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Fundamental limitations and development perspectives of quantum nanoelectronics

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Over several decades the tendency for miniaturization of micro- (or nanoelectronic) components has followed the Moore's law: doubling of the number of elements per chip over each 18 months. However, nowadays all authorities come to conclusion that the progress in miniaturization of commercial nanoelectronic circuits will come to saturation very quickly (in 2017-2019), based on different estimations. Typically, two main reasons are provided. First, is purely technical: the dramatic increase of energy dissipation per unit volume of a processor. Second problem is of fundamental origin: below a certain size limit (rough estimation ~10 nm) the electron transport does not follow the laws of classic physics, but is rather described by quantum mechanics. The behavior of an ultra-small system (e.g. transistor) becomes qualitatively different from behavior of a "classic" (macroscopic) device. Some potential solution of the first problem might be the rejection of CMOS technology and utilization of superconducting materials in critical elements of the circuit. However, contrary to the first problem, the second one does not have a solution in foreseen future. All solid conductors like metals, semiconductors or superconductors (the last being already by the very nature the macroscopic quantum objects) - below certain scales exhibit various quantum size effects. Those quantum size phenomena dramatically alter properties of electric conductors: with reduction of electric conductivity and transition to insulating state being a typical manifestation. Obviously the mentioned size limitations should be carefully taken into account in designing ultra-small nanolectronic devices of the next generation. However, beside the negative influence, quantum effects can be used for building the qualitatively new generation of nanoelectronic devices essentially based on quantum physics: e.g. qubits - elements of quantum logic, to be used in quantum information and processing systems. Utilization of such quantum devices opens up qualitatively new horizons for such disciplines as informatics, telecommunication, metrology and computing. In addition to applications in such crucial fields as space and defense industry, national security, quantum nanoelectronics opens-up new fields of research in basic studies. Quantum nanoelectronics cross-fertilize interdisciplinary links between subjects like linguistic and quantum cryptography, brain research and quantum informatics. Here, we outline the mentioned technical and fundamental limitations for miniaturization of nanoelectronic elements, as well as suggest certain alternatives for the field development.

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