when used to store information, can be managed and felt by already existing mesoscopic-scale tools of the giga scale integration (GSI), with high parallelism and access speed, but fundamental and practical considerations suggest that the reachable density is in the order of 10^{12} bit cm^{-2} (the tera scale integration, TSI).

Understanding the ultimate density limits of circuit integration could shed light on the final perspectives of silicon technology, which should reach the TSI era in approximately 20 years, but it is also a fascinating speculation involving fundamental principles of quantum and statistical mechanics. We have analyzed the ultimate limits of computation in the hypotheses that computation is a process occurring in a medium obeying the underlying physical laws and immersed in a thermal reservoir at assigned (room) temperature. The consideration of these factors leads to the conclusion that the most efficient way to manage information at room temperature involves light ions.

However, independent of the information carrier, the computational figure of merit is then reduced by the need of transforming the microscopic computation outcome into a macroscopic event. We have also estimated the resulting loss of performances, in the hypothesis that the microscopic state is sensed with an apparatus where the amplification is achieved via a metastable mesoscopic system in contact with the microscopic system.