At the Beginning of the Nano–Composite Era

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As microelectronics is approaching the lateral scale of 10 nm, several fundamental questions arise. What are requirements for devices at the 10 nm scale, when the physics becomes quantum? Is it good or bad? Shall we worry at all?

It is important to remember that one of the major requirements for any device is operational stability against thermal escape of carriers.[1,2] In this connection, it is worthwhile to compare a few well–known systems, such as Si/SiO_2, metal/silicon, or self–organized SiGe or InAs/GaAs nanostructures. To be used in microelectronics, e.g. for data storage, semiconductor quantum dots (QDs) must have significant localization energy. The localization energy of electrons, e.g. in InAs/GaAs QDs are at most 200–300 meV, corresponding to about 10 $k_B T$ at room temperature, whereas a localization energy about 100 $k_B T$ is required for data storage.

A few approaches to overcome this challenge can be proposed and analyzed. One is the use of ensembles of QDs consisting of $N >> 1$ (tens to hundreds) dots as data storage units, where relative fluctuations of electric charge are suppressed as $N^{-1/2}$.[1] These ensembles can be realized by stacks of coupled QDs or mesa structures comprising QD layers. We can then discuss:

- Which ensembles will be the best ones, coupled or uncoupled QDs?
- What are the interconnections between the desirable shape, size and the density of QDs?
- Whether the size dispersion of QDs[3,4] is a real disadvantage?
- Can growth on self–organized nanofaceted surfaces help?
- What are the conditions for efficient Coulomb blockade in coupled QDs?
- How will these ensembles be addressed electronically?

Another approach is the search for material combinations yielding ultra-small QDs with ultra-high localization energies, e.g. nanoinsertions of some "nominal" metals in semiconductors:

- Which material combinations can work?
- How are the metal properties affected or changed in the ultra-small particle limit?
- What are the energy requirements?

The prospects of approaching the minimum size of the device features attainable by the above methods will be discussed.

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[1] V. A. Shchukin *et al.*, *Epitaxy of Nanostructures*, Berlin: Springer-Verlag, 2003.

[2] V. A. Shchukin and D. Bimberg. *Rev. Mod. Phys.* **71**, 1125 (1999).

[3] V. A. Shchukin *et al.*, *Phys. Rev. Lett.* **90**, 076102 (2003).

[4] V. A. Shchukin *et al.*, *Phys. Rev. Lett.* **75**, 2968 (1995).